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Research and development for sustainable management of semi-arid miombo woodlands in East Africa

Martti Varmola, Sauli Valkonen and Sirkka Tapaninen (eds.)

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Abstract

MITMIOMBO – Management of Indigenous Tree Species for Ecosystem Restoration and Wood Production in Semi-arid Miombo Woodlands in Eastern Africa – is a two-year project partly funded by the European Commission (FP6, INCO/SSA). It has six participant organizations: Finnish Forest Research Institute (METLA; FIN) (Coordination), University of Joensuu (UJOE; FIN), Swedish University of Agricultural Sciences (SLU; SWE), Sokoine University of Agriculture (SUA; TNZ), Tanzania Forestry Research Institute (TAFORI; TNZ), Tanzania Association of Foresters (TAF; TNZ).

The MITMIOMBO project is a small-scale effort to explore and experiment with tools that forest research can provide for development and extension efforts in semiarid miombo woodlands. This target has been pursued through joint application of state-of-the-art research methods and the interaction and dissemination of knowledge with researchers, professionals and local stakeholders for addressing management challenges involving indigenous stands. Major results of the activities are presented in the papers included in this publication. Experiences with methodologies applied in studies based on data from the experimental plots near Morogoro, Tanzania, are presented and assessed with future applications in mind. Results on the structure and dynamics of the stands as well as tree increment and its periodicity are presented. Experiences gained through extension and interaction with representatives of local communities and stakeholders about forest management are summarized. In review papers, current issues and future pathways towards sustainable management of miombo woodlands in Tanzania and beyond are addressed, including charcoal and biofuel production, water and nutrient balances, and economics.

Keywords

forest ecosystems, forest management, semi-arid, silviculture, tropical forestry, woodlands

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Evaluation of tree species enumerated in Kitulangalo Mitmiombo plots by uses and benefits

Mathew A. Mndolwa[1], Luther L. L. Lulandala[2] and Elisha Elifuraha[1]

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A study to get peoples' use patterns and perceptions of different tree/shrubs uses and benefits was conducted at Kitulanghalo Forest Reserve (Tanzania) in three MITMIOMBO demonstration plots. All trees in the plots were identified by local botanists and verified botanically by experts for easy marching of uses. Guided questions were used to collect data from main stakeholders and local experts. Secondary information was obtained from the existing literature. Ranking was used to analyse species uses/benefits. The highest priority was ranked 5 and lowest 1 while 0 indicated not known. Nine tree species were categorized as most desirable, 45 as desirable species and 18 less desirable ones. Many trees had multiple uses with medicinal use ranking high (87.7%). This was followed by firewood (75.3%), poles (71.2%), food and fodder (61.6%), charcoal (58.9%) and timber (25.7%). Removal of trees for timber, charcoal and fodder are heavily fueled by good infrastructure to the Dar Es Salaam city which provides readily market. The major use (83%) indicated in less desirable tree species was medicinal values. Observations made in this study are specifically for Kitulaghalo area and can not be applied in other places as preferences may differ from place to place. However, it provides a guidance of what to be done especially when thinning is considered as one of the management approach in miombo woodland.

Keywords: Kitulangalo, uses and benefits, multiple use

1 Introduction

Trees/shrubs have different uses/benefits depending on time, location and culture. Variations in uses of tree products from miombo woodlands depend on the priority of the product in contribution to household economies. For example, Monela et al. (2000) showed that households living in miombo woodlands in Tanzania derive more than 50% of their cash incomes from selling of different forest products such as vegetables, honey, wild fruits, charcoal, firewood and timber. Importance of each of these varies from one local community to another. Increase in population and technology have brought about more variation in uses of miombo trees. Through these, trees which were formally considered not useful in terms of size and quality are presently been taken on board.

There is a very big range of tree uses such that it becomes very difficult to have one tree with only one use. Mbuya et al. (1994) grouped these uses into five use/benefit groups (Table 1).

Table 1. Summary uses of trees uses and benefits.

Major group	Uses/benefits
Wood	Firewood, charcoal, timber/furniture, poles/posts, flooring/paneling, roof shingles/ beehives, veneer, tool handles, carvings, utensils, pulp, fiberboard, boat building
Food	fruits/food/nuts, vegetable, flavouring, drink and medicines
Fodder	Fodder and bee forage
Environment	Shade, ornamental, mulch, nitrogen fixation, soil conservation, soil improvement and wind break
Other uses	Fiber/weaving/rope, thatch/roofing/mats, resin/gum/glue/latex, basketry, tannin/ dye, toxin/insecticide, cosmetic/soap/perfume, live fence/dry fencing, ceremonial/ boundary marking, toothbrush/stuffing

Source: Mbuya et al. 1994

This causes a very big problem when one needs to categorize or prioritize uses of the same tree. It is also true that the priority use of particular tree in one community may not be the same in another community.

Communities within miombo woodlands have limited alternatives for energy and are also limited in terms of income generation activities. This leads to different experiences in the needs and use of miombo tree species. However, different uses of the woodland may lead to change of the vegetation out of which change in preferences and priorities may occur. To ensure good management and sustainable production in miombo woodlands, one needs to know the priority use of different trees in that particular area. It was the objective of this study to get peoples' experiences, perceptions and use patterns of different tree uses in miombo woodlands at Kitulangalo Forest Reserve. This is very important especially when one considers thinning or removal as one of the management approach. The obtained information will contribute in how the miombo products and services can be optimized and the same time ensure their sustainability and stable ecosystem.

2 Methods

2.1 Study area

The study was conducted at Kitulangalo Forest Reserve in the three MITMIOMBO demonstration plots. The physical and climatic conditions of Kitulangalo Forest Reserve are as reported elsewhere (Petro et al. 2005).

2.2 Data collection

All trees in the demonstration plots were identified by local botanists and marched with botanical identifications. Identification using local botanists was important as local people know the importance of these trees reflected by their physical observation or names. Guided questions were used to collect data from main stakeholders participating in management of the demonstration plots and some other local experts who are familiar with the forest ecosystem. Secondary information from the existing literature was used to confirm the information.

2.3 Data analysis

Ranking was used to analyse species uses/benefits. The highest priority was ranked 5 and the lowest 1 while 0 was used for no particular use. Group consensus was used to attain the end results.

3 Observations

Three categories of preferences (most desirable, desirable and less desirable) were used to group uses and benefits. A total of 73 tree and shrubs species were identified in the demonstration plots. Few (9 species) were categorized as most desirable, 46 species as desirable species and 18 as less desirable ones. Just like in many other places, many trees at Kitulangalo demonstration plots do not have one specific use. Luoga (2000) found a total of 133 tree species in Kitulagalo Forest Reserve of which 69% had a variety of uses. There is no formal way of categorizing tree uses within miombo. For example, Luoga (2000) indicates over twelve uses of miombo trees in the Eastern Tanzania. Summary of percentages of trees found in demonstration plots grouped per particular use is as shown (Table 2).

Table 2. Percentages of tree species found in MITMIOMBO demonstration plots in different use groups.

Major use	Percentage of total number of tree species
Timber	25.7
Charcoal	58.9
Firewood	75.3
Food and fodder	61.6
Medicines	87.7
Poles	71.2

It is clear that many trees have medicinal values. These are followed by firewood, poles, food and fodder, charcoal and timber. However, these uses do not reflect what is actually happening on the ground. This is due to the fact that for some uses like medicines, food and fodder in many cases it is not the whole plant/tree which is removed but only part or its products. While, for the case of uses like timber and charcoal production whole trees are usually cut. The major tree uses in the area which have considerable impact are extraction for timber, charcoal, firewood and poles. It was observed that priority trees for timber in the area include *Julbernadia globiflora* and *Pterocarpus angolensis* which are very common timber trees within miombo (Frost 1996). High ranking trees for charcoal production include *Julbernadia globiflora, Acacia nigrescens, Brachystergia spiciformis, Brachystergia boehmii* and *Combretum molle*. Rampart use of *Julbernadia globiflora* and *Brachystergia* in charcoal production in miombo woodlands is also reported by Abdallah and Monela (2007). Other tree species heavily extracted for charcoal in miombo include *Pterocarpus angolensis* and *Afzelia quanzensis* (Abdallah and Monela 2007). Priority trees for firewood production in Kitulangalo, include *Julbernadia globiflora, Brachystergia spiciformis, Brchystergia* *boehmii* and *Combretum molle*. Important trees for poles include *Pterocarpus rotundifolius* var *polynthus* and *Spirostachys africana*. Despite the fact that tree sizes and quality are important factors in allocating different tree species into different uses (Nshubemuki and Mbwambo 2007) this has been changing with time. Because of present technological development many trees of different sizes can now be easily included in charcoal production. This brings about the problem of sorting out particular trees and sizes for charcoal production. At the same time priorities of these species change with time.

It was observed in the study area that the same trees which are heavily removed for charcoal are also removed for fuelwood. Removal of these trees are heavily fueled by the location of this particular area as it is well connected to Dar Es Salaam city which provides readily market for these forest crops. Increasing removal of trees for charcoal, timber and poles have a potential negative effect on the woodland ecosystem. According to Chidumayo (1991) the unique ecosystem of the miombo woodlands is currently undergoing various forms of degradation related to human activity. Of these, charcoaling and fuelwood collection for both domestic and marketing, and land clearing for agriculture rank high.

A few species (18) which have been indicated to be less desirable may actually be very important ecologically. This is because ecological balance in arid and semi-arid environments in which miombo trees are is delicate. Sometimes trees physical uses are not reflected to be related to other growths and associations with the others which may be seen less desirable. As former superior trees get finished people have tendency of going to inferior ones. This means the priority tree for certain use today might not be the same tomorrow. In this category (less desirable) almost none has been indicated to be useful for timber and charcoal. The major use (83%) indicated in the less desirable species was on medicinal values. Use of these trees for the purpose might have no direct impact ecologically and they might fall victims of been first considered for thinning/removal.

4 Conclusions

Observations made in this study are specifically for Kitulangalo MITMOMBO demonstration plots area and can not be applied in other places as preferences may differ from place to place. However, it provides a guidance of what one has to expect from miombo woodland areas. In any case application of thinning as one of the management approach has to bear this consideration and approach.

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Structure and dynamics of miombo woodland stands at Kitulangalo Forest Reserve, Tanzania

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The purpose of the study was to assess the feasibility of the empirical individual tree-level, spatially explicit research approach, combined with experimental silvicultural treatments, to study stand structure and dynamics under miombo conditions. Additionally, preliminary results on key structural and dynamic features of the experimental stands at Kitulangalo Forest Reserve, Tanzania are presented based on a short (12-month) observation period. Stand structures were very complex with species, tree size and tree location intermixed in various ways. Trees of the highly desirable, primary timber species constituted a majority (55%) of the current standing volumes. Ample regeneration of the primary and other species groups was present. Existing stand structures would probably provide a good starting point for selection silviculture if preferred. The individual tree-level, spatially explicit approach to study stand structure and dynamics seemed to work well. With an observation period of 3–5 years, consequential results can be obtained. Fire must be incorporated in future experimental studies.

Keywords: growth, miombo, regeneration, semi-arid woodlands, stand structure

1 Introduction

Given the vast extent of the ecosystems and their importance in rural livelihood and local economies (cf. Celander 1983, Campbell et al. 1996, Chidumayo 1997, Varmola et al. 2007, Kuutti 2008), the silvicultural information base for the development of feasible management regimes is underdeveloped for Tanzanian and other miombo areas. With a better knowledge base, the true potential of miombo woodlands could probably be harnessed and developed in a socially, economically, ecologically and culturally sustainable way instead of the current extensive exploitation resulting in large-scale degradation and deforestation (cf. Campbell et al. 1996, Varmola et al. 2007). The complex array of uses, products, benefits, goals, and stakeholders makes each management situation and its information needs unique. One of the key questions is which species, types, and sizes of trees to promote, and how to do it in order to establish and sustain a balance of outputs and goals (Abdallah and Monela 2007, Makonda and Gillah 2007, Nshubemuki and Mbwambo 2007, Monela and Abdallah 2007). Research methods applicable to miombo stands with their very large and complex inherent and human-induced variability in structure and dynamics between and within the stands are urgently needed.

Stand structure has three main components: species composition, tree size distribution, and spatial distribution. The number, proportion, and spatial status of individual trees of different species, forms, sizes and canopy layers are the primary components.

Stand dynamics include tree growth, mortality, and regeneration. Knowledge on the growth of trees of different species and sizes, and other attributes controlled by stand density and structure, is essential to the manager of complex stands. Knowledge on the rate and factors of mortality, especially in relation to stand density and structure, are equally important. Regeneration is an essential component of the dynamics of structurally complex stands managed with selection systems or regenerated naturally. Stand structure and dynamics are controlled by ecological site factors and silvicultural treatments.

It is comprehensible that such elements constitute a system where none of the elements is independent of the others. The more complex issues with more interaction and interdependence of the components, the greater the need of more general and flexible analysis tools (like models) becomes. However, the basic structural and dynamic elements are often initially analyzed one by one, providing the basic insight to the key constituent parts on which to built further elaborations. That is the case in this study too.

The purpose of this paper is to
1. Assess the feasibility of the empirical individual tree-level, spatially explicit research approach, combined with experimental silvicultural treatments, to study stand structure and dynamics under miombo conditions.
2. Preliminarily introduce the key structural and dynamic features of the stands encountered on the experimental plots established in the study stands at Kitulangalo, Tanzania. Because the observation period of one year was too short to yield reliable estimates on tree growth, mortality, and regeneration dynamics, the emphasis was on structural elements such as stand density, species distribution, diameter distribution, and the number of saplings currently present. The observation period was too short (one year) to permit but preliminary conclusions on stand properties and management implications.

2 Material and methods

The study area is located at the Kitulangalo Territorial Forest Reserve near Morogoro in Tanzania. It can be characterized as semi-natural dry miombo woodland (precipitation <1000 mm a^{-1}) with some transitional characteristics of the coastal woodland mosaic also discernible. The reserve has existed for 15 years with enforced restrictions on tree harvesting. Prior to that, extensive selective cuttings had been practiced, resulting in substantial forest degradation.

Two stands were selected for a setting of study plots. Each stand has six study plots in within two blocks. One block was fenced and one not fenced. Three treatments were randomly selected on the tree plots of each block: thinning (removal of trees of the least desirable species, about 15% of volume), promotion of regeneration through soil preparation (manual soil workup to 20 cm depth around large primary species), control (no treatment). Fires were prevented from entering the plots during the observation period. Plot size was 30 m * 30 m. A stand had thus 6 * 0.09 ha = 0.54 ha of area within plots, totaling 1.08 ha for the two stands.

All trees breast height diameter (d) ≥ 5 cm were measured for species, coordinates, d, vigor and timber content. Local residents identified the common species names and local taxonomic experts the scientific species names. A sample of trees was measured additionally for height, crown height and width, and timber length. The sample trees were selected randomly within 10-cm diameter classes, weighting larger diameter classes. Regeneration (saplings breast hight diameter < 5 cm and for height ≥ 20 cm) was surveyed on 25 regeneration plots per plot. Regeneration plot midpoints were selected systematically in terms of a 5 m * 5 m grid. The regeneration plots were circles with a radius of 1.1 m. Number of saplings by species were counted, and the individuals were measured for breast height diameter and height. All measurements were repeated 6 (second measurement) and 12 (third measurement) months after the first measurements. Dendrometer bands were installed onto 53 selected tree individuals of 10 most common species to monitor their radial growth. A chance of diameter could be detected with an accuracy of 0.1 mm. Readings were made every second week for one year, starting mid-March, 2007 (cf. Elifuraha et al. in this publication).

Stand structure (diameter distribution, species composition, spatial structure) was assessed subjectively through tabulation and plotting of the data and with visual interpretation. Tree species were grouped into four categories based on market or other value (Nshubemuki and Mbwambo 2007, Mndolwa et al. in this publication). Timber species were assigned to “primary species”, from which *Julbernardia globiflora* was indicated separately in some cases because of its abundance in the stands. “Secondary species” consisted of trees yielding other wood products as poles and charcoal, or second-rate timber, or some other products with market value. “Other species” were seen to have little or sporadic use. The categories and species are presented in Table 1.

Tree diameter-height relationship was described through the application of the Näslund (1936) height model to the sample tree data with nonlinear regression by a variety of species or species groups. Gross stem volume (V) including branches was calculated with the equations of Malimbwi et al. (1994). The Stand Visualization System (McGaughey 2001) was used to illustrate stand structure in three dimensions (cf. Kiluma et al. in this publication). Differences between treatments could not be materialized in such a short time, and little attention was paid on them in this study.

3 Results

3.1 Stand structure

Species distribution

A total of 77 species was encountered on the plots (total 1.08 ha) (Table 1). Of them, 9 belonged to the “primary species”, 45 to “secondary species”, and 23 to “other species”. The “primary species” were rather dominant in the stands: they comprised 55% of the basal area, of which *Julbernardia globifora* was 27%, *Sclerocarya birrea* 11%, *Acacia nigrescens* 10%, and other primary species 7%. Species with individuals with d ≥ 5 cm (“trees”) numbered 32, whilst 45 species appeared only as “saplings” (d < 5 cm).

Table 1. The categories and species represented Kitulangalo Forest Reserve stands plots.

Primary species	Secondary species	Other species
Julbernardia globiflora	*Dalbergia nitidula*	*Catunaregam spinosa*
Pterocarpus angolensis	*Combretum collinum*	*Diplorhynchus comdylocarpom*
Acacia nigrescens	*Combretum molle*	*Bridelia cathartica*
Dalbergia melanoxylon	*Combretum adenogonium*	*Diospyros* sp.
Brachystegia spiciformis	*Acacia* sp.	*Flugea virosa*
Brachystegia boehmii	*A. senegal*	*Asparagus africanus*
Pterocarpus rotundifolius var. *polynthus*	*A. nilotica*	*Mostuaea* sp.
Sclereocarya birrea	*A. robusta*	*Allophylus robifolius*
Spirostachys africana	*A. sieberiana*	*Turraea nilotica*
	Pteleopsis myrtifolia	*Ehretia amoeana*
	Albizia amara	*Ochna moccambiscensis*
	Albizia harveyi	*Hoslundia opposita*
	Albizia vesicolor	*Hibisus micranthus*
	Dicrostachys cinerea	*Acalypha ornata*
	Terminalia mollis	*Rinorea* sp.
	Annona senegalensis	*Harrisonia abyssinica*
	Boscia salicifolia	*Cissus cornifolia*
	Ximenia caffra	*Croton* sp.
	Lannea schimperi	*Brackenridgea zanguebarika*
	Markhamia sp.	*Dalbergia obovata*
	Makamia zanzibarika	*Acacia pentagona*
	Makamia obtusifolia	*Mbena* (only common name could be assigned to this one)
	Lonchocarpus bussei	
	Zahna africana	
	Pseudolachnostylis maprouneifolia	
	Zantoxylum chalybeum	
	Kigelia africana	
	Comiphora africana	
	Dombeya rotundifolia	
	Erthrina abisinica	
	Lamprothamnus zanguebaricus	
	Grewia bicolor	
	Diospyros kirkii	
	Cassia abreviata	
	Mystroxylon ethiopica	
	Senna afro - fistula	
	Lannea schweinfurthii	
	Margaritaria discoidea	
	Burkea africana	
	Ormocarpun kirkii	
	Baphia kirkii	
	Vitex sp.	
	Pterocarpus tincaris	
	Vangueria infousta	
	Mdaa-i (only common name could be assigned to this one)	

Stand density

The average stem number (N; $d \geq 5$ cm) was 544 ha^{-1}. Variation between the 12 plots was small (461–639). The thinning treatment reduced stem numbers by an average 30% on those plots. Changes during the 1-year observation period were small, resulting from slight mortality and very little ingrowth up to the 5-cm class. The initial stand basal area (G) varied from 6.9 to 11.0 m^2 ha^{-1} with an average of 9.3 m^2 ha^{-1}. Thinning reduced it by just 13.5% on the 4 thinned plots. Stand volume averaged 47.7 m^3 ha^{-1} with a variation of 33.6-54.0 m^3 ha^{-1} between plots (Fig. 1). Thinning reduced the volume by only 15.9% on the 4 thinned plots. Net stand volume growth during the one-year observation period was negative (average –1.09 m^3 ha^{-1} $year^{-1}$): mortality had exceeded growth. This was mainly due to the death of one large tree (d = 61 cm) in the Control treatment in Stand 1. That plot set aside, the average growth rate was +0.98 m^3 ha^{-1} $year^{-1}$.

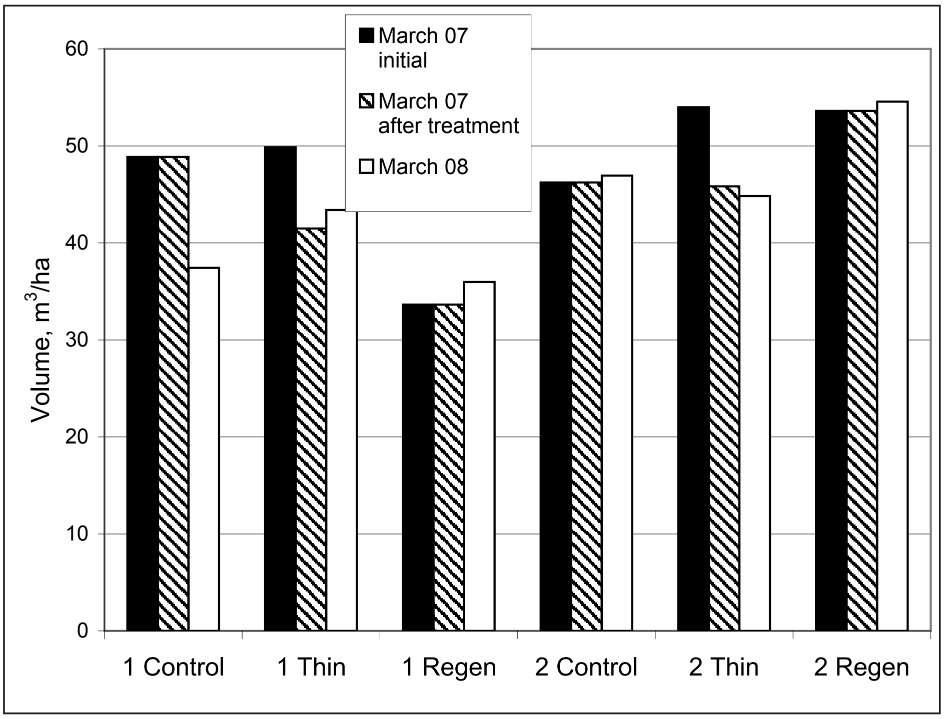

Figure 1. Stand volume by stands, treatments, and measurements (1st and 3rd).

Diameter distributions

The diameter distributions of the stands resembled those of uneven-aged stands with a constant reduction towards the larger classes (Fig. 2). There seemed to be rather many small and few large individuals, respectively. It is noteworthy that there were less than 50 stems ha^{-1} of trees with $d > 20$ cm on average. The largest tree was 62 cm in diameter.

Spatial structure

An example in Fig. 3 illustrates that the spatial stand structures were truly complex with a high degree of variation in tree sizes, gaps and denser parts, and species admixtures within a small scale. Distinct canopy layers could not be detected.

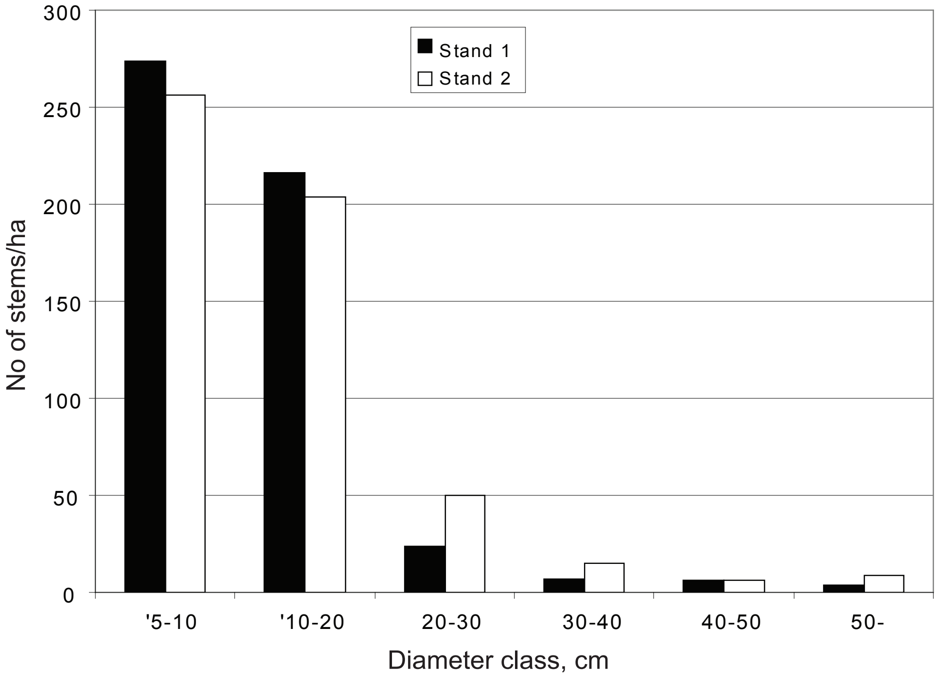

Figure 2. Diameter distributions (10-cm classes) by stands.

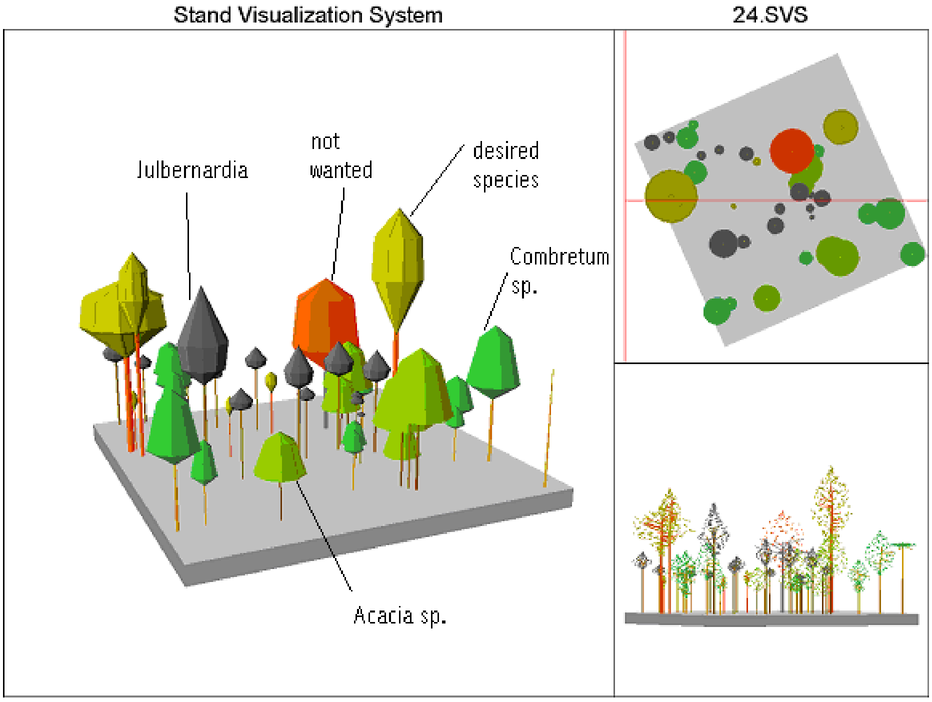

Figure 3. Stand spatial structure illustrated with the Stand Visualization System (McGaughey 2001). Stand 2, Plot 4.

3.2 Tree growth

Observations on tree diameter growth (i_d) during the one-year monitoring period were derived from repeated caliper measurements for all trees and girth bands attached to 46 sample trees. Due to the initial settling period of the girth bands, those growth band observations included an element of systematic error of unknowable magnitude (see Nöjd et al. in this publication). Thus the current 12-month observations could not be used for growth studies. A large component of measurement error was included in the observations from the caliper measurement. Only exploratory analyses were possible. The basic relationships between tree growth, its size, and stand density were probably realistic, at least in form (see Valkonen et al. in this publication). An exploratory sketch of the form of one relationship is shown in Fig. 4. The maximum diameter growth rate was observed at about 20–40 cm of diameter. The largest trees grew very slowly in comparison.

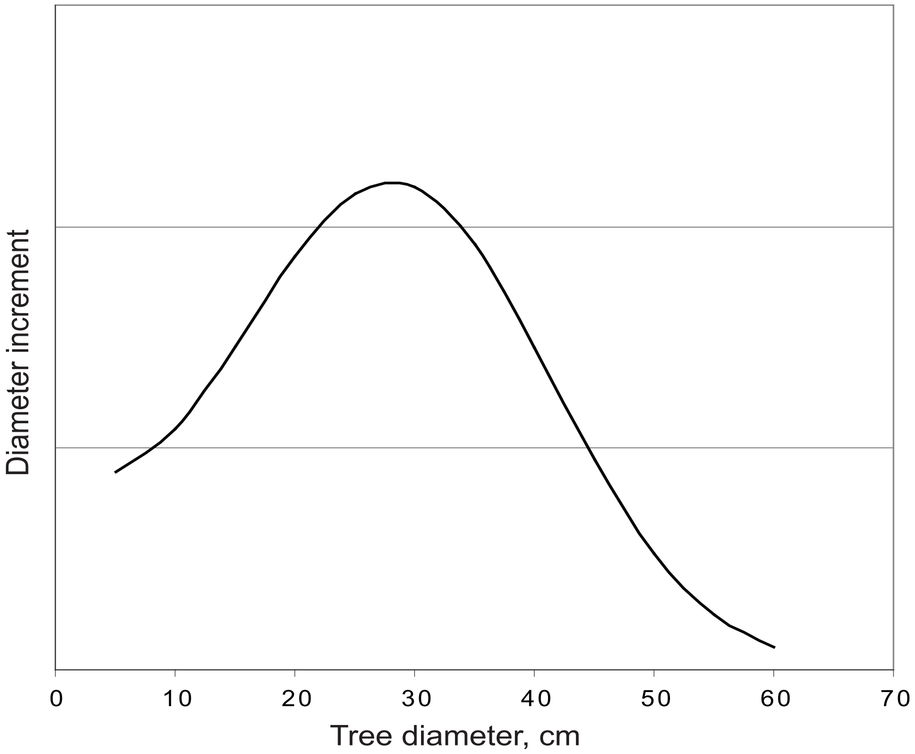

Figure 4. Relationship between tree size and its diameter increment according to the experimental model constructed on the plot data. For details see Valkonen et al. in this publication.

In general, the average annual diameter increment of miombo trees has varied between 1.8 mm to 7.0 mm in various studies (cf. Kuutti 2008, p. 46–47).

Tree height data would be useful in studies on stand dynamics, because mutual shading is closely correlated with height differences. However, good height increment data is very difficult to obtain for the flat-topped miombo trees. This problem was clearly exhibited in the repeated measurements data from the plots. The observation period was only 12 months, and tree growth was very slow compared to measurement errors. Consequently, any relevant analysis was impossible with the data (see Valkonen et al. in this publication). For basic description purposes, it is often sufficient to study the height-diameter relationship of the trees. There is a strong correlation between

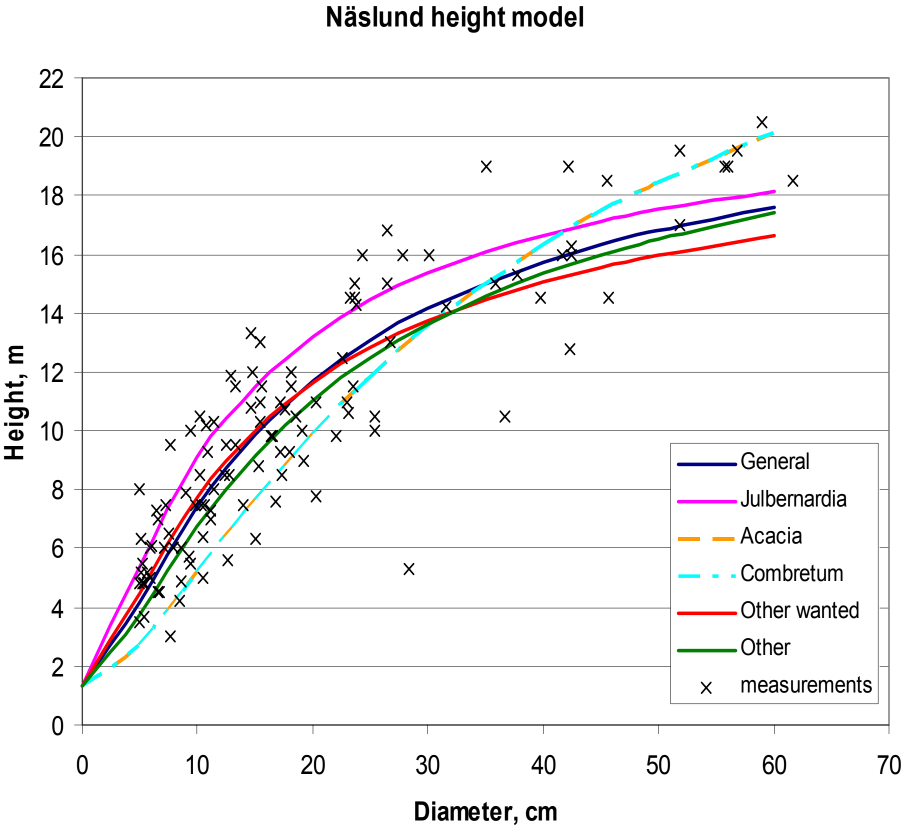

Figure 5. Relationship between tree diameter and height on the study stands. Observations and height curves (Näslund 1936) by species groups.

tree diameter and height within a species that heights can be estimated with sample trees and models (h = f(d)) in most applications. The relationship may vary between species, due to differences in inherent growth patterns and competition between trees. On the study plots, the height curves of the major species and species groups were rather similar (Fig. 5).

3.3 Regeneration

The average number of saplings (h > 20 cm, d < 5 cm) throughout the study stands was 29 000 ha^{-1} seedling in the first measurement. Of that, 10 900 was *Julbernardia*, 1 400 other primary species, 11 000 secondary, and 5 700 ha^{-1} other. The figures had changed only marginally from the first to the third measurement one year later. However, the site preparation treatment seemed to have resulted in enhanced emergence of seedlings and sprouts, but they were still less than 20 cm high and thus not measured. For practical management purposes, the proportion of stocked area is at least as essential parameter as the total number of stems. It was described as the number of regeneration plots (each 3.80 m^2) with at least one sapling of a species or species group present. 67% plots were thus stocked with *Julbernardia*, 34% with other primary species, 74% with secondary species, and 56% with other species. A more elaborate analysis on regeneration is presented in Piiroinen et al. in this publication.

4 Conclusions

Stand structure parameters (species distribution, N, G, V, diameter distribution) were fully in line with those observed in previous studies in the Kitulangalo Forest Reserve and dry miombo in general (cf. Isango 2007, Kuutti 2008). The plots were thus successfully established in stands representing the Kitulangalo Forest Reserve. Stem number seemed to represent the higher end of the range in dry miombo, but basal area and volume were not higher than average, respectively. Smaller trees are more dominant in Kitulangalo than elsewhere, and there are relatively few large trees (d > 20 cm) there, much less than what was observed by Isango (2007) for relatively less disturbed miombos in Iringa area. Kitulangalo is an area of regrowth miombo still in the process of recovery from past selective cuttings 15 or more years ago. The abundance of *Julbernardia* regeneration provides further support for that proposition. The diameter distributions resembled those of uneven-aged stands managed with selection systems. However, since the actual tree ages were unknowable, any conclusions on the actual age structure of the stands would be unjustifiable.

Stand structures were very complex with species, tree size and tree location intermixed in various ways. Trees of the highly desirable, primary timber species constituted a majority (55%) of the current standing volumes. A very minor part of the trees was estimated to have little or no use as wood or non-wood materials or services. It seems that the existing stand structures would provide a good starting point for selection silviculture if preferred. A further asset in that respect is that there is ample regeneration present of the primary and other species groups. It must be borne in mind though that each species may have a specific regeneration strategy and reproductive mechanisms, which must be attended to in management if the species is to be retained or promoted. It is not only products and services that count, and ecological sustainability, including diversity of species, is a value in itself.

The applied treatments (thinning, site preparation) were just a demonstration of some factors of potential interest for future studies targeting ways of rehabilitating degraded lands. Practical treatments are to be designed based on real objectives and expected effects, which are highly variable between and specific to stands, areas, communities, ecologies anthropogenic disturbances etc. The thinning treatment influenced stand structure directly on the 4 thinned plots. However, it was a very light thinning (30% of N, 15.9% of V) and consisted mainly of smaller trees of the undesirable species. The intensity was too low and the observation period too short for the thinning to show up in any way in tree growth and stand dynamics. Due to the death of one large and several smaller trees, stand volume growth was negative during the one-year period. This emphasizes the necessity of acquiring data from a much longer observation period and on a larger number of plots for growth studies. Soil treatment seemed to have promoted regeneration, but this was not captured in the sapling survey results. The emerging seedlings were still smaller than 20 cm in height, and were thus not measured. The absence or presence of fires, including prescribed burning as a tool, is a major dynamic aspect that needs to be incorporated in future experimental studies.

