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MITMIOMBO – Management of Indigenous Tree Species for Ecosystem Restoration and Wood Production in Semi-Arid Miombo Woodlands in Eastern Africa

Proceedings of the First MITMIOMBO Project Workshop held in Morogoro, Tanzania, 6th–12th February 2007

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

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

Title

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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 miombo woodlands. This target is 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.

The project commenced on November 1, 2006. The first project meeting was held 6th–12th February 2007, in Morogoro, Tanzania. A major part of this meeting consisted of presentations by participants. This publication is a compilation of papers presented at the meeting. Together they are intended to provide the reader with a compact overview to the status of the management of miombo woodlands in Tanzania and beyond, and to research methodologies relevant to miombo tree stands characterized by complexity of structures and dynamics.

Keywords

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

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Muita tietoja

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Opening Speech

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Sokoine University of Agriculture Faculty of Forestry & Nature Conservation, Morongoro, Tanzania
pgillah@suanet.ac.tz

MITMIOMBO Research Project Coordinator, Dr. Sauli Valkonen, MITMIOMBO Research Project Team, I am told you are 14 altogether here, 6 from Tanzania Forestry Research Institute, Sokoine University of Agriculture and Tanzania Association of Foresters, 8 from the Finnish Forest Research Institute, University of Joensuu (Finland) and Swedish University of Agricultural Sciences in Sweden.

Ladies and Gentlemen

Today, I am standing before you to officially open the one week First Workshop of the MITMIOMBO Project's activities implementation (6–12 February 2007). Allow me to start by extending my sincere and profound gratitude to the Project Coordinator and the Organizing Committee of this MITMIOMBO Research Project for according me this opportunity and honour to officiate the opening of this Workshop.

The development of this research project and eventually a success in getting funding was brought to my attention by the collaborating researchers from the Faculty of Forestry and Nature Conservation of Sokoine University of Agriculture. I therefore congratulate all project members for winning this project from European Union Fund. I also commend research project team efforts of coming up with a team from different countries, organizing yourself to a point of winning the project.

I am aware that this project is a collaborative research programme on the management and conservation of the miombo Woodlands between six international institutions i.e. METLA and UJOE in Finland, SLU in Sweden, SUA, TAFORI and TAF in Tanzania. Such collaborative efforts in research are highly commended since the project is likely to benefit from research experiences of different researchers coming from different geographical regions.

The research work for this project is going to be conducted in the miombo woodlands in Kitulangalo area, Morogoro, Tanzania. I presume this is the area leased to Sokoine University of Agriculture by the Ministry of Natural Resources and Tourism and managed by the Faculty. I am also told that today more than 25 researchers of this project including other invited scientists have assembled here to plan the implementation of the research activities.

1 am also informed that during this workshop over 15 scientific papers on the various aspects of miombo forest management and conservation will be presented to facilitate the discussions and shape the research plans, that you will also be visiting the research sites on Saturday and that actual field research work will be following up immediately after the workshop next week.

Let me, at this juncture, ladies and gentlemen, cordially welcome you all to SUA, in particular the Faculty of Forestry and Nature Conservation, your contact institution, and to this first memorable workshop. Allow me to similarly indicate our awareness with regard to this project. MITMIOMBO project is currently a two years project funded by European Union starting in November 2006 and will extend to October 2008, with a potential of being renewed for a longer term extension and expanded national and institutional collaborative participation following a successful completion of the current part. Considering the level of researchers involved, all of them being serious researchers, I am sure the project will be very successful and it has all chances of being renewed upon completion of a very successful first phase. My Faculty and indeed this Institution wish you a successful implementation of this project.

I am also aware that the ideas that formed the foundation of this project were conceived by our colleagues from METLA in Finland almost two years ago, who, also stood the rigours of the European Union programme demands to the programme's fruition and making this meeting possible. I heartily acknowledge and commend these efforts and particularly those personal efforts by Dr. Sauli Valkonen, the Project's Coordinator. Also allow me to recognise the roles played by our Tanzanian researchers from SUA, TAFORI and TAF in enabling this funding.

As mentioned earlier you have also organized presentation of different papers from different resource persons from this country and from outside this country, especially those addressing challenges in miombo woodlands. I believe this is meant apart from facilitating discussion, giving a room of knowing each other, identifying resource base, getting important information or literature which will also be resourceful in project planning and implementation.

