.

Contribution of Charcoal Extraction to Deforestation: Experience from CHAPOSA Research Project.

By

*R.E., Malimbwi, E. Zahabu, *G. C., Kajembe and E.J. Luoga*

Department of Forest Mensuration and Management
Faculty of Forestry and Nature Conservation,
Sokoine University of Agriculture,
P.O. Box 3013, Morogoro, Tanzania.
**Corresponding author: kajembe@suanet.ac.tz*

Abstract

The Charcoal Potential in Southern Africa (CHAPOSA) project which commenced in November, 1999 aimed at increasing the understanding of the effects of utilization of charcoal in three countries of Zambia, Mozambique and Tanzania in southern Africa. The main ecological activities carried out in order to understand the impact of charcoal production on the ecology include: determination of species composition and diversity through forest inventory; determination of mean annual increment for Kitulangalo area from two time series measurements of 1996 and 1999; charcoal tree species and size gradient as influenced by proximity to access roads in Kitulangalo and Mbwewe areas through forest inventory; kiln efficiencies, species and tree sizes preference for charcoal making for Kitulangalo, Mbwewe and Bana areas; woodland cover change between 1991 and 1998; and 1991 and 2000 in the northern and southern catchment parts respectively using satellite imageries. Socio-economic data were collected from Kitulangalo, Mbwewe and Bana. The selection criteria for these sites were: presence of actual charcoal production activities; accessibility relative to other areas in the earmarked catchment area for the study; representative-ness of the study sites in making broad conclusions of the study and availability of ecological and socio-economic data.

This study demonstrated that charcoal production and cultivation have an impact on large-scale deforestation that has occurred in the area between 1991 and 1998. Tree species suitable for charcoal production have been depleted at the roadside and the average distance to charcoal production sites has increased. Tree cover is worse today than ten years ago due to charcoal production. These observations have wide policy implications, given the increased demand for charcoal from the growing urban population with no reliable and affordable alternative sources of energy. Only 74% of the closed and 54% of the open woodlands, remain relatively unchanged; most of these were in forest reserves. However, these areas were also undergoing modification due to encroachment for charcoal, timber and other forest products.

It is true that in the absence of any further disturbance after tree cutting, the areas may progressively revert to woodland. However, in the face of increased population and the demand for agricultural land, such areas may not be given enough room to regenerate. This calls for appropriate management strategies to ensure regeneration so that the remaining woodlands continue to supply charcoal to Dar es Salaam city and other urban areas. This study has shown that substantial regeneration has occurred in areas previously cut, if they have not been converted to farmland. This increases the potential of the regrowth woodland to supply charcoal over a much longer time period.

1. Introduction

In Tanzania forests and woodlands cover about 34 million hectares (Hurskainen, 1996; URT, 1998). These forests have unique environmental and biodiversity values, and make available a wide range of products for subsistence use. The most predominant use of wood is in the form of firewood and charcoal by the majority of Tanzanians in both rural and urban areas. Firewood is preferred in rural areas simply because it is obtainable free of charge. Charcoal is preferred in urban areas on account of its being cheap, easy to transport, distribute and store. It is almost smokeless and has higher calorific value (30 MJ/kg) than firewood (15MJ/kg).

In the SADC region, households consume about 97% of wood energy mostly for cooking, heating and cottage industries while industrial sector is the second to household sector (SADC Energy Sector 1993 in Monela & Kihiyo, 1999). Fuelwood accounts for 92% of the primary energy consumed in Tanzania while petroleum and electricity account only for 7% and 1 % respectively (Ishengoma & Ngaga, 2001). Most of the industrial wood energy is consumed by small-scale industries which include food processing industries and service sectors such as brewing, fish smoking, salt production, baking, restaurants, schools, hospitals and food vending; agro-processing industries such as tobacco curing, tea drying and beeswax processing; and production of building materials such as burnt bricks, lime, smiths, foundries, pottery and ceramics. These industries and domestic activities which rely upon wood energy provide employment and income for rural people particularly during off-season in agricultural production (Monela & Kihiyo, 1999).

The Tanzania energy policy of 1997 stresses on development and use of indigenous energy sources such as bio-energy, coal, natural gas and hydropower (URT, 1997). However, less than 2% of energy development budget is allocated to wood energy programs, and fuelwood is still regarded as a minor forest product with little market value (URT, 2001). Yet still, the majority of woodfuel consumers cannot afford the high investment costs associated with alternative commercial energy sources (Moyo *et al.*, 1993). Availability, reliability of supply and cheaper prices renders wood fuels more preferable than alternative sources of energy.

Looking at the present economic forces, the majority of urban population in Tanzania will continue to depend on fuelwood for unforeseeable future (Moyo *et al.*, 1993; URT 1998; Luoga *et al*. 2000). Furthermore due to the anticipated steady increase in population (at an annual growth rate 2.8%) it is expected that actual consumption of firewood and charcoal will continue to rise to a greater extent. This will put stress on natural forests from where the charcoal is obtained, possibly resulting in deforestation of the forest ecosystems.

Currently, little is known on the dynamics of charcoal production in terms of ecological and socio-economic impacts. It is against this background that some recent researches were done. This paper summarizes the contribution of charcoal consumption to deforestation in Tanzania mostly drawn from the CHAPOSA research project carried out from 1999 to 2002. The project aimed at increasing the understanding of the effects of charcoal use in three countries in southern Africa. Charcoal is used for cooking mainly in the cities, but it is produced in the rural areas. One of the objectives of the project was to assess the extent of environmental degradation due to charcoal production, and to identify indicators that can show where such degradation is taking place, and the conditions for it. The other objective was to identify policy alternatives that can address the issue of non-sustainable charcoal production while allowing production that is sustainable in the long run.