The individual tree-level, spatially explicit approach to study stand structure and dynamics seemed to work well in this case. The preliminary results were consistent, despite the short observation period. With an observation period of 3–5 years, consequential results can be obtained.

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Application of modeling to study tree diameter growth in miombo woodland stands at Kitulangalo Forest Reserve, Tanzania

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Results of a preliminary effort to apply empirical modelling to a preliminary tree increment data from study plots at Kitulangalo Forest Reserve in Tanzania are presented. Quality of data from a 12-month observation period from caliper and permanently attached girth band measurements as well as height measurements was assessed. Rudimentary models for tree diameter increment were constructed and applied for exploratory analyses on tree growth patterns. The exploratory exercise indicated that the empirical modelling approach can be applicable in miombo conditions. In this case, the one-year observation period was far too short to produce real increment data for genuine modelling work; periods of 3–5 years would be required.

Keywords: growth, miombo, regeneration, semi-arid woodlands, stand structure

1 Introduction

The true potential of miombo woodlands to provide resources and services on a sustainable way could probably be harnessed and developed through the utilization and management of the existing indigenous stands. To develop successful management guidelines for a great variety of situations requires information from all possible sources, including research and practical experience. In the complex stands of miombo woodlands, analysis and research methods are different from those applied to plantation forests. They must be capable of accounting for the inherent and human-induced variability within the stands. They must be able to deal with the variation in characteristics, role, and mutual interaction of individual trees and regeneration. Ecology, site, management, and disturbances all have their influence of both tree and stand level attributes.

Approaches and methodologies of silvicultural and forest growth and yield research applied for structurally complex stands in temperate and boreal forests can in all probability work for miombo stands too. Modelling is currently the state-of-the art approach used in studies on the structure and dynamics of complex stands (cf. Hasenauer 2006, p. 4–5). Methodologies utilizing the **empirical modelling** approach are generally based on data from experimental plots, including elaborate measurements on structurally and functionally important tree dimensions, tree growth, and regeneration. Measurements and analyses are often spatially explicit, i.e. the complex interactions of the various kinds and sizes of trees can be accounted for in terms of the stand structure and its manipulation at the individual tree level. Analyses of such data are most efficiently based on modelling, which, if successful, facilitates interpolation and prediction with the individual models. The next step can be the construction of simulation systems and decision support tools, involving many interdependent models and other elements. Whatever the purpose of a specific study or project may be, modelling is a very useful way of extracting results and constructing tools from empirical data acquired from research plots. Empirical models are attempts to summarize the essentials factors of tree properties in terms of flexible sets of functions with statistically estimated parameters based on knowledge and hypotheses on biological processes (biological realism). Tree growth prediction is the key component in most applications. Generally, tree growth can be consistently and rather comprehensively predicted with a few basic types of variables: species, tree size (e.g. diameter), site productivity (site index or some classification), and competition for resources and growing space (e.g. stand density or individual tree level competition measures). Introduction to the basic features of state-of-the art of empirical modelling is presented in Hasenauer (2006) with current examples.

The purpose of this paper is to present the results and conclusions of an effort to apply empirical modelling to the preliminary tree diameter increment data extracted from the study plots established at Kitulangalo Forest Reserve in Tanzania in terms of the MITMIOMBO Project.

2 Material and methods

The study site is located in Kitulangalo Territorial Forest Reserve near Morogoro in Tanzania. It can be characterized as semi-natural dry miombo woodland (precipitation <1000 mm a^{-1}) with some transitional characteristics of the coastal woodland mosaic also discernible. The reserve has existed for 15 years with enforced restrictions on tree harvesting. Prior to that, extensive selective cuttings had been practiced, resulting in substantial forest degradation.

Two stands were selected for a setting of study plots. Each stand has six study plots in within two blocks. One block was fenced and one not fenced. Three treatments were randomly selected on the tree plots of each block: thinning (removal of trees of the least desirable species, about 15 % of volume), promotion of regeneration through soil preparation (manual soil workup to 20 cm depth around large primary species), control (no treatment). Fires were prevented from entering the plots during the observation period. Plot size was 30 m * 30 m. A stand had thus 6 * 0.09 ha = 0.54 ha of area within plots, totaling 1.08 ha for the two stands.

All trees (breast height diameter (d) ≥ 5 cm) were measured for species, coordinates, d, vigor and timber content. The measurement point was marked on each tree for remeasurement at the same point. A second diameter measurement was taken perpendicular to the first measurement, and diameter was calculated as their average. Local residents identified the common species names and local taxonomic experts the scientific species names. A sample of systematically selected trees was measured additionally for height, crown height and width, and timber length. Dendrometer bands were installed onto 53 selected tree individuals of 10 most common species to monitor their radial growth at breast height. A chance of diameter could be detected with an accuracy of 0.1 mm. Readings were made every second week for one year, starting mid-March 2007.

Tree diameter increment (i_d) was calculated as the difference of the caliper measurement or the difference of the girth band readings (converted to d) of a tree at establishment and 12 months later. Tree height increment for 12 months was calculated from the repeated height measurements, respectively. A visual interpretation with scatter and column plots was first performed to check the basic properties of the data and its validity for modelling. A variety of candidate models with alternative variable recombinations were fitted to the data. The statistical method was mixed linear models. Since the data permitted only preliminary trials, the model structure was kept at a very simple level, including fixed effects plus variance components to account for the hierarchy in the data (trees within plots within stands) (see chapter Models).

3 Tree growth estimation

In the caliper measurement-based increment data, measurement errors were large compared to the real diameter increment during 12 months. Bark peeling and other true but random phenomena may also have contributed. A large component of random error was thus included in each increment observation, making the observations rather inconsistent. This showed up as a number of negative increment estimates (Fig. 1). Similarly, some of the largest increments probably were unrealistic as well.

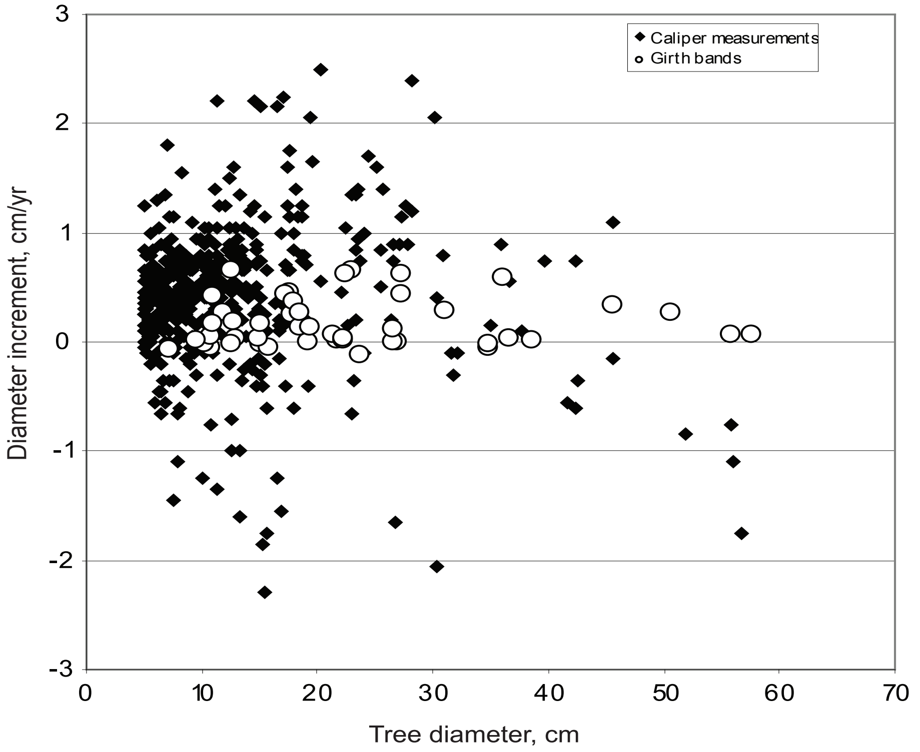

Figure 1. Tree diameter increment observations derived from the caliper measurements (n = 441) and girth bands (n = 46).

The girth band-based data was not free of error either. As shown by Elifuraha et al. (in this publication), the bands needed some time to properly settle on the trunks before starting to reflect real diameter variations, including increment. This means that the observations for the initial months included an element of systematic error, i.e. underestimation of unknowable magnitude (Fig. 1). Thus the current 12-month observations were no more useful for modelling than the caliper-based data, and they were not used at all.

Assuming that the errors with the caliper method were random with no systematic error, a preliminary modelling effort with diameter increment data was considered possible but without any prospects of producing final, utilizable growth estimates.

Height measurements for the flat-topped miombo trees with their convoluted, branching and forking stems with no clear leader shoots also involved a high degree of measurement errors (Fig. 2). Some of the negative height increment estimates were true for trees with their tops broken or died during the observation period. An expected relationship between tree height and height growth was not observable in the data. Modelling efforts for height increment were discontinued.

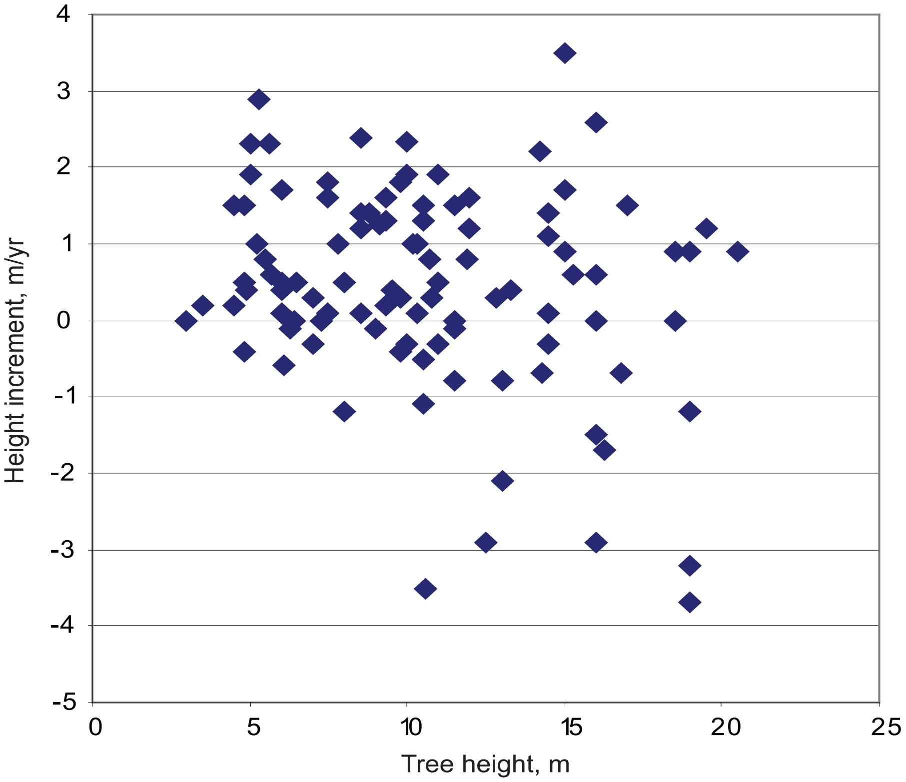

Figure 2. Tree height increment observations (n = 101).

4 Models

Experiments with empirical models were based on two basic hypothetical principles:

1. Tree growth according to tree size generally follows an inherent growth rhythm where small trees rapidly enlarge their metabolic (photosynthesizing) structures and accelerate growth. As their catabolically active structures inevitably expand at an increasing rate, the increment rate culminates at some point, and a decreasing development begins.
2. In addition to its inherent growth rhythm, tree growth is strongly influenced by its competition for resources like light (shading), water, nutrients.
   2 A. The overall density of the stand reduces the average resource availability for all trees.
   2 B. Between individual trees, a large tree closer to a tree competes more intensely than a small tree further away from it.

Tree size was represented by diameter, and stand density by plot basal area (G). The final model form thus became

$$\ln\left(i_{gijk}\right)=b_0+b_1d_{ijk}+b_2d_{ijk}^{\ 2}+b_3\ln\left(G_{jk}\right)+b_4CI_{ijk}+\beta_k+\beta_{jk}+\varepsilon$$

where

i_{gijk} = basal area increment of tree i on plot j in stand k
d_{ijk} = diameter of tree i on plot j in stand k
G_{jk} = stand basal area on plot j in stand k
CI_{ijk} = competition index of tree i on plot j in stand k
$b_{1...4}$ = fixed parameters
β, ε = random parameters for stand and plot level effects and random error

For competition between trees, three alternative competition index (CI) formulations were applied. They were modified from the elementary formulations of Hegyi (1974) and Biging and Dobbertin (1992). They were based on tree size and distance between the competitors, and were tried in candidate models. The maximum distance of inclusion of a tree was $s_{im} \leq 10$ m or 5 m, alternatively. Plot edge bias was controlled with the method of Martin et al. (1977).

1. $CI_{ijk}=\sum d_{mjk}$
2. $CI_{ijk}=\sum\left(d_{mjk}/\left(s_{im}+1\right)\right)$
3. $CI_{ijk}=\sum\left(d_{mjk}/\left(s_{im}+1\right)d_{ijk}\right)$

CI_{ijk} = competition index for subject tree i on plot j in stand k within distance
d_i = diameter of subject tree i
d_m = diameter of competitor tree m
s_{im} = distance from tree i to tree m

Of the alternative CIs, number 2 with $s_{im} \leq 10$ m showed the closest correlation on tree increment and was thus selected.

It must be pointed out that the logarithm transformation, necessary for homogenizing variances, eliminated all negative increment observations that were plentiful in the data (Fig. 1). The measurement errors seemed random, i.e. distributed normally in terms of tree size. Thus the relationship between tree increment and its size can be considered realistic, but the increment itself will be overestimated with the model. The results are thus experimental and preliminary only. For that reason, the parameter values are not published here. Use of the experimental model will be restricted to a few preliminary demonstrations only.

5 Tree growth as predicted with the model

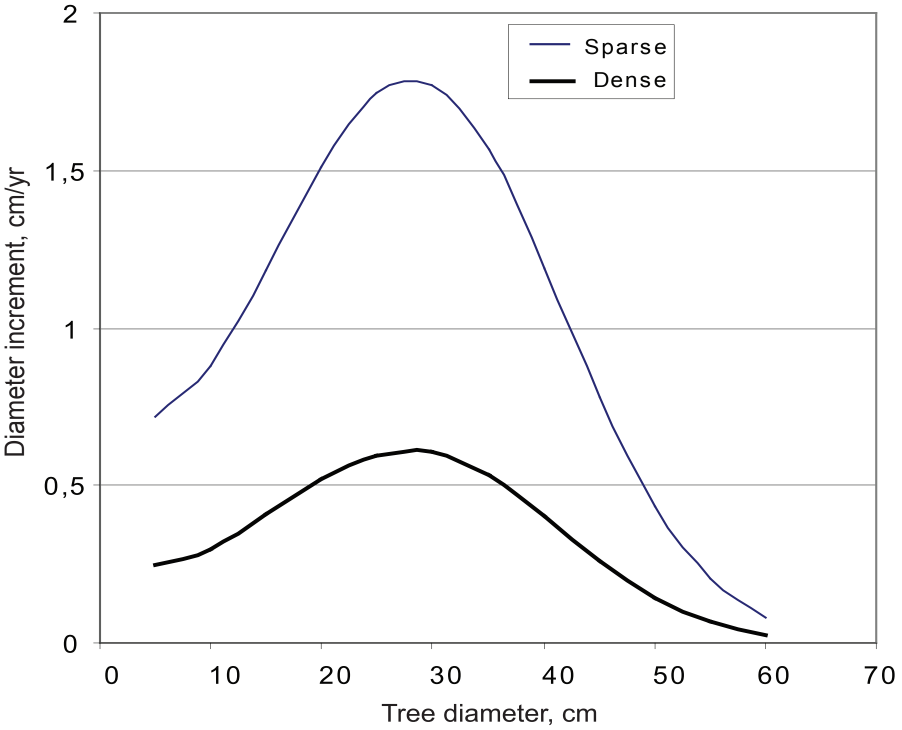

Figure 3. Tree diameter increment tree size and stand density. Stand basal area for “sparse” G = 5 m^2 ha^{-1}, “dense” G = 14 m^2 ha^{-1} (minimum and maximum of study plots, respectively).

The constructed preliminary model was applied to describe tree diameter increment in relation to tree size and stand density. A preliminary result is shown in Fig. 3. The maximum diameter growth rate for was observed at about 20–40 cm of diameter. The largest trees grew very slowly in comparison. Stand density (within the range of variation encountered on the plots) had a very remarkable influence on tree growth in this preliminary calculation.

The preliminary model was also applied to an experimental simulation. The diameter development of a tree initially 10 cm in diameter was projected 20 years at 1-year time steps. The initial stand basal area was set at 10 m^2 ha^{-1}, representing the current average on the plots, and it increased 0.5 m^2 ha^{-1}, also close to the average rate on the plots (Kuutti 2008). Plot average competition index (CI) was similarly set at the average value of 80 in the data, and it increased by an estimated 3 units a year. In the thinning alternative the stand was thinned by removing 30% of G and CI at the beginning and at 10 years. The other alternative was no thinning. The results in Fig. 4 show that thinning can substantially contribute to the diameter development of individual trees. It must be borne in mind that the results are just experimental and presented for demonstration purposes only.

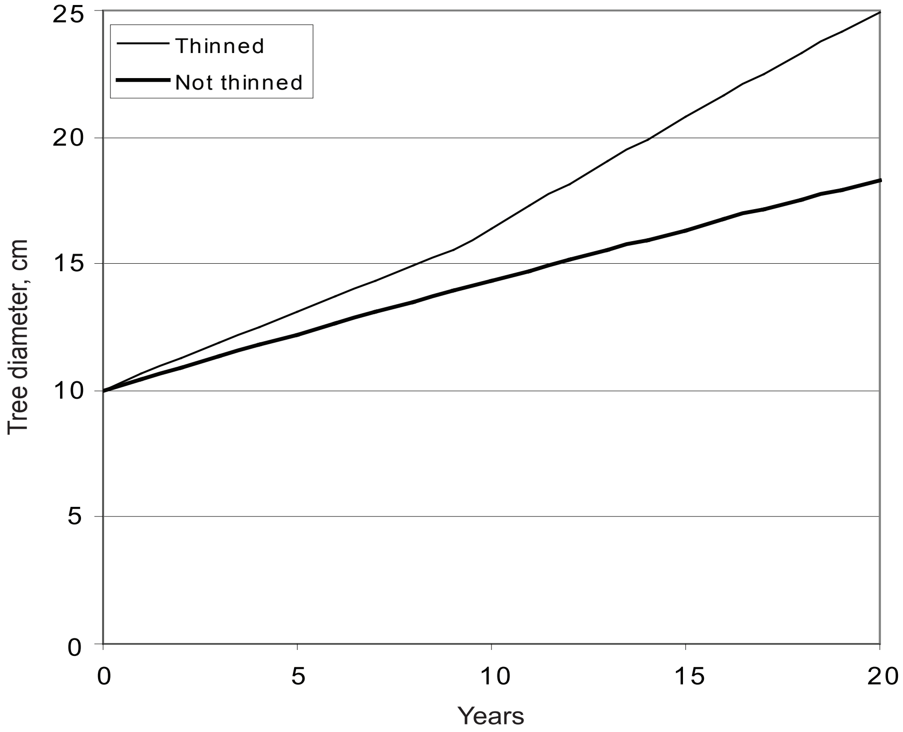

Figure 4. Diameter growth of a 10-cm thick (d) tree during a 20-year simulation period with and without thinning, as estimated with the model.

6 Conclusions

The results and conclusions on tree growth analysis and modelling are preliminary and exploratory due to the weaknesses in the data. The one-year observation period was too short to produce but exploratory increment data. The measurement errors were too big compared to real increment rate. Observation periods of 3–5 years would be required to obtain good data on diameter growth with the caliper method. No more than 18–24 months would be required for the girth band method to produce technically valid data with little systematic or random errors (Elifuraha et al. in this publication). However, longer observation periods would be necessary to account for growth variations between years. One problem is that only a limited number of trees can be monitored with this method. Height measurements for the irregularly shaped miombo trees are so problematic that 5 years would probably be a minimum observation period. This also applies to regeneration, whether measured as ingrowth to the smallest tree diameter class, or emergence of seedlings. The regeneration process is very complex in miombo conditions, influenced by tree species and properties, weather, fire, herbivory etc. (Piiroinen et al. in this publication). The same applies to mortality. However, with large enough data sets (number of stands, number of plots, repeated measurements, observation periods) such data could be acquired. The principle “we learn as we go” would continue to apply for a long time. A good example of an earlier success is the work of Isango (2007) in another area.

The semi-successful exercise with preliminary modelling indicates that the approach (empirical data from measurements on plots, modelling, simulation) can be applicable for miombo conditions. It can be a powerful alternative to the classic experimental approach, where a variety of treatments are established on sets of plots with ample replicates and monitored for years or decades before yielding meaningful results. Of course, a combination of both approaches is often the best solution. In a study with an experimental design like on these demonstration plots, for instance, regeneration treatments could yield valuable data within a few years to be combined with tree growth estimates acquired through modeling within the same time frame.

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Visualization of miombo woodland stands at Kitulangalo Forest Reserve, Tanzania

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The Stand Visualization System (SVS) was used to create graphic images for the miombo stand plots at Kitulangalo Forest Reserve in Morogoro Tanzania. SVS is a program that has been developed by Bob McGaughey of USDA forest service in Washington, U.S.A., for generating graphic images for depicting stand structure and conditions. SVS was used to show the images for all the plots (12). SVS uses a list of stand components and plant form definitions. The stand component list describes the species, size and location of each component in a stand. Plant form definitions describe the appearance of each species and, optionally, the appearance of individuals exhibiting different growth forms within a species. They are highly flexible and adjustable, and rather realistic basic forms could be developed for miombo trees. At Kitulangalo Forest Reserve species categories were developed basing on the use value by the local people and therefore the categories were assigned different colours. Visualization was particularly illustrative in introducing the applied thinning methodology and its influence on the stand structure.

Keywords: stand visualization, miombo, plant form, stand structure

Introduction

Research efforts on experimental plots, as well as estimation and simulation with models, usually produces stand and tree data in numerical form. For experienced practitioners familiar with the local conditions and forests, such data is easily interpretable for considerations on stand structure, dynamics, and treatments. However, complex stand structures shall preferably be observed in three dimensions and taking the individual trees with their highly variable characteristics into consideration. This can be difficult with numerical data only, especially for people with no research or forestry background. Visualization (i.e. the generation of artificial images from the data) can be a very powerful tool in such cases, particularly when working with complex structures. That is the case in miombo woodlands. This is a pilot effort to apply visualization to the data from the experimental plots established at Kitulangalo Forest Reserve, Tanzania, in terms of the MIT-MIOMBO project.

Objectives of the study

- Creating visualizations for our study plots for use by all
- To illustrate stand structure for study and discussion
- Getting to see the effects of thinning treatments
- Learn the technique
- Create a visualization benchmark for Miombo in Tanzania (and beyond)

Study site and plots

The study area is located in Kitulangalo Territorial Forest Reserve near Morogoro in Tanzania. It can be characterized as semi-natural dry miombo woodland (precipitation <1000 mm a^{-1}) with some transitional characteristics of the coastal woodland mosaic also discernible.

Two stands were selected for a setting of study plots. Each stand has six study plots in within two blocks (Fig.1). One block was fenced and one not fenced. Three treatments were randomly selected on the tre e plots of each block: thinning (removal of trees of the least desirable species, about 15 % of volume), promotion of regeneration through soil preparation (manual soil workup to 20 cm depth around large primary species), control (no treatment). Fires were prevented from entering the plots during the observation period. Plot size was 30 m * 30 m. A stand had thus 6 * 0.09 ha = 0.54 ha of area within plots, totaling 1.08 ha for the two stands.

All trees (breast height diameter (d) $\geq$ 5 cm) were measured for species, coordinates, diameter at breast height, vigor and timber content. Local residents identified the common species names and local taxonomic experts the scientific species names. A sample of trees was measured additionally for height, crown height and width, and timber length. The sample trees were selected randomly within 10-cm diameter classes, weighting larger diameter classes. Regeneration (saplings $d < 5$ cm and for height $\geq$ 20 cm) was surveyed on 25 regeneration plots per plot. All measurements were repeated 6 (second measurement) and 12 (third measurement) months after the first measurements.

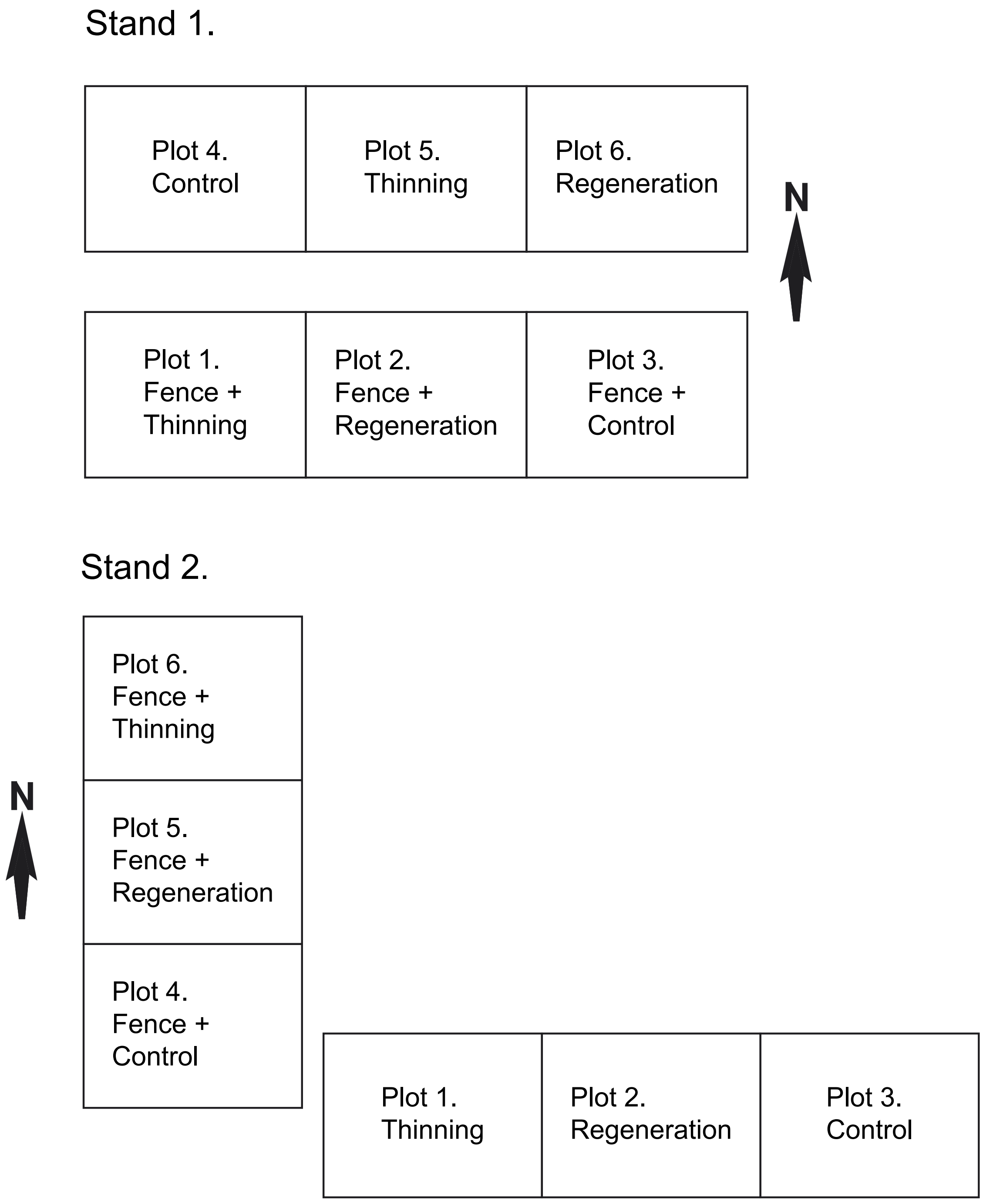

Figure 1. Plot layout.

Data analysis

The SVS software (McGaughey 2001) is currently used for visualizing the structure forest stands by a wide variety of users in many parts of the world in private industry, academics, and research organizations. SVS is a very powerful tool as it has the following capabilities:

- Display overhead, profile and perspective views of a stand.
- Differentiate between stand components using different plant forms, colors, or other types of marking as specified by users.
- Provide a mechanism that allows users to define plant growth form, stem color, and foliage colors based on species, growth form, and plant position within the canopy.
- Provide tabular and graphical summaries of information represented in a stand image.
- Facilitate the design of silvicultural treatments by allowing users to select individual stand components and specify treatments.
- Display information describing individual stand components as they are selected by the user.
- Can be used as teaching tool.

Data requirements

SVS requires two primary types of data: a list of stand components and plant form definitions. The stand component list describes the species, size and location of each component in a stand. Plant form definitions describe the appearance of each species and, optionally, the appearance of individuals exhibiting different growth forms within a species. Trees are depicted using species, diameter, height, crown radius, crown ratio, and many optimal characteristics.

The simplest input suitable for use in SVS consists of a simple stand table describing the species, dbh, height, crown ratio, and density of trees in a stand. The included TBL2SVS utility converts such stand table input into a list of individual components.

Plant form definitions

Users define the appearance of each species represented in a component list using a plant form definition. Form definitions describe the overall growth form; geometry and number of branches or leaves; and color of the stem, branches and foliage. SVS provides a "tree designer" to help users develop form definitions for the species and growth forms in their area. SVS uses the species identifier as the primary link between the component list and the plant form definitions. However, two additional parameters, tree class and crown class, can be used to distinguish individuals within a species. Interpretation and use of these two parameters is under the complete control of the user. SVS reserves the value of 99 for the tree class and crown class to represent a "wild-card" value.

Estimated tree parameters

Tree height models developed by Kuutti (2008, Mbwambo et al. in this publication) were used to predict tree height from diameter, except for sample trees which had been measured for height. Tree crown dimension models were developed, since those parameters had been measured from the sample trees only. They were simple linear models, parameters of which were estimated from the sample tree data with Ordinary Least Squares. Since species differences were small, common functions covering all species were constructed for this purpose. Stand and plot level variations were small and did not require further attention. The crown parameter models were thus of the form

$$y = b_0 + b_1 ln(x) + \varepsilon$$

where
y = dependent variable
x = independent variable
b_i = arameters

Stands visualizations

Stands can be visualized in three forms:

- Over head view – gives a view of the stand from the top
- Profile view – shows a stand outline
- Perspective view – shows side view of a stand.

In Figs 2–8 four shades are used to descibe the tree species as follows:

- Light green: *Julbernaria globiflora* (the most common one of the most preferred species)
- Dark green: Most preferred species (except *Julbernaria globiflora)*
- Yellow: Other preferred species
- Orange: Other species

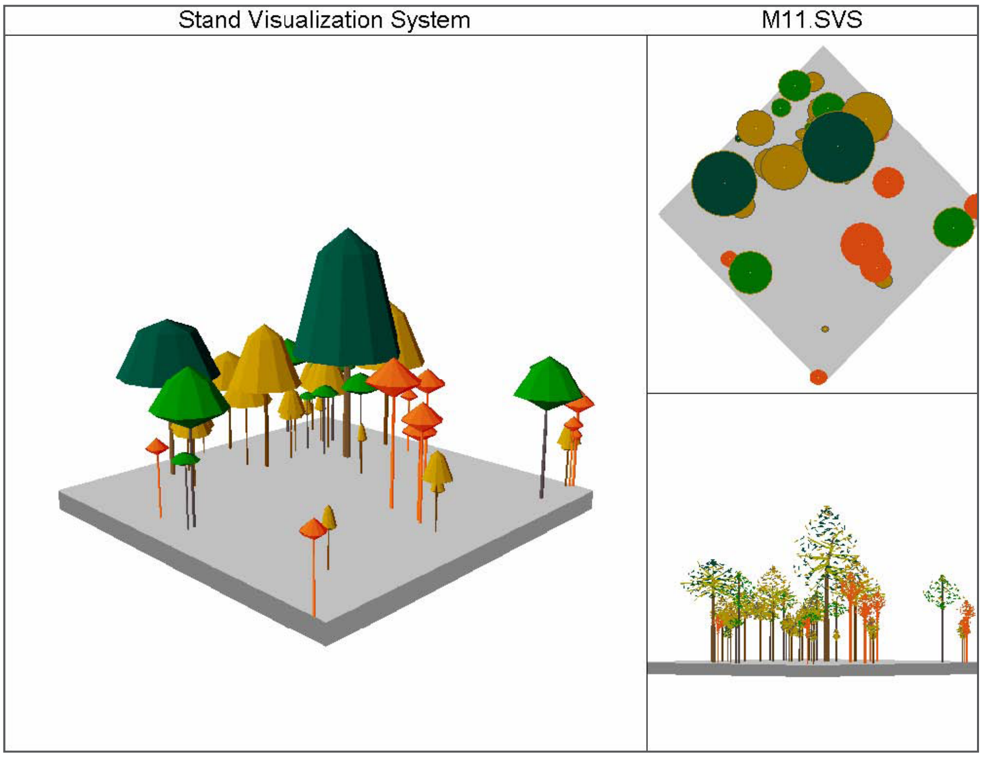

Figure 2. Stand 1, plot 1 before thinning.

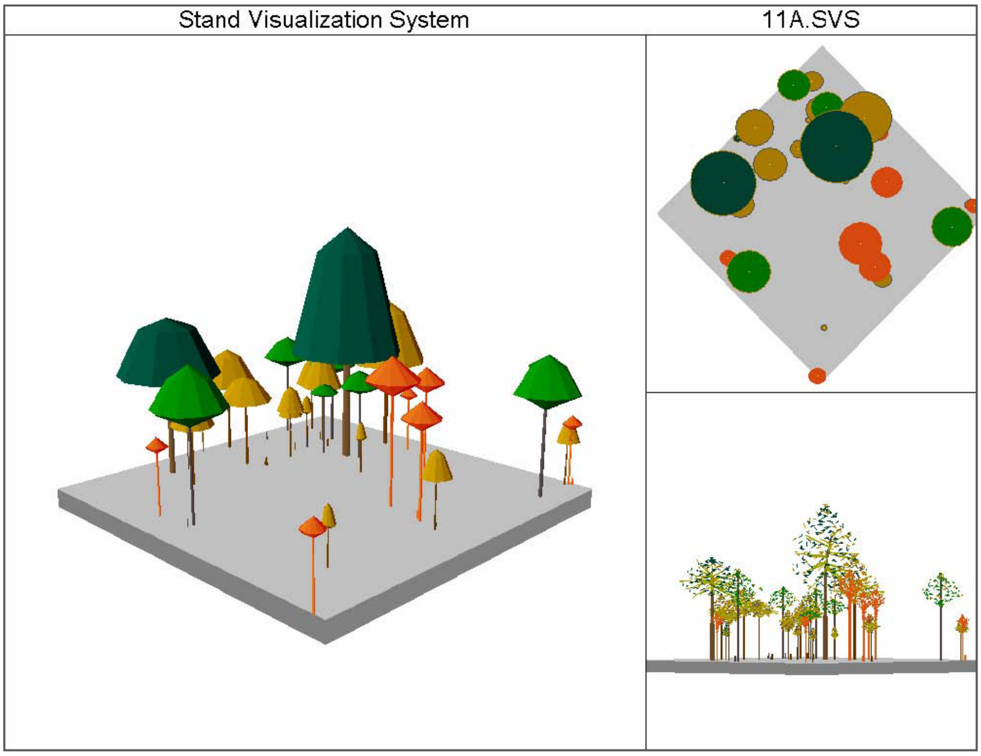

Figure 3. Stand 1, plot 1 after thinning.