Allow me to recognize with appreciation the willingness of these researchers who devoted their commitment and time to prepare the presentations to share with you their experiences. Since these are papers carrying valuable information, it will be helpful for the project to make arrangement (which I believe you have) to either publish or come up with a proceeding, which can be accessed and shared by many researchers or stakeholders.

Allow me on behalf of the Faculty of Forestry and Nature Conservation to once again thank the European Union for funding this project. The Faculty has always been ready to cooperate and work hand in hand with fellow scientists or researchers from within and outside this country for activities that promote sustainable management of natural resources. Since MITMIOMBO project deals with management and conservation of miombo woodlands, then this project is touching our interest and is within the Faculty mandate. Please feel free to consult us whenever you think the Faculty assistance is required for smooth implementation of your research project.

Finally, I again welcome you to Sokoine University of Agriculture, Faculty of Forestry and Nature Conservation in particular, and I wish you a nice stay and a fruitful MITMIOMBO Research Project Planning Workshop.

Having said all these, I now declare the workshop activities officially opened.

Participants of the Workshop. Front row (from left to right): L.L.L. Lulandala, S. Valkonen, P.R. Gillah and L. Nshubemuki, middle row: A. Malmer, V. Kuutti, J. Saramäki, M. Varmola, M. Mndolwa, L. Mbwambo and K. F. Hamza, back row: H. Roininen, G. Nyberg, A. Chitiki, J. Isango, J.M. Abdallah, P. Nöjd, R. Petro and F.B.S. Makonda.

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Overview of Miombo Woodlands in Tanzania

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Miombo woodlands make up a significant proportional of total forested land in Tanzania, and most of it it is in general lands. The main concentrations of this formation are found in the western and the southern part of the country. Miombo woodlands are central to the livelihood systems of millions of rural and urban dwellers in Tanzania for domestic and some agro-industry activities. Utilization of miombo woodlands is unsustainable and inefficient. Deforestation is alarming, marketing and improvement of processing techniques of miombo products is crucial. To develop alternative energy sources and to make them accessible to the poor community is paramount. To invest on addressing constraints emanating when implementing collaborative management is crucial.

1 Introduction

1.1 Background Information

1.1.1 Description, Characteristics and Distribution

Miombo is a vernacular word that has been adopted by ecologists to describe those woodland ecosystems dominated by trees in the genera *Brachystegia*, *Julbernardia* and *Isoberlinia* (*Leguminosae*, sub-family *Caesalpinioideae*). These genera are quite gregarious, are found mostly in the upper canopy, and may represent up to 80% of all trees present (Dykstra 1983). Recently, the World Wide Fund for Nature (WWF) (WWF-SARPO 2001) defined the miombo as an ecoregion complex dominated by the miombo *sensu stricto* and related dry woodlands, namely the *Baikiae* and *Colophospermum* woodlands which are slightly less dense but function similarly in an ecological sense to the Miombo *sensu stricto*. The two genera *Baikiea* and *Colophospermum* are also in the sub-family *Ceasalpinoideae.* Among other distinctive features of miombo woodlands are the number of tree species with meso- and microphyllous compound leaves (van der Meulen and Werger 1984); the flush of new leaves before the rains (Tuohy and Choinski 1990); the dominance of tree species with ectomycorrhizae (Högberg 1982, 1992, Högberg and Piearce 1986), and the low biomass of large herbivores.

The woodlands constitute the largest more-or-less contiguous block of deciduous tropical woodlands and dry forests in the world (Campbell et al. 1996), and are home to over 40 million people and the sources of products that serve the basic needs of an additional 15 million urban people

(Campbell et al. 1996). Miombo occurs in seven countries in eastern, central and southern Africa; namely Angola, Malawi, Mozambique, Tanzania, Zaire, Zambia and Zimbabwe Fig. 1, (White 1983).