The study focussed at two locations, Dar es Salaam city (consumer) and the surrounding charcoal production sites. Dar es Salaam was chosen for the CHAPOSA project because it is the largest city in the country, serving as the commercial and industrial capital. It was anticipated that the greatest impact of charcoal dynamics would be realized in Dar es Salaam and its surrounding ecosystems. The original catchment area (sources of charcoal for Dar es Salaam) which was studied in detail is between latitudes 5°50’ to 7°00’ south and longitudes 37°53’and 39°00’ east. This is about 10 000 km^2 which extends 100 km north and 140 km west of Dar es Salaam. Detailed ecological surveys were carried out in two sites of Kitulangalo area and Mbwewe. Kitulangalo is located at about 50 km from Morogoro town along the Dar es Salaam highway at latitudes: 6°34’ and 6°45’ South and longitudes: 37°53’and 38°04’ East. Mbwewe is located along the Chalinze –Segera highway at latitudes: 6°00’ and 6°15’ South and longitudes: 38°00’and 38°15’ East. In both sites, data were collected from both general land (formerly known as public land) and forest reserves. Also land cover changes determination was done using satellite imageries.

2. Charcoal production system

2.1 Charcoal making process.

Usually charcoal is produced in earth mound kilns made by covering a pile of logs with earth blocks, igniting the kiln and allowing carbonization under limited air supply (Figure 1). Source of labour for charcoal making activities is mainly household labour.

Charcoal making process that is usually done in public lands involves wood cutting, kiln preparation, carbonisation and finally unloading charcoal from the kiln. While 13, 10 and 14 days are spent for wood cutting, kiln preparation and carbonization, respectively, unloading the charcoal kiln takes only about 4 days (Zahabu, 2001).

Figure 1. Typical charcoal kiln under preparation at Kitulangalo area.

It was observed that there are special months for charcoal production. These are off-season months for agriculture and cover the period of June through November. Charcoal production is usually done to supplement farm income which is the major economic activity. On the average, each household produces about 35 bags a year, mostly for sale. No charcoal is produced intentionally for home use except that which is left after sale and usually it is very minimal.

2.2 Suitable tree species for charcoal making

The most preferred tree species for charcoal in this area are listed in Table 1. Mkambala *(Acacia nigrescens)* – 23% seem to be the most used tree species followed by Mnhondolo/Mhangala (*Jurbernadia globiflora)* – 18%, Myombo (*Brachystegia boehmii* - 17% and Mhungilo (*Lannea schimperi)* 17%. These results are in line with those of Nduwamungu (1996); Monela *et al*. (2000) and Luoga *et al.* (2000) with addition of some few tree species. However there are variations between sites. Particular tree species in the miombo woodlands are favoured for charcoal production of high calorific value due to dense and hard charcoal they produce (Monela *et al.* 1993).

In terms of suitable tree sizes used for charcoal making there is also variation between sites. Trees from 5 cm dbh are used for charcoal production at Dakawa, Kongowe and Kitulangalo areas while at Mbwewe the smallest tree felled for

.

charcoal had 19 cm dbh. This implies that the Mbwewe area is still having large trees of preferred species for charcoal making compared to the other studied sites. Distance from towns and cities may explain this difference in the extent of exploitation. While Dakawa and Kitulangalo are closer to Morogoro town (50 km), and Kongowe is closer to Dar es Salaam City (50 km), the nearest city to Mbwewe is Dar es Salaam that is about 198 km. As such Mbwewe site appear to be remote and hence less exploited for charcoal making compared to other sites. Generally charcoal makers expressed preference to use large trees due to concentrated wood volume near the kiln thus utilizing economies of scale especially for labour which is relatively scarce.

2.3 Charcoal kiln efficiency

Data from twenty-one sampled kilns revealed that the mean kiln efficiency was 19.1% ranging from 11-30%. This value is in line with those reported by Chidumayo (1991), Sawe & Meena, (1994) and Kaale (1998). These previous studies provided charcoal kiln efficiency values ranging from 10-20%. Apart from tree species involved, kiln efficiencies are known to vary depending on the construction of the kiln and the monitoring of the carbonization process.

Table 1. Mostly preferred tree species for charcoal making at eastern Tanzania.

Local name	**Botanical name**	**Use preference (%age vol. In the sampled kilns)**
Mkambala	*Acacia nigrescens*	22.8
Mnhondolo/Mhangala	*Jurbernadia globiflora*	17.9
Myombo	*Brachystegia boehmii*	16.8
Mhungilo	*Lannea schimperi*	16.7
Mbona	*Brachystegia spiciformis*	3.9
Mkongowe	*Acacia gerrardii*	3.0
Msolo	*Pseudolachnostylis maprouneifolia*	2.9
Mlama mweusi	*Combretum molle*	2.5
Mgama	*Mimusops kummel*	2.3
Mkwaju	*Tamarindus indica*	1.9
Mgovu	*Pteleopsis myrtifolia*	1.8
Mnyenye	*Xeroderris stuhulmanii*	1.4
Mkongo	*Afzelia quanzensis*	1.2
Mzikoziko	*Crossopteryx ferbrifuga*	1.1
Mfumbili	*Lonchocarpus capassa*	0.9
Msisimizi	*Albizia harveyi*	0.7
Mtonga	*Strychnos spinosa*	0.4
Mnyinga	*Pterocurpus mildebriedii*	0.3
Mcharaka	*Spirostachys africana*	0.3
Mguluka	*Boscia salicifolia*	0.3
Mtanga	*Terminanalia mollis*	0.2
Mgonji	*Pteleopsis myrtifolia*	0.1
Msakulankw'ale	*Margaritaria discoidea*	0.1
Kifunganyumbu	*Acacia nilotica*	0.1
Mtogo	*Diplorhynchus condylocarpon*	0.1
Mkole	*Grewia* sp.	0.0
Kisasa	*Acacia goetzei* subsp. *goetzei*	0.0
Mtopetope	*Annona senegalensis*	0.0
Msosowana	*Dombeya rotundifolia*	0.0
	Total	**100**