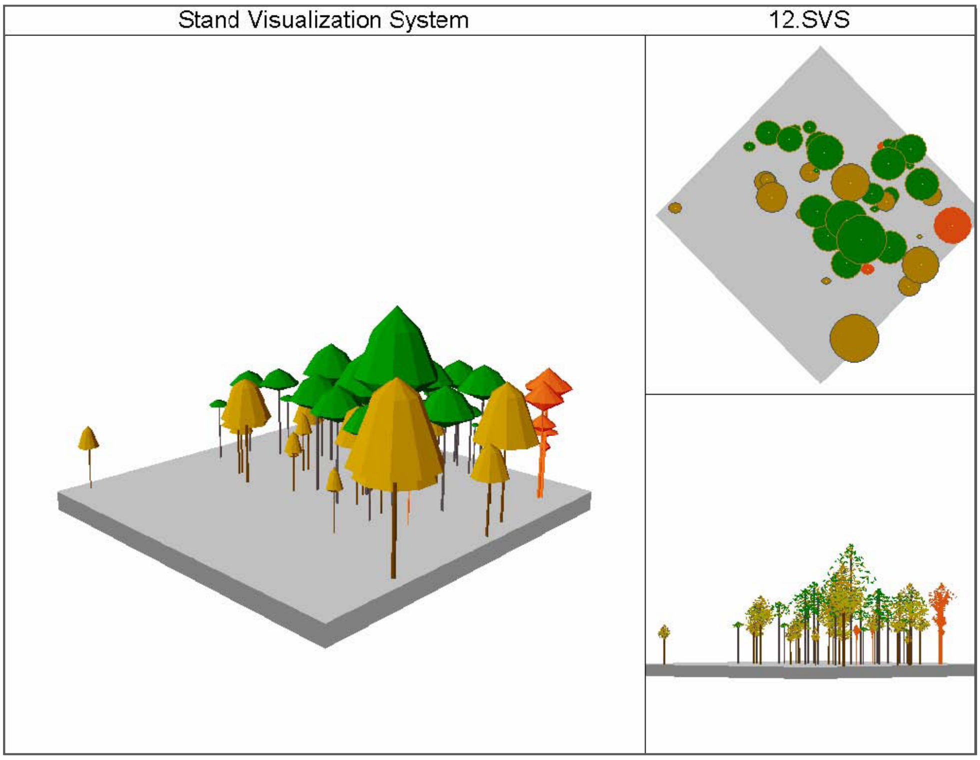

Figure 4. Stand 1, plot 2.

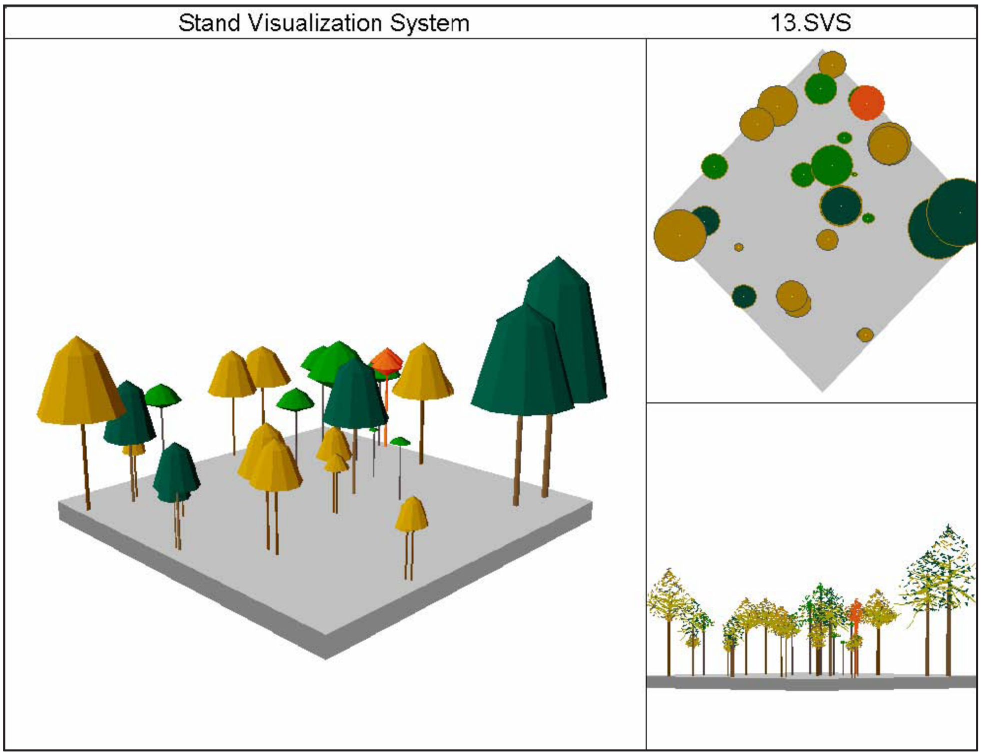

Figure 5. Stand 1, plot 3.

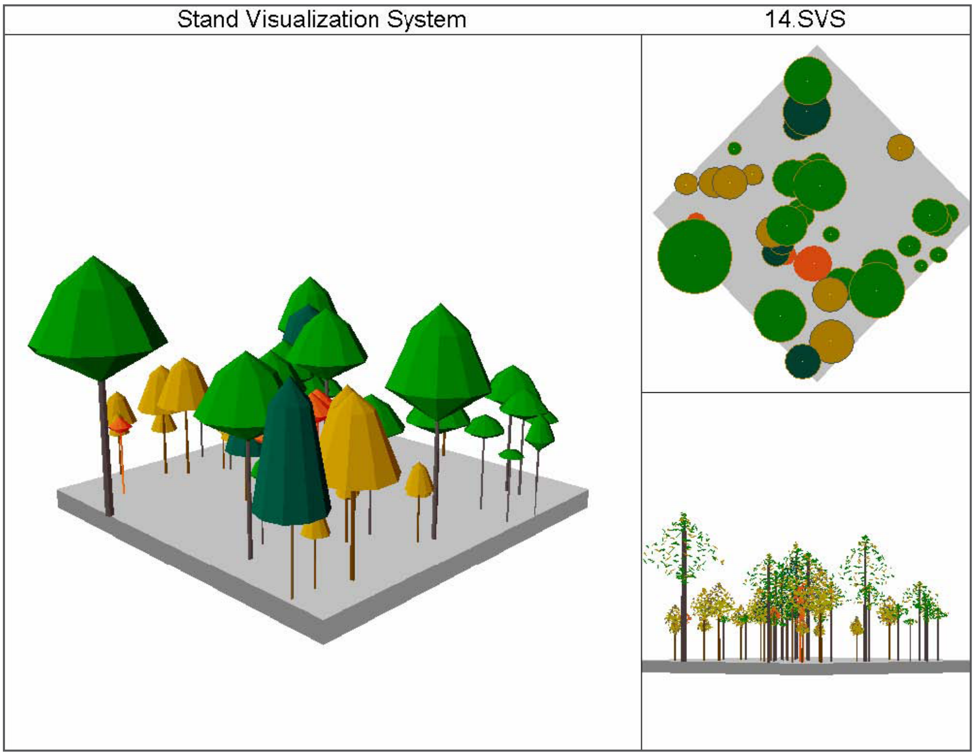

Figure 6. Stand 1, plot 4.

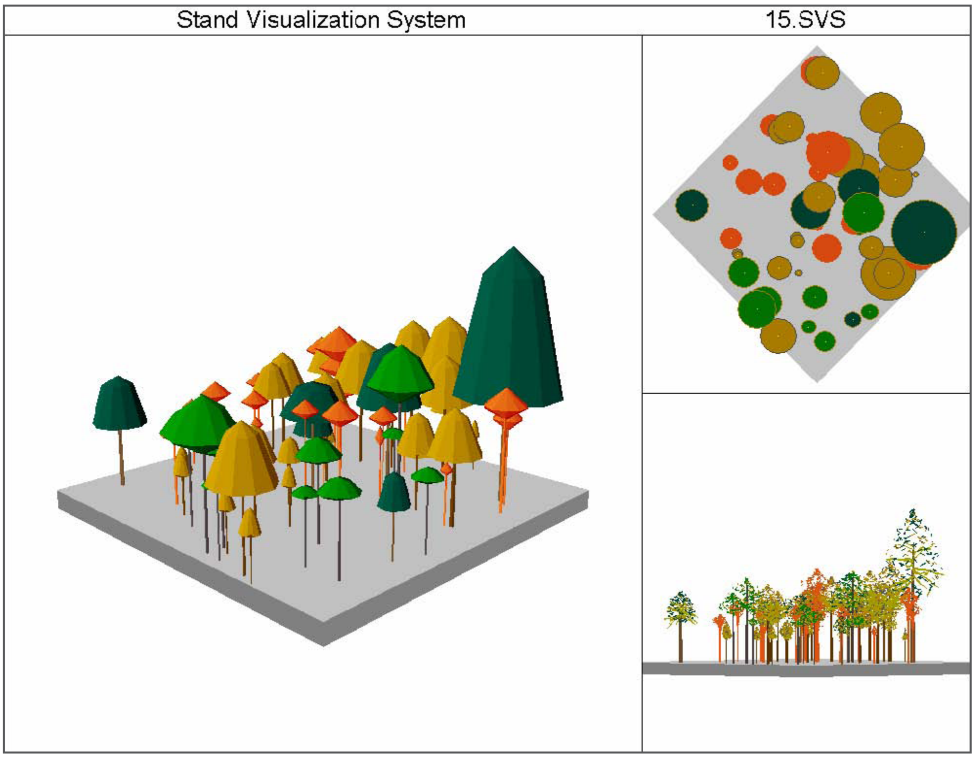

Figure 7. Stand 1, plot 5 before thinning.

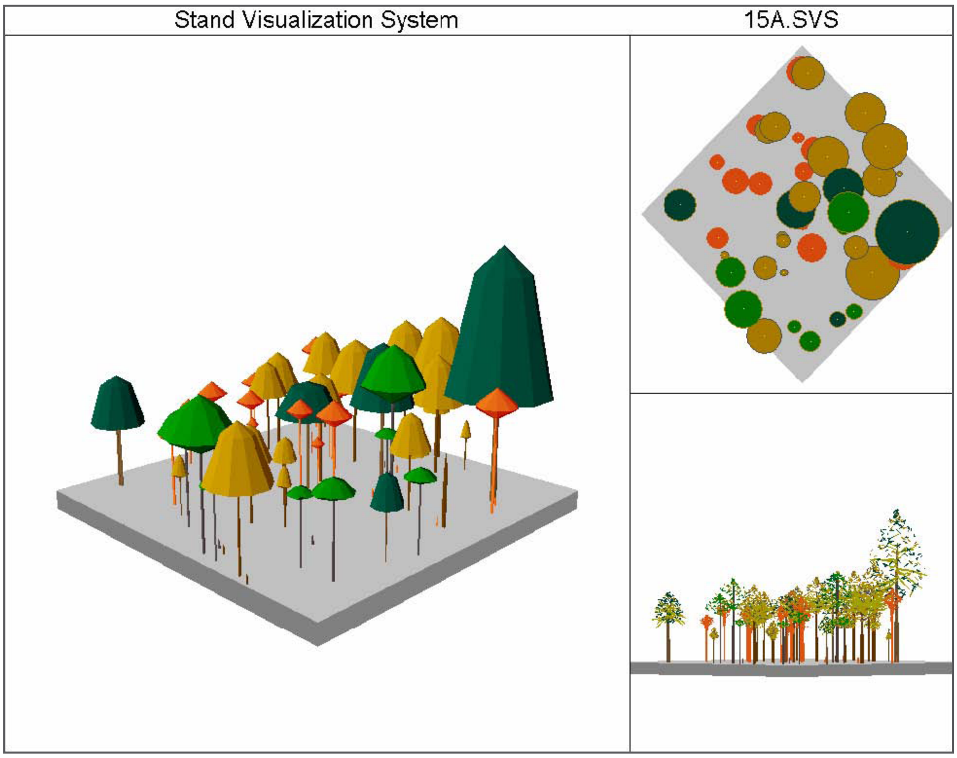

Figure 8. Stand 1, plot 5 after thinning.

Conclusions

SVS is a very flexible system since everything about trees and views can be customized and redrawn so long as there is an availability of spatial measurement data on species, coordinates, diameter and height. It is also easy to measure a few sample trees for crown dimensions, then models can be constructed to predict for those not measured. However, it takes a couple of days to learn the technique and to create realistic tree shapes. Thinning as an effective means of promoting the most desired species of miombo has been demonstrated very well and it can be used for further management of Kitulangalo Forest reserve as shown in the SVS.

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Short term growth of miombo tree species at Kitulangalo

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The short term growth of typical miombo tree species was studied at the Kitulangalo study site of the MITMIOMBO-project. Trees were monitored from July 2007 to July 2008 using manual girth bands, which record the circumference of the tree to within 0.1 mm. The monitored species produced rather varying growth rates and differencess were also observed in the annual pattern of growth. However, the majority of annual increment occurred during a rather short period from February to May, which coincides with the period of heavy rainfall.

1 Introduction

Very limited information is available on the growth periodicity of miombo tree species in Tanzania and also in other regions in Africa with a similar climate (Nobuchi et al. 1995). In tropical regions the pattern of annual growth can be highly variable. Some species may form new woody material more or less throughout the year, while others display an active period followed by a cessation of growth. Even species with a fairly regular pattern of two distinct growing periods each year have been discovered. Worbes (1995) gives a comprehensive review of measuring growth periodicity in the tropics.

Growth periodicity is usually studied using girth bands. A girth band is a measurement tape around the tree stem, which records changes of tree circumference. Attached to a data logger an automatic girth band can collect continuous information with a short time step between measurements. The accuracy is also high (typically 0.01 mm). The draw-backs of the method include frequent technical problems, especially sensitivity to sudden voltage peaks caused by lightning, and the high cost of the equipment. A manual girth band is a cheap alternative yielding measurement results to within 0.1 mm. Their use requires frequent visits to the forest, and thus the time interval between measurements is bound to be longer.

A general disadvantage of the girth band method is that the result does not directly describe the formation of new wood. The circumference of trees also fluctuate due to changes in stem hydrology. This is a severe handicap for girth band studies in regions were trees grow slowly and the annual variation in weather is large. In tropical regions the drawback is less severe, as trees generally grow fast and the annual temperature range is smaller. However, during dry seasons tree stems can be expected to show a temporary shrinkage.

Nöjd and Isango (2003) studied the short-term growth of *Pinus patula*, a species originating from Mexico. Using automatic girth bands they discovered a growth period, which covered most of the year. Only in June-August, a dry and cool season, growth appeared to cease. These results were obtained for an exotic species at a high altitude (2200 m above sea level) and thus cannot be expected to apply for native tree species in different climatic conditions like miombo woodlands. Indeed, Worbes (1995) cites two studies on the growth periodicity of *Pinus patula* in southern Africa, which both yielded quite different results.

We studied the growth of 8 miombo tree species using manual girth bands for a period of one and a half years. We display results on the growth pattern of each species and discuss possible factors and reasons for the observed differences between species. Knowing the pattern of annual growth can be helpful for planning experimental studies, in which tree growth is analyzed using repeated caliper measurements on permanent plots.

2 Methods

2.1 The study area

The study was conducted at the Kitulangalo Forest Reserve, described in more detail in this publication. The site represents dry miombo woodland dominated by tree species such as *Julbernadia* spp, *Brachystegia* spp*, Combretum* spp*, Albezia* spp. etc. The wet season is experienced from mid February to early June. June, July and August are typically dry and cool. The rest of the year remains dry up to mid February. The soil at Kitulangalo forest is black, sandy soil sensitive to drying. The study was conducted on two study plots, separated by a stream of water, which flows seasonally. The structure of the forest stand was complex.

A total of 53 girth bands were mounted to trees. Ten bands disappeared during the monitoring period and some did not show notable changes during the monitoring period, which may indicate that they did not function properly.

2.2 Data collection

The data were collected by reading of the girth bands manually. The data were collected right after the installation of the bands, February 2007. Thereafter the readings were done every 14 days. From February to July 2007 period the bands produced data of dubious quality. A considerable share of the bands produced negative increment for the period. As February 2007 was rainy and June- July 2007 very dry, these results could reflect reality. However, in girth band studies it is common practise (e. g. Keeland and Sharitz 1993) to allow some time for bands to adjust around the tree stems. We therefore present results from July 2007 to July 2008. Some bands showed little change throughout the study period. Likely, those were not succesfully mounted tightly around the tree stem. To demonstrate the type of problems that may occur, those results are included in the graphs we present.

The precipitation data were collected from the Kingolwira weather station that is about 20 km from thestydy stand at Kitulangalo.

2.3 Data analysis

The girth band data were analysed using Microsoft Excel. The girth band trees were sorted species wise. Data on circumference increment was converted to diameter changes. The conversion assumes a circular form of the tree stems.

3 Results

We present results by grouping the data into groups of trees all from the same genus.

Apart from one individual, the *Pterocarpus* sp. (Fig. 1) show relatively slow growth. The diameter of the trees satrted to increase in October 2007, at the time new leaves were formed. However, the increase was temporary and in December most trees had reverted back to the level prior to the increase. Thereafter a permanent increase occurred from February 2008 to April 2008.

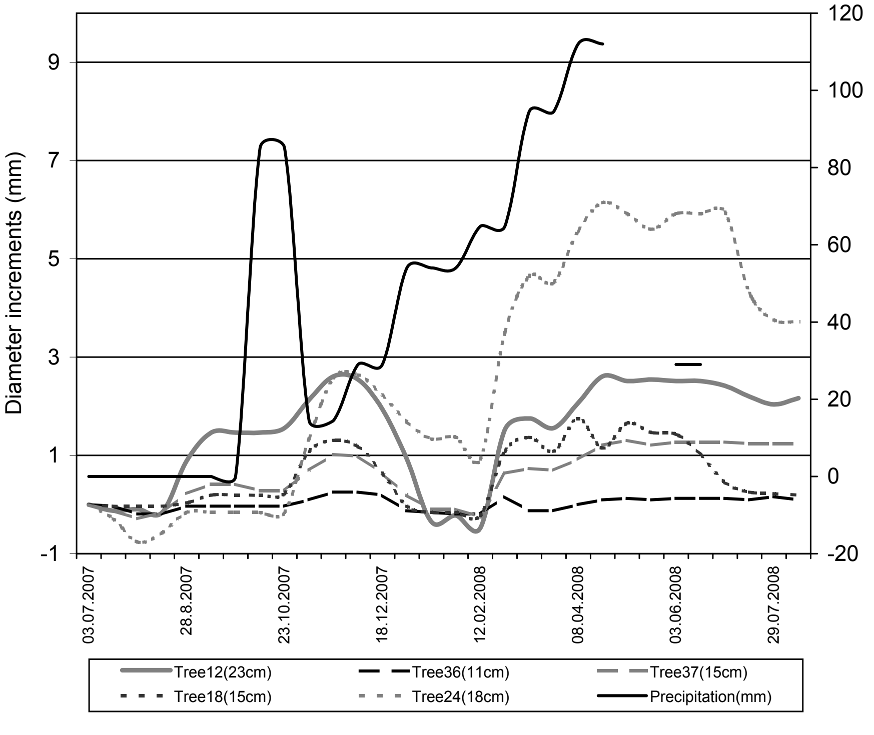

Figure 1. Diameter change of *Pterocarpus (P. angolensis* and *P. rotundifolia*) sample trees during 3.7.2007–12.8.2008.

Dalbergia melanoxylon show a rather similar development as *Pterocarpus* sp. (Fig. 2). One small-sized individual grows fairly well, others rather slowly.

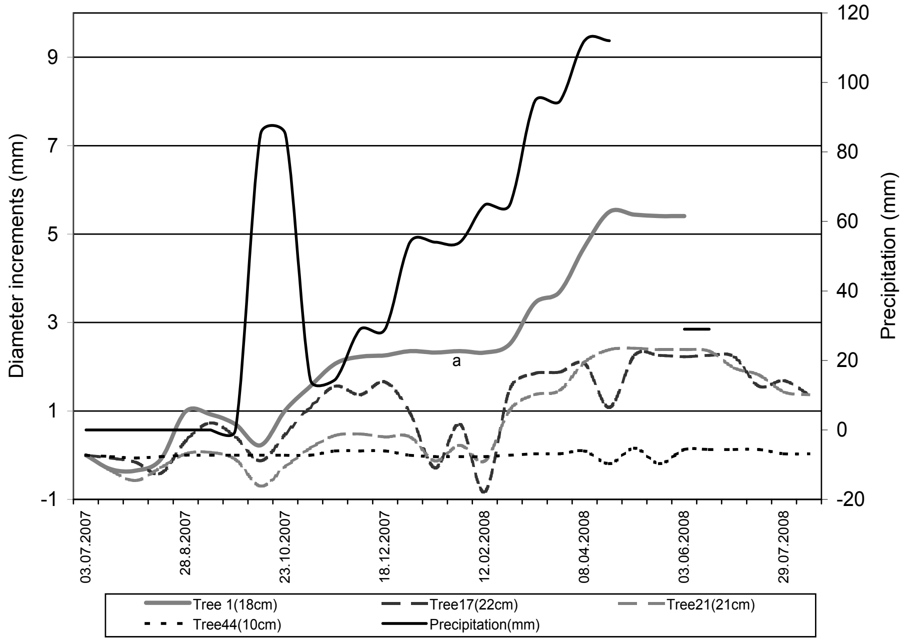

Figure 2. Diameter increment of *Dalbergia melanoxylon* sample trees during 3.7.2007–12.8.2008.

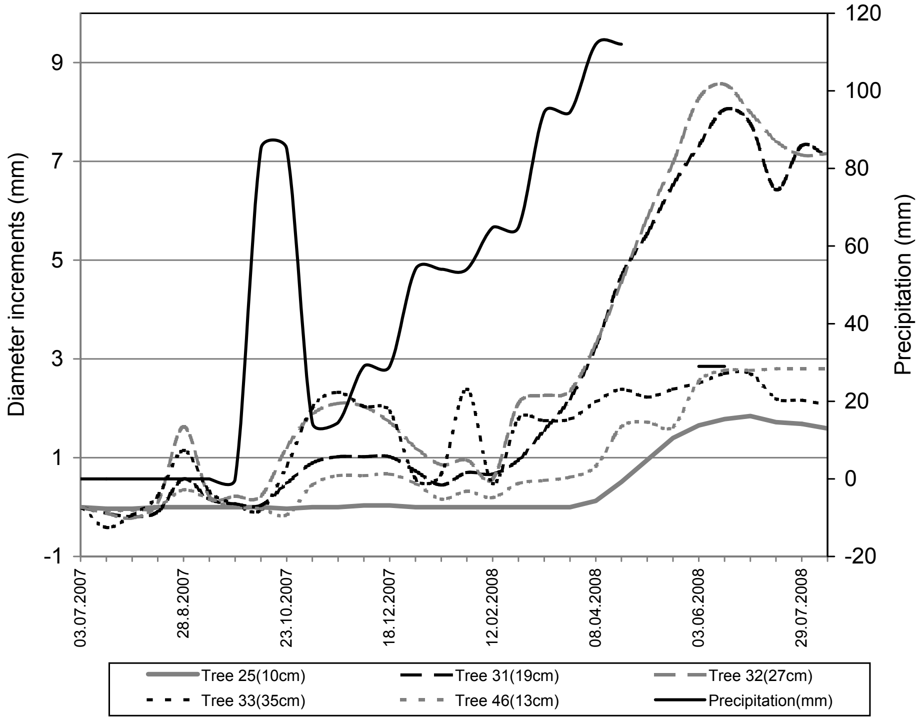

Figure 3. Diameter increment of *Brachystegia boemii* sample trees during 3.7.2007–12.8.2008.

Even for *Brachystegia boemii* the pattern is rather similar: slight increase of tree diameters after the rainy period in October 2007 and a reversal to the original level in December (Fig. 3). Slow-growing individuals produced most of their annual increment from February 2008 to April 2008, while the two faster growing trees continued to show increment until early June 2008. It is of interest that hese two fast growing trees are situated close to the river: Thus, better water availability could explain the fast growth.

Sclerocaria birrea shows large fluctuations, possibly related to bark characteristics of the species. Again, permanent increment began in February 2008 (Fig. 4).

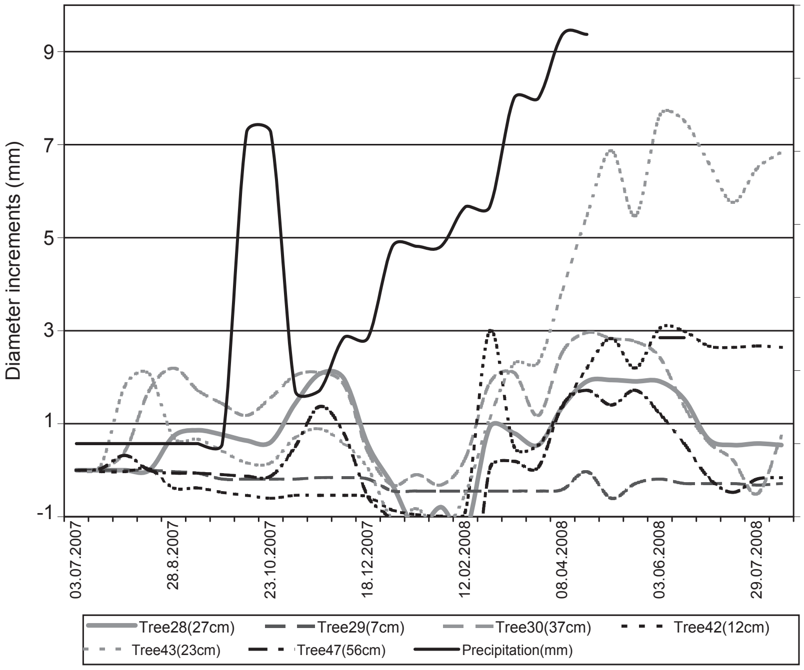

Figure 4. Diameter increment of *Sclerocaria birrea* sample trees during 3.7.2007–12.8.2008.

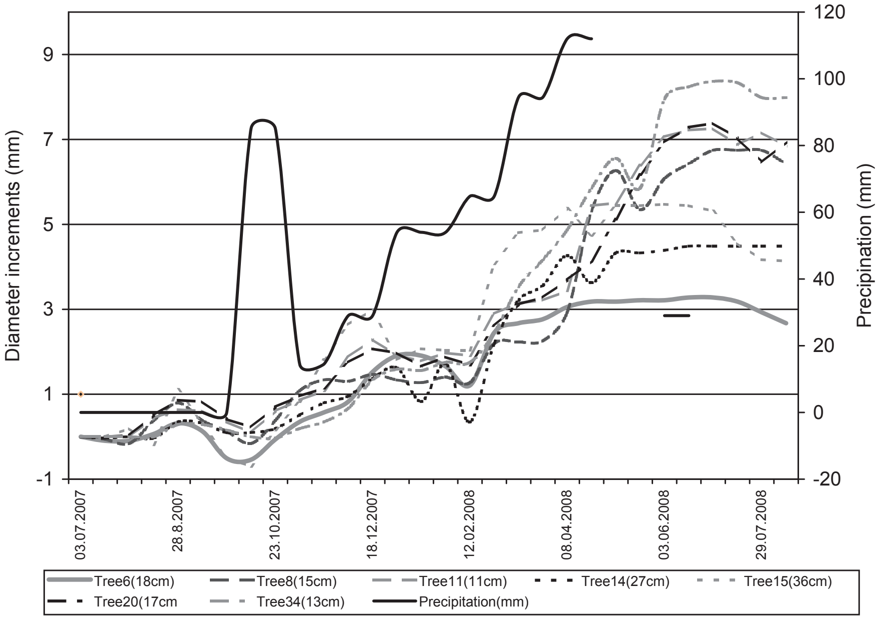

Figure 5. Diameter increment of *Julbernardia globiflora* sample trees during 3.7.2007–12.8.2008.

Julbernardia globiflora grows systematically faster than the other species (Fig. 5). Most of the monitored *Julbernardias* are rather small. Small ones produced the highest increments, but the two larger ones also produced an annual diameter increment between 4 and 5 millimeters. In contrast to other species the increase in October 2007 was permanent. However, again the largest increment occurred during the wet season.

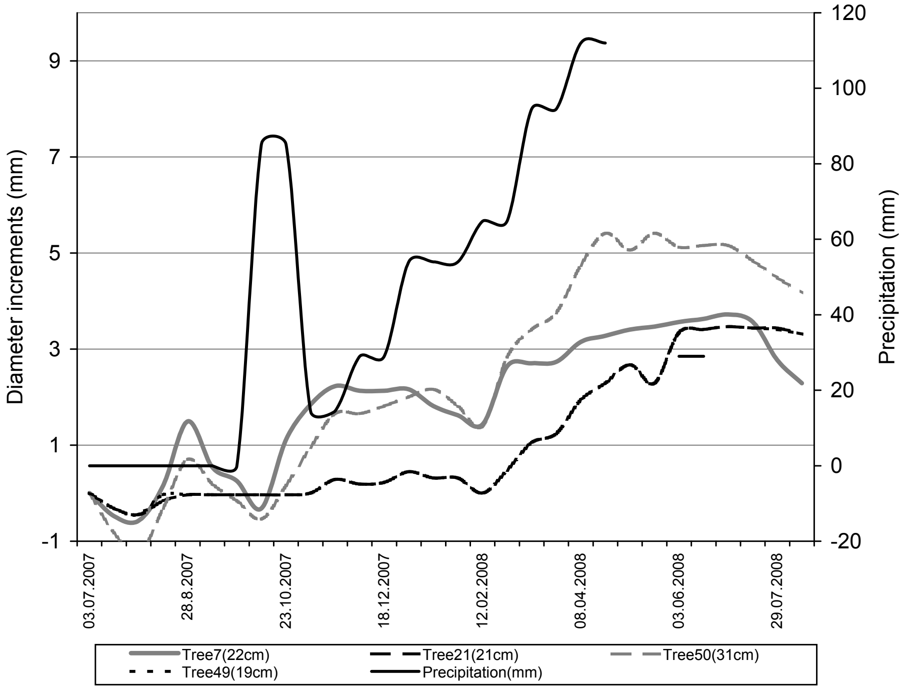

Figure 6. Diameter increment of *Pteliopsis myrtiflora* sample trees during 3.7.2007–12.8.2008.

Pteliopsis myrtiflora showed faster than average growth (Fig. 6). The pattern was somewhat similar to *Julbernardia globiflora* in that increment in october 2007 was permanent, not reversible.

Apart from one individual, the Acacias (*Acacia negrescens*, *Acacia senegal, Acacia nilotica*, *Acacia robusta*) showed slow growth (Fig. 7). The species also show relatively small temporary fluctations of stem diameter, a feature likely associated with bark characteristics.

Combretum molle showed systematically slow increment (Fig. 8). Annual diameter increments of less than 2 millimeters are actually so small, that one year is not a sufficiently long period for monitoring the growth of this species with manual girth bands.

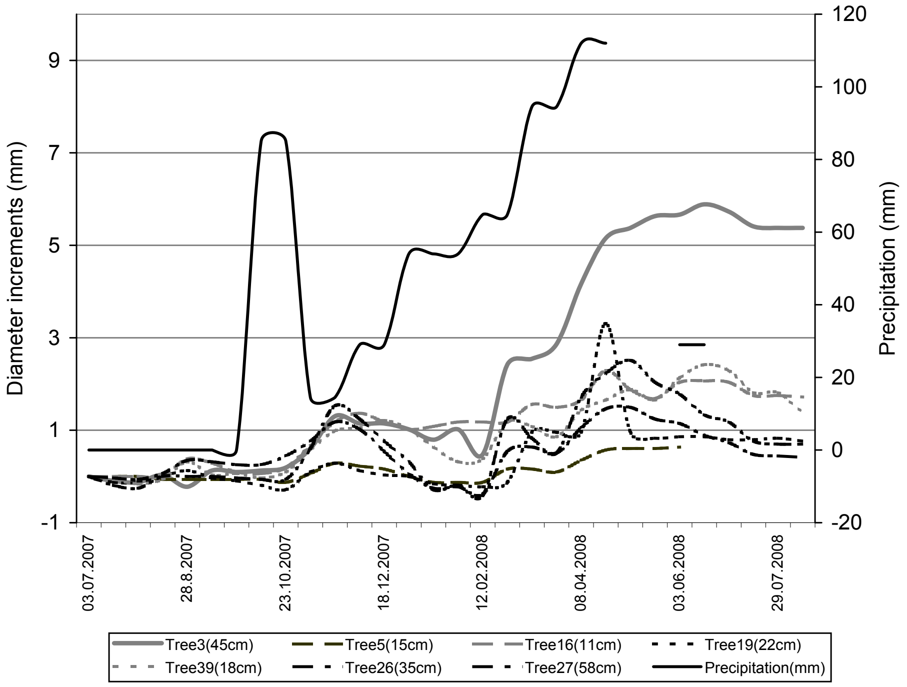

Figure 7. Diameter increment of *Acacia* spp. sample trees during 3.7.2007–12.8.2008.

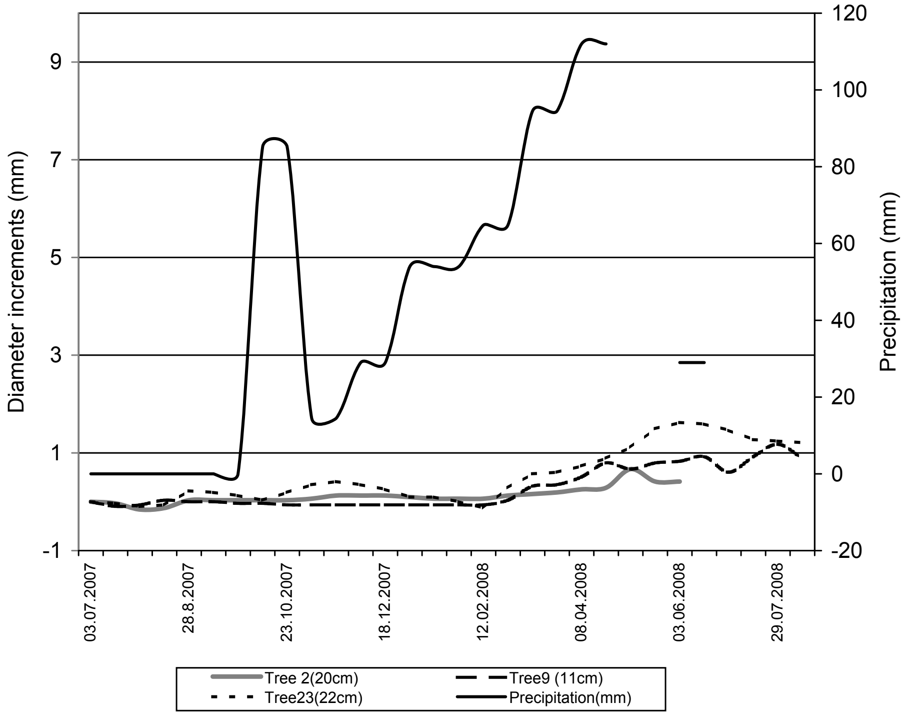

Figure 8. Diameter increment of *Combretum molle* sample trees during 3.7.2007–12.8.2008.

4 Conclusions

Even though differences between species were observed, there were also common increment patterns. From July 2007 to September 2007 none of the species showed notable increment. During October 2007 (a very rainy month) the diameter of all species increased. For most species (*Combretum, Brachystegia, Sclerecaria, Combretum, Acacia* spp.) the increase was temporary and the diameter reverted back to the prior level by the end of the year 2007. However, for *Julbernardia* and *Dahlbergia* the increase starting from October 2008 was permanent. However, even *Julbernardia* or *Dahlbergia* did not show notable growth in December 2007 and January 2008. Thus, the miombo trees in the rather dry conditions of Kitulangalo do not grow continuously.

The majority of annual increment was observed during the relatively short period from February to May. The finding was quite different than that observed by Nöjd and Isango (2003) for *Pinus patula* at 2220 m above sea level, where the effect of drought probably is not as significant as at Kitulangalo.

Julbernardia globiflora proved to be the fastest growing species at the study site at Kitulangalo. Some individuals of other species (*Brachystegia, Sclerocaria, Dalbergia*) also produced high diameter increment. *Combretum molle* and most Acacias grew notably slowly.

There seemed to be differences in the way trees react to shortage of water in that *Julbernardia* and *Dahlbergia* produced permanent, irreversible diameter increment during October 2007–December 2007, while the other species did not.

Some problems occurred during the monitoring period. Ten bands disappeared completely during the monitoring period of one and a half years. A few other did not show any notable changes of tree diameter. Most likely the initial mounting around tree stem was not succesful, although the result may at least in some cases reflect reality: trees with poor vitality may not show much diameter changes. In general, the studied miombo species have a rather thick bark. Absorption of water into the bark may cause some of the temporary variation that was observed. Considerable rusting of some defective band springs occurred, which may have had effect on the results.

The methodology worked fairly well in this particular environment. Continued observation through several years would be required to produce conclusive results, as the short-term increment very likely is strongly connected to the precipitation regime of each year.

Our results suggest that the time of year when tree diameter is most stable and temporary fluctuations are least likely to occur is roughly in July. Thus, if one studies tree growth with repeated caliper measurements on permanent sample plots, this time of year should be preferred for remeasurements. However, in view of our one-year measurements July and August might be equally good choices. Naturally it is not advisable to make any remeasurements immediately after a heavy rain regardless of the time of year.