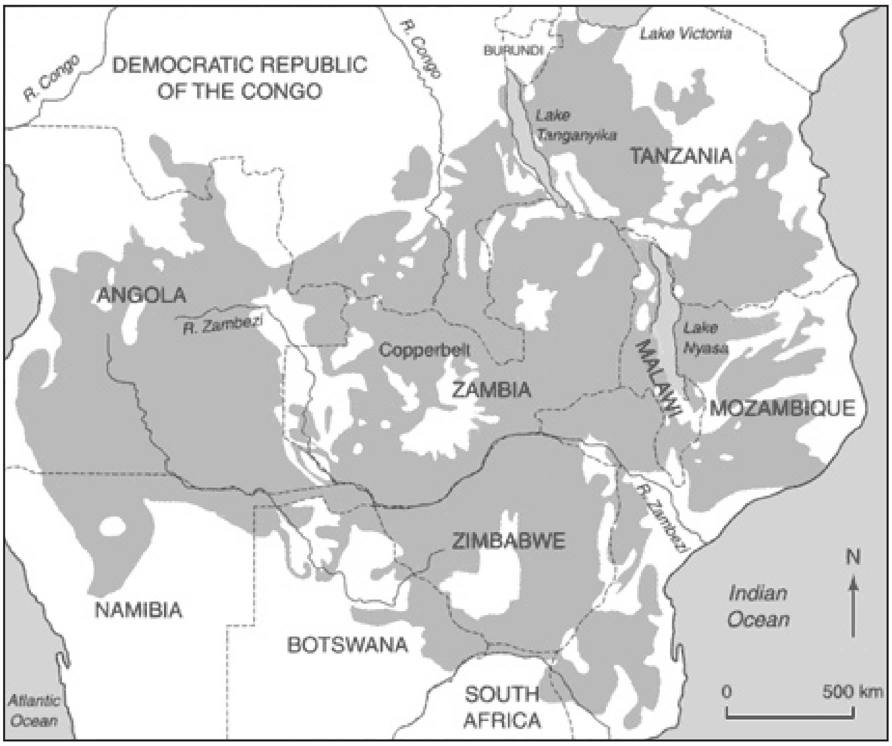

Figure 1. Distribution of miombo woodlands.

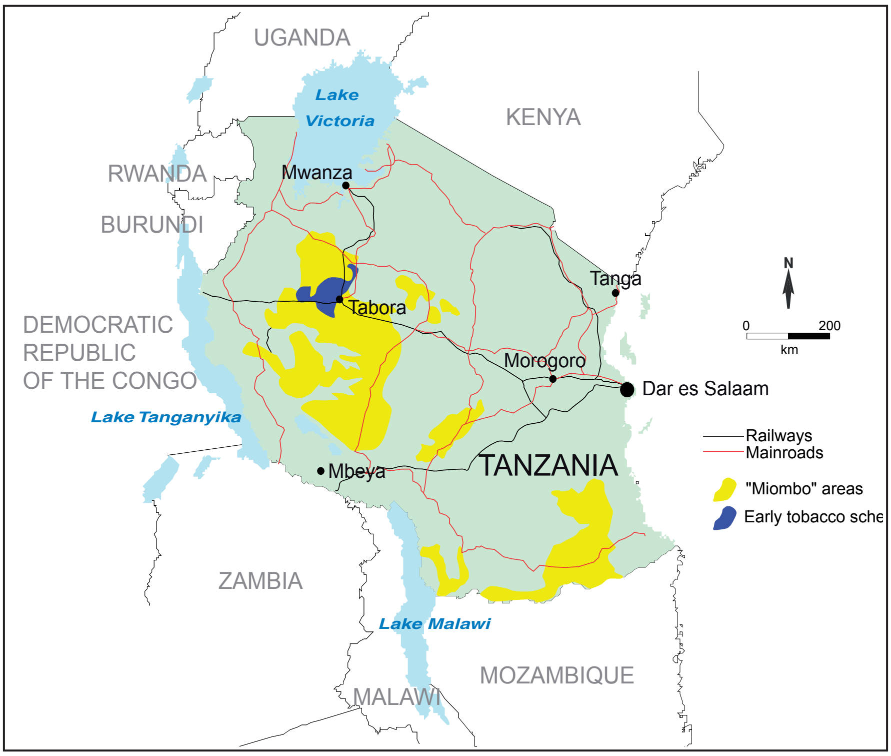

Figure 2. Location of major miombo areas in Tanzania.

They occupy an area of about 2.7 million km^2, almost equal to the combined land area of Mozambique, Malawi, Zimbabwe, Tanzania and Zambia (Desanker et al. 1997). Miombo woodlands in East and Central Africa can be divided into dry and wet (White 1983). The dry miombo woodlands occur in areas receiving less than 1000 mm rainfall annually. They occur in Zimbabwe, central Tanzania, and the southern areas of Mozambique, Malawi and Zambia. Canopy height is less than 15 m and the vegetation is floristically impoverished. The wet miombo woodlands occur in areas receiving more than 1000 mm rainfall per year and these are found in eastern Angola, northern Zambia, south western Tanzania and central Malawi. Canopy height is usually greater than 15 m reflecting generally deeper and moister soils, which create favorable conditions for growth. The vegetation is floristically rich (Frost 1996). The present day distribution of miombo reflects its history, particularly past climatic changes and past and present human activities (Scott 1984).