While this study was based on miombo tree species, species used in the previously reported studies were not mentioned. Miombo tree species are said to produce denser charcoal compared to trees of other vegetation. On average 18 trees of dbh of 32 cm were used for every 26 bags each weighing 53 kg of charcoal were produced from these areas. One m^3 yields 3 bags of about 53 kg of charcoal. Other calculations using a conversion rate of 1 m^3/0.85 tons (Malimbwi *et al*., 1994), and kiln efficiency of 19 % also show yield of 3 bags of 53 kg each.

3. Species composition and diversity

3.1 Dominant species

At Kitulangalo, the dominant species in the general lands (public lands) were *Julbernardia globiflora* and *Combretum molle* while in the SUA training forest reserve *Julbernardia globiflora* was dominant with *Brachystegia boehmii* (Table 2). At Mbwewe, the dominant species include *Acacia polyacantha* and *Lannea schimperi* in the general land and *Brachystegia boehmii* and *combretum molle* in the forest reserve (Table 3).

3.2 Size distribution

In terms of size distribution, general land has higher mean stem numbers per ha but lower mean basal area and volume per ha than the woodland in the reserve in Kitulangalo (Table 4). The large number of stems per ha in the general land (1424 stems/ha) is an indication of increased exploitation and subsequently increased regeneration.

Table 2 Stand parameters for the ten dominant species at Kitulangalo

Species	**General land**									
	Roadside			5 km to the road			10-15 km to the road			IVI
	Stems /ha	m^2 /ha	M^3 /ha	Stems /ha	m^2 /ha	m^3 /ha	Stems /ha	m^2 /ha	m^3 /ha	
Julbernardia globiflora	1141	2.12	8.70	-			5	0.05	0.29	45
Combretum molle	183	0.34	1.36	578	0.87	3.56	99	0.41	2.48	33
Spirostachys africana	-	-	-	-	-	-	140	1.13	7.32	21
Combretum zeyheri	369	0.68	2.75	-	-	-	21	0.06	0.7	18
Combretum adenogonium	11	0.05	0.27	143	0.97	5.60	19	0.23	1.58	16
Acacia nigrescens	119	0.24	1.04	37	0.42	3.07	4	0.30	2.93	14
Dombeya rotundifolia	-	-	-	2	0.08	0.63	55	1.12	3.64	12
Acacia gerrardii	11	0.03	0.13	-	-	-	12	0.86	8.23	11
Brachystegia boehmii	11	0.03	0.13	5	0.11	0.73	47	0.33	2.08	10
Pterocarpus angolensis	178	0.44	2.01	-	-	-	-	-	-	9

	SUA training forest reserve			
	Stems / ha	m^2/ha	m^3/ha	IVI
Julbernardia globiflora	64	1.36	11.02	32
Brachystegia boehmii	47	1.61	14.31	31
Combretum adenogonium	81	0.60	3.54	24
Combretum molle	69	0.46	2.61	20
Acacia goetzei subsp.goetzei	37	0.52	3.40	19
Acacia nigrescens	17	0.97	9.77	18
Diplorhynchus condylocarpon	37	0.53	1.26	14
Xeroderris stuhlmannii	8	0.55	5.15	12
Lonchocarpus sp.	32	0.15	0.85	10
Bridelia cathartica	27	0.11	0.56	9

***Notes**: m^2 /ha: Basal Area per hectare; m^3 /ha: Volume per hectare; IVI: Importance Value Index*

Table 3 Stand parameters for ten dominant species at Mbwewe

Species	Mbwewe general land									
	Roadside			2 km to the road			4-6 km to the road			IVI
	Stems /ha	m^2 /ha	m^3 /ha	Stems /ha	m^2 /ha	m^3 /ha	Stems /ha	m^2 /ha	m^3 /ha	
Acacia polyacantha	14	0.30	1.72	50	0.64	3.51	-	-	-	21.0
Lannea schimperi	5	0.45	3.76	5	0.53	4.66	9	0.37	3.04	19.3
Spirostachys africana	-	-	-	64	0.21	0.77	12	0.50	3.48	18.7
Pterocarpus angolensis	8	0.07	0.41	-	-	-	26	0.28	1.71	15.1
Mchala (Albizia sp.)	-	-	-	24	0.47	2.8	4	0.13	0.85	13.7
Acacia gerrardii	5	0.08	0.42	27	0.24	1.33	1	0.09	0.76	11.5
Combretum adenogonium	11	0.03	0.05	-	-	-	24	0.16	0.77	10.5
Acacia nigrescens	2	0.16	1.32	-	-	-	14	0.17	1.23	9.6
Brachystegia boehmii	3	0.06	0.41	-	-	-	1	0.04	0.27	5.4
Combretum molle	-	-	-	21	0.08	0.32	-	-	-	3.4