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Regeneration of miombo woodlands: Effects of herbivory, management and competition

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Miombo-woodland area has decreased substantially because of unsustainable management practices. However, not enough is known about miombo dynamics making conservation and management difficult. Object of this study was to investigate the role of herbivores and tree-grass interactions in regeneration of miombo woodlands, if certain forest management practices can be used to enhance regeneration and if responses can be seen only after a short-term study. Research was conducted by setting up a permanent experiment in a natural miombo forest. Experiment was composed of two stands on which same treatments were conducted. Treatments were thinning, cultivation, fenced thinning and fenced cultivation. Fenced and unfenced control plots were established on both stands. Grass coverage was estimated, saplings were identified by species and measured for height and diameter, and sapling damage cause, damage severity and sapling vigour were estimated. Exclusion of grazers led to increase in grass coverage. Some indications that silvicultural measures might play a role were visible but study period was too short to determine their usability. A longer study is needed to uncover the impacts of herbivore exclosure and silvicultural measures. Competition between trees and grasses is one determinant of miombo-forest structure. Conducted measures might alter the interaction and therefore influence tree regeneration indirectly.

1 Introduction

Climate, especially precipitation determines the vegetation type of savannas but it is also heavily influenced by herbivory and fires (Shorrocks 2007). Due to unsustainable forest practices miombo woodlands are diminishing and many tree species are facing local extinction (Chidumayo and Frost 1996). Grazing and especially frequent fires damage saplings and regeneration is not fast enough to cover losses (Dirninger 2004). Natural regeneration may be a better alternative to planting in the tropics for certain ecological purposes (Moura-Costa 1996) but knowledge on regeneration of miombo forests is insufficient (Dirninger 2004). More research is needed in order to develop effective silvicultural practices to promote natural regeneration.

Kitulangalo has very few natural mammal herbivores but cattle are fairly common. Natural herbivores are both grazers and browsers but cattle mainly feed on grasses (Taylor and Walker 1978).

Grasses are easier to digest where as trees contain high concentrations of lignins and metabolites. However, occasionally cattle also browse in which cases it has been observed to significantly restrict regeneration of trees (Lehmkuhler et al. 2003, Allcock and Hik 2004).

Trees and grasses compete for living space, light, nutrients and water (Scholes and Archer 2006). Interactions are diverse and influenced by abiotic and biotic factors of surrounding environment and species in question. Trees might improve nutrient and humidity conditions under canopy and thus promote growth of grasses. On the other hand grasses might also suffer from lack of light and increased resource competition. Grasses in turn might compete with saplings for light, water and nutrients. Grasses also regulate fire frequency and intensity. Denser grass coverage leads to more intense fires which in turn cause more damage to saplings and might hinder their growth.

Fires have significant role in miombo dynamics (Dirninger 2004). Frequent fires suppress saplings thus slowing down growth and regeneration. Grasses on the other hand recover from fires fast. Fires hence maintain the landscape open. Grazing reduces grass coverage thus reducing the amount of combustible plant material (Mwendera et al. 1997). This will lead to lower frequency and intensity of fires (Roques et al. 2001, Savadogo et al. 2007).

Object of this study was to examine interactions between tree saplings and grass coverage and study how the interaction is regulated by silvicultural practices and exclusion of grazers. Effects of silvicultural practices and exclusion of grazers on sapling numbers, growth, vigour and sapling species composition were examined. Level of insect herbivory was evaluated and its effect on regeneration was studied. Tree competition effect on saplings and grass coverage was also examined. Aim was to examine if certain silvicultural practices can be used to enhance regeneration of miombo forests, define the role of mammal herbivores and evaluate how competition between trees and grasses should be taken into consideration when designing forest management.

2 Materials and methods

Permanent experiment was established into a natural miombo forest in Kitulangalo, Tanzania. Experiment consisted of two stands with six 30 m x 30 m, plots. Treatments conducted were cultivation, thinning, fenced cultivation and fenced thinning. Fenced and unfenced controls were established. On cultivated plots soil under canopy of big trees (breast height diameter (dbh) > 20 cm) was hoed in depth of 15–20 cm to increase humidity, reduce competition and promote sprouting. On thinned plots trees and shrubs were cut or pruned in order to promote economically important species. On control plots no silvicultural measures were executed. Fencing was conducted to exclude mammal herbivores.

On each plot 25 subplots with radius of 1.1 meter were established. From each subplot grass coverage was estimated. All saplings with minimum height of 20 cm were identified and measured for height. Saplings above 130 cm were also measured for breast height diameter if it was below 5 cm. From groups of similar saplings only the highest was measured and others just counted in total number. Vigour, stem quality and damage severity were estimated and cause of damage was defined. If saplings were regenerating from a visible, single stump, also the diameter of the stump was measured. Seedlings from seeds above 20 cm in height were counted. All trees (dbh > 5 cm) were measured for dbh and data was used to calculate competition indices; $CI_{ds} = \Sigma d_j / (s_j + 1)$, where s is the distance between centre of the subplot and tree and d is dbh.

Data was analysed with SPSS using split-plot Anova and Spearman's correlation.

3 Results

Grass coverage increased on all treatments during study period but the increment was more distinct on fenced treatments (Fig. 1). Effect of fencing on grass coverage was significant (Anova; F = 862.22, p = 0.02) but thinning or cultivation did not have a significant effect.

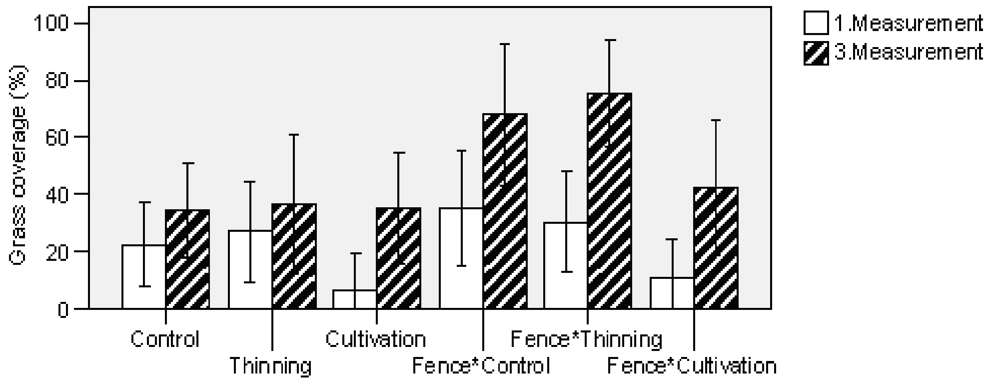

Figure 1. Change in grass coverage (% ±SD) between first and third (one year after) measurements.

Number of saplings showed decrease on all treatments but treatments had no significant effect (Fig. 2). No seedlings from seeds were detected during measurements although exclusion of grazers was tentatively significant (Anova; F = 59.08, p = 0.08). Number of sapling species and species composition was similar on all treatments and showed no major changes over the study period, treatment effects being insignificant. Sapling height increased on all treatments and sapling diameter increased on all but fenced control, where it stayed constant. Treatment effect was not significant for either sapling height or diameter. Overall herbivore damage increased on all but thinned treatment and fenced control. Stem vigour both increased and decreased but neither treatments nor herbivore damage had effect on this.

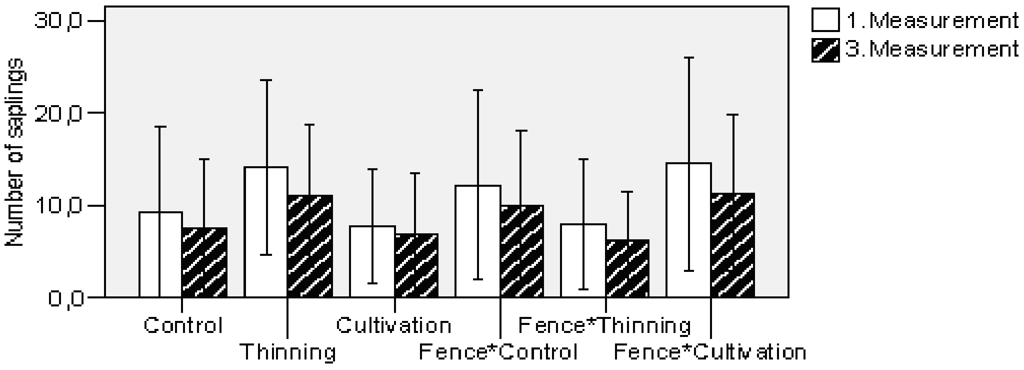

Figure 2. Mean number of saplings (±SD) on different treatments on first and third (one year after) measurements.

Grass coverage correlated mainly negatively with number of saplings. However correlation was negatively significant only on fenced and thinned treatment on first stand (Spearman's correlation; $r_s = -0.44$, $p = 0.03$) and positively significant on cultivated treatment on first stand (Spearman's correlation; $r_s = 0.58$, $p = 0.01$). No differences between treatments could be found, however, due to dissimilarity of stands. Grass coverage also correlated mainly negatively with number of sapling species and correlation was significant though not linear on fenced and thinned treatment (Spearman's correlation; $r_s = -0.53$, $p = 0.001$) and on fenced control (Spearman's correlation $r_s = -0.49$, $p = 0.01$). On all cultivated treatments, however, grass coverage and number of species correlated positively, though not significantly. Grass coverage was not found to correlate significantly with sapling height or diameter.

Tree competition indices correlated mainly negatively with grass coverage but there were differences between the two stands. Correlation was positively significant only on control on first stand (Spearman's correlation $r_s = – 0.53$, $p = 0.01$) and negatively significant on fenced and thinned treatment on second stand (Spearman's correlation $r_s = – 0.55$, $p = 0.01$). Effects of tree competition on sapling numbers had no general trend, effect being significant only on fenced and cultivated treatment on first stand (Spearman's correlation $r_s = – 0.50$, $p = 0.01$). Competition had no significant effects on number of sapling species nor did the correlation have any conformity. Tree competition correlated both negatively and positively with sapling height and diameter on different treatments without having conformity. Some significance was detected but there were differences between stands.

Intensity of browsing was low throughout the study period. Exclusion of mammals prevented browsing but otherwise treatments had no effect on browsing intensity nor did browsing have effect on sapling vigour or regeneration. Insect herbivory was intense and evenly distributed throughout the treatments but no effects on sapling vigour or regeneration were found.

4 Discussion

Absence of seedlings regenerating from seeds supports observations that miombo trees mainly regenerate from root suckers (Trapnell 1959). This is thought to result from frequent fires which inhibit development of seedlings (Pomeroy and Service 1986).

Mammal herbivores on study area were discovered to be mainly grazers. Intensity of browsing was low and herbivore exclusion had visible effects on grass growth. Exclusion of grazers was seen to result in increase of grass coverage already in short term. Effects of exclusion to sapling growth and number of saplings were not detected.

Correlation between grass coverage and number of saplings was mainly negative, as was correlation between grass coverage and number of species. Grass cover had no effect on sapling growth. Negative correlation between grass coverage and sapling numbers was also discovered by Obiri et al. (2002) on their study of tree composition in Kitulangalo. Denser grass coverage was noticed to lead into decrease in sapling numbers. Exclusion of herbivores might thus influence regeneration in longer term since grass coverage increased on fenced treatments.

Management practices were not observed to have effect on regeneration over the one year study period. Number of saplings decreased on all treatments but treatments had no effect on this. Sapling height and diameter increased constantly on all treatments but again, no significant effect of treatments was found.

Negative correlation between tree competition and grass coverage was found. There was also negative correlation between tree competition and sapling height and diameter but not between competition and sapling numbers nor species numbers. Increase in tree numbers and diameters will thus reduce grass coverage but it might also hinder sapling growth. Thinning as a management practice might in a longer term enhance regeneration. According to Mugasha and Chamshama (2002) number of saplings increased on disturbed areas of miombo forests because disturbance creates canopy gaps thus increasing light intensity and soil temperature and enhancing natural regeneration. On the other hand thinning has been noticed to enhance grass growth and increase grass coverage (Gambiza et al. 2000, Barnes 1979). If grass coverage increases substantially due to reduced competition the effect of thinning on tree regeneration might be negative. When conducting measurements, thinning was noticed to have strongly enhanced coppicing but due to lack of thinned trees on regeneration plots the effect was not uncovered in data.

No fires occurred in the forest during study period. Due to high fire frequency of the area, fire will however eventually become inevitable as the amount of burning material increases. If grazing is excluded denser grass coverage will lead to more intense fires which in turn could be more destructive to saplings. Cultivation did not have any short term effects on tree regeneration. Effects however might not be recovered yet for only saplings above 20 cm were counted and measured. Also not all regeneration plots under cultivation were hoed because cultivation was only done under big trees. This might as well lessen the effects of cultivation in collected data. Grass coverage was noticed to regenerate shortly after cultivation. Cultivation might promote tree regeneration in long term indirectly when in absence of dense grass coverage fires would become rare and low in intensity. This would however require cultivation to be conducted repeatedly before grass cover regenerates.

No noticeable changes in sapling species composition were detected during the study. *Julbernardia globiflora* continued to be the most prevalent species and treatments had no effect on species distribution. Lack of responses might also result from short time period of experiment.

Changes in grass cover can be seen after only a short term study but longer time is needed for possible effects of silvicultural measures and exclusion of mammal herbivores on tree regeneration to develop detectable. This is especially integral since tree-grass interactions are major determinant of savanna structure. However, it seems that intermediate grazing favours tree regeneration by suppressing grass growth. Hence exclusion of mammal herbivores might lead to more open savannas.

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Use of the Kitulangalo plots and study results in education at Sokoine University of Agriculture and beyond: current and future considerations

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The present paper, foremostly, provides a historical background of training in forestry, wildlife and related natural resources fields in the Faculty of Forestry and Nature Conservation at Sokoine University of Agriculture, Morogoro, Tanzania, since the forestry education was started in 1973. It also informs about the Faculty's capacity in terms of manpower, resources, facilities that support training including the Kitulangalo Forest Reserve and briefly illustrates the outputs so far made in terms of products and services. Specifically the paper reviews the nature and scope of the Kitulangalo MIT-MIOMBO study plots and the extent to which the results have been used in education at this University and beyond. It more critically examines the inherent conceptual contents of the study in relation to furthering the future training needs and their promise in revolutionalising forest resources systems management strategies for sustained quantity and quality supplies of goods and services locally and globally. Among other things it recommends the begun studies to be continued in greatly expanded formats in terms of scope of factors to be tested and replications in both space and time.

1 Introduction

Sokoine University of Agriculture was establishment on 1st July 1984 by Parliamentary Act No. 6 of the same year (SUA Act 2004, Gillah 2008) and repealed in 2005 by the Universities Act No. 7 (SUA Act 2005). It was created from the former Faculty of Agriculture, Forestry and Veterinary Science of the University of Dar es Salaam. It is situated 3 km from the centre of Morogoro Municipality, which is about 200 km west of Dar es Salaam (Gillah 2008).

The University is currently made of four campuses namely the Main Campus and Solomon Mahlangu Campus in Morogoro, the Olmotonyi Campus in Arusha and Mazumbai Campus in Lushoto, Tanga. The Main Campus lies at the foot of the Uluguru Mountain slopes at an altitude of 500-600 masl and receives rainfall of between 600 and 1000 mm (Gillah 2008).

According to SUA Strategic Plan (SSP) (SSP 1998, 2005), Gillah (2007, 2008) and SUA Prospectus (2007), the Main Campus has a total land area of 3,350 ha out of which 2,300 ha are reserved for the University farm. The farm is used for a range of purposes including training, research and demonstration by students and staff. It is also used for management and production of crops, forest products and livestock. In addition to this land, the University also owns Towelo Morning Site (6.0 ha) and the Mvomero farm (20 ha) both located at an altitude of about 1 300 m asl on the Uluguru Mountains. This sites experience a temperate climate and serve for training and research in temperate crops.

The University has four Faculties and six Directorates/Institutes which include the Faculty of Agriculture, Forestry and Nature Conservation, Veterinary Medicine and Science. The Directorates /Institutes include the Institute of Continuing Education (ICE), Development Studies Institute (DSI), Directorate of Research and Postgraduate Studies (DRPGS), Computer Centre (CC), Sokoine National Agricultural Library (SNAL), SUA Centre for Sustainable Rural Development (SCSRD) and SUA Pest Management Centre (SCPMC). The University offers undergraduate training leading to the awards of Bachelor of Science (BSc) degrees in Agriculture General, Agronomy, Home Economics and Human Nutrition, Horticulture, Animal Science, Food Science and Technology, Agricultural Engineering, Agricultural Education, Agricultural Extension, Agricultural Economics and Agribusiness, Forestry, Wildlife Management, Environmental Sciences and Management and Veterinary Medicine (BVM) and BA in Rural Development and Tourism Management.

The University also offers postgraduate training leading to the award of Master of Science (MSc) and Doctor of Philosophy (PhD) degrees in the respective fields of Agriculture, Food Science, Human Nutrition, Forestry, Management of Natural Resources for Sustainable Agriculture, Veterinary Medicine, Preventive Veterinary Medicine, and Rural Development. The ICE offers short-term in-service programmes to field and operational staff as well as training and extension services to farmers and community leaders. The DSI acquaints undergraduate students with the challenges of development and how to overcome them.

2 Training in forestry and related fields

According to the Dean, prof. P. Gillah (Gillah 2007, 2008), training for the forestry profession and related fields in the Faculty of Forestry and Nature Conservation (FFNC) started in July 1973 with the establishment of the Department of Forestry as a constituent component of the Faculty of Agriculture and Forestry (FAG & FOR) of the University of Dar es Salaam. In 1974 its status was elevated to the division to form the Division of Forestry. In July 1984, it became the Faculty of Forestry following the establishment of Sokoine University of Agriculture. In 1994, the name of the Faculty was changed to Faculty of Forestry and Nature Conservation in order to attain a wider mandate. In 1998, the Faculty expanded to include training in Wildlife Management (WLM) and Management of Natural Resources for Sustainable Agriculture (MNRSA) – with the latter providing training at the Master of Science (MSc) degree level only. Training in Tourism Management at the Bachelors level (BTM) is commencing this academic year (2008/2009) (Gillah 2008).

In order to efficiently and effectively carry out its training mandate, the Faculty is organized into six discipline-based departments that include five forestry departments and one on wildlife management (Table 1).

Table 1. The six academic departments constituting the Faculty of Forestry and Nature Conservation at Sokoine University of Agriculture.

Name of Department	Year of establishment
Forest Biology (FBL)	1984
Forest Engineering (FEN)	1984
Forest Economics (FEC)	1984
Forest Mensuration & Management (FMM)	1984
Wood Utilization (FWU)	1984
Wildlife Management (WLM)	1998

Source: Dean, Faculty of Forestry and Nature Conservation (May 2008)

Table 2. The number of students who have graduated from the Faculty of Forestry and Nature Conservation since the programmes started until November 2007.

BSc		MSc			PhD	Total
FOR	WLM	FOR	WLM	MNRSA		
340	254	120	54	70	30	922

Source: Board, FFNC (July & September 2008)

Table 3. The number of students who will be graduating from the Faculty of Forestry and Nature Conservation in November 2008.

BSc		MSc			PhD	Total
FOR	WLM	FOR	WLM	MNRSA		
48	46	20	5	26	4	149

Source: Board, FFNC (July & September 2008)

Table 4. The number of students who are at the various levels of their degree study programmes in the Faculty of Forestry and Nature Conservation as from September 2008.

Year of study	BSc		MSc			PhD	Total
	FOR	WLM	FOR	WLM	MNRSA		
1st	80*	108*	16	11	48	12	275
2nd	56	48	9	4	19	4	139
3rd	46	64	-	-	-	-	110
Overall total							524

Sources: Board, FFNC (July and September 2008)
* SUA Admissions Office (September 2008)

Overall, 922 students have already graduated, in various fields and levels, from Faculty of Forestry and Nature Conservation, since training in forestry and the related fields started (Table 2) (Gillah 2008). Other 149 students (Table 3) will be graduating in November 2008 following successful completion of all the requirements of their respective degree programmes (Board, FFNC 2008).

Table 4 provides information on the numbers of students who are currently at the various levels of their degree study programmes.

In addition, the Faculty has provided partial academic supervision roles to over 300 students registered in various higher education training institutions in Tanzania and abroad who normally come through various academic arrangements (Table 5). Besides those originating from locally based institutions, many of those originating from abroad have mainly come from various institutions in the United States of America (USA), Canada, Ethiopia, Finland, Germany, Norway, Sweden, United Kingdom (UK), France, Italy, Israel and Japan.

Table 5. The various training programmes being carried out by the Faculty of Forestry and Nature Conservation, Sokoine University of Agriculture, for field staff, the communities and students registered in training institutions elsewhere.

Training programme	Areas covered by the programme
Field Training Excursions	Students in Universities elsewhere with field practicals in forestry and related fields conducted in Tanzania jointly with SUA staff (Academic)
Occasional Students	Students registered in Universities elsewhere but take occasional credit training in some interest courses from SUA
Research Associateships	Research for theses or dissertations submission elsewhere with SUA providing local supervision
Short Courses	Short duration programmes normally organized for provision of specific skills for field staff and local communities
Small Research Tasks	Students come and carry out short term research tasks with SUA providing local supervision. This has, especially been with Swedish students
Special Students	Students on familiarization programmes only with the assistance of local staff

Sources: Various miscellaneous sources of information and personal knowledge

Training of the communities and field staff is normally intended to provide specific knowledge or skills that are occasionally found to be critically required in improving their work performance in the field. It addresses identified constraints in the provision of extension services to the communities and shortfalls among the communities that are seen to limit the absorption and adoption of new innovations and technologies.

3 Facilities for effective training in forestry and related fields

Besides the strong capacities in terms of human resources (i.e. 70 academic and 119 technical and administrative staff) and physical infrastructure at the two University Campuses (i.e. Main and SMC campuses) where most of the teaching is conducted, the Faculty, also, has four forest facilities (Table 6) where field training for practical knowledge and skills in the various forestry sciences and related fields are conducted (Gillah 2008, personal knowledge).

Table 6. The currently available forest facilities that support training in forestry and related fields in the Faculty of Forestry and Nature Conservation at Sokoine University of Agriculture, Tanzania.

Forestry facility	Characteristics and role
Mafiga Agroforestry, Botanical Garden & Forest Plantations, Morogoro	About 1 000 ha lying close to the two Campuses. Field training in Agroforestry, plantation forestry, ecology and botany
Kitulangalo Natural Forest Reserve, Morogoro	About 500 ha of natural forest, 50 Km from Morogoro Municipality and 170 km from Dar es Salaam along the Dar es Salaam – Morogoro Highway. Represents the semi-dry low altitude Miombo woodlands. Botanical, ecological, environmental and various socio-economic interactions field practicals for dry ecosystems are carried out here
Mazumbai Natural Montane Forest Reserve, Usambara Mountains, Tanga	Nearly 320 ha of more or less intact high potential Montane forest in the Usambara Mountains. About 380 km from Morogoro, 25 km off the Morogoro – Moshi Highway. Botanical, ecological, biodiversity etc. practical for high altitude forest systems
Olmotonyi Training Forest, Arusha	Approximately 840 ha of mostly conifer plantations (mainly Pine and Cypress) on the Meru Mountain slopes on the outskirts of Arusha Municipality. Field practicals in Forest management planning, Silvicultural systems, Harvesting systems, Economic appraisal and various forest operations

Sources: Gillah (2008), Luoga (2000), Luoga et al. (2002), Malimbwi and Kielland-Lund (1998)

The Mafiga and Kitulangalo forest stations provide facilities for research, practical training and continuous education in issues related to climatically dry lowland forest ecosystems while the Olmotonyi and Mazumbai field stations are for natural forest resources issues related to climatically high potential montane forest ecosystems (Gillah 2008).

4 The Kitulangalo miombo woodlands

The 500 ha FFNC managed Kitulangalo forest reserve, is part of the wider area of the 1 700 ha Kitulangalo Forest Reserve system of which 1,200 ha remain under the direct central government management. The current overall Kitulangalo forest reserve system (1 700 ha) represents an over 6% shrink from the original area of over 1,900 ha that were gazetted and reserved in 1955. According to Luoga et al. (2002), this reserve is surrounded by the currently less than 7 000 ha of highly degraded public woodland that has shrunk by 50% from the original forest area of more than 14 000 ha through various degradation forces, the main of which include conversion into farmland, settlements, charcoaling, timber harvesting and annual wildfires with most of the conversions taking place during the period between 1964 and 1996. Both the forest reserve and public woodlands are part of the miombo woodlands of Tanzania that comprise 90% of all the country's forest and woodland vegetation (Luoga 2000, Luoga et al. 2002, Malimbwi and Kielland-Lund 1998).

Being the forest vegetation most close to SUA and because of its unique character of vulnerability to intensive utilization pressures with accompanying consequences of far reaching implications, the Kitulangalo forests and woodlands are being extensively used for training, research, and outreach programmes (Luoga 2000). Table 7 presents the number of candidates at various levels of study programmes whose data for their theses, dissertations and special projects were collected from these forests. A large number of other students have collected data from these forests for dissertations and theses submissions for degree programmes elsewhere. Similarly a lot of journal and other media publications on data based on these forests, are available locally and internationally (Luoga 2000, Luoga et al. 2000, Malimbwi et al. 1998, 2000).

In addition to meeting the above study requirements, the Kitulangalo forests are annually used for field practicals for the undergraduate and postgraduate students in forestry and wildlife, especially on the biological, botanical, socio-economic, socio-ecological, socio-hydrological and resources management fields (Professors E.J. Luoga and P.K.T. Munishi – Heads of Departments of Forest Mensuration & Management and Forest Biology, respectively, personal communication and general knowledge).

Table 7. Number of candidates who have graduated from SUA whose data for their theses/dissertations/special projects were collected from Kitulangalo forest reserve.

Level of degree study	Number of candidates
PhD	6
MSc	20
BSc	30
Total	56

Source: Misc. sources, FFNC

5 Use of Kitulangalo plots and study results in education at SUA and beyond

Background information

There is, already, voluminous information in literature on the escalating degradation of the natural forest vegetation globally (Houghton and Skole 1990), especially in the tropical world (Houghton 1990, Myers 1980) and miombo woodlands in particular (Campbell 1996 et al., Luoga 2000, Luoga et al. 2000, Zahabu 2001, Abdallah and Monela 2007) that is triggered by various change drivers that include human and animal population growth (URT 2002), climate change (Solomon et al. 1993), international trade of the various forest products (FBD 1999, FAO 2001) and general poverty (Chamber 1987). These, in turn, have motivated resources management adjustments (MNRT 1998), revisions in the legislations and policies at the local, national, regional and international scales (Kihiyo 1998, MNRT 1998b, Petersen and Sandhovel 2001, Hamza and Kimwer 2007) including formulation of new strategies for effective forest resources management such as Participatory Forest Management (PFM) that include Community Based Forest Management (CBFM) and Joint Forest Management (JFM) (MNRT 1998a, 2001, 2006, Roe 1998, Ramadhani 2003).

All these policy changes and new strategies in resources conservation and management are directed towards regulation of utilization pressures, sustenance of products supplies from the existing forest resources and equitable benefit sharing mechanisms. Improvements in the conversion and utilization technologies such as charcoal kilns, charcoal and firewood stoves and briquetting (Malimbwi in this publication) and spreading the demand pressures to the wider range of the forest resources biodiversity by promoting the currently less utilized species to a higher utilization pressure (Gillah et al. 2007, Ishengoma et al. 1997, Makonda and Gillah 2007), are all balances in the modes of forest resources off-take. The overall effect of these measures is temporal sustenance of the sought product supplies and services. The total long-term ecological, hydrological, environmental and socio-economic implications on the ecosystem balances, including the sustenance of the individual species product supplies, are generally negative. Thus management approaches or methodologies that would provide positive additions or improvements to the overall status of the resources base or make the declining and most threatened desirable individual tree species be more plentiful and in the desirable qualities, methodologies that would enhance the total being or reverse the current negative trends of forest ecosystem development, need to be urgently developed and brought into practice. In Tanzania, for instance, such methodologies are particularly and urgently required to provide incentives for accelerating adoption of the currently advocated Participatory Forest Management (PFM) approaches (Ramadhani 2003, MNRT 2006, Wily 2000, Wily and Dewees 2001) such as Community Based Forest Management (CBFM) and Joint Forest Management (JFM) (FAO 2000, MNRT 2001).

Based on these vital considerations and the need to speedily act on them, recently scientists in the temperate north, Finland in particular, initiated a research programme in this direction – development of management methodologies appropriate for the complex, multiple species and diverse age-classes forest ecosystems (Valkonen 2007). Observing favourable indications, a vision of extending these efforts to the wider scientific community and more complex tropical forest ecosystems especially the miombo woodlands which are highly threatened by various degradation pressures was formulated. Thus, in November 2006, a preliminary small-scale two years (November 2006 – October 2008) international collaborative research project titled "Management of Indigenous Tree Species for Ecosystem Restoration and Wood Production in Semi-Arid Miombo Woodlands in Eastern Africa – conveniently shortened "MITMIOMBO", with the funding of the European Commission, was started and implemented in the Kitulangalo miombo woodlands, Morogoro, Tanzania. It brought together more than 20 scientists, directly involved in the project activities, and six different institutions from the three international countries (Table 8) with METLA playing the Project Coordination role (MITMIOMBO Project document 2006, Valkonen 2007a, b).

Table 8. The countries and institutions that are participating in the MITMIOMBO research project.

Participating country	National institutions involved
Finland	Finnish Forest Research Institute (METLA) University Of Joensuu (UJOE)
Sweden	Swedish University of Agricultural Sciences (SLU)
Tanzania	Sokoine University of Agriculture (SUA) Tanzania Forest Research Institute (TAFORI) Tanzania Association of Foresters (TAF)

Source: MITMIOMBO Project document (2006) and Valkonen (2007a, b)

Establishment of the plots

The Kitulangalo MITMIOMBO research plots were established in Kitulangalo forest reserve in February 2007 following its official lounging during the 6–13 February workshop that was held in Morogoro, Tanzania, during which, also, consensus decisions on the study site and set of stand treatments were reached (Table 9).

Table 9. The plot treatments of the Kitulangalo MITMIOMBO research project.

Number	Treatment applied
1	No special treatments applied – remained (control)
2	Cultivation of the ground to promote regeneration
3	Removal of less desirable plants to favour the development of the desirable ones

Sources: Valkonen (2007a, b)

These three treatments were replicated on four blocks of which two were fenced by wire-mesh to limit out herbivores. Half of the four blocks (i.e. fenced and unfenced) are located in the SUA managed part of the forest reserve while the other half are in the government managed part. Some sample trees were selected for short-term diameter growth monitoring around which growth-bands (girth-bands) were attached at the 1.3 m level above the ground surface. Comprehensive counts of individuals, measurement of height and diameter growth of all the woody plant ≥5 cm, canopy cover, identification of all woody plants found in each plot, including herbivore effect (damage) and stand visualization, were carried out six monthly while growth-band readings were recorded at two weekly intervals (Elifura et al., Kiluma et al., Mbwambo et al., Piiroinen et al. and various other papers in this publication). Until the time of this workshop, three comprehensive measurements and 46 growth-bands readings had been taken.

Use of plots and study results in education at SUA and beyond

Until the time of holding the 1–6 September 2008 International MITMIOMBO Workshop at Wilolesi Top Hill Hotel in Iringa, Tanzania, the MITMIOMBO Project had been in existence for only 22 months (i.e. November 2006 – September 2008) with the Kitulangalo research plots being only 19 months old (i.e. February 2007– September 2008) (Valkonen 2007a, b).

Besides the short period these research plots have been in existence, they have intensively been used for training in professional forestry, general forestry education to the wider community and in the provision of technical and operational skills to the various involved stakeholders. Already over 170 people have been trained at various levels of forestry education (Table 10) using these plots. In addition, the MITMIOMBO research programme has facilitated the bringing together over 70 international professionals and general practitioners in forestry by way of research collaboration and interaction and through the media of the three international MITMIOMBO workshops (Table 11). In addition, three young Tanzanian forestry scientists had a one and a half months exchange visit training programme in Finland for further interaction with the local research scientists of the project there.

Table 10. The various stakeholders who have received training/education through the methodologies being developed using the Kitulangalo research plots.

Stakeholders	Number of beneficiaries	Training activity
13 MSc students	2 Finnish	Data collected from the plots and dissertation submission and graduation at UJOE, Finland UJOE, Finland
	1 Swedish	Data collected from the plots and dissertation submission and graduation at SLU, Sweden
	1 Tanzanian	Data collected from the plots and dissertation submission and graduation at SUA, Tanzania
	9 Tanzanian	Excursion field training for familiarization with the methodologies being developed
Foresters and SUA staff	10 Tanzanian	Familiarization with the methodologies being developed, associated concepts and expectations
Local farmers	84 Tanzanian	Sensitization and education on the forests, their values and roles. Needs of their effective conservation and management including those in public lands, CBF, forests under JFM and PFM. Purpose of the management methodologies being developed
Local pastoralists	66 Tanzanian	Sensitization and education on the forests, their values and roles. Needs for their effective conservation and management including those in public lands, CBF, forests under JFM and PFM. The positive and negative influences of livestock including reconciliatory measures. Purpose of the management methodologies being developed

Sources: Various Misc. WP6 report documents including that by Mndolwa et al. (in this publication)

Table 11. The two MITMIOMBO international workshops that brought together over 70 forest professionals to discuss about the management methodologies to be tested, establishment of the research plots, results obtained and the way forward.

Period of Workshop	Venue	Participants
6-13 February 2007	SUA, Morogoro, Tanzania	6 Finnish (METLA & UJOE)
		2 Swedish (SLU)
		16 Tanzanians (SUA, TAFORI and TAF)
13-18 April 2008	METLA, Helsinki, Finland	7 Finnish (METLA & UJOE)
		5 Tanzanians (SUA & TAFORI)
1–6 September 2008	Wilolesi Top Hill Hotel,	4 Finnish (2 METLA & UJOE)
	Iringa, Tanzania	1 Swedish (SLU)
		1 CIFOR Scientist
		34 Tanzanians (SUA, TAFORI, TAF, MNRT, MRCFO and IRCFO)
		2 others (UDSM & NGO)

Sources: Roster of workshop participants, February 2007 and September 2008

The latter workshop provided an opportunity for/and facilitated the decision on continuing these research efforts in the future with more expanded scope in terms of area coverage (i.e. replications to more sites in Tanzania, Malawi and Zambia), issues covered (i.e. to include issues on water, charcoal, carbon and other socio-economics), participation in the research collaboration (i.e. bringing in University of Dar es Salaam (UDSM), Copperbelt University of Zambia (CBUZ), CI-

FOR, NGO company on carbon trading), and network development to link various interest stakeholders (Malambo and Syanpunggani, Malmer and Nyberg in this publication).

This time is, indeed, too short for anyone to realistically expect indicative results on appropriate methodologies of managing natural forest ecosystems with most of the tree species requiring over 70 years to attain merchantable industrial timber sizes, despite being in the tropical environment in which plant growth rates are high. Even the very fast growing exotic plantation tree species such as most conifers (e g. Pine and Cypress) and angiosperms (e.g. Teak and Cedrela), have rotation ages in excess of 20 years (Evans 1983, 1984, Iddi et al. 1996, Kumar et al. 1998, Malimbwi et al. 1992a, 1992b, Maliondo and Chamshama 1996, Maliondo et al. 2007). Thus, although some real and useful data have been obtained as indicated in the various reports in this publication, and already being extensively used for scholarly and practical discussions on their merits and potentialities, the real values of these plots will be ascertained when the methodologies being developed now will have been confirmed and applied widely as management tools following the various adjustments, modifications and modeling (Valkonen 2007b, Valkonen et al. 2007) that have started and would likely continue to be made on them and the possible additional future intra and international replications for improvements over the many years to come, that would take on board the varied rotation ages and desirable quantities and qualities of products of the various tree species that characterize the miombo woodlands ecosystem.

6 Conclusions

Sokoine University of Agriculture, particularly through its arm of the Faculty of Forestry and Nature Conservation, has done tremendous training work in forestry, wildlife, conservation biology and other related natural resources fields to produce a large number of professionals, field practitioners and backstopping and spearheading community development within and beyond Tanzanian national boundaries. The Kitulangalo Forest Reserve, as one of the field practical training facilities in natural resources, has provided tremendous contribution to the generation of knowledge in the various forest sciences, dry woodland ecosystems dynamics, socio-ecological interactions a and wide range of socio-economic ramifications. Besides the significant impacts on capacity building, direct support to the development of the local communities and provision of unique platform and opportunity for interactions between a wide spectrum of categories of stakeholder interests and sharing of rich experiences in natural resources management, the concepts that shape the two year old Kitulangalo MITMIOMBO research plots are providing us with new foci of thinking and challenges in developing up twin conservation and management pathways that lead to positively sustainable, regenerative and desirable products endowed systems. Concepts that would provide management methodologies that would practically reverse the inherent resources degradation. The methodologies that are urgently required now as participatory approaches are being adopted as national, regional and global resources management tools.