Recent coverage data of miombo woodlands is lacking. According to Ahlback (1988) this biomes make up about 90% of all forested land in Tanzania, equivalent to 44.6 million ha, out of which 54% is under general lands (URT 2001). The main concentrations of this formation in the country are found in the western zone (Tabora, Rukwa and Kigoma regions) and the southern zone (Iringa, Lindi, Mtwara and Ruvuma regions) (Fig. 2). The major species are *Brachystegia* and *Jubernardia*. Other species commonly found in this group are *Pterocarpus angolensis* (*mninga*), Albizia sp. and *Afzelia quanzesis*. Vast areas occur in the general lands (non-gazetted), which lack proper management institution, and due to lack of responsible institution these forests are rapidly deforested and degraded through socio-economic activities.

1.1.2 Species Diversity in Mimbo Woodlands

Specific species diversity is increasingly of interest within the miombo. However, there are few detailed studies in this line. Generally, the diversity of canopy tree species is low, although the overall species richness of the flora is high (Frost 1996). Woody plants make up more than 95% of plant biomass in mature woodlands but interspersed within the woodlands are broad, grassy depressions called “dambos” or “mbuga”. These seasonally waterlogged bottomlands can cover up to 40% of the landscape in some areas. “Dambos” are not old river systems, as is often supposed, but are set into the landscape through differential weathering and subsurface removal of material by the lateral flow of groundwater. They are important sites for cultivation and livestock grazing. Another notable characteristic feature of miombo woodlands are their apparent uniformity over large areas. This uniformity is partly due to the remarkably similar physiognomy of the dominant canopy trees, a reflection of their origins in the *Caesalpinioideae*, and partly due to similar environmental conditions. The miombo woodlands typically comprise an upper canopy of umbrella-shaped trees, a scattered layer, often absent, of subcanopy trees, a discontinuous understorey of shrubs and saplings; and a patchy layer of grasses, forbs and suffructices (Frost 1996). Typicall dominant tree layer (canopy layer) is 15 m to 18 m in height with density of about 65 stems per hectare, under canopy trees 8 m to 12 m in height with density of 80 stems per hectare, and saplings, shrubs and herbs layer less than 8 m in height with density of 375 to 500 stems per hectare.

In Tanzania miombo woodlands species diversity differs from place to place. For example in Kitulanghalo Forest Reserve in Morogoro region a total of 532 trees and shrubs distributed in 99 different species were recorded by Nduwamungu (1996). In the same area Luoga (2000) noted a total of 133 arborescent species in 31 families of which 69% had a variety of uses. Abdallah (2001) in Urumwa Forest Reserve Tabota region identified 99 species. In Iringa district, 131 species were identified from the miombo woodlands’ forest: *Brachystegia boehmii* Taub. contributed about 10% to the total number of stems, *Brachystegia spiciformis* Benth. about 7% and *Vitex payos* (Lour.) Merr. about 5%. With respect to the family managed forests, the most dominant species were found to be *Combretum zeyheri* Sond (about 20%), *Vitex paro* (Lour.) Merr. (19%) *Markhamia obtusifolia* (Bak.) Sprague (18%) and *Lannea humilis* (Oliv.) Engl. (8%). With respect to the forest reserves, the main dominant species were *Brachystegia boehmii* Taub. (12%), *Diplorhynchus condylocarpon* (Muell. Arg.) Pichon (8%), *Acacia tortilis* (Forsk.) Hayne (7%).

1.1.3 Potentials of Miombo Woodlands for Livelihood Improvement

Miombo woodlands are central to the livelihood systems of millions of rural and urban dwellers in Tanzania. Goods and services provided by miombo woodlands to livelihoods of local communities are products such as medicines, energy, food, fibers, and construction and craft materials. The services include cultural and spiritual values, climate regulations, erosion and hydrological control. All of the products and services mentioned above cover the basic needs (i.e. food, shelter, health and spiritual well being). Therefore the ranges of products from the miombo woodlands support rural living from medicines and food to building timber and fuel (Abdallah 2001). Luoga (2000) found that in Eastern Tanzania apart from using miombo woodlands for farming, local people have eleven types of uses for the trees including charcoal, firewood, poles, timber, medicine, withies, food, ropes (fibre), live fences, carving and rituals.