	Uzigua forest reserve			
	Stems / ha	m^2/ha	m^3/ha	IVI
Brachystegia boehmii	58	1.27	9.28	48.0
Combretum molle	58	0.36	1.8	27.6
Acacia gerrardii	40	0.47	2.59	25.5
Acacia polyacantha	27	0.43	2.73	19.9
Mchezi	36	0.31	1.73	18.8
Xeroderris stuhlmannii	18	0.51	4.29	15.4
Acacia nigrescens	13	0.57	5.51	14.3
Pterocarpus angolensis	14	0.28	1.85	10.8
Brachystegia microphylla	10	0.45	4.28	10.0
Combretum adenogonium	4	0.04	0.20	2.7

Table 4 Standing crop parameters for general land and forest reserve at Kitulangalo

Parameters	**General land**				**SUA training forest reserve**			
	1	2	3	Total	1	2	3	Total
Stocking (Avg stems/ha)	1275	113	36	1424	391	165	71	627
Basal area (Avg m^2/ha)	2.67	1.77	2.32	6.76	1.57	2.57	6.04	10.18
Volume (Avg m^3/ha)	6.88	11.16	21.93	39.97	5.89	16.02	56.25	78.16

Notes: - Size class1: 5-10 cm DBH; - Size class 2: 10.1-20 cm DBH; - Size class 3: > 20 cm DBH

Table 5 Standing crop parameters for general land and forest reserve at Mbwewe

Parameters	**Mbwewe general land**					**Uzigua forest reserve**				
	R	1	2	3	Total	R	1	2	3	Total
Stocking (Avg stems/ha)	2845	141	52	26	219	3720	226	108	57	391
Basal area (Avg m^2/ha)	-	0.65	1.00	2.42	4.07	-	1.06	1.84	5.07	7.97
Volume (Avg m^3/ha)	-	2.81	5.81	22.21	30.83	-	4.47	10.6	45.51	60.58

Notes: - R: Regeneration (individuals < 5 cm)

Table 6 Harvesting intensity in the forest reserve and the general land

Removals	**Parameters**	**Whole Kitulangalo Forest reserve (n=34)**	**General land (n= 30)**
New	Stumps (Stems / ha)	5.00 ± 3.18	47.00 ± 17.58
	BA (m^2/ha)	0.14 ± 0.54	1.38 ± 0.54
	Volume (m^3/ha)	1.12 ± 0.68	6.38 ± 2.39
Old	Stumps (Stems / ha)	50.00 ± 8.55	135.00 ± 22.28
	BA (m^2/ha)	1.04 ± 0.19	2.61 ± 0.51
	Volume (m^3/ha)	5.98 ± 0.86	13.24 ± 2.18
All	Stumps (Stems / ha)	55.00 ± 8.96	182.00 ± 24.19
	BA (m^2/ha)	1.28 ± 0.24	4.03 ± 0.64
	Volume (m^3/ha)	7.11 ± 1.18	19.62 ± 2.58

Source: Luoga *et al*. (2002)

At Mbwewe, standing crop in the forest reserve is double that of the woodland on general land in all the size classes distribution (Table 5). There were 16 and 14 new stumps per ha (approximately the annual wood removals) in general land and forest reserve respectively. Most of the individual trees cut were for charcoal since most of them were found near kiln sites.

3.3 Removal intensity

The harvesting intensity estimated from new and old stumps revealed that there is more harvested wood in general land (19.6 $\pm$ 2.6 m^3/ha) than in the forest reserve (7.1 $\pm$ 1.2 m^3/ha) (Table 5). The largest amount of wood harvested in both general land and forest reserve is for charcoal, followed by land preparation for agriculture in general land and firewood in the forest reserve (Luoga *et al.*, 2002). Nduwamungu (1996) estimated an average of 12 stems per ha with dbh greater than 20 cm of species suitable for charcoal removed annually in miombo woodlands of Kitulangalo SUA Training Forest Reserve. Most of these trees cut were intended for charcoal production and were mainly from *Julbernardia, Combretum* and *Brachystegia* species.

3.4 Growth rate and sustainability

Currently, regeneration is mostly through natural regrowth, largely through coppice and root suckers (Luoga *et al.*, 2004). In Mbwewe however, there are a few planted tree species in general land. The Mean Annual Increment (MAI) for the period of three years (1996-1999) is 2.35 $m^3 ha^{-1} year^{-1}$ in the forest reserve. For disturbed woodlands in Tanzania, however, Nilsson (1986) and Temu (1980) estimated an annual growth rate of 1-2 $m^3ha^{-1}year^{-1}$. This is in line with a mean annual fuelwood increment of 1.96 $m^3ha^{-1}year^{-1}$ in dry miombo reported by Chidumayo (1988). However the rate is contrary to that provided by Malimbwi *et al* (1994) of 0.54 $m^3ha^{-1}year^{-1}$ for regrowth miombo woodland and 7.4 $m^3ha^{-1}year^{-1}$ together with 7.3 $m^3ha^{-1}year^{-1}$ in the old growth miombo and semi-evergreen miombo, respectively. Small coverage of the study by Malimbwi *et al.* (1994) may have been the source of the discrepancy, but also the results caution against applying existing growth rate data in new locations due to the high variation that may exist between different miombo ecosystems.

The estimated annual removal of 6.38 m^3/ha/year in general land (Table 6) greatly exceeds the mean annual increment (MAI) which is estimated to be 2.3 m^3/ha/year in the Kitulangalo SUA training forest. Thus interventions are needed if sustainability of forest product supply from woodland on general land is to be achieved, assuming removals are on annual basis and land is scarce.