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Experiences and conclusions on interaction with local stakeholders around Kitulangalo Forest Reserve, Tanzania

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A study was conducted at Kitulangalo Forest Reserve (Morogoro) with the objective of getting experiences on the interaction between local stakeholders and the MITMIOMBO project. This also included linking research to effective application of solutions through group discussions on Miombo management and disseminating and discussing the project's experiments with stake holders. Villagers from Gwata, Maseyu and Lubungo villages including pastoralists and staff members from various institutes around Morogoro participated. Participants from villages were participatorily and purposively selected. Involvement of local communities and other stakeholders in management and regeneration of the miombo woodland research was much appreciated in the communities and contributed essential information and knowledge to the project.

Keywords: Kitulangalo, interaction, local communities, knowledge

1 Introduction

Woodland ecosystems are important areas in resource provision to many local communities. Management of these indigenous tree species for the restoration of ecosystems, management of the water balance, provision of resources for rural livelihood, and sustainable production of wood are of great importance in semi-arid areas of East and Southern Africa. Effective measures are necessary to stop/limit deterioration of these ecosystems including desertification. Without these poverty will increase, leading to accelerated urbanization in despair.

Wood extracted for fuel is among important products accrued from the woodlands. About 90% of the energy consumption in Tanzania is derived from wood, mostly from overexploited indigenous woodlands. Contribution from plantations provided no considerable amount of wood products.

Management of these woodlands is also poor. The management of woodlands with the intensive involvement of local communities seems to be a key alternative.

Much as it is, indigenous woodlands face management challenges. This entailed establishment of the MITMIOMBO project which focused on developing methods for the management of indigenous forests of semi-arid East Africa. Communication and application of established research methods was organized by initiating experimental studies in Kitulangalo Forset Reserve (Tanzania) and integrating it with the exchange of experiences between external with Tanzanian researchers. The local farmers and communities were consulted for knowledge of local needs, expectations and practices. The woodland is very important to the local communities as a source of mainly woodfuel, timber and local construction materials. The supply of these materials keeps on declining with time. Interaction was accomplished by fulfilling the communication and dissemination strategy including internal seminars and workshops, several exchange assignments of 1–3 months each in Finland and Tanzania and group visits to experimental sites and local offices.

On fulfilling the communication and dissemination strategy, knowledge of local stakeholders becomes important. There is increasing recognition that the use and application of indigenous knowledge and indigenous natural resource management systems provide effective strategies for the conservation of biological diversity and the sustainable use of natural resources (Kamara 1994). Therefore, dissemination has simply to go well beyond traditional vehicles of journal publication and academic conference presentations. It involves a process of extracting the main messages or key implications derived from research results and communicating them to targeted groups of decision makers and other stakeholders in a way that encourages them to factor the research implications into their daily work. This necessitates involvement of many stakeholders. This helps to get rid of most of the issues that are raised when the technology package is ready for adoption. This was achieved by taking villagers and other stakeholders onboard the MITMIOMBO project. It was the objective of the planned work to spread gained knowledge to other stakeholders including Government and Non Government organizations in terms of understanding regeneration for improvement and sustainable management of the miombo ecosystem. However, interaction is a continuous process. The conducted international workshop which discussed the MITMIOMBO project results was also a continuation of the dissemination strategy.

2 Methods

2.1 Study area

The study was conducted at Kitulangalo Forest Reserve where MITMIOMBO demonstration plots are. Climate and other conditions within study area are as explained elsewhere (Petro et al. 2005).

2.2 Collection of information

Group focal discussion method was used to collect information from different people/participating groups. Group dissemination method was observed to be useful as it was also the most effective in Shinyanga (Msuya et al. 2006). Information was collected from members of the three villages (Gwata, Maseyu and Lubungo) and others from Sokoine University of Agriculture (SUA), Morogoro Forest District offices, Tanzania Tree Seed Agency (TTSA) and some staff from Tanzania Forestry Research Institute (TAFORI). Members from the villages also included pastoralists who are very important in the miombo ecosystems. Participants (both men and women) from villages were selected participatorily and purposively by members of the respective village.

3 Observations

A total of 20 members (both men and women) from each village were expected to appear for the exercise. Actual participation included 20 villagers from Gwata, 12 from Maseyu and 20 from Lubungo (including pastoralists). Other participants included staff from SUA, TAFORI, TTSA and Morogoro District council.

It was observed that the present project (MITMIOMBO) increased the understanding of the stakeholders including villagers and pastoralists on regeneration, production and management options of miombo woodlands. This helped building of stakeholders' knowledge on miombo woodlands and is expected to be lasting. This cumulative body of knowledge is expected to be handed down through generations by cultural transmission (McCall 1996). The obtained information was a result of intensive discussions.

There was a lot of exchange of knowledge and experiences between MITMIOMBO experts and other stakeholders. It was realized that for the miombo to regenerate properly, human interference need be minimized. This has to go hand in hand with cooperation with communities around respective resources.

It was found that absence of trees substitute in and around villages is detrimental to miombo woodlands. Establishment of woodlots by villagers can improve miombo conservation by reducing encroachment. This can be done through planting, enrichment planting or improvement of fodder plants and trees in the villagelands. Among the species suggested by villagers to be planted included teak (*Tectona grandis*) and eucalypts. These and other species can be included in the agroforestry system so as to improve wood productivity. However, much of the current endeavor in agroforestry development in the miombo has focused on only increasing crop yields to meet the needs for human subsistence (Akinnifesi et al. 2006a). This has to be adjusted to also increasing trees crop production. It was the suggestion by many villagers that they would like to include tree nurseries in future project. On these lines the need for capacity building on tree nurseries and tree planting was also found pertinent.

Villagers also proposed inclusion of other economic activities like bee keeping in their daily economies. These have been noted to have minimum disturbance to the woodland. However, people need to have technical know how on how to go about. This has also to go hand in hand with improvement of agriculture outputs. In this way proper land use system is heavily needed. If agricultural productivity is to be sustained and the miombo woodland conserved, alternative land use strategies are urgently needed (Sileshi et al. 2007).

Villagers questioned the use and importance of fire in the woodland. Fire was indicated to be a potential problem within miombo. Despite good service it provides in influencing seed germination to some tree species, its negative effect like providing openings for invasive species (Sileshi et al. 2007) and effect to other trees was observed to be prominent. This controversy is arguably a result of a gap in existing knowledge and lack of informed literature on the importance of fire for socio-economic and environmental survival in miombo environments. Despite the fact that fire is a threat to biodiversity, it is also a prerequisite for biodiversity (without any disturbances some native species might die out).

Despite appreciation of the treatments used in the trials in respect to their results, stakeholders especially villagers were worried on the cost involved especially in the wire fenced plots. However, it was realized that other methods like use of live fences and thorns could be used to exclude wild and domestic animals.

Many of miombo trees produce seed which cannot be raised and domesticated easily. Many have long term dormancy and are in many cases not readily available. They can not be obtained much easily like seed from exotic tree species. Just like in other forest areas, shortage of tree seeds, seedlings and other propagation materials is one of the most important constraints in dissemination and adoption of technologies (NASCO 2006). More study needs to be conducted to come up with cheap, proper and scientific miombo seed germination technologies and even a sort of catalogue can be produced.

Despite the fact that the experiment was short lived, a remarkable difference in terms of grass biomass and accumulated regenerants was clear especially in the enclosed plots. For a well developing woodland, limited removal of the dead wood from the woodland was recommended. These recycle nutrients, houses other organisms and food for many other living organisms in the woodland including birds. This will ensure ecosystem stability (URT 1998) and is in compliance with National Policy and law (Matose and Wily 1996). However, this is not always the case as sometimes wood needs to be extracted for management purposes.

Participation of women was very crucial as they were encouraged to take part in the whole process to improve gender perspective in the values of the woodlands. This was important so as to improve the existing traditional institutions which provide norms and procedures that shape people’s actions which consist of codes of conduct that define practices, assign roles and guide interactions (Fisher 1993). These are generally instrumental in natural resource management and rural development processes at large and were sustainable over a period of hundreds years (Pretty 1990). However, MITMIOMBO project strived to, and managed to include women in discussion which improved gender perspective.

Stake-holders were very interceded and positive to experimental treatments and engaged and concerned in miombo management and regeneration. Their contribution was supplemented by the fact that this community lived with these resources for quite a long time. They presumably have the best skills and knowledge to manage the resources (Kowero 2003) which can be interacted with experts’ knowledge. However, this traditional management may no longer be suitable with the present population pressure, pressure on resources and developed technologies.

4 Conclusions

Interaction is a very important process and needs to be continuous during the whole project lifetime. It helps in clearing doubts in the earlier before end of the project and results. Participation of local stakeholders within MITMIOMBO project took on board the idea. Interaction acted as a bridge in methods and results dissemination. It works as two way traffic in exchange of ideas and principles. Ideas provided by the local stakeholders played a very important role in shaping and managing the experiments hence its importance should not be overemphasized.

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Forest and water relations in miombo woodlands: need for understanding of complex stand management

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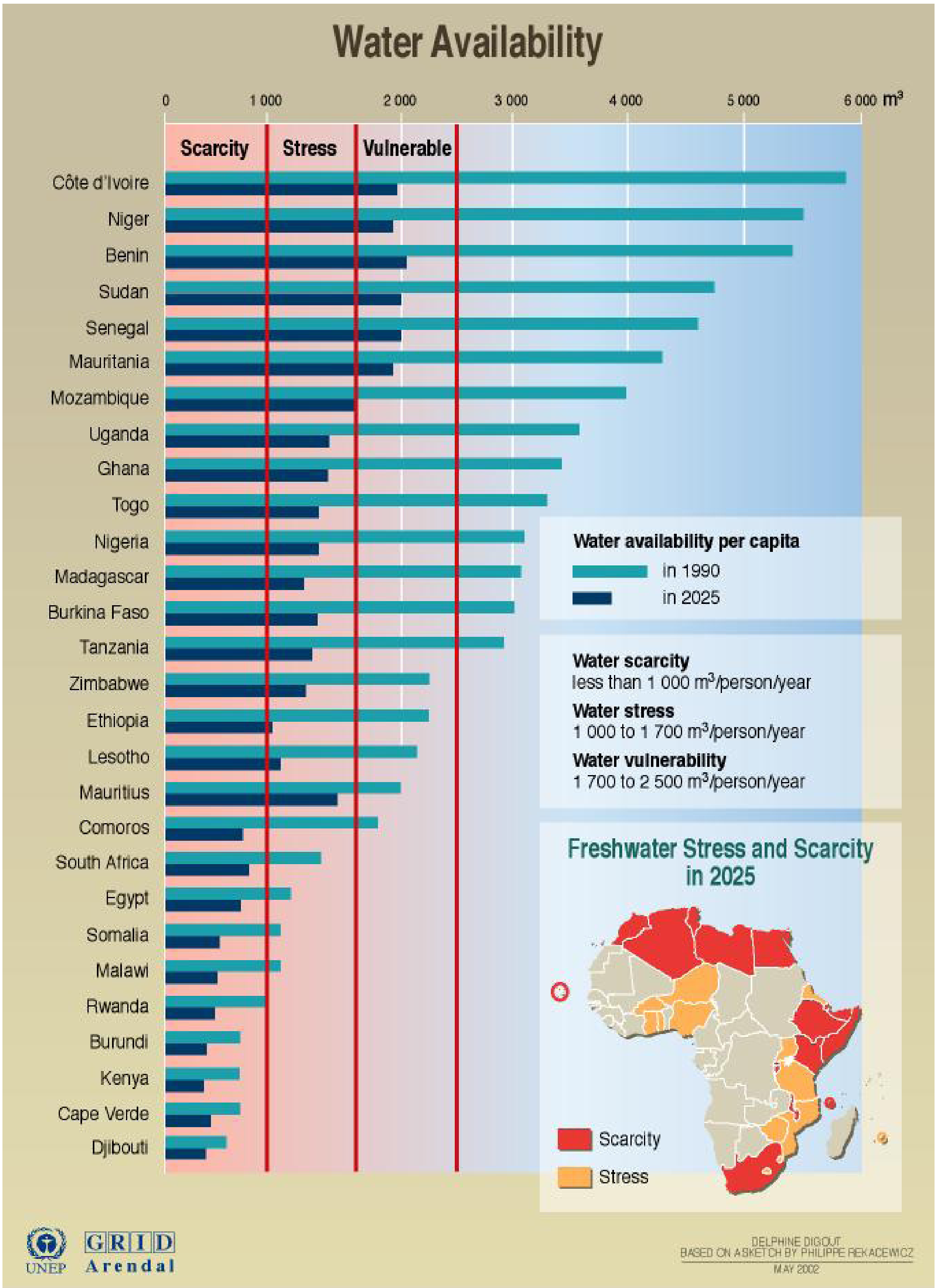
Miombo is a significant biome covering about 10% of the African landmass. Climate semi-aridity is the main edaphic determinant. Range of annual rainfall and dry season length is high, but the unimodal rainfall distribution is common for all miombo. Water is increasingly an issue of trade-off between different land uses and increasing demand on biomass production. This review gives a basic description of major components in the relations between tree cover and water in semi-arid landscapes. From this, in lack of relevant research within miombo landscapes, a scientifically based discussion is given on how future uses and management of these complex woodlands could serve in better management of scarce water resources and in what ways more research in these aspects could enlighten this discussion. It is concluded that, like for other semi-arid landscapes, there is need for understanding and developing more complex stand management to optimize biomass production and water use efficiency. At the same time climate change adaptation will add to this need of deepened biophysical process understanding.

Keywords: water soil, management, organic matter, vegetation, woodlands

1 Background

The understanding and wise management of miombo woodlands is crucial to a large part of Africa. It supports the livelihood of 100 million people in the area or outside, relying on products from this distinct and unique biome (Campbell et al. 2007). Under dynamic societal change (Falkenmark and Molden 2008) and for climate change adaptation there is need for a deeper and higher resolution of ecologically and land-use based understanding of the system (Malmer 2007, Milly et al. 2008). Projected water demand and supply for Africa is problematic (Fig. 1), not least for countries in the miombo region. This review aims to give a basic description of major components in the relations between tree cover and water in semi-arid landscapes. From this, in lack of relevant research within miombo landscapes, a scientifically based discussion is given on future uses and management of these complex woodlands and in what ways more research in these aspects could enlighten this discussion. The discussion is also mainly directed towards the positive relation or trade off between plant (forest) production and water available for other uses. It does not cover more established effects of deforestation on degrading water quality and risks for flooding.



Source: United Nations Economic Commission for Africa (UNECA), Addis Ababa ; Global Environment Outlook 2000 (GEO), UNEP, Earthscan, London, 1999.

Figure 1. Predicted water availability in African countries.

2 Defining the miombo landscape

Miombo woodland is a significant biome covering about 10% of the African landmass (c:a 2.5 – 4 million km^2 depending on definition, White 1983, Millington et al. 1994). Miombo can be found in most countries of Southern and Central Africa and it is the dominant forest component of Angola, Zambia, Tanzania, Malawi, Mozambique and Zimbabwe (Fig. 2). Miombo ranges of physiognomic and functional properties as well as within landscape spatial variation is high which makes definitions broad and overlapping with deciduous forests and open savannas. Frost (1986) gave a useful definition; ”Those tropical and some near tropical ecosystems characterised by continuous herbaceous cover consisting mostly of heliophilous C_4 grasses and sedges that show clear seasonality related to water stress. Woody species (shrubs, trees, palms) occur but seldom form a continuous cover paralleling that of the grassy layer.” However, there are many definitions and in common language terminology varies with terms like; woodland, bushland, thicket, wooded grassland and savanna.

Miombo trees are dominated by generas *Brachystegia, Julbernardia* and *Isoberlina* (*Fabaceae, subfamily Caesalpinioideae)*. Miombo is also related to Sudano-Sahelian parklands which have the abundant genera *Isoberlina* in common. These later eco-systems for long time have had zones of strong human influence on structure of vegetation. While small-scale shifting cultivation is dominant in miombo (Campbell et al. 1996), the parkland of West Africa is dominantly under more permanent traditional agroforestry systems (Pullan 1974).

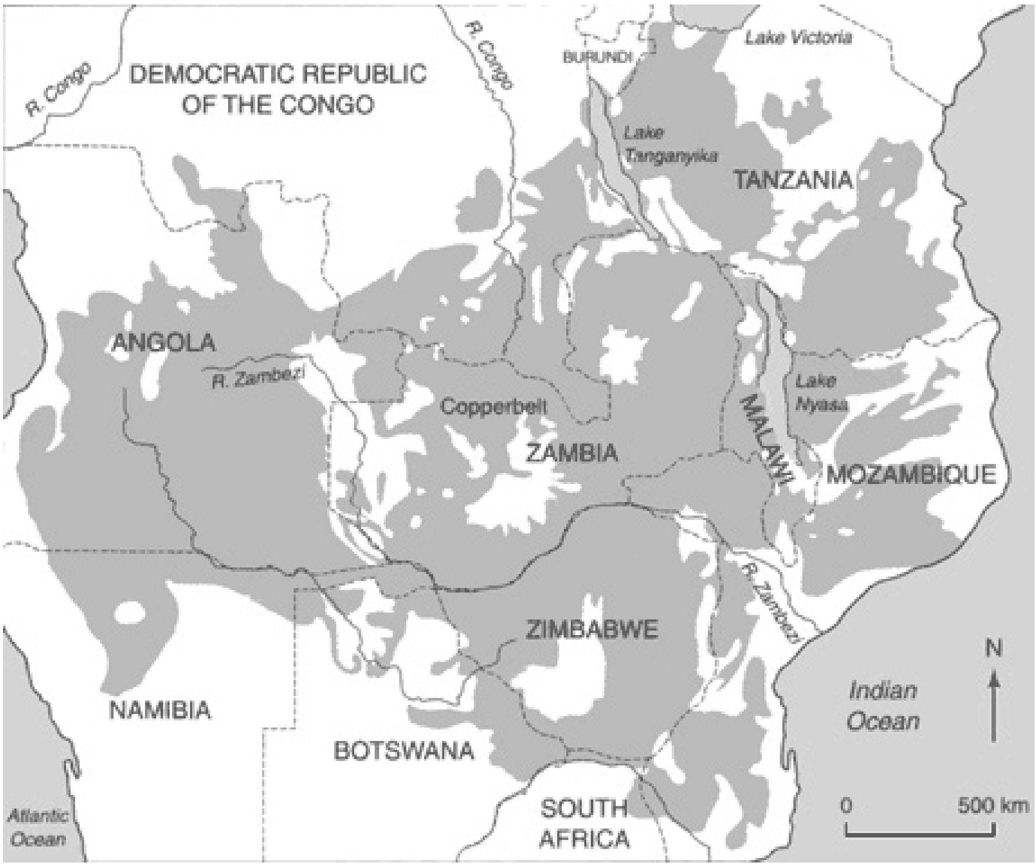


Figure 2. Distribution of Miombo woodlands. (White 1983)

2.1 Semi-natural miombo and planted forests in miombo landscapes

Deforestation is an old and ongoing process in miombo (FAO 2007), but large areas are still covered by miombo in various states. Long-term human impact is often profound on forest structure and species composition in many areas (Campbell et al. 2007). Forest management and tree planting has mostly been focussed on exotic species in plantations and woodlots (Gerhart and Nemarundwe 2006), even if, more recently, there are increasing numbers of interesting examples of natural forest management in Zimbabwe (Gerhart and Nemarundwe 2006) and elsewhere (Campbell et al. 2007).

Tanzania and Zimbabwe are the concerned central miombo countries that have the most forest plantations. Total areas are still moderate and about half of them are industrial (Varmola and Del Lungo 2002). Looking ahead, with increasing demands of energy, industrial wood and carbon credits there is a growing interest for plantation forestry in the relatively low populated miombo region, not least in Tanzania (e.g. Stave 2000).

So, the miombo landscape hosts a very varied structure and net primary productivity of the continuum from degraded miombo over well managed miombo to even-aged forest plantations. This has large bearing on impact on water management, both trough water use by the trees as well as by the impact on soils and potential groundwater recharge as will be described below.

2.2 Dambos – wetlands in the miombo landscape

Dambos are wetlands attributed to flatter lower laying parts of the miombo landscape (Mapaure and McCartney 2001). Mainly covered with grass, these wetlands can make up up to one third of the landscape (Whitlow 1985). They are shallow and often dry out seasonally (Campbell et al. 1996), but have often been positively perceived to delay downstream streamflows into the dry season (Balek and Perry 1973).

2.3 Isolated high mountains draw rainfall and host other forest types

In Tanzania rainfall in the highland is much related to relief (Jackson 1972a, TNRIC 2008). Isolated mountain massifs in the eastern part of Tanzanian miombo, like Uluguru and Rubeho mountains, receive more than 2000 mm annually and have higher rainfall intensities (Jackson 1972b). These mountains display various wetter montane forests (Burgess et al. 2007) and play an important role for water distribution into the surrounding miombo. Here and globally, for tropical moist cloud forest (TMCF) the effect of forest conservation in such mountains have been discussed as a prerequisite for the high moisture input, and distribution to surrounding regions, by the ability of tree crowns to catch horizontal rain and to “strip clouds” (Bruijnzeel 2005). However, as there are very few empirical studies both globally and in Tanzania (Uebel 1997), this specific effect remains unproven.

3 Edaphic determinants for miombo

3.1 Climate

Climatic semi-aridity is the main edaphic determinant. Precipitation is typically unimodally distributed (Fig. 3). However, high ranges (annual rainfall 550–1200 mm; length of dry season 3–7 months; mean annual temperature range 15–25 °C, Frost 1996) give way to division into dry and wet miombo woodlands with wide floristic and functional differences (White 1983). The dry miombo is found in areas of less than 1000 mm annual rainfall. Wet miombo has higher tree height (typically > 15 m) and has higher floristic diversity. Wet miombo mainly occurs in the northern part of miombo distribution; eastern Angola, northern Zambia, south-western Tanzania and central Malawi.

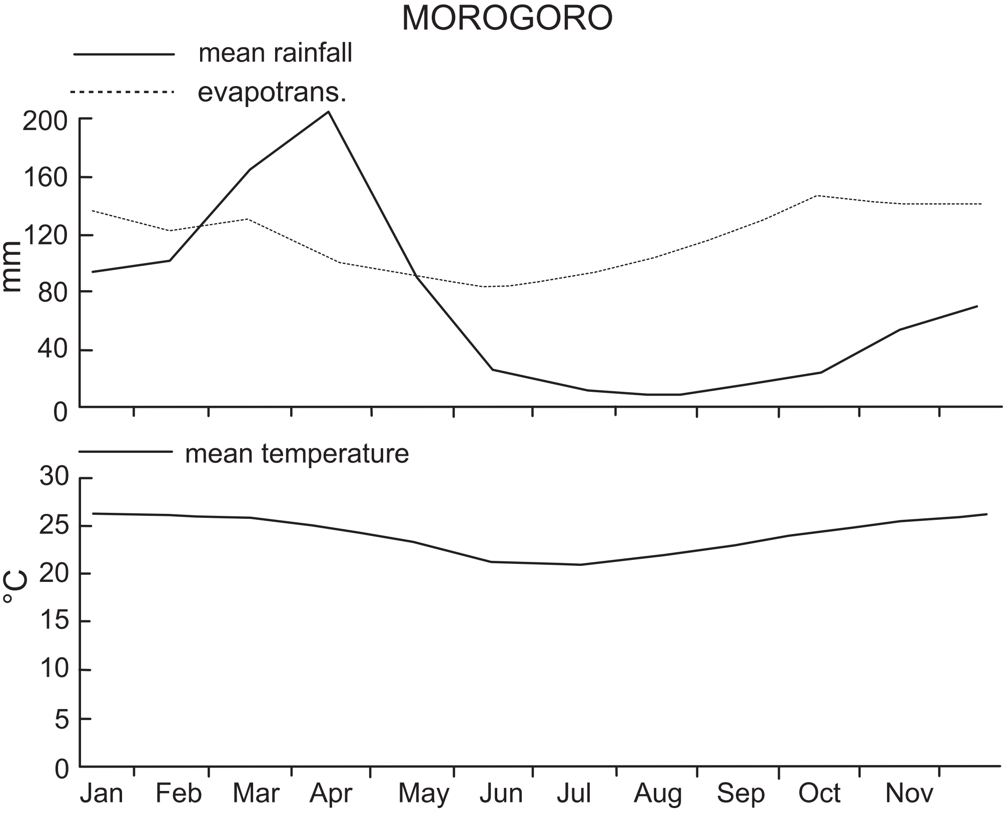


Figure 3. Typical intermediate miombo monthly rainfall, potential evapotranspiration and temperature with unimodal rainfall distribution (Morogoro, Tanzania, source FAO 1984).

3.2 Geology, carbon, soils and root symbiosis

Apart from sections of inselbergs or enscarpments miombo geomorphology is dominated by old surfaces of low relief. In these areas the balance of weathering and erosion over long time has produced relatively deep soils (typically > 3 m, FAO 1974). Soils have a wide range in mineral properties but means of pH, cation exchange capacity and total exchangeable bases are low (Frost 1996). In general it has been argued that richer geology and mineral soils support more open *Acacia* savannas (Frost et al. 1986, Campbell et al. 1996), but miombo do occur on as wide soil groups as Ferralsols, Acrisols, Luvisols and Nitisols (FAO 1974, Frost 1996).

Top soil organic content is typically low (Frost 1996, Walker and Desanker 2004). On average, agricultural soils contain 40% less soil carbon than the natural miombo woodlands. Soil carbon declines logarithmically with depth within all land use types. Clay content is typically positively correlated with soil carbon in the top 40 cm and therefore areas of higher clay content contained elevated carbon levels (Walker and Desanker 2004). In a nutrient poor system, soil organic matter (SOM) can play an important role in the stability, quality, and fertility of the soil. Farmers and land use planners are therefore interested in land use management that will enhance soil carbon levels. Also important for climate/carbon management, as is common in drier systems (Woomer et al. 1997), in the miombo woodlands ecosystem of South-Central Africa roughly 60% the total carbon stock is found belowground (Campbell et al. 1998) (Table 1). Nitrogen availability is low as a result of the frequent fires and relatively slow decomposition from high acidity.

The strong dominance by *Caesalpinioideae* in miombo has not been fully understood, but the main reason is surely the widespread associations with ectomycorrhizae (Högberg and Nylund 1981). Poor soils and the loss of N (and P) by regular fire makes the mycorrhizal association an important advantage. Nitrogen fixing species are also important for replacing N lost. Like in other ecosystems N concentrations are considerably higher in leaves from N-fixing miombo species (Högberg 1996).

Table 1. Carbon content in different biomes. Biome C densities from Houghton et al. 1983 (except for miombo from Chidamayo 1994 and Cambell et al. 1998).

Biome	Veg. C density ton/ha	Soil C density ton/ha	Total ton/ha
Tropical moist forest	200	120	320
Tropical seasonal forest	160	120	280
Miombo	30–70	100	~150
Tropical woodland and schrubland	30	70	100
Tropical grassland	20	40	60
Temperature grassland	10	190	200
Cultivated land	5	60	65
Pasture land	10	190	200

3.3 Fire a principal disturbance

About 1.3 million km^2 of fire adapted savanna and grassland burn annually in Africa (FAO, 2001). Dry season fire is a main determinant for succession of vegetation and soils in a stand-age time perspective. Principal fuel for fires is the dry herbaceous layer and dry components of litter and top soil humus. Most mature trees and woody plants are fire resistant. This makes fire swift and relative C and N atmospheric losses moderate. Various amounts of fuel make fire contribute to the high spatial structural variability of miombo. Estimates of fire return intervals for miombo lies between 1.6 – 3 years (Frost 1996). Reliable studies of fire frequencies are scarce and it can be debated what is “natural”. Human use of fire (to improve grazing and/or for hunting) has probably been part of the miombo fire regime for millennia (Clark and van Zinderen Bakker 1964).

In general, for many tropical forest ecosystems, the increasing human impact today and changing vegetations (and fuel) make any estimate of what is "true" fire patterns very difficult (Malmer et al. 2005).

4 Perceptions and empirics on water dynamics in semi-arid forests

4.1 General implication of forest management on water budgets

Falkenmark (1997) introduced a useful terminology with "green and blue water". Green water is the return of water to the atmosphere as evapotranspiration (ET, including transpiration by vegetation, evaporation from soil, lakes, and water intercepted and evaporated from (mainly tree) canopy surfaces), i.e. to a large part water that is used to produce food and environmental services by forests and agricultural crops. Blue water is on the other hand what is left for deeper groundwater and stream runoff, ie. water available for animal and human consumption for example in downstream urban areas. Critical processes are the partitioning of rainfall between green and blue water, which is 1) infiltration of water into the soil or surface runoff and 2) uptake of soil water by plants or recharge of groundwater.

It is an empirically and theoretically well established general scientific paradigm that forests use more water than lower vegetation and rain-fed agriculture. This could also be expressed as a positive relationship between biomass production and water use (Rockström 2003). Consequently, empiric evidence is strong that cutting forest results in increased streamflows (Bosch and Hewlett,1982). Typically, also regenerating forests and afforestation is shown to partition more of the rainfall to green water, reducing availability of blue water (Farley et al. 2005, Scott et al. 2005).

4.2 In contrast: Old forests in semi-arid areas may work as "sponges" to better recharge groundwater and retain higher dry season flows

The role of forests for partitioning between green and blue water in tropical semi-arid regions is under long term scientific and policy debate (Bruijnzeel 2004). In the first partitioning step described above, forests have been shown to maintain high infiltrability by superior litterfall and soil protection (eg. Bruijnzeel 1990). Increasing surface runoff after deforestation and possible soil deterioration leads to more "blue water" in streams momentarily. In the semi-arid situation this means that less water during the wet season in the second partitioning to contribute to long term ground water recharge and subsequently to maintain dry season streamflows. This is often observed by rural people, but physically this is elaborate and time consuming (expensive) to investigate in environments of low infrastructure. Consequently only a few studies have reported the expected long term decline in dry season flows (Bruijnzeel 1989, Sandström 1998). So in these aspects we have some evidence that a "sponge effect" can be lost by deforestation and subsequent soil degradation, but the conclusion can hardly be made general for all semi-arid forest ecosystems.

Upon massive evidence on how tree litterfall and soil protection can improve soil quality and reduce surface runoff and erosion (eg. Hurni and Tato 1992), the restoration of a "forest sponge effect" have generally been taken for granted (Kaimowitz 2005). This has been the paradigm behind numerous forest/tree planting projects and one of several drivers for positive development in agroforestry. However, in this case there are many local witnesses to tell that new forests often make wells and streams drier. As for scientific studies also in this case long term studies are scarce. In contrast to the "lost sponge effect" the few studies made in semi-arid environments all confirm that new forests use more green water than they may contribute to blue water in terms of groundwater recharge. This effect of "not enough ground water recharge effect" is manifested in these studies as generally declining streamflows (Scott et al. 2005).

4.3 Physical interpretation to why new forests use more water

The new forests established are most often planted exotic species like Eucalypts and Pines. They are chosen for high productivity. Many of the species used are pioneer species in their respective original ecosystems, and increasingly they are genetically improved for fast wood production. Furthermore, these new forests are monocultures of vigorously growing young trees in contrast to old growth forest, which are mixes of species and old trees, young trees and treeless gaps.

Studies of sap flow in plantation trees also confirm high water use (eg. Cienciala et al. 2001), but notably also indigenous tree species in secondary "bush vegetation" may use as much water as the exotics (Fritzsche et al. 2006). Deep rooted Eucalypts are often given as the "bad example" of the highly water consuming exotics. However, other trees pecies may be as "bad" (or effective biomass producers) if used in the concept of highly productive, landscape-covering, mono-culture plantations.

4.4 Lack of semi-arid field research is a global problem

The few studies mentioned above to verify the higher water use by semi arid plantations are made in areas where dry season streamflow have been very seriously affected, and in some cases approached closed water basins (meaning no streamwater outflow from the watershed, Falkenmark and Molden 2008). These are regions in South Africa and India, where former non-forested grasslands and savannas have been afforested. In contrast there is no designated long-term study on the effect of streamflow where forestation is made on degraded soil. For this case the partitioning by improved infiltration, relevant to typical rain intensities, is securely established (Ilstedt et al. 2007). In the cases in India and South Africa the natural grasslands probably already had reasonable infiltrability, so the effect of the afforestation was possibly only on increased water use (Bruijnzeel 2004).

Long-term studies of forest water use are typically catchment studies where the treatment covers all or a large part of the studied area (the whole landscape). With many industrial plantations this is often also the case. However, to be able to make recommendations on how large, or in what part of the landscape, forest would be recommendable, is then not possible from the "black box approach" of the catchment study. In lack of ecologically based studies including soil water partitioning, sometimes models only looking at forest water use are applied (eg. Calder et al. 2004). This mostly results in negative recommendations towards forestation, possibly underestimating water benefits of forested areas.

On the global scale, under the challenges of meeting demands of biomass production for the Millenium Development Goals (and adding recent increasing demand on biofules), specifically the more efficient partitioning of rainfall is key and limiting for success (Rockström et al. 2007). This is increasingly stressed for Sub-Saharan Africa (Falkenmark and Rockström 2008), while data resolution for these regions remain too poor to verify current landscape based ecosystem models (Ilstedt et al. 2007).

5 Empirics about miombo specifically and what can be hypothesised?

5.1 Few studies confirm decreasing dry season flows for various reasons

In an early study in Sao Hill, Tanzania, *Eucalyptus saligna* planted in miombo landscape showed to result in much lower annual and dry season streamflows than from nearby grassland, while the streamflow reduction by *Pinus patula* was much less (Mhando 1991, Fig. 4). This study did not have a reference period to study how different the catchments were before treatments, which makes the results insecure, but it is another indication of high water use by Eucalypts, also form the miombo region. This may be due to deeper roots, higher productivity, etc. in comparison with

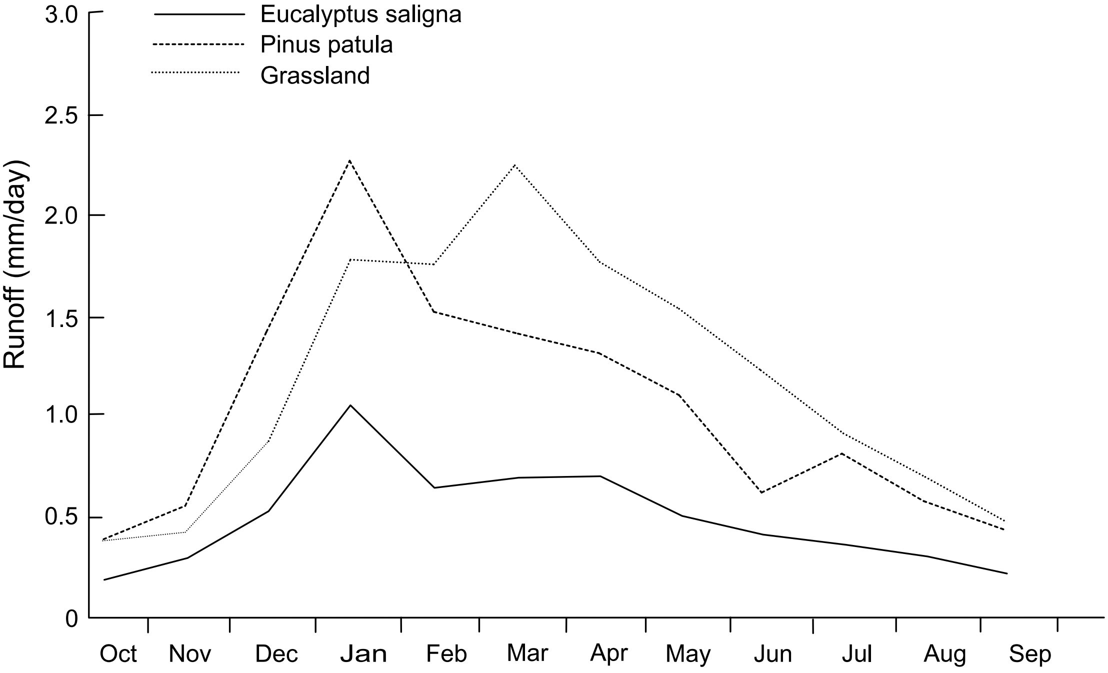
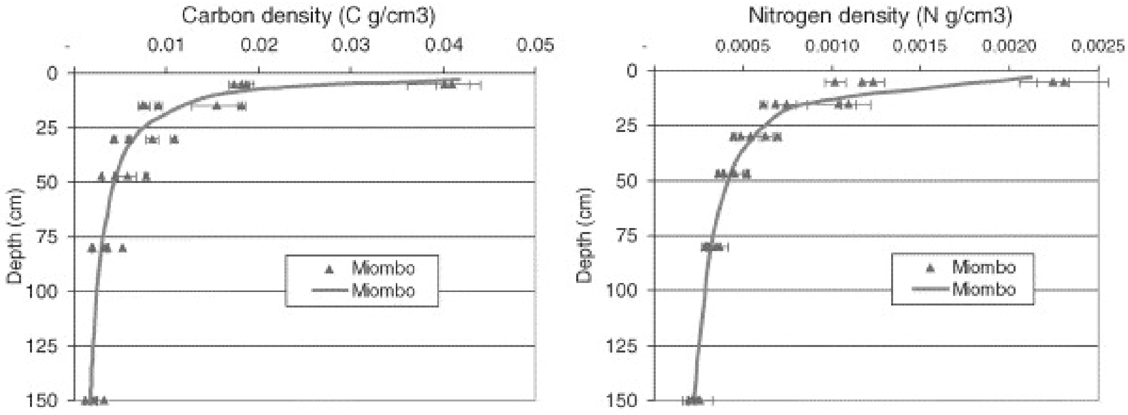
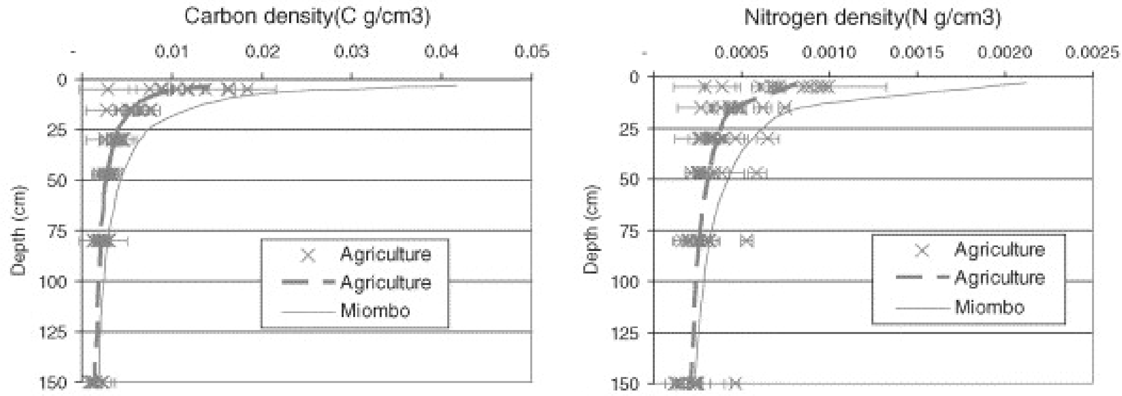


Figure 4. Monthly mean daily runoff of eucalypt plantation and pine plantation and grassland in Sao Hill, Tanzania 1981–1989 (Mhando 1991).