Rainfall in the miombo area is variable, resulting in periodic food shortages. On these occasions, the availability of wild foods and fruits, as well as other natural products that can be harvested and sold or exchanged for food, can be crucial for survival (Desanker et al.1997). 83 indigenous tree species, which bear edible fruits and nuts throughout the year, have been identified in the Tanzania miombo (Temu and Msanga 1994), while more than 50 fruit trees are found in Tabora region miombo (Temu and Chihongo 1998). The rural communities recognize and consume a variety of these edible fruits, which are normally gathered and eaten within the locality, while some are sold in the local markets. Most of these fruits are normally available in the dry season when there is food shortage and make a significant contribution to the diet and income of the rural communities. It is estimated that humans use only 10% of the fruits potential and the rest goes to waste, due to the poor markets and rudimentary processing technologies (Nsubemuki et al. 1997). The collection of wild products is an integrated part of other types of off-farm activities and consumption frequently occur outside the home. This type of consumption results in under-reporting in many studies.

In Tanzania about 97% of all annual wood production is consumed in form of woodfuel, accounting for 91% of Tanzania's total energy consumption (FAO 1981). Wooodfuel in Tanzania is used for cooking and in rural and urban agricultural industries. However, quantitative information on consumption of woodfuel for various activities is inconsistent and sometimes is lacking. For example, previous studies revealed inconsistent results in relation to small-scale tobacco curing: e.g. Temu (1979) reported that 20 m^3 of miombo woodlands is used to cure 1 ha of tobacco, while Wahid (1984) revealed that 15 m^3 is used to cure 500 kg. On average, of recent tobacco farmers use about 1 m^3 firewood to cure 57 kg of tobacco (Abdallah and Sauer 2007). However, the actual amount of firewood used varies with the design of the barn. Most farmers use any species type and size they found, but frequently used are *Julbernadia globiflora, Brachystegia* spp. and *Combretum* spp.

Firewood in Tanzania is regarded as free good even if it is used to generate cash. For example although flue-cured tobacco had higher gross margin of compared with alternative crops (maize, sunflower and tomato) in Iringa, but environmental cost-benefit analysis of tobacco production had a negative NPV, suggesting that small-scale flue-cured virginia growing on miombo woodlands would not be economically viable under current practices. Fish smoking and frying, and bricks burning are among socio-economic activity use woodfuel. Information on the amount and extent of woodfuel utilization during fish smoking and frying, and bricks burning is scarce.

Charcoal making is crucial activity in miombo woodlands and is increasingly becoming a lucrative business. Species frequently used (in case of Tabora) are such as *Pterocarpus angolensis*, *Afzelia quanzesis*, *Brachystegia* and *Julbernadia*. A traditional kiln in Tabora can take an average volume of 13.96 m^3 of billetts of various tree species to produce 20 to 30 charcaol bags each weighing 40 to 55 kg depending on species used. The current method of charcoal production by using traditional earth kilns has been preferred by most Tanzanians as they need very little skill and low capital investment. But, traditional conversion of wood to charcoal, wastes as much as 70% of wood caloric value, thus accelerating pressure in destruction of miombo woodlands. Furthermore charcoal production venture is growing high because it is taken as part time job to supplement farmers' income. The incentives from the ready existing markets in cities and towns encourage charcoal production as a full-time income generating work. The main market is urban areas. A bag of charcaol in Morogoro is valued at TAS 12,000 while in Dar es Salaam is at 18,000. Charcoal makers can generate a profit of up to TAS 8000 from one bag of charcoal. The business is forecasted to continue in future, partially due to stagnant in technological development and inability of many consumers to switch over to alternative energy sources.

A further review of energy sector in Tanzania shows that the country has considerable amounts of alternative indigenous energy resources such as hydroelectricity, natural gas, solar energy and coal. But they do not play important role in rural and urban household energy sector because they are poorly developed with relatively high running costs. For instance, hydroelectric power is relatively playing role to the community compared to natural gas, solar and coal, its potential is estimated at 4.7 GW, of which only 10% has actually been developed.