3.5 Changes in standing stock as an indicator of ecological degradation

The distribution of stem numbers, basal area and wood volume by distance from the highway for the tree species and sizes used for charcoal making in the public land is shown in Table 7.

Table 7 Distribution of stocking, basal area and wood volume by distance from the highway in public lands.

Distance from the highway	N Stocking Number ha^{-1}	G Basal area m^2ha^{-1}	V Volume m^3ha^{-1}
At road side	2480	5	22
5 km away	2029	7	48
10 km	819	6	50
15 km	365	7	61

Both volume and basal area are increasing with distance from the highway while stem numbers show a reverse trend. More stem numbers observed at roadside indicate regeneration of the woodland following cutting for various purposes including charcoal making. Miombo species regenerate largely through coppice re-growth and root suckers rather than seeds (Chidumayo & Frost, 1996, Luoga *et al.*, 2004). The forest conditions at about 10

.

and 15 km away from the highway are comparable to those of the forest reserve.

Among the species found in Kitulangalo area, *Acacia polyacantha subsp. campylacantha* (Muwindi) seems to be the most dominant species at the road side for trees > 10 cm dbh. The species is a pioneer and not suitable for charcoal as its charcoal easily breaks down into small pieces during transportation. Also its thorny stems make it unattractive to handle. *Sclerocarya birrea* (Mng'ongo), *Diplorhynchus condylocarpon* (Mtogo) and *Spirostachys africana* (Mharaka) are the dominant tree species at 5, 10 and 15 km away from the highway, respectively. Neither *Sclerocarya birrea* nor *Spirostachys africana* are suitable for charcoal production. Although *Diplorhynchus condylocarpon* is listed as a charcoal species it is not frequently used because of its charcoal produce a lot of smoke.

Table 8 shows the distribution of stem numbers, basal area and volume by size of exploitable trees for charcoal at various distances from the highway. The overall trend suggests that the woodland at roadside has been depleted, probably mostly for charcoal extraction because of easy accessibility compared to far distance woodlands from the highway. Eighty percent of the interviewed respondents said that the distance from where they were doing charcoaling has increased, and about the same proportion of the respondents said they move to the next kiln site due to scarcity of preferred tree species for charcoal. The remaining proportion of respondents (20%) might have stayed to browse whatever tree of preferred species that attained exploitable size for charcoal making. Almost all the respondents in the studied area said tree cover is thinner today than 10 years ago due to charcoal making activities in the area. Sixty seven percent of respondents in Bana, Mbwewe, and Kitulangalo areas also believed that charcoal is scarce today than ten years ago as a result of depletion.

Table 8 Distribution of tree species of suitable size for charcoal making in the public lands.

Distance	DBH classes						***Total***		
	10 – 20 cm			>20 cm					
	N	G	V	N	G	V	N	G	V
Road side	5	0.05	0.29				5	0.05	0.29
5 km	106	1.68	11.06	12	0.50	4.20	119	2.18	15.27
10 km	90	1.64	11.23	35	2.48	23.96	125	4.13	35.19
15 km	59	0.97	6.5	45	3.00	28.01	103	4.00	34.55

N : Stocking number ha^{-1}; G : Basal area m^2ha^{-1};V : Volume m^3ha^{-1}

Table 9 Time lapse for degraded woodland to recover for charcoal production.

Distance / Location	Present exploitable volume (m^3/ha)	Years to attain forest reserve situation	Volume to be attained (m^3/ha)	Years to attain situation at 10 and 15 km in public land	Volume to be attained (m^3/ha)
Forest reserve	53				
Road side	0.3	23	53	15	35
5 km	15	16	53	8	35
10 km	35	8	53		
15 km	35	8	53		

3.6 Potential of the woodland to produce charcoal

From Table 8, the weight of charcoal that can be extracted from the woodland at the roadside is 0.29 m^3ha^{-1} (fresh wood) x 0.85 $tonsm^{-3}$ x 0.19 $charcoalbiomass^{-1}$ = 0.047 $tonsha^{-1}$ or 47 kg of charcoal, equivalent to only about one bag of charcoal per hectare. Similarly 46 bags may be expected at 5 km distance while 106 bags may be extracted from beyond 10 km from the highway

It is clear that, the general lands from 5 km away from the highway and the reserved forest have progressively higher potential of producing charcoal compared to the woodland in the public land at road side. Knowing that the woodland growth potential is 2.35 $m^3ha^{-1}year^{-1}$ and that the desirable forest condition for charcoal making is that of the forest reserve which has an exploitable volume of 53 m^3ha^{-1} (cf. Table 9), the general forest lands management 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:

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

where n is the number of are years for the forest to grow before harvesting
'Y' is the desired forest situation with Y m^3ha^{-1}
'Z' is the forest with Z m^3ha^{-1}needed to attain a desired situation and
2.35 ($m^3ha^{-1}year^{-1}$) is the volume mean annual increment

Based on the above formula, the time needed for the degraded woodland to attain harvestable status, i.e. the forest conditions of the forest reserve with 53 m^3ha^{-1} of preferred tree species for charcoal making, will be about 23 and 16 years for the woodland at roadside and at 5 km away from the highway, respectively (Table 9). This suggests that for the woodland at 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 within shorter cycles of 8 to 15 years.