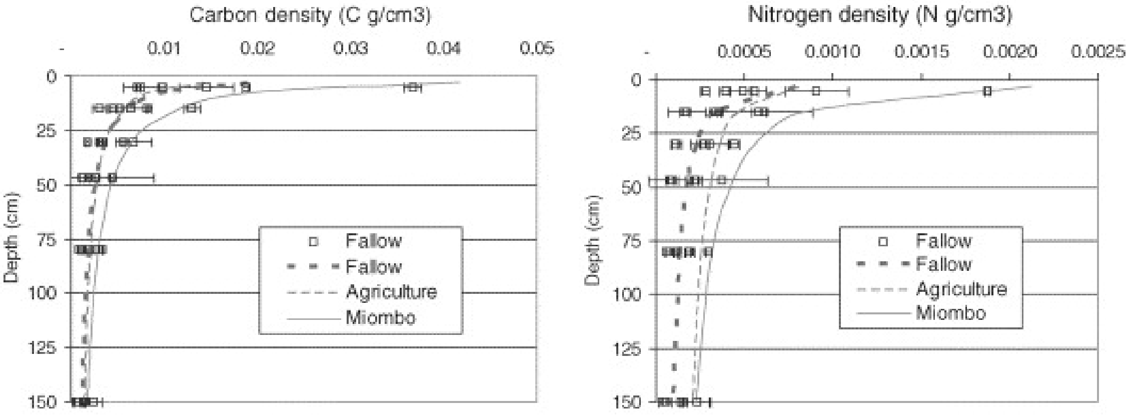
Miombo
log C density = -0.995+(-0.807*log cm) R^2= 0.83

Miombo
log N density = -2.4+(-0.58*log cm) R^2= 0.84



Agriculture
log C density = -1.56+(-0.595*log cm) R^2= 0.66

Agriculture
log N density = -2.93+(-0.35*log cm) R^2= 0.465



Fallow
log C density = -1.379+(-0.719*log cm) R^2= 0.62

Fallow
log N density = -2.85+(-0.54*log cm) R^2= 0.32

Figure 5. Regression of carbon and nitrogen density with depth by land use type (Bars denote SE, after Walker and Desanker 2004).

the pine plantation, and certainly in comparison with the grass.
In another study using long term data, Kashaigili et al. (2006) show dramatically decreasing dry season flows (60–70%) between 1958 to 2004, downstream the Usangu wetlands in Tanzania. In the upstream areas woodlands have decreased strongly on behalf of cultivated land and bare land. In this case it may be tempting to hypothesise on "lost sponge effect", but Kashaigili et al. (2006) use modelling to show that the major reason for declining dry season flows are due to reverting of blue water into green water in a strong increase of irrigation in the same period.

In the above study of the Usangu wetland, the wetland itself is called a "scarcity enhancer", even if possibly delaying flows into the dry season, the evapotranspiration from the wetland is considerable. In another study of dambo hydrology in Zambia, von der Heyden and New (2003) showed that the dambo studied dried out in the dry season. In that case the downstream baseflow was maintained by deeper groundwater, i.e. stemming from infiltration upstream.

5.2 In miombo or planted forest – soil organic matter and soil fauna are important

Management of organic material in soils is crucial for soil quality and fertility. Harvesting, grazing and fire add to decomposition in reducing soil organic matter by reduced litterfall and oxidation. In miombo already low topsoil organic contents are typically reduced up to 50 % by agriculture (Fig. 5). Soil organic matter also determines top soil physical properties. The soil structure (soil aggregates increasing amount of large pores) determines to a large extent the partitioning between surface runoff, erosion and soil infiltrability (Bruijnzeel 1990, Malmer et al. 2005). In various land use in Zambia, the structural stability of the soil was shown to be direct positively related to soil organic carbon (King and Campbell 1993)

Soil crusting is a common reason for reduced infiltrability in semi-arid areas. Perrolf and Sandström (1995) described various processes for crust formation in Tanzania and Botswana and concluded vegetation cover to be determinant apart from soil texture. Similarly, Casenave and Valentin (1992) from 87 sites in semi arid West Africa found also intensity of surface sealing, vegetative cover and soil faunal activity to be determinant for infiltrability.

From data in meta-analysis by Ilstedt et al. (2007) it is clear that soil infiltrability is restored with much different success under different trees (Fig. 6). In Zambia also King and Campbell (1993) could show rather different size distributions of soil aggregates, more larger aggregates under *Pinus patula* than under closed miombo and *Eucalyptus grandis*. In Sao Hill, Tanzania, Ngegba et al. (2001) also had highest soil organic matter in top soils under *Pinus patula* plantation compared with *Eucalyptus saligna* and poorly stocked miombo, but in this study differences were small compared to those observed in the Zambian study.

As already mentioned in the general section above, the heterogeneity of miombo stands have to be stressed. Nord (2008) measured infiltrability in miombo with various stocking and in *Albizia vesicolor* plantation. Her major finding was the very high variability of infiltrability in these stands making statistical differences show only between extremes, with the *Albizia* having highest mean infiltrability and the most degraded miombo the lowest.

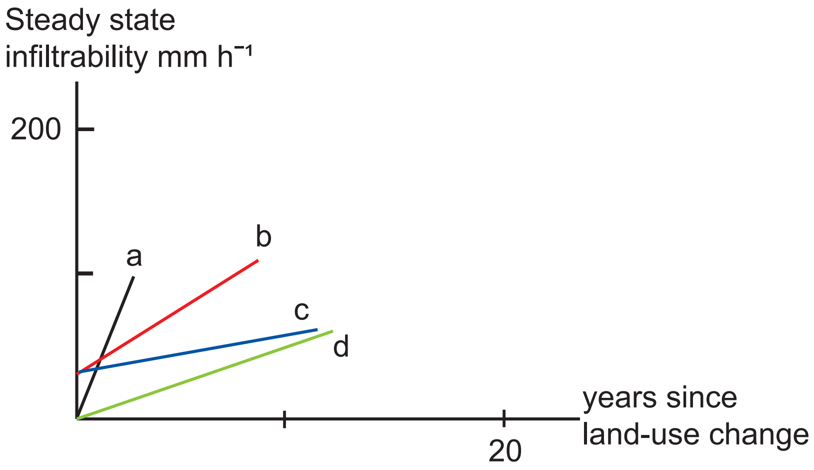


Figure 6. Rehabilitation of infiltrability after planting trees of different species and in different situations. a) open land to *Sesbania*, b) open land to *Leucena* agroforestry, c) grassland to *Tectona* (teak) and d) tractor track rehabilitation under rainforest (after Ilstedt et al. 2007).

5.3 Forest and water management in miombo landscapes based on current knowledge

Already Hough (1986) identified the major problems for semiarid areas described above; 1) increasing dry season flows, 2) trees preserve infiltrability and reduce surface runoff and erosion, but 3) trees/forests use more water than other vegetation. Not much research to resolve "conflicts" and underlying process explanations between these three points have happened since Hough (1986) where he elaborated on miombo management options to reduce evapotranspiration while at the same time retaining good soil quality. The following management options and their effects given below in this section are from Hough (1986), unless otherwise cited.

5.3.1 Conversion to grassland

Grasses may have considerable biomass production potential but they have less deep roots than trees. Hence, miombo conversion to grass consume less water and increase streamflow. In contrast, grassland after deforestation often shows lower infiltrability and thereby may increase surface runoff, erosion and stormflows. Furthermore, the conflicting results on unaffected or reduced groundwater recharge/dry season streamflows should be kept in mind (c.f. section 4 above). Also, not suppressed grasses build up very flammable fuels for severe dry season fires.

5.3.2 Forest structure modifications

Thinning and crown pruning have lowering effect on evapotranspiration, but the stand adapts soon to make the change very temporary. Alternatively, maintaining stands with dominantly young trees might mean fewer deep roots to reduce water acess/transpiration. However, even if deep-root studies still are scarce, for example studies on *Acacia mangium* have showed full rooting depth (2–3 m to the bedrock) within two years (Boström 2000). Hough also discussed reduction of woody understory to, again, reduce more relatively deep rooted individuals.

5.3.3 Species selection within moimbo

If differences in rooting depth and water use would be better known, species with lower water consumption could be chosen. The problem is then that this would most probably mean a trade off with productivity.

5.3.4 Grazing

Intensive grazing in miombo keeps grass short and reduces regeneration of young woody plants. This may reduce transpiration, but again, induces risks for soil compaction by trampling and thereby reduced infiltrability.

5.3.5 Phreatophytes eradication

Phreatophytes is a tree form that is adapted to the riparian zone along streams. The removal of these trees would reduce transpiration at large (practiced in South Africa), as they reach water all year around. Tree removal might jeopardize stream bank stability, but exchange with deciduous trees might reduce water use in the dry season.

5.3.6 Dambo management

Hough put emphasis on the evapotranspiration from the wetlands and discussed how drainage would decrease water use and increase base flows. On the other hand, in the longer run drainage would lead to forest establishment and increased water use in the concerned area. Drainage might also dramatically negatively affect possibilities for dry season grazing in these areas.

6 Urgent research needs

From above it would be clear that there is an unsatisfactory scientific clarity in biophysical process knowledge and lack of empirical data on basic links between trees and water budgets for miombo as well as for semi arid ecosystems as a whole. This especially concerns the possible trade off or mutual benefit between forest production and groundwater recharge/dry season flows (green and blue water partitioning of rainfall). Scott et al. (2005) express that possibly in most cases productive forests might use more water than they contribute to groundwater recharge. On the other hand, with increasing demand on high production of both wood and food, the alternative with continued deforestation and continued deterioration of miombo stands is hardly a viable alternative.

6.1 Forestry must develop with understanding of use and conservation of water

In agriculture, much of expected increase in food production is expected from semi-arid areas and rain fed agriculture. Falkenmark and Rockström (2008) stress the importance of increasing efficiency in cultivation systems to shift losses in evaporation to productive transpiration, Makurira et al. (2007) giving a good example from Tanzania. In the same manner there is need for fundamental process knowledge about rainfall partitioning in forest ecosystems to be able to elaborate on effects of forestry applications like the ones discussed above. Specific fields of study include 1) study of not only infiltrability but actual groundwater recharge, 2) links between groundwater recharge and macropore flow, top soil carbon and aggregation and (miombo) tree species, 3) tree root development and symbiosis, deep roots and water uptake by (miombo) trees, 4) (miombo) tree species transpiration in relation to productivity, 5) interception (evaporation from tree canopies) by various forest structures and species.

For better efficiency of biomass productivity also forestry itself needs to develop in the understanding of multispecies systems like miombo or intensively managed miombo. Multi-species plantations in general are shown by meta-analysis to be more productive than monospecies plantations (Piotto 2008).

6.2 Long term environmental monitoring valuable

Long term monitoring programs and qualified analysis have been behind much of the success in development of northern forestry. In this sense there is also an urgent need for such monitoring programs and trials (eg. long term stream and rainfall monitoring and long term forestry trials) and academic capacity building in the miombo region. This base for research is not least important for understanding of climate change, its effect on forest production and water management and possibilities for adaptations to climate change.

7 Conclusions

In general it can be concluded that descriptive data for key ecological variables are lacking to apply process based modelling of soil development and water in complex miombo landscapes. Not least is this a problem for the understanding of miombo land use under climate change and the proper representation of the biome in regional and global modelling and policy formation.

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Economics of forest products in Tanzania

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This paper reports on ongoing research on socioeconomic aspects of forest use in Tanzania. The research has two components: to examine the socioeconomic impacts of participatory forest management (PFM) reforms recently carried out in Tanzania; and to explore the economic determinants of households' fuel choice. Preliminary findings suggest that different PFM schemes have had quite different impacts in different parts of the country, depending on both the local and regional context. In some areas, reduced use of protected forests has simply meant that people have switched to using other forests instead, so that the net impact on deforestation may be limited. Household characteristics influence whether PFM is perceived as successful: rich households, and households with own tree plots or other alternative sources of forest products, are more likely to perceive PFM as a success, poorer households who have lost access to forest products less so; this suggests that the distributional impacts of the current PFM strategies may be problematic. The research on determinants of fuel choice began more recently, and there are few findings from this research as yet. However, although mostly focused on demand for fuel in urban areas, this research has crucial implications for the sustainable management of miombo woodlands. Fuel use in the cities, particularly charcoal, is currently a major driver of deforestation in large parts of the country. In order to reduce pressure on forest areas it is important to have a better understanding of why households make the fuel choices that they do.

Keywords**:** Economics, forest use, fuel choice, participatory forest management

1 Introduction

Economic analysis of environmental management and natural resource exploitation is important for Tanzania because such analysis can shed light on how the country's environment and natural resources contribute to the welfare of the Tanzanian people. It is against this background that the University of Dar es Salaam, with the support of the Swedish International Development Cooperation Agency (Sida), has recently established the Environment for Development Tanzania Center for environmental economics policy research. The aim of the center is to offer support in terms of economic analysis to national environmental management and policy in Tanzania, in view of promoting sustainable national welfare and reducing poverty. As one part of the center's work, several research projects on socioeconomic aspects of forest use have been undertaken. The research on the impacts of the Participatory Forest Management (PFM) reforms began in 2007 and the research on determinants of fuel choice began in 2008.

2 Socioeconomic Impacts of the participatory forest management reforms

2.1 Setting and literature

PFM is a relatively new approach in Tanzania to conceptualizing the role of forests within the livelihoods of rural people that has been proposed as a way of both protecting Tanzania's forests and reducing rural poverty. The policy advocates private and Community Based Forest Management (CBFM) and provides legal basis for Joint Forest Management (JFM) of the forest reserves with catchments or biodiversity values. Under CBFM, villagers can declare and gazette forest areas on village land as "Village Land Forest Reserves." Villagers take full management responsibility, setting and enforcing rules and regulations over the forest management and use, including the collection of Non-Timber Forest Products (NTFPs). Under JFM, more restrictive extraction rules are typically implemented, particularly in preservation reserve forests that are especially important for ecosystem services and biodiversity protection. In these forests, effective JFM could result in villagers becoming responsible for protecting the forests, and taking on the costs of protection, but losing their current *de facto* rights to collecting NTFPs such as fuelwood and forest vegetables and fruits (Kajembe and Nzunda 2002, Ramadhani, as reported in Mertz 2005, Lovett 2008).

These possible consequences of PFM on both ecosystems and the rural poor have not been considered sufficiently, in part because of the lack of data concerning the current contribution of Tanzania's forests to the nearby communities, and in part because of the lack of an appropriate analytical framework for addressing and measuring the impact of PFM on both forest resources and rural livelihoods.

Theoretical research identifies two distinct effects when villagers are excluded from an area where they have traditionally collected resources: a "displacement effect" in which the villagers extract more intensively elsewhere, thereby displacing the problems of degradation to other forest areas; and a "replacement effect" in which villagers replace the extracted product either with a purchased product (thereby possibly increasing pressure on more distant forests supplying the market, (Robinson et al. 2002, 2005) or by cultivating substitutes on their own land, e.g., by planting woodlots.

2.2 Approach

We collected our data from 50 villages in two regions, Tanga and Morogoro, where PFM initiatives have been implemented, using both an individual household survey administered to 20–25 households per village, and village level focus group discussions. The individual household data provided information on villagers' individual perceptions of the impact of PFM in terms of the impact on the forest itself, other less-protected forests, and villagers' own access to forest resources. The village-level focus groups provided us with village and PFM level data such as access to markets, the number of forests around the village, and whether the local forest initiative was a CBFM or JFM initiative.

We relied on villagers' perceptions of PFM success because there is very little baseline data available. Moreover, because it is not obvious how we should define PFM success, given that it was introduced with a dual aim, both to improve the quality of forest resources and to reduce poverty, we consider both these distinct dimensions of success when evaluating the initiatives. Moreover, we explicitly consider both the PFM forests themselves and other less protected nearby forests that villagers also can collect NTFPs from.

2.3 Findings

All the households that we surveyed were predominately agricultural rural communities dominated by farming as their primary economic activity (89%). About 30% of the heads of household in the sample were uneducated; about 57% had finished at least basic primary education; with the remaining 13% having some secondary education. A clear majority of the households (71%) rely on the nearby forests for fuelwood, though we did find that about 29% of the households collect fuelwood from their own farmland. Other NTFPs are collected from the forests by fewer households (for example, 10% collected mushrooms in the week before we visited, 25% collected forest fruits and vegetables) but very few building materials (timber, poles, ropes) or weaving materials are collected, suggesting that strict measures preventing access to the PFM forests have been undertaken.

Perceptions of the success of PFM initiatives could be driven by characteristics of individual households; the nature of the specific PFM initiative or by local and regional characteristics. Our results confirm that all three matter. For example, household expenditure, which we use as a proxy for household income, appears to have a positive and significant impact on the household perception with regards to the success of the PFM. A higher household expenditure increases the probability that a household perceives the PFM initiative to be very successful. Men are more likely than women to perceive the quality of PFM forests to have improved as a result of the initiative; larger households, better-off households, and those with their own source of fuelwood are also more likely to perceive JFM forest quality to have improved. Households who are more reliant on forests for their fuelwood are less likely to perceive that the quality of the JFM forest has improved considerably.

We find regional differences: respondents from Morogoro region appear less likely than those from Tanga to perceive PFM as very successful in their villages. Villagers are more likely to rate PFM as being successful if the PFM initiative is in a JFM preserved forest and less successful if the PFM initiative is in a JFM production forest or a CBFM forest. This finding is in line with the expectation that access restrictions should be greatest in the JFM preservation forests, and therefore the quality improvement for these forests should be greater than for other forests where PFM is introduced.

One of the objectives of PFM is to improve forest quality and also contribute towards poverty reduction. We investigated this by controlling for villagers' livelihoods. We found that households were indeed less likely to perceive that PFM is very successful if their own livelihoods have worsened as a result of PFM, suggesting that villagers do take into account the impact on their livelihoods when considering the success of PFM.

We were particularly interested in the impact of villagers' access to other forested areas on the PFM forest itself. We found that villagers in villages with one or more unprotected forest in addition to the PFM forest were significantly more likely to perceive that the PFM forest quality had improved considerably as a result of the initiative. This suggests that PFM is more likely to be successful – in terms of the impact solely on the PFM forest – when villagers simply displace their extraction activities into other less-protected forests, and is in keeping with the predictions of Robinson et al. (2005) and others.

Villagers' perceptions of the impact of the introduction of PFM in their village appears to confirm concerns that protecting one forest may simply displace degradation into other forests. For example, we asked village-level focus groups how they felt that different forested areas around the village had been affected by the introduction of CBFM and PFM (Table 1).

Table 1. Perceptions of impact of PFM on forests around the village.

Number of village focus groups that answered					
	Much less degraded	Somewhat less degraded	About the same	Somewhat more degraded	Much more degraded
Impact on CBFM forest	9	2	0	0	0
Impact on JFM forest	15	3	0	0	0
Impact on unprotected forests	0	1	1	6	4

Even with this relatively small village-level data set, we can see that the members of the focus groups perceive PFM to have benefits for the specific forest that is protected through the initiative, whether a CBFM or JFM forest, but other forests around the village have been harmed. The household level survey, in which we asked similar questions, confirms this perception. Although villagers typically perceive PFM as being successful in terms of improving the quality of the actual PFM forest, it has often been at the expense of villagers' access to forest resources, and other less protected forests. Many villagers feel that their own livelihoods have been negatively affected by the PFM forest, and the data suggest that this is nearly always because they have lost access to forest resources that they have traditionally collected.

Another objective of PFM in Tanzania is to create a situation where the household and communities are engaged in tree planting. In our sample we found that about 54% of the households surveyed have indeed planted trees on their own farms, though not necessarily in response to the PFM initiative.

Currently there is insufficient understanding of how villagers in Tanzania are affected by PFM. Villagers have been encouraged to understand the importance of PFM for the environment, including ecosystem provisioning. And indeed we found a lot of support for PFM in the villages that we visited. But we also found that most villagers perceived themselves to be worse off after the introduction of PFM, because of temporary or permanent moratoria on the collection of NTFPs. The extent to which villagers were worse off as a consequence of a nearby PFM initiative naturally was influenced by the importance of the forest to their livelihoods. But it also became clear from informal discussions in the villages that villagers were less likely to be negatively affected by PFM if there were alternative less protected forests nearby to which they could switch their extraction activities. Such a finding may seem intuitive. But forest policy in Tanzania, as in many countries, by not taking a landscape approach, and ignoring the possibility that villagers "displace" their extraction activities from more to less protected forests, is likely to overstate the ecological benefits of forest protection (Lewis 2002, Robinson et al. 2005).

3 Determinants of households' fuel choice

This research looks specifically at the extent to which price and income changes influence households' choices over their use of fuelwood, charcoal, and kerosene, particularly for cooking and heating.

Biomass has always dominated energy consumption in Tanzania. For example in the 1980s, 88 percent of total energy consumption was from firewood, 4% from charcoal, 7% petroleum, and 1% from electricity hydropower. The situation is similar today. In rural areas fuelwood is the dominant choice of energy. In urban areas such as Dar es Salaam, charcoal dominates, being the main energy source in 65% of households, followed by kerosene (26%) and electricity (9%) with only 2% of any households using fuelwood.

Charcoal has been identified as a major factor in deforestation in Tanzania. The government recently attempted to reduce the use of illegal charcoal in urban areas through a crackdown in charcoal production in the rural areas. At the same time the government is considering increasing taxes on fossil fuels, including kerosene. Yet little if any research has been undertaken to determine the impact of these policies on prices, overall demand for energy, demand for different energy sources, and livelihoods, particularly the distributional impact of such policies.

In this project we will determine households' demand for energy for cooking and heating, and the extent to which price and income influence whether households choose tree-based energy sources (fuelwood and charcoal) or alternatives that are likely to be fossil-fuel based such as kerosene and electricity. Our focus will be urban areas, and we will make use of Tanzania's household budget survey for our data.

This research will permit us to make estimates of the price differentials required for households to switch between fuels. We anticipate that there are costs of switching, both in terms of the type of stove required, and in terms of cooking techniques and approaches, that will result in some "stickiness" of fuel choice. There is therefore a need to explore what conditions, and how large price changes, will lead individual households to change their choice of energy.

4 Conclusions

Tanzanian forests form part of a complicated social and economic network, with forest products being used both by the rural communities that harvest them, and by urban and rural communities elsewhere that purchase these products. Changes in forest policy that protect some forests may have unintended side effects in terms of increased pressure on other forests, either directly by shifting rural households' collection of forest products to these forests or indirectly by encouraging households to purchase forest products that are collected from these forests. Similarly, improved infrastructure may open new markets for forest products from a region and thus increase the pressure on the forests in this region. Likewise, changes in policies with regard to other fuels can affect forest use indirectly, by making tree-based energy sources such as fuelwood and charcoal less (or more) attractive by comparison.

In order to understand deforestation it is therefore not enough to study the forest itself; it is important to study the entire social and economic network that the forest is part of. Environmental economic research thus has an important contribution to make, both by helping us understand the role that forest use currently plays in the livelihoods of rural and urban populations, and by helping us understand the broader social and economic interactions that the forest use is part of.

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Woodlands and the charcoal trade: the case of Dar es Salaam City

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1 Introduction

Tanzania has a total area of about 94.5 million ha out of which 88.6 million ha is covered by landmass and the rest is inland water. Forests and woodlands in Tanzania cover about 34 million hectares making about 40% of land. Gazetted forestland is about 13 million hectares, predominantly managed by the Central Government. Only 600 000 hectares of the gazetted forest land are under the ownership and management of Local Governments. Game reserves and national parks constitute about 2 000 000 ha. Non gazetted forests in public lands cover about 19 million hectares and this is where forests are facing serious conversion to competing land uses. Non gazetted forests are also known as general land forests which are essentially open access. Deforestation in Tanzania, which is estimated at between 130 000 to 500 000 hectares per annum occurs mostly in the general land forests as well as degradation (loss of biomass) over much of the total forest area.

Establishment of village forest reserves under Participatory Forest Management (PFM) which started in 1990s was found to retard deforestation in unreserved forestland. To date more than 3 million ha are under PFM (MNRT 2006) which is about 11% of total forest area. This reduces the open access forest area in the general land from 19 million ha to about 16 million, which is 47% of the entire forested land (Table 1).

Table 1. Tenure status of Tanzanian forests (MNRT 2006).

Forest Reserves			Game Reserves	General land forests	Total forest area
Central	Local Government	PFM			
12 400 000	600 000	3 000 000	2 000 000	16 000 000	34 000 000

Table 2. Major forest vegetation types in Tanzania (MNRT 2006).

Vegetation type	Area ha	% of total forest area
Woodlands	32 544 000	95.72
Plantations	200 000	0.59
Mangrove	115 000	0.34
Others (montane forests, tropical rain forests, coastal forests)	1 141 000	3.36
Total	34 000 000	95.72

Woodland is by far the most dominant vegetation type in Tanzania occupying 95% of the entire forest area (Table 2). It is therefore logical to link the high rate of deforestation and degradation to be impacted on the woodlands because of its wide distribution in the country.

Reasons for deforestation and degradation are harvesting for woodfuel (charcoal and firewood) and timber, and land clearing for the expansion of agriculture. This paper looks into the potential of the woodland as main source of charcoal for Dar es Salaam city.

2 Charcoal production

Charcoal is a woodfuel produced in rural areas and consumed in cities and towns. Some of the factors influencing the choice of using charcoal instead of firewood in urban areas include (Kaale 2005):

- Charcoal has a higher calorific value per unit weight than firewood (about 31.8 MJ per kg of completely carbonized charcoal with about 5 percent moisture content as compared to about 16 MJ per kg of firewood with about 15 percent moisture content on dry basis).
- Due to its high calorific value per unit weight, it is more economic to transport charcoal over longer distances as compared to firewood.
- Storage of charcoal takes less room as compared to firewood.
- Charcoal is not liable to deterioration by insects and fungi which attack firewood.
- Charcoal is almost smokeless and sulphur free, as such it is ideal fuel for towns and cities.

2.1 Major sources of charcoal for Dar es Salaam city

In Tanzania most of the charcoal is produced in dry woodlands. These range from the *Brachystegia – Julbernardia* (miombo) and *Acacia* to savanna woodlands. However observations in the Coast Region, Tanzania, revealed that farm land trees, mainly cashew nut and mango trees, and the mangroves are also used for charcoal production.

A recent study by WWF Tanzania (Malimbwi et al. 2007) showed that the amount of charcoal entering the city was 6 777 bags[1] of 56 kg each per day. Contrary to observations made by CHAPOSA (2002), the highest amount of charcoal is currently through Kilwa road, which accounts for the 50% of the total amount, followed by Morogoro road (24%). Formally the charcoal producing areas in the Kilwa route were limited to within 100 km. Since the completion of the Mkapa Bridge in early 2005 charcoal is coming from beyond that limit as far as Mtwara (565 km), Lindi (420 km) and Kilwa (210 km), almost doubling the amount of charcoal passing through Kilwa road since 2001. Other major charcoal entry routes to Dar es Salaam that were observed were Pugu/ Nyerere, Bagamoyo and the Railway lines (Fig. 1).

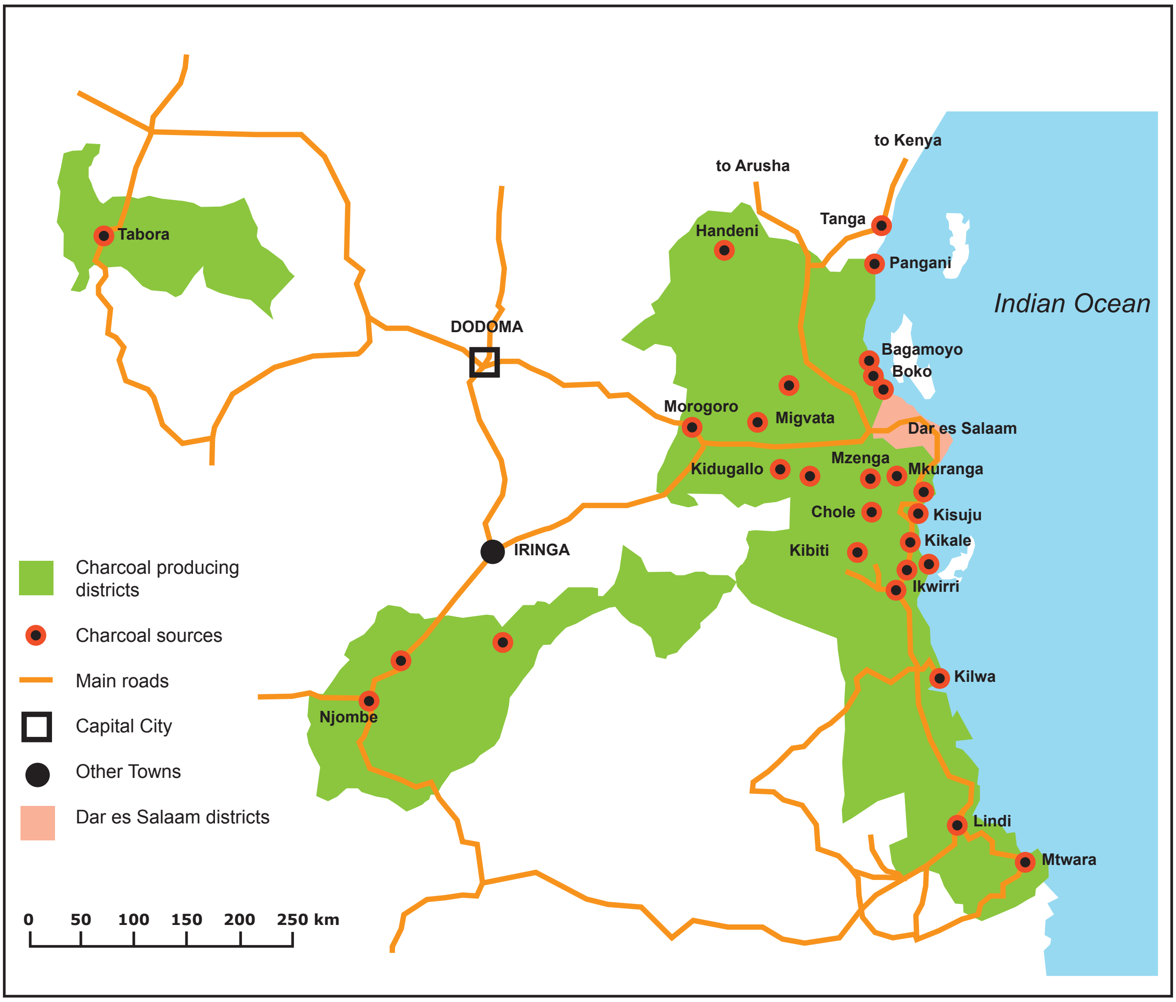

Figure 1. Charcoal sources for Dar es Salaam city.

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[1] This is the amount recorded at check points. The actual amount of charcoal consumed per day in Dar es Salaam is more than 28 000 bags.

In the other routes charcoal comes from as far as Njombe in Iringa Region which is about 770 km, Handeni, 310 km (Tanga Region), and even some places of Tabora Region (1 050 km), using the railway. Previous studies indicated that charcoal production sites for Dar es Salaam city were located in Coast and Morogoro Regions and had changed from 50 km radius in 1970s' to about 200 km in the 1990s' (van Beukering et al. 2007). It is evident that the distance to charcoal sources is significantly increasing, signalling scarcity.

2.2 Charcoal producers

The economy of people in the charcoal producing areas largely depends on subsistence agriculture. There are three main charcoal producers in the charcoal market: full time, seasonal and occasional producers. Full time producers live within the forest areas and produce charcoal throughout the year, shifting to new areas when the sources become depleted. These are in most cases migrants to the charcoal producing areas. In one of the active charcoal making areas in eastern Tanzania (Gwata area in Morogoro Region) about 60% of charcoal makers are immigrants from other parts of the country (Zahabu 2001). Seasonal producers practice agriculture as their main occupation and produce charcoal only in off-farming period of the year. Occasional producers make charcoal to meet specific cash needs during the year (CHAPOSA 2002). This category includes those who make charcoal in the process of land clearing for agriculture.

In eastern Tanzania, annual household income of communities adjacent to the Morogoro – Dar es Salaam highway observed from 1992 to 2002 range from US$ 176–645 (Table 3). This indicates a growing dependence on charcoal for household income whereby about 75% of farmers in charcoal producing areas had charcoal as an important source of income.

Table 3. Household income from charcoal in Eastern Tanzania.

Year of study	Household income (US$ yr^{-1})	Source
1992	176	Monela et al. 1993
2000	445	Monela et al. 2000
2002	645	CHAPOSA 2002

This income from charcoal was also found to be above the minimum wage paid to most of the government and private sectors employees, hence attracting more people to engage in charcoal making. As already pointed out, migration to charcoal producing areas is a common phenomenon. Charcoal making requires neither formal education nor large capital investment although it is time consuming and labour intensive. In eastern Tanzania, 40% of the charcoal makers have no formal education (CHAPOSA 2002). The required labour is usually drawn from household members or other producers collaborating for specific tasks in the production process. While men carry out most of the masculine production activities such as tree felling, cross-cutting and kiln building, women participate in breaking the kiln after carbonization and in recovering and bagging the charcoal (CHAPOSA 2002). Manual tools such as axes, hoes and shovels are used. Given the low education level required, the income may be attractive for other people to join the business, and thus more deforestation to the woodlands.

2.3 Charcoal making process

Charcoal can be produced by a range of methods, from simple earth kilns to brick or metal kilns and retorts that capture condensable volatile compounds or combust them as gases, using the heat generated to drive the charcoal-making process. Charcoal is produced in kilns by a process called pyrolysis, i.e. breaking down the chemical structure of wood under high temperature in the absence of air. During the process, first the water is driven out from the wood (drying), and then the pyrolysis starts when the temperature in the kiln is high enough. When the pyrolysis is complete, the kiln gradually cools down, after which the charcoal can be removed from the kiln. Because some of the wood is burned to drive off the water, dry wood produces better charcoal at a higher efficiency. Typically, around two-third of the energy is lost in the process, but charcoal has advantages over firewood because of its higher efficiency and convenience in handling, storage and distribution (Hofstad 1995).