Moreover, the coverage of electricity is only 10% and less than one percent in urban and rural areas respectively. Even in urban areas there is significant number of districts still not connected to national electric grid at all. Regions with lowest electricity coverage are Coast, Lindi, Mtwara, Ruvuma, Singida, Rukwa and Kigoma. Also, its services and related infrastructure are largely weak in both urban and rural areas, but also use of electricity for cooking is reported by only 1% of households in the country (National Bureau of Statistics 2002). Probably because the electric tariffs of 42.97 TAS/Kwh charged by Tanzania Electricity Supply Company (TANESKO – the only national electric supplier in the country) for domestic use is the highest in the SADC region (Mwandosya et al. 1997, Ubwani 2003). But the fact that prices of electric appliances are unaffordable by many households and agro-based industries, compared to the associate costs of firewood utilization, which is regarded as a free commodity could be the contributing factor for dependence on woodfuel. Therefore forests remained to be the main source of fuel for unforeseeable future in Tanzania. The main challenge is to develop these alternative energy sources and make them accessible to society.

Other important values of the miombo woodlands include revenue and employment creation, raw material supply to households and industries as well as producing a variety of non-woody products. There are other indirect contributions from these natural forests among which soil conservation, water catchment, and fodder for livestock as well as wildlife are major components (Kowero and O'Kting'ati 1990).

2 Post-Independence Modes of Development (pre 1975) and Management of Miombo Woodlands

Miombo woodlands management has a long history in Tanzania, and this can be reflected from the policy transitions since independence. For example, after a promising start during the first decade of independence, economic performance in Tanzania started to weaken in the late 1970s, and by the early 1980s. The country plunged into an economic crisis of unprecedented proportions.

Various internal and external factors can be identified behind the abrupt negative turn in Tanzania's economy. Some of contribution factors for this include: since the mid-1970s Tanzania traded in an environment of escalating world prices of oil and manufactured goods, while simultaneously, a global recession dampened the demand for primary commodities. High import prices and low export earnings led to a drastic worsening of Tanzania's terms of trade. The reduction in import capacity hit especially the newly established large-scale industrial units which, financed and planned mainly with foreign assistance.

Furthermore, increase military spending related to the 1978-79 war with Iddi Amini's Uganda depleted Tanzania's economic resources and adversely affected its foreign exchange position. In the fiscal year 1979 the share of defense in total expenditure reached a high 23.3%. Finally another exogenous shock came from break-up of the East African Community in 1977, which not only ended trade with its nearest partners, but also caused the country to incur unexpected start-up costs for the new structures of civil aviation, railways and telecommunication systems.

Most of the factors contributed to the economic crisis of the late 1970s and 1980s, can be connected to the wrong choice of development policies and strategies, and misappropriation of domestic and external resources. The economy suffered from policies and administrative decisions such as:

1. Neglect of the agriculture sector, forcing it to struggle with a shortage of available funds for investment, low producer prices, little expenditure on supportive infrastructure and extension services, poor marketing arrangements for agricultural products and a poor distribution network for agricultural inputs.
2. The "villagization" programme, which forced rural people to move to communal centre, causing disruption in rural areas and, at least in the short term, involving losses of agricultural output.
3. An emphasis on large-scale industry, which was both capital- and import-intensive and suffered from technological and managerial dependencies, which aggravated problems of foreign exchange shortages.
4. Expansion of the public sector beyond the country's technical, financial and managerial capacities, resulting in a proliferation of unproductive bureaucracies and excessive administration costs across the whole system.
5. Excessive government intervention in the economy, including quantitative restrictions on all categories of imports, the fixing of interest and foreign exchange rates at artificial levels and government monopolization of various key sectors of the economy.
6. Drastic changes in policies, e.g. towards institutional arrangements in the key areas of agricultural marketing and input distribution, which paid little attention to efficiency, caused serious disruptions and prevented long-term development of the institutions involved.

When the first signs of the economic crisis emerged in the late 1970s, there was a lag before policies reacted adequately. The Government spending increased by 47.5% between 1978 and 1980 relative to a 27.6% increase in revenue. The ratio of the overall budget deficit to GNP rose by 53.4% over the same period. Similarly, government borrowing increased dramatically and averaged 65% of total domestic credit in 1981–84. In total, ineffective counter-cyclical management characterized the onset of the economic crisis in Tanzania and deepened various imbalances in the national economy. By the early 1980s Tanzania was deep in economic crisis, which is reflected in the development of macro-economic indicators for that period. This trajectory had various implications in forests management including miombo.