3.7 Woodland change

3.7.1 Land cover change between 1991 and 1998

Much of the charcoal that enters the city of Dar es Salaam comes from the closed and open miombo woodlands and to some extent bushland. In eastern half of the study area, woodland was the dominant cover in 1991, occupying a total area of 300 000 hectares or more than half (54%) of the total land surface (excluding water) (Table able 10). Out of the woodland, 180 000 hectares (33%) were covered with open woodland while closed woodland covered 120 000 hectares (21%). Bushland covered 27% of the area.

Table 10 Areal extent of land use/cover types in the study area in 1991

Cover class	Area in Hectares	Percentage
Open woodland	183 000	33%
Bushland	152 000	27%
Closed woodland	119 000	21%
Mixed cultivation	60 000	11%
Distortions	14 000	3%
Grassland/fallow	12 000	2%
Annual cultivation	5 900	1%
Thicket	4 900	0,9%
Mangrove forest	4 100	0,7%
Bushed grassland	3 500	0,6%
Sand soils	1 800	0,3%
Bagamoyo Town	300	0,1%
Plantation	200	0,04%
Thicket w/t emergent trees	0	0,0%
Total	560 400	100%

In 1998, however, bushland had become the dominant cover type occupying 220 000 hectares representing 41% of the total land surface (Table 11). Woodland covered 190 000 hectares (1900 km^2) representing 35% of the total land area. Out of these, closed woodland constituted 91 000 hectares (17%) while open woodland covered 99 000 (18%).

Table 11 Areal extent of land use/cover types in the study area in 1998

Cover type	Area in Hectares	Percentage
Open woodland	99 000	18%
Bushland	223 000	41%
Closed woodland	91 000	17%
Mixed cultivation	94 000	17%
Distortions	9 100	2%
Grassland/fallow	3 200	0,6%
Annual cultivation	2 700	0,5%
Thicket	3 500	0,6%
Mangrove forest	4 100	0,7%
Bushed grassland	19 000	3%
Sandy soils	400	0,1%
Bagamoyo Town	300	0,1%
Plantation	300	0,1%
Thicket w/t emergent trees	500	0,1%
Total	549 600	100%

Changes in land use/cover between 1991 and 1998 are presented and summarized in Figure 2 and Table 12. Comparison of 1991 and 1998 Landsat TM imageries for the eastern half of the study area has shown a tremendous change of land use/cover over the years. Woodland has decreased while bushland, bushed grassland and mixed cultivation, show a tremendous increase in a real extent. Similar observation have been found by Luoga *et al.*, (In press). Other cover categories, which have undergone a negative change, are grassland/fallow and annual cultivation.

Both open and closed woodland decreased between 1991 and 1998. Open woodland experienced the highest annual rate of loss while the rate for closed woodland was. A similar trend has been observed in the Chongwe area in Zambia with woodland cover having decreased at a rate of 3.2% p.a. with the highest rate of change of 8.8% occurring in Munga woodland (Chidumayo, 1988). Thicket and grassland also decreased while bushland, bushed grassland and mixed cultivation increased.

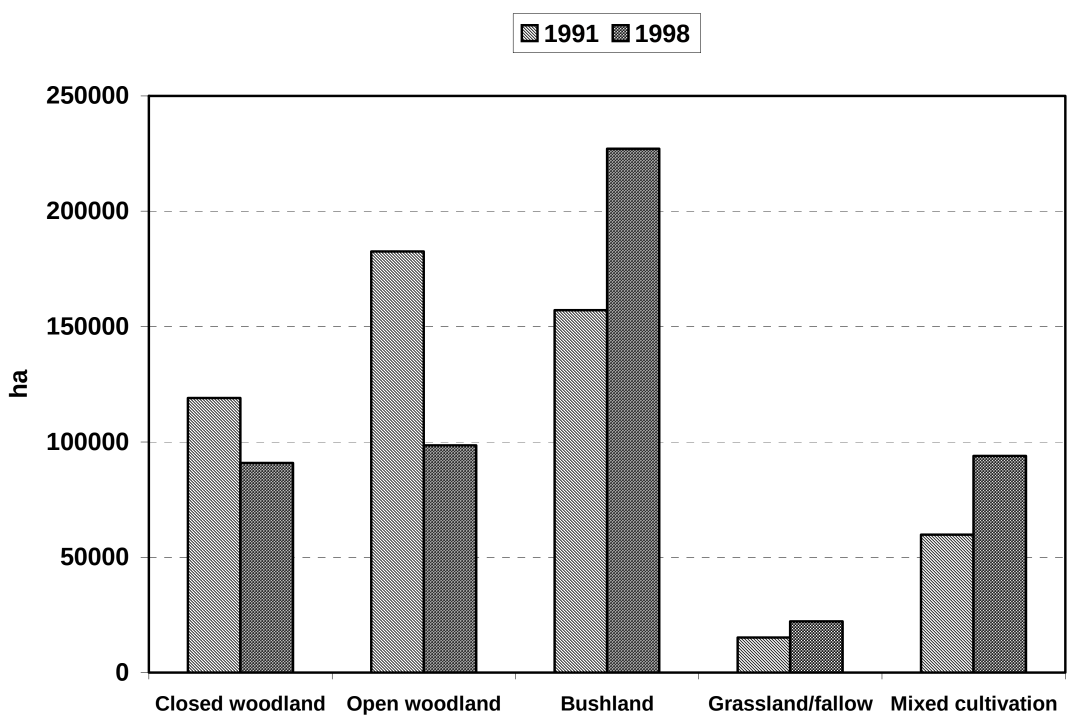

Figure 2 Land cover changes in the study area (1991-1998)