The oldest and still the most widely used method for charcoal production is the earth kiln. Two varieties exist, the earth pit kiln and the earth mound kiln. An earth pit kiln is constructed by first digging a small pit in the ground. Then the wood is placed in the pit and lit from the bottom, after which the pit is first covered with green leaves or metal sheets and then with earth to prevent complete burning of the wood. The earth mound kiln is built by covering arranged pile of wood on the ground with earth. The Tanzania Timber Harvesting Guidelines recommend charcoal producers to adopt the pit kiln, but generally the mound kiln is preferred over the pit where the soil is rocky, hard or shallow, or the water table is close to the surface. Also the mound requires less labour than the pit kiln. Mounds can also be built over a long period, by stacking gathered wood in position and allowing it to dry before covering and burning.

In most parts of Tanzania, charcoal is produced in earth mound kilns made by covering a pile of logs with earth, igniting the kiln and allowing carbonization under limited air supply (Monela et al. 1993, CHAPOSA 2002, Malimbwi et al. 2005). Typical earth mound kiln the dimensions differ depending on the amount of wood available around the kiln site (Fig. 2).

With this type of kiln, the process of charcoal making involves wood cutting, kiln construction, carbonization and finally unloading charcoal from the kiln. For a kiln with about 1.5 tons of charcoal, it takes an average of about 13, 10 and 14 days for woodcutting, kiln preparation and carbonization, respectively (Malimbwi et al. 2005). Unloading the charcoal takes an average of 4 days. During carbonization time the household may decide to prepare more kilns. As such a charcoal making household could have more than one kiln in a month. There are also some cases where a number of households may combine forces for the activities like wood cutting and kiln preparation. In such cases fewer days are spent and some more charcoal might be produced by a household.

There are no special months for charcoal making. However during the wet season, the seasonal charcoal makers devote most of their time in agriculture while the full time charcoal makers continue to make charcoal with easy availability of kiln construction materials, earth blocks and grass. During the wet season, earth blocks which are used to cover the kiln are more coherent and hence easy to handle and grass material becomes plenty and available. In the dry season, there is scarcity of grass material and the soil is too loose to produce the needed earth blocks.

Figure 2. Typical earth mound charcoal kiln under preparation at Gwata area, in Morogoro.

2.4 Suitable trees species for charcoal

As pointed earlier most of the charcoal is produced in dry woodlands that are in public lands with no or little harvesting control. This is because woodlands species produce heavier charcoal and with more concentrated fuel compared to fast growing softwood species and tropical rain forest species. However, not all woodland tree species are equally suitable for charcoal making. Tree species preference is based on the species property to produce charcoal with high recovery percent, high calorific value and which does not break easily during transportation (Monela et al. 1993, Nduwamungu 1996, Malimbwi et al. 2005).

In Eastern Tanzania most of the woodland species are preferred for charcoal making (Malimbwi et al. 2005) and they include; *Acacia* spp*, Julbernadia globiflora, Brachystegia* sp, *Lannea schimperi, Pseudolachnostylis maprouneifolia, Combretum* sp, *Mimusops kummel,* and *Tamarindus indica.* Few un-preferred tree species such as *Acacia polyacantha* sub. sp. *campylacantha, Sterculia africana* and *Adansonia digitata* are either with thorny stems making it difficult to handle or produce lighter charcoal of low calorific value. General observation, however, reveals that tree species selection for charcoal making is only done in areas with abundant trees. In areas where woodlands are already degraded and trees are in short supply, tree species selection for charcoaling is not done. This is also true during the opening up of new agricultural land where trees of all species found in the area are cut and made into charcoal. This constitutes a form of shifting cultivation that is widely spread in most of the woodland parts of Africa.

Whether there is species selection or not, valuable tree species for timber and carvings such as *Dalbergia melanoxylon, Pterocurpus angolensis* and *Afzelia quanzensis* are not exempted from charcoal making. These species are classified as ‘reserved’ trees which are theoretically nationally protected. In spite the fact that usually charcoal production is regarded as a secondary activity following harvesting for timber (Johnsen 1999), charcoal makers do not spare extraction of regenerating timber and carving species. This has the consequence of limiting availability of harvestable valuable timber species in charcoal production areas.

There is hardly any data on how much charcoal is collected from agroforestry home gardens in Tanzania. Observations in Coast region however indicates that farm land trees, mainly old cashew nut, mango and occasionally jack fruit trees are also used for charcoal production (Kaale 2005).

2.5 Kiln efficiencies

The Earth-Mound Kiln (EMK) is the most common method of making charcoal in sub-Saharan Africa with a conversion efficiency of 10–20% (Bailis 2003). Experience from CHAPOSA (2002) shows that kiln efficiencies in Tanzania ranged from 11 to 30%. In Zambia, the kiln efficiencies ranged from 20–28% while in Mozambique the range was 14–20%. These values are in line with those reported by Sawe and Meena (1994) and Hofstad (1995). In Tanzania, at an average of 19% kiln efficiency, 18 trees of 32 cm diameter at breast height (dbh) on average are used to produce 26 bags each weighing 56 kg of charcoal. That is 1 m^3 of wood yields 2.7 bags of about 56 kg of charcoal (CHAPOSA 2002).

According to Hofstad (1995) factors contributing to kiln efficiency variation are moisture content of wood involved in kiln preparation and its specific weight. Therefore tree species involved in kiln preparation contribute greatly to kiln efficiency variation. Lack of proper control during carbonization process is also reported to reduce efficiency due to some complete combustion of wood (Ishengoma and Nagoda 1991). It was noted from CHAPOSA (2002) that experienced specialized charcoal burners attain much more wood-charcoal production efficiency compared to seasonal burners.

There are currently two known improved kiln efficiency projects in Tanzania, the Half Orange Brick Kiln (Fig. 3) and the Improved Earth Mound Kiln (Fig. 4). The average carbonization efficiency of these improved technologies is estimated to be in between 27–35%.

The half orange brick kiln may not be the best option due to:
- high initial investment cost,
- the need to process the billets into specific sizes which is time consuming,
- the need to transport the billets to kiln site since the kiln is not moveable, and
- the need to continuously smear with mud on the outer surface to cover cracks; this may be a problem especially in most of the charcoal producing areas where water is not readily available.

Figure 3. Half Orange Kiln at Mazizi, Morogoro, Tanzania.

Figure 4. Improved Earth Mound Kiln at Ruvu Fuellwood Pilot Project, Coast Region, Tanzania.

Use of the Improved Earth Mound Kiln (IEMK) with better kiln management could be a better option. The IEMK is based on the traditional earth mound kiln modified by limiting air supply thereby controlling inlet air and limiting the exhaust air to a single chimney. With this type of kiln about 4 days are enough for the carbonization process to be completed which is an improvement from 10 days taken by the traditional earth kiln. The charcoal from these kilns are also said to be of high quality (Sago 2007, per. comm.).

2.6 Potential of the woodlands to produce charcoal

The potential for woodland to produce charcoal mainly hinges on the ability of the woody species to regenerate and grow.

Woodland regeneration

Woodland regeneration generally involves seed production, seedling development and vegetative regeneration. In absence of intense disturbance such as frequent late fires and overgrazing, the dominant trend in regenerating woodland is towards recovery to original state. Unless the trees have been thoroughly uprooted, most of the subsequent development of woodland will derive from re-growth of coppice from the surviving stems, stump/root sucker shoots and recruitment from old stunted seedlings already present in the grass layer at the time of tree cut, fall or death (Chidumayo 1993). Thus, one year after clearing a miombo woodland stand, the sapling population in re-growth may consist of one third coppiced stumps and two thirds seedlings recruited from the stunted seedling pool (Chidumayo 1997). Frost (1996) recognised four phases in regenerating woodland: (i) initial re-growth, just after sprouting and coppicing (most woody plants in the initial re-growth phase are less than 1 m tall), (ii) dense coppice, some two to five years after clear felling, (iii) tall sapling phase, starting from six to eight years after regeneration, and (iv) mature woodland.

Most seedlings and other tree regeneration (e.g. suckers and coppices) experience a prolonged period of successive annual die-back during their development phase. Their success to attain the canopy generally depends on their ability to survive fires and to exhibit rapid growth in years without grass fires. In general, fire and water-stress during the dry season are responsible for the annual shoot die-backs. This is probably why seedlings in miombo woodlands grow very slowly in height as they initially allocate more biomass to root growth. The underground parts of seedlings of many miombo trees grow faster than shoots during the establishment period (Chidumayo 1993). At least eight years may be needed for miombo woodland seedlings to reach the sapling phase.

After removal or death of the above ground parts of the trees, most woodland stumps produce many sucker shoots. However, during the establishment period the number of shoots would decrease as a result of inter-shoot competition and only dominant shoots contribute to the next generation of re-growth woodland. Sucker shoots grow relatively faster than shoots of stunted old seedlings. This is because stumps retain their well-developed root systems after tree cutting. However, stem height growth in re-growth woodland declines after 5–6 years and remains extremely slow thereafter (Chidumayo 1993, 1997).

Woodland productivity and charcoal yield

The stand density of woody plants in dry forests varies widely. For instance, in miombo woodland the stand density of woody species mostly ranges between 380 and 1400 stems ha^{-1} (Malaisse 1978, Nduwamungu 2001). In most miombo stands, the basal areas range from 7 to 25 m^2 ha^{-1} (Lowore et al. 1994, Nduwamungu 2001). Both stand basal area and mean biomass increase with increasing rainfall of a site (Frost 1996). Stand basal area is linearly related to both harvestable volume and aboveground woody biomass. In Tanzania, harvestable miombo woodland has the potential to produce 35 m^3 ha^{-1} (Malimbwi et al. 2005) whereas the mean harvestable volumes range between 14 m^3 ha^{-1} in dry miombo of Malawi (Lowore et al. 1994) and 117 m^3 ha^{-1} in Zambian wet miombo (Chidumayo 1988). Average aboveground biomass in old growth miombo woodland varies mostly from around 30 tons per ha to about 140 tons ha^{-1} (Malaisse 1978, Malimbwi et al. 1994) generally depending on the amount of annual rainfall and edaphic properties.

The annual increment of girth varies widely depending on species and site conditions. In an area protected from fire and human disturbances, the mean growth in girth range from 0.27 cm yr^{-1} (Grundy 1995) to 2.2 cm yr^{-1} (Chidumayo 1988). The mean annual volume increment (MAI) in mature miombo woodland ranges from 0.58 to 3 m^3 ha^{-1}yr^{-1} (Zahabu 2001, CHAPOSA 2002). The mean annual increment of biomass in coppice woodland range from 1.2 to 3.4 tons ha^{-1}yr^{-1}, which is about 4–7% of above ground biomass (Chidumayo 1993). In mature woodlands the mean annual biomass increment is estimated at 2–3% of the standing stock (CHAPOSA 2002).

2.7 Impact of charcoal production on forest resources

According to CHAPOSA (2002), charcoal production was responsible for degradation of 29 268 hectares (24.6%) of closed woodland and deforestation of 23 308 hectares (19.58%) of closed woodland and 92 761 hectares (50.8%) of open woodland in the catchment area to the west and north of Dar es Salaam that supplied charcoal to Dar es Salaam City. It has been noted that where there is bushland, most of it is regenerating from coppice, indicating that trees had been cut most probably for charcoal production.

A number of factors, however, play important role in influencing the trend of woodland development in the current and previous charcoal production areas. Woodland cut for charcoal production would normally regenerate by coppicing and recruitment from stunted saplings. Because of regeneration in areas previously cut, and if there is no further disturbance, such areas may revert to woodland, thus increasing the potential of the area to supply charcoal over a much longer time period. According to Hosier (1993) woodland appears to recover relatively well following harvesting for charcoal production. Human disturbances, such as grazing, frequent fires and extended cultivation periods may prolong the recovery period.

2.8 Management of the woodlands for sustainable charcoal production

For wood to be harvested sustainably from the woodlands, selective harvesting of trees with minimum dbh is recommended with careful attention paid to avoiding over-harvesting. Division of the forest into annual coupes will be necessary. Each year one annual coupe is selectively harvested thus allowing the remaining small trees to grow. By the time the last annual coupe is harvested the first coupe which was harvested in year one will have matured, ready for harvesting and hence the phenomenon repeats. The number of years passing before an annual coupe is revisited will depend on time required for the harvested annual coupe to re-mature, which will in turn determine the size of the annual coupe. Malimbwi et al. (2005) estimated the rotation period to be eight to 15 years for selective harvesting of trees with minimum dbh of 10 cm.

3 Charcoal trade

Charcoal is produced in rural areas and transported to urban areas by dealers/transporters who either buy charcoal from producers or hire labourers to produce their own charcoal. Usually trees used for charcoal production are obtained free of charge from the general land woodlands in charcoal producing areas. In urban areas, charcoal dealers sell their charcoal either to charcoal vendors or directly to consumers who buy charcoal in large quantities. Charcoal vendors who are spread all over the urban areas then sell the charcoal to final consumers usually in small quantities.

3.1 Charcoal transporters

Charcoal transporters are officially categorised at checkpoints mainly in two groups: the commercial dealers who include the cyclists and those who use vehicles to transport more than 10 bags; and non-commercial transporters who use vehicles to transport less than 10 bags for private uses. Of the estimated amount of 6 777 bags of charcoal entering Dar es Salaam City every day, 84% were transported by commercial vehicles, 11% by bicycles and only 5% by non-commercial vehicles (Table 4). Although vehicles transport most of the charcoal, transportation by bicycles employs the largest number of people (Table 4).

Table 4. Number of people engaged in charcoal transportation to Dar es Salaam city per day by vehicle type.

	Commercial Vehicles	Bicycles	Non-commercial	Total
Kilwa road	54	102	93	249
Morogoro road	22	54	40	116
Pugu road	14	125	3	142
Bagamoyo	2	33	4	39
Total	92	314	140	546
Percentage (%)	17	58	26	100

Truck transporters

These dealers use open trucks to transport their charcoal (Fig. 5). About 73% of respondents use lorries of more than 2 tons that carry 55 to 80 bags of 56 kgs Transportation of natural resources including charcoal is only allowed during day time between 6:00 am to 6:00 pm. Most of the charcoal passes through checkpoints very early in the morning between 6:00 to 6:59 am and late in the evening between 5:00 and 6:00 pm (Fig. 6). This is because most of the vehicles used are more than 10 years old (79%), and as such drivers tend to avoid traffic police.

To start the business as a charcoal dealer, one needs to apply for charcoal transportation license which costs TShs 55 000 including an application fees of TShs 5 000. The charcoal dealer then goes direct to the producer, enters into an agreement on the amount of charcoal required and pays in advance. Sometimes the transporters can also produce their own charcoal through hired labour.

Figure 5. Typical vehicles transporting charcoal to Dar es Salaam.

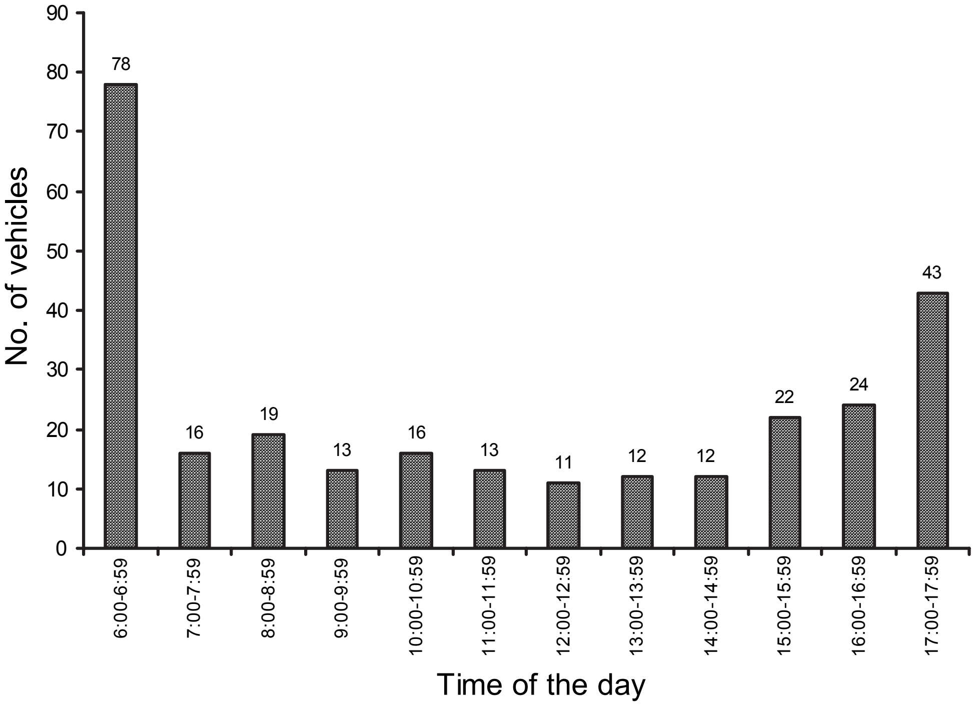

Figure 6. Current observed number of commercial vehicles passing through checkpoints at different times of the day.

Table 5. Average prices of charcoal at production sites for the past four years.

Year	Price per bag (Tshs)	
	Wet season	Dry season
2004	3000	2500
2005	4000	3500
2006	6000	4000
2007	8000	*

*Data not available as the study was carried out during rain season

For the past four years the average prices of charcoal at production sites have increased considerably (Table 5).

Other major costs in the charcoal transportation business are:
- tax paid to the Central Government (TShs 1 200 per bag of 56 kg),
- tax paid to the District Council (TShs 200 to 400 per bag),
- tax paid to the Village Government (TShs 100 to 400 per bag), and
- transporting the charcoal (TShs 4 000 to 6 000 per bag).

These costs in charcoal transportation differ depending on distances. There is no fixed tax charged for a bag of charcoal, therefore the taxes vary between District Councils and between Village Governments.

On average dealers using small lorries of less then 2 tons get a profit of about TShs 1 500 per bag while those who use lorries greater than 2 tons earn TShs 3 000 per bag. This is probably due to scale of economies when one uses a larger vehicle while the fixed costs are the same. It was also observed that there is increase in profit following the government ban of charcoal transportation in January 2006 (van Beukering 2007) which created shortage of charcoal in most of the urban areas and hence resulting in price increase.

Charcoal transporters encounter the following constraints:
- vehicle breakdown due to poor road conditions and use of old vehicles hence high maintenance costs,
- high taxes,
- corruption at traffic police checkpoints where the transporters claim to bribe up to TShs 30 000 per trip otherwise the truck is declared defective, and
- frequent changes in charcoal business regulations.

Bicycle transporters

Bicycle is also an important means of charcoal transportation into the city of Dar es Salaam. Although bicycles carry fewer bags than vehicles, they employ highest number of people (58%) (Table 4). This indicates that most charcoal transporters are low income class. They operate within a radius of up to 60 km from the city. Lack of alternative employment is the main drive for their engagement in charcoal transportation. Most of them (60%) are residents of production areas and the rest (40%) are from the city. Based on 2007 data, normally they buy charcoal from producers at a price range of TShs 9 000 to 13 000 per bicycle load and sell in the city at a price of between TShs 20 000 and 23 000.

The bicycle loads vary considerably in their weight, packing and size depending on the nature of the charcoal. For example, charcoal from Pugu and Morogoro roads is heavy (up to 140 kgs) compared to charcoal from other routes because it comes from natural woodlands. Cyclists in these routes have adopted a way of balancing the weight by putting two bags on opposite sides of the bicycle and a third on top of the two bags (Fig. 7a). Charcoal from Bagamoyo and Kilwa roads is usually lighter (up to 60 kgs) as it is made from cashew nuts and mango trees, therefore cyclists are able to carry large bags without a need of strategically balancing the weight while transporting (Fig. 7b and c).

(a) Pugu road

(b) Bagamoyo road

(c) Kilwa road

Figure 7. Charcoal bicycle loads captured at different routes.

Cyclists usually transport charcoal every other day during the morning and evening hours to avoid the hot sun during the day. They are required to pay tax of TShs 1 200 for a bag of 56 kg to the Central Government and TShs 400 to the District Council. As such the Pugu road cyclists pay a total of TShs 3 200 per bicycle load as it is considered as two bags while those of Bagamoyo, Kilwa and Morogoro are considered as a single bag. However, if actual weights were considered the Pugu bicycle load could have been considered as three bags while those of Bagamoyo, Kilwa and Morogoro roads as two bags. Cyclist who pass through checkpoints, strategically exceed the charcoal bag weights to evade tax otherwise most of them bypass the checkpoints. The profit realized range between TShs 3 000 to TShs 5 500 per bicycle load after paying for bicycle maintenance and all other running costs. Charcoal transporters who use bicycles claim that the business is difficult with high risk of road accidents. Also the distances to charcoal sources are ever increasing.

3.2 Charcoal vendors

Charcoal vendors are retailers who buy charcoal from transporters and sell it to end users. The average purchasing prices from the whole sellers over the last five years have increased with the highest rate of increase observed between 2006 and 2007 where the prices have almost doubled (Table 6). Similar observation was also made by van Beukering et al. (2007). This is because transportation of all forest products including charcoal was restricted following the government ban of January 2006. Although other costs associated with charcoal trading have also shot up, charcoal traders took advantage of the circumstances and retained higher prices even after the ban was lifted.

Table 6. Charcoal purchasing prices by vendors in Dar es Salaam city.

Year	Price range (TShs)	Average prices (TShs)	Change in price (TShs)
2007	19 000 to 25 000	22 000	9 000
2006	10 000 to 16 000	13 000	4 500
2005	8 000 to 9 000	8 500	3 000
2004	5 000 to 6 000	5 500	2 000
2003	3 000 to 4 000	3 500	

Charcoal vendors sell their charcoal in small measures of empty paint tins (kopo), buckets (sado) and small sacks (viroba). From a bag of charcoal they get 40 to 60 tins and 10 to 12 buckets. Based on 2007 prices, a tin is sold at about TShs 600 while a bucket is sold at TShs 1 750. On average charcoal vendors get about TShs 30 000 from a bag with a profit margins of about TShs 8 000 per bag. To increase profit margin the vendors normally manipulate, sizes and shapes of tins, buckets and bags while packing. Most of the tins and buckets used are deformed (Fig. 8). This manipulation is also done by producers and transporters of charcoal and the final burden goes to consumers. Large scale vendors have to pay for municipal permit, site construction, security and salaries for one to two employees while small scale charcoal vendors who sell charcoal at their home premises usually have less running cost.

Figure 8. Some measures used for charcoal vending.

3.3 Transportation of charcoal to Zanzibar

About 70% of charcoal used in Zanzibar comes from the Mainland. According to 2007 survey, the total amount of charcoal transported to Zanzibar daily is 10,500 bags out of which 7 500 bags enters the island illegally. Most important of the charcoal sources to Zanzibar are Tanga Region (Pangani District), Coast Region (Bagamoyo), Dar es Salaam (Mbweni, Bunju), Lindi and Mtwara. Charcoal from these sources is transported to Zanzibar through un-official ports that are out of reach of the taxation system making charcoal rather cheap. The distance to Zanzibar is only around 50 km from most of the unofficial ports, transporters charges are very low compared to road transportation to urban areas such as Dar es Salaam or Tanga. This is justified by the means of transport used i.e. by dhows which use no fuel. Charcoal dealers transport charcoal using dhows to Zanzibar because relatively small capital is needed compared to road transport to urban centres in the mainland where by one is also required to acquire the necessary permits.

3.4 Current charcoal consumption in Dar es Salaam

Low income households have a tendency of buying charcoal on retail scale (tin) on daily basis while those from high income tend to buy larger amounts (at least a bag) which stay longer (Malimbwi et al. 2007). On average a household uses a tin of about 1 kg of charcoal sold at TShs 600 to prepare one hot meal, 2 times a day. This is equivalent to a bag of charcoal per month since a bag has 40–60 tins. Therefore a household on average spends TShs 1 200 per day for charcoal alone. This makes an average of TShs 36 000 per month. On the other hand, the high income class also uses one bag of charcoal per month bought at about TShs 22 000. Households from high income levels who use charcoal as a major cooking energy therefore spend less money compared to those from low income class. This is contrary to what was reported by van Beukering et al. (2007), who argue that low income class buy charcoal more cheaply than the high income group. Various mechanisms have been deployed to reduce the quantity of charcoal consumed per day, these include:

- use of improved stoves
- combining charcoal with other types of energy
- cooking food that consumes less energy and
- improving kitchen management e.g. putting off charcoal after use.

It is estimated that charcoal is consumed by 94% of the households either alone or mixed with other fuels. Only 6% of the households do not use charcoal. About 78% of households in Dar es Salaam city use charcoal as their first choice energy source (Table 7).

Table 7. Household fuel preferences for 1991/92, 2000/01 and 2007.

Type of fuel	Percentage preference		
	1991/92	2000/01	2007
Charcoal	51	69	78
Kerosene	28	25	13
Electricity	15	4	5
Firewood	1	2	4

Source: CHAPOSA (2002) and field study done in 2007

There is energy declining shift for kerosene by 12% between 2001 and 2007. At the same period users of charcoal as a primary source of energy have increased from 69% to 78%. While the percentage of electricity users as a first choice source of energy has remained constant, users of firewood have increased from 2 to 4%. (Table 7). These energy shifts indicate an increase in biofuel consumption in the city of Dar es Salaam.

Assuming the current population of Dar es Salaam of 3 million people and average household size of 4.2, the total number of households is 714 286. The percentage of household using charcoal as their primary source of energy being 78%, the corresponding number of households using charcoal is therefore 521 429. Assuming also that two hot meals are prepared per day and that a bag of 56 kgs has 50 tins, 22 526 bags are consumed daily by households using charcoal as their primary source of energy in Dar es Salaam.

Apart from the households, charcoal is also the major source of energy for various organizations. Quantity of charcoal consumed per day depends on the number of persons served and the level of energy mix. Table 8 shows the amount of charcoal used by various organizations to prepare one hot meal.

Table 8. Amount of charcoal used by various organizations to prepare one hot meal.

Organization	Amount of charcoal used to prepare one hot meal
Hotels, bars and small scale food vendors	3 bags for 1 000 persons
Schools	1 bag for 150 students
Hospitals	1 bag for 200 patients
Army camps	2 bags for 1 000 army staff*

*Most army camps use firewood

However, there is high variation in terms of the total amount of charcoal consumed by these organizations, especially hotels, bars and small scale food vendors because most of them are informal/not registered and hence difficulty to track and quantify the amount they use. The charcoal consumed by organizations was therefore estimated having considering these limitations.

- Assuming that two persons from each household (714 286) get one hot meal from a hotel, bar and small scale food vendor a day and 3 bags of charcoal prepare one hot meal for 1 000 people, 4 200 bags of charcoal are consumed per day by these organizations in Dar es Salaam.
- The number of school going students in Dar es Salaam is about 300 000. These get one hot meal outside their homes prepared using a bag of charcoal for 150 students. The total amount of charcoal consumed by schools is therefore estimated to be 2 000 bags per day.
- The amount of charcoal consumed in hospitals is estimated to be only 25 bags per day. This was derived from the assumption that there are 5000 beds in hospitals in the Dar es Salaam city.
- Most of the army camps in the city use firewood for cooking. However, charcoal is sometimes used as an alternative energy source. The total amount estimated to be consumed is 8 bags per day.

Based on the above analysis, the current total daily charcoal consumption in Dar es Salaam is estimated at 28 759 bags of 56 kg (Table 9). CHAPOSA 2002 estimated 24 576 bags while van Beukering et al. (2007) estimated 24 951 bags which assume constant consumption since 2002. Due to population increase and the increase on the percentage of households using charcoal as the first choice fuel, the current estimates (Malimbwi et al. 2007) seem to be realistic despite the crude estimation especially of the consumption by organizations. A larger sample survey of households and organizations would probably give a more reliable estimate.

Table 9. Total amount of charcoal consumed in Dar es Salaam daily.

Organization	Amount of charcoal (bags of 56 kg/day)		
	This study (2007)	CHAPOSA (2002)	van Beukaring et al. (2007)*
Households	22 526	18 158	
Hotels, bars and food vendors	4 200	8 047	
Schools	2 000	8	
Hospitals	25	2	
Army	8		
Total	28 759	24 576	24 951

*Based on 2005 estimation of 17 million bags of 30 kg per year

The second major energy source for cooking in the city of Dar es Salaam is kerosene that 13% of the household use it as their first choice (Malimbwi et al. 2007). According to the respondents, preference to use kerosene is due to its efficiency compared to charcoal, which takes longer to lighten and sometimes one is forced to use kerosene to lighten it. When compared to previous studies, the general trend shows that percentage of households using kerosene is declining (Table 7) indicating a shift of energy use from kerosene to charcoal. The major reason for the reduction on the quantity of kerosene consumption is price increase for the past five years. Although the government removed Value Added Tax (VAT) on kerosene during the 2006/7 budget, the price of kerosene remained high and therefore failing to serve the purpose of encouraging more use of kerosene for charcoal (Table 10).

Table 10. Tanzania Kerosene tariffs (2000–2007).

Price + 28% VAT (Tshs)/Litre	Years							
	2000	2001	2002	2003	2004	2005	2006	2007
Minimum	470	480	489	498	583	828	830	880
Maximum	495	497	506	551	775	964	1100	1000
Average	482	489	498	524	679	896	965	940

Source: Mbwambo et al.(2005) and Malimbwi et al. (2007)

Electricity is another energy type used by 5% of households in the city of Dar es Salaam as a major source of cooking energy. The percentage of households using electricity has not increased since 2001 (Table 7). Reasons given by various households for not using electricity include: increased tariffs (Table 11) and unreliability of electricity due to power rationing in the dry seasons in the country.

Table 11. TANESCO electricity tariffs from year 2000–2007.

Tariff category	2000–2003		2004		2005		2006		2007	
	0–100 kWh	101–500 kWh	0–50 kWh	> 50 kWh	0-50 kWh	> 50 kWh	0-50 kWh	> 50 kWh	0–50 kWh	> 50 kWh
Low usage domestic (TShs)	24.00	-	30.00	-	38.00	-	38	-	40	-
High usage domestic (TShs)	-	38.75	-	115.00	-	115.00		121		126

Source: TANESCO HQ in Mbwambo et al. (2005), Malimbwi et al. (2007)

Most of the households (71%) combine more than one type of fuel such as charcoal, firewood, kerosene, electricity and gas (Malimbwi et al. 2007). Charcoal is the most combined fuel since 94% of the households use charcoal in one way or another.

According to CHAPOSA (2002) most of the households (88%) combine two or more types of fuels. There is therefore a decline in number of households that combine fuels compared to the 88% reported by CHAPOSA (2002). This suggests that there is more reliance on few energy sources mostly charcoal compared to other fuels.

Gas and other energy sources such as coal briquette are used at a very low rate in the city. Usually gas is combined with other energy sources such as electricity and charcoal. Only 3% of the households use gas. There is also emerging group of few households from medium income class that use oryx gas cookers. The low adoption of use of gas for cooking is attributed to:

- Low awareness: Users still have the mentality that gas is very risky and if not properly handled can explode. However, gas cookers have now been improved and explosion controlled.
- Price of appliance is also high for low income households forcing them not to opt for gas.

3.5 Supply and demand linkages

The demand for charcoal has increased due to increase in the number of households using charcoal as their first choice fuel from 69% observed in 2002 to 73% in 2007. The number of households who use charcoal is also very high (94%) indicating high demand for charcoal owing to the fact that population growth for Dar es Salaam city is estimated at about 6% (National Bureau of Statistics 2002). In 2006 the Ministry of Natural Resources and Tourism temporarily banned harvesting of forests for charcoal production. This reduced the amount of charcoal supply and hence increased demand and the price on the consumer side. At the supply side the price also rose since the producers were risking making charcoal illegally. When the ban was lifted the prices remained high because distances to charcoal sources as well as cost of transportation have increased. Forests that were previously found in the outskirts of the city have been depleted forcing traders to fetch charcoal far from Dar es Salaam.

The current total charcoal consumption in Dar es Salaam is about 28 759 bags of 56 kg of charcoal per day. This figure is about five times higher than that observed at the checkpoints meaning that only one fith of the charcoal that goes into the city is taxed. The same observation was also made by CHAPOSA (2002). This suggests that the incentive to evade check points is extremely strong, and that, in fact, most of the charcoal is unaccounted for in the check points. As a result the government loses more than 38 million shillings per day as shown in Table 12. The illegal charcoal usually passes the checkpoints at night or in closed vehicles. There is also a possibility of bypassing check points especially by cyclists. Laxity and probably corruption at the checkpoints may also be other reasons. Most of the check points have no space for inspection and storage of impounded products. Also they are in most cases not conspicuous making it difficult to be identified by new dealers. These problems could be minimized by

- strengthening the checkpoints including furnishing them with proper offices, signboards and communication facilities,
- strengthening patrol crews and providing them with reliable transport,
- install checkpoints in the railway system,
- certification of charcoal to ensure sustainable production at the sources, and
- effective accountability to ensure taxes are paid at all levels.

Table 12. Daily amount of tax collected against evaded at checkpoints.

Tax admin authority	Amount of tax per bag of charcoal	Expected total tax (TShs)	Amount of tax collected (TShs)	Evaded tax (TShs)
Central Government	1 200	34 510 800	8 132 400	26 378 400
District Councils	300	8 627 700	2 033 100	6 594 600
Village Governments	250	7 189 750	1 694 250	5 495 500
Total	1750	50 328 250	11 859 750	38 468 500

With a kiln conversion efficiency of 19%, about 3 million tons of wood are required annually to produce the 28 759 bags consumed every day in the city. This is equivalent to about 3.6 million m^3 of wood at a weight/volume ratio of 0.85 (Malimbwi et al. 1994). Ishengoma and Ngaga (2001) estimated the annual wood volume required to produce charcoal for Dar es Salaam to be 1.9 million m^3/year while CHAPOSA (2002) estimated 2.3 million m^3/year. The difference may be due to different assumptions of several parameters, but suggests that the order of magnitude is realistic and more volume for charcoal is needed for Dar es Salaam. At a mean annual increment of about 2.4 m^3 $ha^{-1}yr^{-1}$ (Malimbwi et al. 2005) it would take the growth of 1.5 million hectares to produce the wood needed annually.

Considering that harvestable miombo woodland has the potential to produce 35 m^3 ha^{-1} (Malimbwi et al. 2005), it would require 104,000 ha of miombo to be harvested annually for the provision of charcoal to Dar es Salaam. The only other sources of charcoal for Dar es Salaam apart from miombo are the agroforestry systems around the city which supply 204 bags and the wattle plantations in Njombe (160 bags), making a total of 364 bags. These are equivalent to 39 159 tons or 46 069 m^3/yr, of which 25 819 m^3 are from cashew nut and mango trees. Assuming a large cashew nut or mango tree has 6 m^3 of wood, 4 303 trees would be cut annually for charcoal production. Obviously this has consequence on the environment and livelihood of the people as cutting the trees deprives them with regular income from sales of fruits. Non-the-less the charcoal from the wattle and agroforestry systems save 1 316 ha of miombo deforestation yearly so that only 102 684 ha would be cut annually. This indicates that agroforestry systems and plantations have a potential to reduce the rate of deforestation due to charcoal production.

3.6 Efficiency of charcoal stoves

Traditional charcoal stoves are made from un-insulated metal moulded and welded into a circular or rectangular shape. It has a perforated metal plate in the middle on which the charcoal is put and an ash collecting tray at the bottom. The thermal efficiency of these charcoal stoves in Tanzania is reported to range between 12% and 15% (MEM 1998), hence inefficient since most of the heat is lost throughout the surface of the stove. The improved stoves technology is built on these traditional stoves by adding an insulating clay lining inside the metal case in order to reduce the heat loss. As such improved stoves retain the heat much longer with relatively less charcoal used. Stoves which have double liner (clay and metal) enforcement attain up to 70% efficiency (TaTEDO 2007).

In Dar es Salaam city, the number of households using charcoal efficient stoves has increased from 49% (CHAPOSA 2002) to 72% in 2007 while only 20% of the organizations use efficient stoves (Malimbwi et al. 2007). Availability of these stoves has largely contributed to the increase in number of users.

However, most of the improved charcoal stoves currently in use have low durability. Some groups that manufacture these stoves also admitted making less durable stoves (12–18 months life span) purposely done in order to get regular customers. A well prepared efficient stove has a life span of 3 years at a cost of around TShs 4 000–50 000 depending on size and design whereas the traditional ones range between TShs 1 500–18 000.

3.7 The potential of Dar es Salaam charcoal efficiency production and use for carbon trading

From the above observations it is obvious that the demand for charcoal is increasing at the expence of the environment. An attempt was made to try to utilize the carbon trade opportunity to attract the adoption of efficiency technologies to reduce charcoal consumption.