Economic crisis in this period reflected very well to small-scale farmer's hardships. This necessitates changes in income sources, which reflected changes in priorities and activities in the rural areas, hence changes in the rural structure. They reflect a growing dependency on non-farm activities for livelihood. How this translated into dependence on forest resources such as miombo as sources of income in this period remained unclear.

In that period there was a rapid increase in production of staples which was accompanied with increase in their real producer prices while there was decline in both production and real producer prices of major export crops. Information on the extent to which increased production drew land from forested areas such as miombo woodlands is scarce and much localized in Tanzania. For example, in Iringa region, Abdallah (2006) revealed that annual miombo woodlands deforestation rate for the period 1959–1978 was 335.7 ha/year, while for 1978–1999 the deforestation rate was 56.9 ha/year. The higher deforestation rate in 1959–1978 period could be attributed to the increased agriculture/tobacco area (173.6 ha/year), structured by firewood utilization and shifting cultivation.

On the other hand Tanzania adopted the policy of villagization in 1967 as part of a national strategy for development. It was assumed to be the best means by which the welfare and standard of living of the majority of people in rural areas could be improved. Since the majority of the population lived in isolated homesteads, large-scale resettlement was recommended as the first step in the direction of modernization. This policy entailed, among other things, the resettlement of all households outside areas of dense settlements into villages. By 1975, it was estimated that over 75% of the national population was resident in such villages. Judging from the effects of the implementation of the villagization policy, it seems that major environmental implications of large-scale resettlements were not fully considered before the plan was carried out. The extent of deforestation resulting from implementing this policy during this period remains unclear. Also, some farmers who would have moved to new villages in the preceding period would still open new farms, probably by encroaching more forests and woodlands. Consequently, the poor location of new settlements on land of inferior quality led to a sharp decline in agricultural production in the years followed villagization. Moreover, villagization necessitated the intensification of land use, a practice unfamiliar to most of the people and unsuitable for fragile environments. The result has been the spread of serious cases of soil erosion and the rapid destruction of the natural vegetation.

However, given the difficulty economic climate prevailing in this period, the provision of social services declined dramatically. Accordingly the growth rates in government expenditure on education nationally and on per capital basis were respectively 0.3% and -2.8% in 1980–86. The corresponding statistics for health were -0.7 and -3.7 for the same period. These were also the same rate for the period 1972–79, indicating that perhaps the relative weight for various sectors in government priorities remained unchanged and were therefore not taking into account evolving socio-economic demands. Given the big and increasing deficit in successive government budgets and pressure on balance of payments, it is also likely that in real terms social services received less attention by the Government. This also indirectly increased rural households' reliance on non-farm activities. It is likely that such non-farm income sources included forests and miombo woodland resources.

It is during this period that localized fuelwood scarcity as well as incidences of land degradation due to grazing started to draw national attention. In order to arrest and/or contain such situations the government initiated some specific environmental conservation oriented projects like soil conservation, with acronym HADO and HASHI, initiated in 1973 to contain extensive soil erosion in the central part of the country. In addition, government's village forestry programmes which had been ongoing since 1967/68 gained momentum in the late 1970s. Some forest plantations were established to complement and possibly to substitute for wood supply from the miombo woodlands. However, village forestry programme proceeded very slowly. By 1989 only about 8,000 ha of forest plantations had been established by the government. Therefore the effort to arrest wood demands through afforestation continued to receive decline emphasis. In fact real government expenditure on afforestation declined by slightly more than 50% between 1975 and 1985. This constrained government efforts in complementing and/or substituting for wood supplies from the miombo woodlands using plantation wood.

Overall it would appear that the demand for land has still been driven by demands in agricultural production, villagization programme, habitation due to increased population and perhaps less so from rural infrastructure to support major social services like those of education and health. The extent to which rural communities depend forests such as miombo woodlands as sources of income in this period is unknown, as well as the pattern and degree of their probably deforestation.

3 Institutional Arrangements in Miombo Woodlands

Formal forest management and conservation in Tanzania dates back to the German period, following the realization of unsustainable and destructive forest utilization through uncontrolled harvesting and encroachment for agriculture. A move was followed by the gazettement of the first forest reserve in 1906. The British administration (1920–1961) pursued the forest protection policy initiated under the German rule by protecting more catchment forests as well as other forests bringing the total reserved areas to 13,369 km^2 (Ahlback 1986). After independence, efforts were made to re-survey and demarcate old reserves while few new ones were created and some degazetted. By 1996, Tanzania had about 540 forest reserves ranging from 3 ha to 870,000 ha in size and covering a total of 13 million ha of gazetted forest reserves.