In order to reveal the actual succession of cover types, a change detection matrix was prepared as shown in (Table 12). This reveals that much of the closed woodland has been converted to either open woodland or bushland and other cover types, including cultivation. Out of the original 119,000 hectares of closed woodland in 1991, less than half has remained unchanged (most of this is in protected forest reserves and areas that are not easily accessible), while 25% had been degraded to open woodland and 20% to bushland by 1998. 6000 hectares (5.0%) had been converted to mixed cropland, which is a mixture of annual and tree crops as well as remnant trees of the original vegetation. A similar trend can be seen in the open woodland category where only 43600 hectares (24%) of the 183 000 hectares present in 1991 remained in 1998. Almost half of the open woodlands had been transformed into bushland while 9% had been converted to mixed cropland. On the contrary, only 2348 hectares (1.3%) reverted to closed woodland.

Other significant changes can be observed in bushland category where 7% reverted to closed woodland and 12% to open woodland by 1998. 4% were converted to bushed grassland and 7% mixed cultivation during the same time period while 67% remained unchanged.

The results of this study revealed that much of the woodland in the study area has undergone transformation through the processes of deforestation, degradation and regeneration. Deforestation has resulted in changes from closed and open woodland to bushland, bushed grassland and cultivation. Degradation on the other hand has led to modification of the existing closed woodland cover to open woodland through deterioration in density and structure of vegetation cover. Even in those areas that have remained relatively unchanged (such as in forest reserves), some modification is taking place due to encroachment for charcoal production. This is typical of miombo woodlands in Southern Africa where there is very little unmodified miombo, even amongst the most intact woodlands.

3.7.2 Reasons for changes in woodland cover.

The woodlands in the study area have experienced highest rates of degradation and deforestation compared to other cover classes. This could be attributed to selective cutting for timber and clear-felling of trees for both charcoal production and cultivation. Charcoal production is responsible for degradation of 30 000 hectares (25%) of closed woodland and deforestation of 23 000 hectares (20%) of closed woodland and 93 000 hectares (51%) of open woodland It will be noted that where there is bushland, most of it is regenerating from coppice, indicating that trees had been cut, most probably for charcoal production. Typical of such areas are the areas around Mboga and between Lugoba and Msata, which are characterized by regenerating Combretum bushland. These areas are believed to have had trees in 1970s-80s but were clear-felled for charcoal production. The regrowth was cut again for charcoal in 1990s.

Table 12 Land use/cover change detection matrix for the study area 1991-1998

	Closed nd 1998	Open nd 1998	Bushland 998	Grassland 998	Mixed ion 1998
Closed woodland 1991	55 000	29 000	25 000	1 000	6 000
Open woodland 1991	2 300	44 000	88 000	6 000	16 000
Bushland 1991	12 000	19 000	106 000	7 000	10 000
Grassland 1991	100	200	1 300	12 000	600
Mixed cultivation 1991	0	0	100	4 000	61 000

These results clearly indicate that charcoal production has been a major source of woodland degradation and deforestation. This was also confirmed by 75% of the respondents in Mbwewe, Bana and Kitulangalo areas during the socio-economic survey (Table 13).

Table 13 Observed activities contributing to woodland degradation in the study area

Activity	Percentage
Charcoal making	75
Timber	12
Agricultural expansion	7
Others	6
Total	**100**
Source: Field survey data, 1999.	

Although cultivation has been a major source of woodland change and deforestation in Southern Africa, its contribution in the study area has been negligible compared to charcoal production between 1991 and 1998. Only 5% of the closed woodlands, 9% of open woodland and 7% of bushland have been converted to mixed cultivation, and much less to annual cultivation.

The trend in this study may be explained by the fact that most of the areas where trees are cut are not converted to cultivation; instead they are left to regenerate. This was also confirmed by 75% of the charcoal makers in Kitulangalo, Bana and Mbwewe areas who reported that they were not converting the woodlands to farms after charcoal making. Only 15% used previously charcoal extracted areas for farming. This practice gives room for woodlands to regenerate into secondary woodlands. In Bana area no agricultural activities are allowed as the woodland is owned by the government. A recent Ruvu fuelwood project is operational through community involvement where a household is allocated 3 hectares of the degraded central government forest to intercrop fast growing exotic hardwood for fuelwood production with agricultural crops such as cassava and maize. Tree species planted were *Eucalyptus camaldulensis* and *Acacia spp*.

Regeneration seems to have taken place in areas where trees were previously cut for charcoal production with no subsequent cultivation. Most of the regeneration is from coppicing and root suckers. Miombo species regenerate largely through coppice regrowth and root suckers rather than seeds (Robertson 1984 in Campbell 1996, Luoga *et al*., 2004). Chidumayo (1988), observed that stumps of almost all Miombo woodland trees have the ability to produce sucker shoots. Though also seeds of majority of miombo trees and shrubs germinate immediately after dispersal when there is enough moisture, tree density in regrowth Miombo woodland decreases with time due to moisture and heat stress. When roots are not disturbed, there is reasonable regeneration from root suckers producing bush fallows.

3.8 Conclusion

This study demonstrated that charcoal production and cultivation have an impact on large-scale deforestation that has occurred in the area between 1991 and 1998. Tree species suitable for charcoal production have been depleted at the roadside and the average distance to charcoal production sites has increased. Tree cover is worse today than ten years ago due to charcoal production. These observations have wide policy implications, given the increased demand for charcoal from the growing urban population with no reliable and affordable alternative sources of energy. Only 74% of the closed and 54% of the open woodlands, remain relatively unchanged; most of these were in forest reserves. However, these areas were also undergoing modification due to encroachment for charcoal, timber and other forest products.