Carbon credits are saleable certificates earned through the reduction of carbon dioxide emissions. It is possible to earn carbon credits through production and use of charcoal in a sustainable and efficient way. This is essentially from the reductions in carbon emissions resulting from the amount of wood that is reduced when charcoal is produced or used in efficient ways.

The current charcoal production attains a wood-charcoal efficiency of 19% and this can be improved through the use of improved kilns to about 27 to 35%. The amount of wood used to produce charcoal for Dar es Salaam at present is about 3 million tons just improving the efficiency to an average of 30% will reduce this amount of wood needed to produce the same amount of charcoal 1.9 million tons (Table 13). This reduction is equivalent to about 1 207 728 tons of CO_2. At the selling price of \$ 5 per ton of CO_2, this is equivalent to about UD\$ 6 million.

From the consumption side, the use of un-improved stoves attains only 15% efficiency. This can be improved up to 70% efficiency by the use of improved stoves. Taking an average of 40% efficiency will result to a reduction of the wood for the charcoal making from about 3.8 to 1.4 million tons (Table 14). This reduction is equivalent to the avoidance of carbon dioxide emission of 2.6 million tons CO_2 which is estimated to sell at about \$ 13 million.

Table 13. Estimation of carbon trading potential of the improved charcoal production efficiency for Dar es Salaam city.

Bags per day	Kiln efficiency (%)	Equivalent green wood weight (tons/yr)	Equivalent green volume m^3	Biomass (0.5 green volume)	Carbon (tons/yr)	CO_2 emissions (tons/yr)
28759	19	3 051 481	3 589 978	1 794 989	897 494	3 293 805
28759	30	1 932 605	2 273 653	1 136 826	568 413	2 086 076

Table 14. Estimation of carbon trading potential of the improved charcoal consumption efficiency for the Dar es Salaam city.

Bags per day	Stove efficiency (%)	Equivalent green wood weight (tons/yr)	Equivalent green volume m^3	Biomass (1/2 green volume)	Carbon (tons/yr)	CO_2 emissions (tons/yr)
28759	15	3 865 210	4 547 305	2 273 653	1 136 826	4 172 153
28759	40	1 449 454	1 705 240	852 620	426 310	1 564 557

There is a much more potential for efficient charcoal projects for Dar es Salaam due to the growing market for CO_2. The $ 5 used here as selling price is a bit far less a price since as of June 2008 on the European Climate Exchange, the price of Certified Emissions Reductions (CERs) issued under the Kyoto Protocol's CDM was at € 20 (equivalent to $ 31) per tons of CO_2.

Recommendations

From the afore text recommendations can be made which aim to produce charcoal sustainably while reducing emissions:

- Implement sustainable harvesting for charcoal by introducing selective felling in annual coupes
- Promote agroforestry and plantations as sources of charcoal to reduce pressure in woodlands
- Promote adoption of efficiency projects and initiated a mechanism to explore the possibility of carbon trading from the efficiency projects.

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Forest plantation for biofuels to serve natural forest resources

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Historically, humans have used wood for fuel (charcoal, firewood and briquettes), lumber, paper, and other wood products. With rising focus on regenewable energy sources, the potential of modern wood biomass (biomass harvested with the aim to produce energy carrier) has gained importance and attention. The diverse use of wood is placing the tropical and subtropical forests and woodlands such as miombo into serious threats. With the fact that biofuel production from primary agricultural crops receives severe critics as will contribute to hunger, environmental degradation while deepening poverty the bio-energy frontiers have turned into biofuel from second generation such as lignocelullosic material from forest biomass. To bio-energy demands, more natural forests has to be cleared to allow establishment of fast growing tree species but also the ones modified genetically to produce high amounts of the lignocellulosic material necessary for liquid fuel production. Miombo woodland is likely to be more affected since most of the land identified as being ‘marginal’ or ‘idle’ and hence suitable for bioenergy productions falls in this ecosystem. Establishment of forest biomass in place of natural vegetations is expected to come out with a number of negative impacts including increased soil erosion, increased pollution and emissions, decreased soil quality, reduction of biodiversity, and displacement of the rural poor. This concludes that rush into forest resource use for bioenergy production will certainly affect this ecosystem and its entire inhabitants. Therefore the study recommends that research and development into second-generation biofuels, prioritising technologies that will not require monoculture expansion, nor pose a threat to vulnerable people’s food security or land security as well as biological diversity must be considered in first hand while setting up a comprehensive bio-energy policy for the forest sector.

Keywords: biomass, forest plantations, lignocellulose, land, miombo woodland

1 Introduction

Tanzania is mostly dependent on energy from biomass (fuelwood and charcoal) harvested from forests and woodlands (Malimbwi et al. 2004). About 90% of domestic energy needs are met by firewood (78%) and charcoal (24%), with rural areas more dependent on firewood (Abdallah et al. 2007). Petroleum and electricity supply about 7% and 1%, respectively, of the energy used (Kaale 2006). Whereas electricity is important in urban areas, less than 2% of the rural population have access to electricity, and because of high tariffs, most people in urban areas are also switching to charcoal and firewood. This has in turn forced charcoal prices to increase from 5 000 TShs last year to 20 000 TShs for 56 kg currently. Use of kerosene for cooking and lighting has declined due to high prices, forcing more people to use charcoal and fuel wood. Charcoal supply to urban areas is mainly from woodlands located along the main roads (WWF 2007) but because charcoal making kilns are very inefficient (recovery <25%), extensive woodland have to be cleared to meet the high charcoal demand. Moreover, charcoal making is a cause of many accidental fires. Both harvesting and fires therefore contribute to deforestation and land degradation. In addition, the increased use of fuelwood contributes to indoor air pollution causing serious respiratory health problems.

Large areas of miombo woodlands in Tanzania are annually deforested through land clearing for shifting cultivation, but also to produce fuelwood for curing tobacco. In western Tanzania Abdallah et al. (2007) reported that one ha of miombo woodland is cleared to dry one ton of tobacco. In addition, because of high prices of agricultural inputs, including fertilisers and pesticides, tobacco farmers are forced to practice shifting cultivation, clearing new areas every few years, exacerbating land degradation. An added impact of increased deforestation is its contribution to greenhouse gas (GHG) emissions, which together with land use changes is estimated to account for 21% of total global emissions. Apart from the global effects of deforestation and land degradation, developing countries are threatened with biomass energy crisis, which if not addressed urgently will pose serious security problems. Moreover, while the current fossil fuel energy crisis hits least developed countries more severely, it is part of global energy availability crisis, calling for a search for alternative renewable energy sources (e.g. biomass, wind, solar and hydro power). Thus the shortage of fossil oil, the common transportation fuel (Brown 2007), and fuel wood shortage in less developed countries have the potential to destabilise the world economy.

Over-consumption of fossil fuels by developed countries for transportation and industrial use over the last century is responsible for the oil scarcity, and contributes to global warming. High GHG emissions increase global warming and contribute to climate change (UNEP and UNFCCC 2002) with serious negative social-economic, environmental and biological effects. To face this environmental threat, various initiatives to mitigate and adapt to the effects of climate change are being considered, including reducing the consumption of fossil fuels. It is very clear that the current consumption levels of fossil fuels cannot be sustained, given the notion that oil production is peaking, and that the few reserves that remain will be exploited at very high costs (Deffeyes 2005). Therefore the search for alternative sources is urgent, including the need to explore for suitable and acceptable fuel alternatives including biomass energy. Renewable bioenergy sources are being considered for providing energy for transportation, heating, power generation, and manufacture of by-products, including chemicals.

One of the favoured options to reduce reliance on fossil fuels is to increase the supply of renewable biomass energy materials. In that context, establishing and managing large areas with dedicated forest plantations specifically to produce wood for bioenergy, and establishing agrofuel farms to produce biomass for biofuels are gaining importance all over the world. There is also the option of utilising forest logging wastes and agricultural crop residues to generate bioenergy. This paper will examine the potential of fast growing wood plantations and use of logging residues to provide bioenergy for Tanzania with emphasis on miombo woodlands. There are four key factors driving interest in bioenergy: rising energy prices, in particular oil prices, energy security, climate change, and rural development (TaTEDO 2008).

2 Forest plantations grown to produce wood for energy

In recent years, much attention in various parts of the world has been directed at high-value forests that produce bioenergy and biofuel, or sequestrate large amount of carbon for carbon trade under Clean Development Mechanism (CDM) category in Kyoto Protocol. Large forest plantations have been established in various tropical countries including in Brazil, India, and Congo Republic using Eucalypt clones. These high-value plantation forests are designed for the following purposes:

- To generate forest biomass (pellets, chips, lignin, processing plant wastes etc.) to produce electricity, steam and heat by planting genetically modified species such as hybrid eucalypts, acacias etc.
- To produce forest biomass that can be transformed to liquid or gaseous fuel (biodiesel, bioethanol, biogas, bio-oil, biohydrogen) through gasification, trans-esterification, or biological treatment.
- To produce large amount of carbon credits from carbon sequestration in a plantation forest (generally called carbon forest) where photosynthesis and biomass production are maximized by optimizing growing factors for vegetation.

3 Utilisation of logging residues and wood wastes and agricultural crop residue for bioenergy

One of the alternative energy sources is regenerative energy sources commonly referred to as biofuels. Biofuels are products of biological origin that have been converted into liquid, or gaseous form, depending on the raw material and the technology employed, for energy generation (Cloin et al. 2007). Bioethanol and biodiesel are the most common forms of liquid biofuels. Others include biomethanol, biodimethylether and biogas (Dufey 2007). Solid bioenergy include fuelwood (charcoal and firewood), wood pellets and briquettes. Gaseous biofuels include biogas, biohydrogen, and syngas. In this context forests are seen not only as suppliers of traditional wood sector products, but as a platform for bio energy.

The importance of bioenergy for the 21st century is intuitively attractive, and receives much press, attracting political and social interests (McLaren 2005). However, how bioenergy will contribute to sustainable world economic growth remains unclear. For example, it seems that production of bioenergy from primary agricultural products (oil seed, sugar, and starch) in the absence of subsidies may not be cost-effective, if the value of the crops exceeds the value of the energy produced (Silayo et al. in press). Other studies have shown that unguided rush for biofuels could cause food shortages and increase poverty with a potential for political instability, environmental degradations and loss of biodiversity. The shift to lignocellulosic biomass feedstocks and more efficient conversion pathways provides the opportunity to consider 'next-generation' biofuels. These fuels would be produced by efficient processes that could be based on biological or thermochemical pathways or a combination of both (IEA Bioenergy 2004).

Research on second generation biofuels is taking place in various countries (e.g. Germany, UK, US and Sweden). The use of wood from dedicated short rotation forests, and wood wastes from logging, and agricultural wastes are being investigated. Bioconversion of lignocellulosic agricultural waste - like sugarcane bagasse and sisal waste - for the production of bio-ethanol instead of on-field burning could be an effective method for reducing possible pollution. Logging slash from forest harvesting is normally burnt, or piled, and provides suitable materials for bioenergy conversion. There are however some concerns that extracting lignocellulosic materials from forest logging residues may destroy the soil, disrupt nutrient cycling and hydrological balance, and may delay forests regeneration. Moreover, the capital costs needed to build commercial "biorefineries" are seen as a major barrier.

4 Wood bioconversion

The conversion of lignocellulosic material into biofuels is complicated and not yet a commercial business. According to NTNU (2005) the conversion of wood into fuel goes mainly first through gasification or hydrolysis, followed by downstream fermentation or a Fischer-Tropsch reactor. The most important conversion routes are shown in Fig. 1. Key products include biodiesel, bioethanol, biomethanol, biogas, hydrogen, and pyrolysis oil.

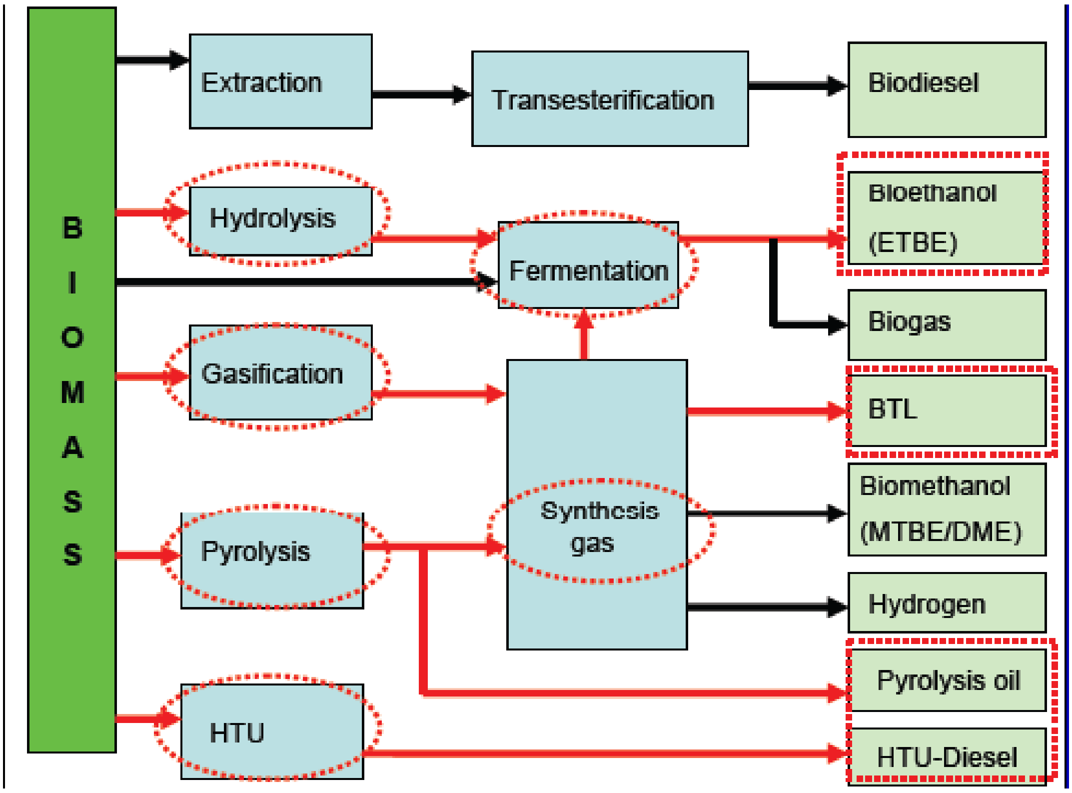

Figure 1. The conversion of lignocellulosic material into biofuels. Routes applicable with lignocellulosic material are marked with red (NTNU 2005).

The energy analysis of the biomass to biofuel routes show that biomass farming and transportation are a minor part of the total energy expended. The major losses lie in the energy conversion into a fuel, and the 'Well to Wheel' (WTW) energy efficiency is lower than conventional fuels. NTNU (2005) found out that biofuels use twice the primary energy compared to conventional fuels, but exhaust only 12% of the CO_2. With the fact that substantial amount of energy is lost during conversions and final uses, it is of no doubt that more wood will be required to produce substantial amount of fuel. This would mean that more forests in the tropics and subtropics will have to be cleared to open up agrofuel farms or new plantations of the fast-growing tree species to meet high demand in the future. Can Tanzania afford to clear large areas of miombo woodlands to produce biofuels to meet mandatory targets for external interests as the EU (10% biofuel blend by 2020). An analysis by Hakiardhi (2008) indicate that this is unsustainable.

5 The growing demand for biomass energy

As oil prices rise, wood is likely to become increasingly attractive as an energy source and the use of wood to generate electricity production is expected to increase rapidly. The current demand for biomass energy is based on the fact that fossil fuel generates GHG emissions, and use of biofuels will release less. According to Graham et al. (1992) there are globally significant environmental benefits that may result from using wood for energy rather than fossil fuels. More benefit can be derived when biomass energy substitutes for coal especially for generating electricity through CHP. The substitution of wood for coal to generate electricity may reduce airborne pollutants including toxic heavy metals, ozone-forming chemicals, and acid rain.

Some textile mills in Tanzania, avoiding high electric tariffs from TANESCO, use wood biomass to produce electricity. These include A-Z and Sunflag textile mills in Arusha which together consumes more that 80 m^3 of wood daily from Meru plantation forests alone (Goodluck 2008, pers. comm.). In areas with no plantations forests to supply wood biomass, some industries harvest illegally from natural forests. If production of liquid fuels become commercially viable, the demands for biomass energy especially from natural forests and plantations of fast-growing species will dramatically increase. Tanzania has recently been invaded by different investors trying to acquire large tracts of fertile land to establish biofuel plantations (e.g. jatropha, oil palm and sugarcane). However, maximum caution is required, especially given the unknown sustainability aspects of biofuels.

6 Ecological implication of producing biofuels

The possible ecological implications of bioenergy production to the miombo woodlands should consider that these woodlands are important for traditional uses including providing timber, food and buffer zones for farm expansion by the rural poor. It is to be noted too that miombo woodlands have been exploited unsustainably.

7 Bioenergy from the miombo forests

Tropical forests including the miombo woodlands provide high quality timber for the local and export markets, while wood biomass meets the energy requirements of rural and urban populations. Miombo trees and shrubs are slow growing, and hence high quality (dense) solid fuel, and are important sources of charcoal, firewood and recently briquettes. However, consumption exceeds production, and poses serious sustainability problems.

8 Types of bioenergy solid biofuels

8.1 Charcoal and firewood

Woodfuels including firewood and charcoal account for about 92% of primary energy consumed in Tanzania, but charcoal is the most preferred source of energy in urban areas. For example, according to WWF (2007) Tanzanians consume more than 2 650 tons of charcoal each day, or 968 488 tons per year. To produce that quantity using traditional methods, the rural population has to clear-cut the equivalent of 331.7 hectares of forest every day. To meet this consumption, more than 121 061 hectares of forests are destroyed. According to the Ministry of Natural Resources and Tourism, the forests of Tanzania shrunk from 44.3 million hectares in 1961 to 33.5 million hectares in 1998, and the same source believes that current annual forest reduction is between and 500 000 hectares, against only 25 000 hectares planted (FBD 2007).

Miombo woodlands in Tanzania are highly deforested, with charcoal pits scattered in the remaining tree pockets. The extent of deforestation is starkly evident in areas along the principal Dar-Morogoro and Segera-Chalinze Roads. Changes in forest cover, soil fertility and water catchment value will have long range impacts unless action to reverse the trend is initiated soon. The global impacts of this deforestation reaches, is highlighted by calculations made by the Edinburgh Centre for Carbon Management (ECCM) showing that each ton of charcoal produced and consumed in Tanzania generates nine tons of CO_2 equivalent emissions. With a production of 968 488 tons of charcoal, this translates into 8 716 392 tons of CO_2. This amount of greenhouse gas emissions is greater than the CO_2 generated from 44 typical coal-fired cement factories. Unsustainable charcoal is responsible for three times more CO_2 emissions per mega joule of energy than coal and six times more than natural gas (WWF 2007). According to the United Republic of Tanzania's Vice President's Office – Environment Division, land use change and forestry (virtually all of which is caused by clearing land for agriculture and charcoal production) account for 57.8% of Tanzania's greenhouse gas emissions (URT 2003). Since Tanzania is endowed with large reserves of coal (911 million tons) and natural gas, it is timely to use these instead of charcoal.

8.2 Compressed briquettes

A compressed briquette is a black, brittle substance that that can be used as a direct substitute for charcoal. Briquettes are carbonized biomass produced by heating carbon-rich plant or animal materials, such as agricultural or domestic waste, in airless kilns. During the heating process, most of the hydrogen, nitrogen, and oxygen in the raw material escape. The resulting black, porous material is then mixed with clay and binder to make a briquette and compressed. The process increases the energy density of the fuel relative to the raw material by 30–40% along with the heat retention of the fuel. In this form, and combined with an efficient cooking stove, the required amount of biomass to provide primary energy for cooking food in a traditional manner is greatly reduced. Unfortunately, most users do not own the ‘efficient stoves’, leading to unnecessary waste of briquettes.

The carbonized material can come from a variety of sources, including charcoal vendor waste (charcoal dust), wood waste, coconut husk, biodegradable domestic waste, among others. Briquettes are produced using simple technology, and briquetting businesses can be easily located in different parts of the country. Several small companies are currently producing briquettes, including East African Briquette Company (EABC) in Tanga, the Kilimanjaro Industrial Development Trust in Moshi, and Appropriate Rural Technology Institute in Dar es Salaam (WWF 2007). The use of charcoal dust to produce briquettes, however, poses a new danger to woodlands as low density tree species not suitable for charcoal might be burnt to produce dust later used for making briquettes, contributing to severe land degradation.

9 Biomass forest plantations

Biomass represents all organic materials that stems from plants and animals. Tree biomass and agricultural and forest residues are important biomass sources. The world derives about 11% of its energy from biomass. Forests can be established and harvested to provide biomass for energy generation. Whereas biomass plantations potentially offer many direct and indirect environmental benefits, there could be negative environmental impacts as well. Provision of biomass for energy generation may be one of the primary benefits, but if they necessitate clearing of natural forests, or displace farming communities, then they are unsustainable. Disruption of water, carbon and nutrient cycles, are some of the more negative impacts, turning fertile lands into marginal land. Silayo et al. (2008) pointed that “as carbon-capturing forests are felled to make way for biofuel crops, CO_2 and NO_2 gas emissions will increase rather than decrease”.

Furthermore, as most biomass plantations are monoculture systems, the use of mechanization and chemical inputs can not be avoided and could increase environmental pollution. According to Donald (2004) and Bravo (2006) intensification of bioenergy production in monocultures, an overall increase in CO_2 emissions is more likely. The extent to which large monocultures, forests will impact the other ecosystem attributes can be speculated to be grave. Increased release of soil CO_2 as forests are clear-cut can be substantial, given that forest soils normally stores four times more C than that in aboveground biomass. Experiences from Brazil show that early mistakes in establishment of eucalypt plantations, along with increasing environmental sensitivity, have led to substantial regulation of the forest industry (Beyea et al. 1991). It is worth noting that negative environmental effects of plantations may occur locally if unmanaged natural forests or forests managed for low intensity uses are removed and replaced with short-rotation biomass plantations.

10 Liquid fuels from lignocellulosic materials

Historically, humans have used wood for fuel, lumber, paper, and other wood products, and tree domestication efforts have traditionally focused on increasing the yield and properties of wood for lumber and paper products (MacKay et al. 1999, Hopkins et al. 2001, Baucher et al. 2003, Burdon and Libby 2006). According to Han et al. 2007 liquid fuels from lignocellulosic materials, such as wood, offer an attractive alternative to fossil fuel. The new approach to use of woody biomass for liquid fuels will require new tree crops having very different wood properties from those developed for lumber and paper. For example, while high lignin content in wood increases the physical strength of lumber, it impedes saccharification of lignocellulosic biomass for generating fermentable sugars. Lignocellulosic biomass is composed of a complex mixture of cellulose, hemicellulose, and lignin. As structural polymers, the matrix of hemicellulose and lignin surround the cellulose component of the plant cell wall to protect it against enzymatic attack.

Advances in biotechnology process will be the key driver to sustainable bioenergy efforts, including high yields of easily fermentable polysaccharides, total lignin content and altering its monomer composition, content and type of chemical extractives in the wood, lowering biomass recalcitrance to fermentation, and wood density. Forests that are routinely harvested are expected to provide an increasing share of the world's fiber and wood resources as access to native forests becomes more restricted and production continues to shift toward fast-growing plantations in the tropics and subtropics. This means more natural forests will be cleared to allow establishment of the biomass plantations of which miombo woodland will be highly affected.

11 Scramble for land to grow first generation biofuels

In Tanzania, there has been a rush into land for biofuel production by big companies and individuals. With the fact that nearly half of Tanzania's land area has been identified as suitable for biofuel production (GTZ 2005). The targeted areas are not marginal as often claimed, but rather fertile areas suitable for food production or biodiversity rich ecosystems. Today, companies are in the process of acquiring big portions of land ranging to 400 000 hectares in many parts of the country especially in the southern and eastern Tanzania. They use procedures that lack transparency and are highly questionable. According to Hakiardhi (2008) Tanzania's land policy confers to investors the "right to buy and sell land" while lacking better clarity, consistency and transparency in identification and alienation of land for bioenergy needs. One of the biggest and real threats of bioenergy is land grabbing and the resultant displacement of village communities along with shattered livelihoods.

Oxfam (2008) cites a case study from the coastal district of Kisarawe where as one of 11 villages are in danger of loosing a total of 8 200 ha 'grabbed' by Sun Biofuels Tanzania Ltd to grow jatropha. Although Mtamba village owns a big share of the forested vegetation it did not participate in the negotiation process but will loose access to a forest which they had depended much for livelihood. The company promised to compensate the farmers for their trees and not land, giving less than $10 per ha, a harbinger for serious social conflicts. Another 1000 farmers in the Wami River Basin – a rice-growing area – currently face eviction to make way for a Swedish investor looking land for sugarcane plantations (African Biodiversity Network 2007). This means that the communities will have to look for other means of sustaining life and off-course turning into the available resources which can be forests if they will within their rich.

12 Conclusion and recommendations

While traditional use of wood for energy and timber is growing to a point of threatening forest sector sustainability, wood is gaining popularity as a source of fermentable sugars for liquid fuel production. Expanding woody biomass energy to the scale of commercial production will require significant improvements in the growth of feedstock as well as its quality. This will call for new biomass plantation establishments in the tropics and subtropics which in-turn will pose serious problems on the existing natural forests and livelihood of the rural poor to whom forests form integral part of their livelihood sustainability in terms of food, water, energy and income security and biodiversity. This study recommends that;

- In order to use wood resources sustainably in the future the governments needs to introduce comprehensive but coordinated policies for the forest sector, rural development and energy sectors.
- Research and development in biofuels, prioritising technologies that will not require monoculture expansion, nor pose a threat to vulnerable people's food security or land security as well as biological diversity must be considered in first hand.
- More efficient use of biomass for energy, including heat and power, has to be emphasised as it is the primary energy source to most Tanzanians.
- Implement and enforce national legislation to protect vulnerable people's access to land, and ensure proper and fair compensation schemes.
- Prior to invest in forest biomass plantations the government must first synthesize and transfer to stakeholder's important knowledge and new technical information concerning conventional forestry systems for sustainable production of bioenergy.

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Opportunities and challenges for sustainable management of miombo woodlands: the Zambian perspective

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Miombo woodland is the most widespread woodland type in Zambia. It is important for various uses namely charcoal, timber, fruits, medicines, mushrooms, etc. These different forms of utilization have varying impacts on both the miombo woodland ecosystem and the individual species. The variation in impacts calls for thorough understanding of the best management approach that has to be employed to ensure sustainability.

1 Introduction

Miombo woodland is one of the six ecoregion in Zambia, namely Zambezian flooded grassland, Western Zambezian grasslands, Cryptosepalum dry forests, Zambezian Baikiaea woodlands and Zambezian and Mopane woodlands (Fig. 1). It is the most extensive Zambian ecoregion covering about 65% of the Country. Miombo is further divided into Central Zambezian and Southern Miombo Woodlands. The central miombo woodland which is predominantly of *Isoberlinia angolensis*, *Brachystegia* spp. and *Julbernadia paniculata* is the dominant vegetation types in Northern, Luapula, North-Western and the northern part of Central Province and part of Kafue National park. However, in the southern miombo woodland, *Isoberlinia angolensis* is absent.

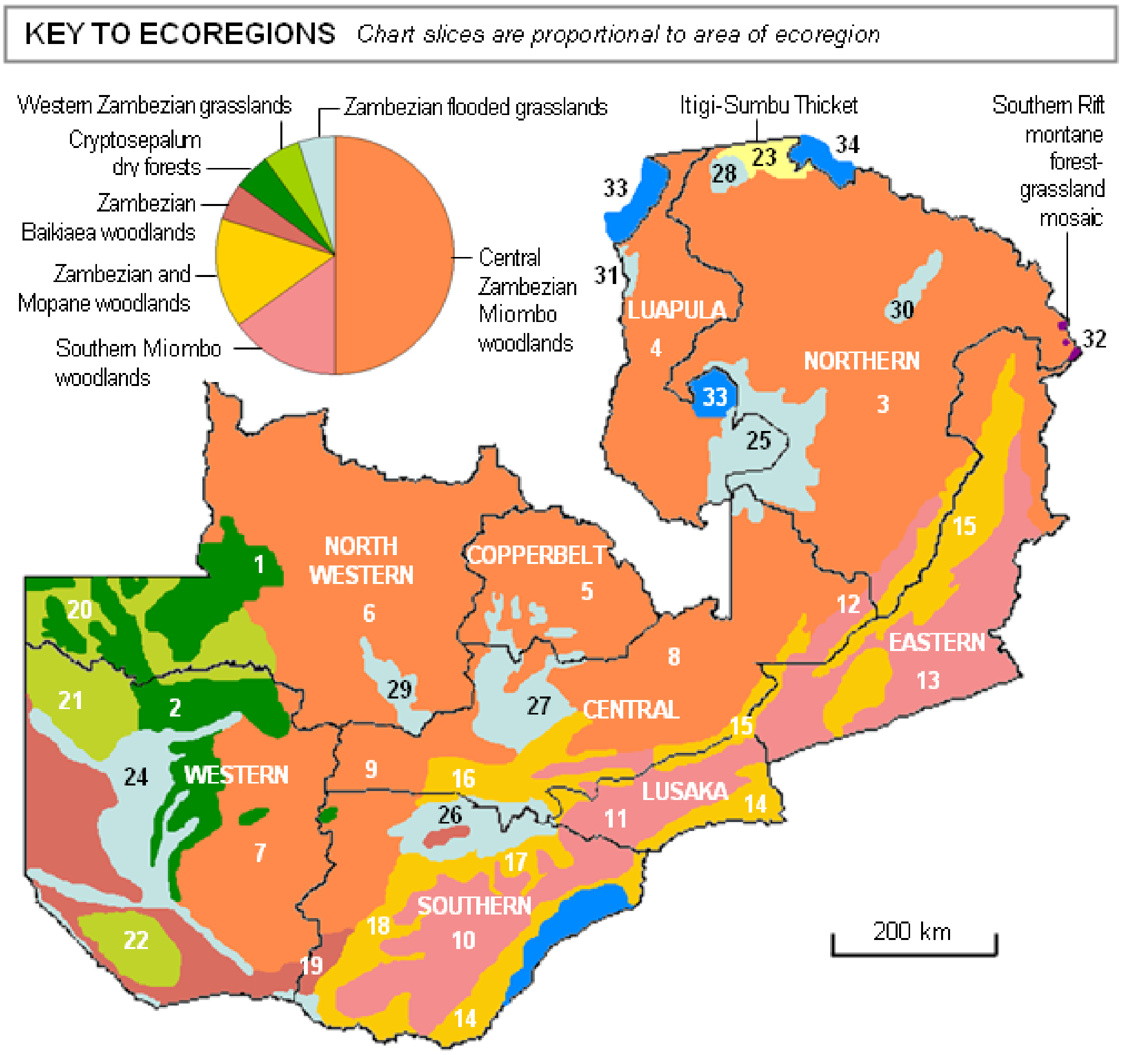

Figure 1. The major ecoregions of Zambia.

2 Miombo utilization

Miombo resources are central to livelihoods of urban and rural dwellers (Campbell et al. 1996, Syampungani 2008) for charcoal production, slash & burn agriculture, timber production and non-wood products.

2.1 Charcoal production

Woodfuel accounts for higher percentages of the total household energy requirements in the ecoregion (Syampungani et al. 2008). About 76% of the Zambian population depends on wood fuel energy (Chidumayo 1997). Woodfuel carter for a high national energy budget in the Country because of relatively high cost of electricity and petroleum based fuels and high poverty levels with low economic grow rates (Campbell et al. 2008). The trend in charcoal production and consumption will continue rising in Zambia (Table 1).

Table 1. Projected charcoal production and consumption.

Year	Wood used (million tonnes)	Yield (million tonnes)	Charcoal consumption (million tonnes)
1969	1.179	0.340	0.330
1980	2.196	0.505	0.490
1990	3.070	0.760	0.685
2000	4.056	0.933	0.905
2010	5.428	1.248	1.211

Charcoal production also saves as the source of cash income and employment for both the urban and rural dwellers. Charcoal is produced in rural areas for onward transportation to cities (Fig. 2).

The increased demand for charcoal entails massive clearing of land for charcoal production (Fig. 3).

Figure 2. Charcoal kiln and the truck loaded with charcoal for onward transportation.

Figure 3. Cleared area and kiln for charcoal production.

2.2 Slash and burn agriculture and timber harvesting

This has resulted in an increased pressure on the forest resources as some other activities such as agriculture is also mounting pressure on the already limited Zambian woodland resources. Timber harvesting of valuable species such as *Pterocarpus angolensis, Brachystegia floribunda, Afzelia quanzensis, Erythrophleum africanum, Pterocarpus rotundifolius, Dalbergia melanoxylon* and *Isoberlinia angolensis* is prominent. Timber harvesting takes form of single tree selection harvesting and as such the woodland appears to remain intact for some time. Lately the woodland is showing signs of opening up. This may be due to the fact that charcoal production is no longer restricted to the preferred species but even unlikely species such as fruit trees like *Uapaca kirkiana* are being cut down for charcoal production.

2.3 Non wood forest products

The non wood forest products from the Zambian miombo include medicinal plants, edible mushrooms, wild fruits etc. which are not only consumed but widely traded by both the rural and urban communities. Zambia has a number of edible mushroom species. *Termitomyces titanicus,* the world's largest and tastiest mushrooms also occurs in Zambia (Piearce 1987). These edible mushroom species exist symbiotically with most of the miombo woodland species. Fruit species include *Uapaca* spp., *Strychnos* spp., *Parinari curatellifolia* and *Anisophyllea boehmii.* These fruits are important dietary components of the rural dwellers in Zambia and they are also sold to meet specific cash requirements in case of crop failure (Akinnifesi et al. 2008). Several species are used in treating various ailments. Often parts of barks or roots are removed for medicinal purposes. This may result in dying of the affected plants.

3 Challenges and opportunities

Charcoal production and slash and burn agriculture are the most controversial uses of miombo woodlands in Zambia. This is because these are often associated with massive loss of biodiversity (fauna and flora) and some high productive ecosystems (Chidumayo 1987, Katsvanga et al. 2008). These are also perceived to contribute to massive global heritage loss and climate change (Forsyth 2003). This is because some authors (Stromgaard 1986) support the idea of non woodland recovery once it is cleared for the above purposes. Furthermore, other authors (e.g. Chidumayo 1992) suggest very low grow rates of miombo woodland species. However, recent studies (Geldenhuys 2005, Syampungani 2008) suggest higher productive miombo woodland ecosystems once disturbances cease. Additionally, other studies (Chidumayo 1988, 1993a, b, 2004) report the development of the woodland overtime.

Timber harvesting is perceived to have no serious negative impacts on the woodland in Zambia (Chidumayo 1987). Various studies in Zambia (Syampungani 2008) and other parts of the miombo ecoregion: Mozambique (Grundy and Cruz 2001), Zimbabwe (Mudenkwe 2006), Malawi (Makungwa and Kayambazinthu 1999) and Tanzania (Luoga et al. 2002) have reported the negative impact of single tree selection at population level. Such species have been reported to exhibit unstable populations. Most timber species are shade intolerant (Werren et al. 1995). Therefore, if not adequately exposed to light, they remain stunted and thus prolonging the period during which they are susceptible to fires, water stress and herbivory (Chidumayo 1997). According to Syampungani (2008), this behavior of different miombo species leads us to the following questions:

- What is good for sustainable management of miombo woodland?
- Is it single tree selection harvesting of timber species that allows very little to no regeneration of the canopy species under the remaining canopy?
- Or is it slash and burn agriculture and charcoal production that result in maximum light intensities on root suckers/stumps and recruitments?
- Is it possible to integrate charcoal production/slash and burn agriculture/single tree selection into sustainable forest management programs?

Studies that compare the impacts of charcoal production slash and burn agriculture and single tree selection harvesting at both population and stand levels are required. The Zambia woodlands in which single tree selection, slash and burn agriculture and charcoal production offers an opportunity to understand and compare the influence of these forms of utilization at both population and stand levels.

Trends in food market are changing globally. There is a growing emphasis on variety and organic products (Akinnifesi et al. 2008). Miombo woodland NWFPs like fruits qualify as organic products and can gain market share and entrance in the niche market for natural products (Akinnifesi et al. 2008). For example, phytotrade estimates a potential regional value of US$3 billion from oil producing wild fruit species (Campbell et al. 2008). The abundance of miombo fruit trees in Zambia provides an opportunity for the Zambia people to take advantage of the wood food trend. However, such an action requires an effective understanding of the relationship between NWFPs extraction and changes in the woodland ecosystem and the ecophysiology of medicinal species. This entails carrying out ecological baseline studies for NWFPs, at both population and forest ecosystem levels. Their assessment requires techniques other than the traditional forest inventories.

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