It is true that in the absence of any further disturbance after tree cutting, the areas may progressively revert to woodland.

However, in the face of increased population and the demand for agricultural land, such areas may not be given enough room to regenerate. This calls for appropriate management strategies to ensure regeneration so that the remaining woodlands continue to supply charcoal to Dar es Salaam city and other urban areas. This study has shown that substantial regeneration has occurred in areas previously cut, if they have not been converted to farmland. This increases the potential of the regrowth woodland to supply charcoal over a much longer time period.

Acknowledgement

This study was achieved with the financial contribution to Charcoal Potential in Southern Africa (CHAPOSA) by the European Commission and co-ordinated by Stockholm Environmental Institute (SEI) according to the contract N. IC 18-Ct98-0278. The authors acknowledge 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

Campbell, B.M, 1996. *The miombo woodland in transition: woodland and welfare in Africa*. CIFOR, Bogor, Indonesia, 266 pp

Chidumayo, E,N., 1988. Early post-felling response of Marquesia woodland to burning in Zambia Copperbelt. *Journal of tropical Ecology* **4**, 361-372.

Chidumayo, E.N. & Frost, P., 1996. Population biology of miombo trees. In: B.M. Campbell (Ed). *The miombo woodland in transition: woodland and welfare in Africa*. CIFOR, Bogor, Indonesia, 266 pp

Chidumayo, E.N., 1991. Woody biomass structure and utilization for charcoal production in a Zambian Miombo Woodland. *Bioresources Technology* **37**, 43-52.

Hurskainen, R. 1996. Privatization of public forest land. Towards solving the deforestation problem in Tanzania. Kansantaloiden Suuntautuumisvaintoehto, Helsingin Kauppakorkeakoulu, Universititas Economica Helsingiensis, 137, pp.

Kaale, B.K., 1998. *An overview of the Energy sector in Tanzania and the Involvement of women as compared to men*. Tanzania National Consultation workshop on woman and sustainable energy. TaTEDO, Dar es Salaam, Tanzania, 13 pp. Unpublished.

Malimbwi, R.E., Solberg, B. and 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.

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.

Monela, G.C. & Kihiyo, V. B. M. S., (1999). Wood Energy in Sub-saharan Africa. In: Palo, M. & Uusivuori, J. (eds). *World Forests, Society and Environment.* Kluwer Academic Publisher, London. 153-160.

Moyo, S. O., Keefe, P. & Sill, M., 1993. *The Southern Africa environment: Profiles of the SADC Countries*. Earth-scan, London. 256 pp.

Nduwamungu, J., 1996. *Tree and shrub diversity in Miombo woodland: A case study at SUA Kitulangalo Forest Reserve, Morogoro, Tanzania*. MSc. dissertation, SUA, 135 pp.

Nilsson, P. 1986. Wood - the other energy crisis. In: J. Boesen, J. Alarenik, R. Odgaard (ed), *Tanzania - crisis and struggle for survival*. Scandinavian Institute of African Studies, Uppsala. 267 pp.

Robertson, E.F. 1984. *Regrowth of two African woodland types after shifting cultivation*. Ph.D. thesis, University of Aberdeen, 210 pp

SADC, Energy Sector, 1993. *Energy Statistic's Year Book for 1991*. TAU Luanda, Angola. 110 pp.

Sawe, E.N. & Meena, J.S., 1994. *Utilization of proven R & O results a case of TaTEDO improved charcoal stoves and ovens*. TaTEDO, Dar-es-salaam, Tanzania, 12 pp.

Temu, A.B., 1980. *Miombo woodland inventory design, a response to fuelwood scarcity in Tabora, Tanzania*. Unpublished PhD Thesis, University of Dar es Salaam, Tanzania. 175 pp.

URT, 1992. *Natural Environment Policy*. United Republic of Tanzania, the Planning Commission, Dar es Salaam. 58 pp.

URT,1998. *Tanzania forestry policy*. Forestry and Beekeeping Division, Ministry of Natural Resources and Tourism, Dar es Salaam. 59 pp.

Zahabu, E. 2001. Impact of charcoal extraction on the miombo woodlands the case of Kitulangalo area, Tanzania. Unpublished MSc. Dissertation, SUA. 109 pp.

.

URT, 2001. Tanzania National Forest Program, Ministry of Natural Resources and Tourism, United Republic of Tanzania (URT), Dar es Salaam.

Luoga, E.J., Witkowski, E.T.F. and Balkwill, K. 2000. Economics of charcoal production in miombo woodlands of eastern Tanzania: some hidden costs associated with commercialization of the resources. *Ecological Economics* 35: 243-257.

Luoga, E.J., Witkowski, E.T.F. and Balkwill, K. 2002. Harvested and standing wood stocks in protected and communal miombo woodlands of eastern Tanzania. *Forest Ecology & Management*, 164: 15-30.

Luoga, E.J., Witkowski, E.T.F. and Balkwill, K. 2004. Regeneration by coppicing (resprouting) of miombo (African savanna) trees in relation to land-use. *Forest Ecology & Management*, 189: 23-35.

Luoga, E.J., Witkowski, E.T.F. and Balkwill, K. In press. Land use and Land cover changes in relation to institutional framework and tanure of land and resources in eastern Tanzania miombo woodlands. Environment, Development and Sustainability.