MNRT (1998) estimated the total area covered by forests and woodlands to be about 33.5 million ha, making up about 38% of total land area in the country. Almost two-thirds of the forest and woodland areas are found on general lands. Besides the forest resources on general lands, which are under open access regimes and the central government forest reserves, other forms of forest-land tenure in Tanzania include local government and village forest reserves and private forests. These tenure systems are in line with the current land policy which divides lands into three tenure categories namely (i) General lands (lands removed from the domain of deemed rights of occupancy), (ii) Reserved lands (lands reserved principally for various conservation purposes) and (iii) Village lands (the rest of rural lands). However, despite the legal status of customary land rights, rural lands and particularly pastoral lands, primarily held through deemed rights of occupancy, have been highly susceptible to allocation by the state often against the will and interests of local communities. Today almost 30% of Tanzania's territory is in the protected areas. Before gazettement as protected areas, these lands and resources were customarily held and utilized by rural people. However, protected areas have became "landscapes of consumption" and not "landscapes of production".

Hence, despite protection efforts by the colonial governments and later the independent state government, forest depletion and degradation has been proceeding at an alarming rate in the country. Data on deforestation rate in Tanzania differs from different source e.g. 91,200 hectares of forests and woodlands are lost each year (FAO 2000). The National Forest Policy (1998) refers to a deforestation rate of between 130,000 ha to 500,000 ha per year. The situation is alarming and therefore there is need to investigate and adopt effective remedial strategies through sound forest management practices and good forest governance.

In Tanzania, the apparent main reasons behind forest depletion and degradation have been reported to include clearing for agriculture, overgrazing, commercial and domestic fuelwood production, mining, forest fires for various reasons (e.g. tsetse eradication, shifting cultivation and hunting) and harvesting industrial wood (Misana 1988a). Shifting cultivation may account for more than 50% of deforestation on Tanzania mainland. Charcoal making becomes the second contributing factor. Illegal harvesting and mining activities are also reported (Iddi 2002) to contribute to deforestation in Tanzania. However, several scholars (e.g. Vanclay 1993, Misana et al. 1996) have argued that not all causes behind forest depletion are real, others are simply apparent or symptoms, and hence, in order to tackle the problem of forest depletion and degradation a clear and deep understanding of the causes of deforestation is essential. For these scholars, the current deforestation problem is a complex socio-economic problem generated by the interaction of economic, social, political, historical and natural factors. Thus, the real causes of forest depletion and degradation, include among others poverty, overpopulation, inadequate agrarian policies, corruption and greed, ignorance and carelessness, undervaluation of natural forests, and open access into public forestlands (general lands). Adequate solution to forest depletion and degradation can only be achieved by addressing these real causes of deforestation.

Forest depletion and degradation has several impacts that affect people's livelihoods and their environment. Some of these impacts include erosion and loss of soil productivity; acute shortages of timber, fuelwood and other forest products and services; drying of water sources and shortage of water for various purposes; floods, sedimentation of rivers, reservoirs and irrigation systems; global warming, and species extinction due to habitat fragmentation and over-exploitation. In Tanzania, due to deforestation, many parts of the country have been experiencing serious soil erosion problem particularly in the central region where miombo woodlands dominate (Misana 1988b, Misana et al. 1996). Deforestation has also affected the potential of water catchment areas in terms of the quantity and quality of water they supply. Increased sedimentation of rivers and dams, river sands and frequent flash floods are reported in several parts of the country (e.g. recent floods in Mwanza, Shinyanga and Tabora where 60% of total forest is miombo woodlands). The resulting lack of water and poor quality of water have been, in many cases, associated with incidences of many water-borne diseases such as typhoid, diarrhoea and cholera. Addressing effectively the problem of forest depletion and degradation will mitigate/reduce or eliminate those hazards and improve rural livelihoods. This can be achieved through good miombo woodland governance and sound management practices.

Tree planting campaigns in Tanzania is done national wide. First day of January each year is set aside specifically for planting trees. There are also private initiatives and incentives for tree planting by small farmers such as free distribution of seedlings. However, these settings do not frequently take into account the opportunity costs of the land, land tenure problems, availability and accessibility of markets, and so on.

Therefore, although tree planting can be seen as a suitable rejoinder to fuelwood shortages, regrettably, too often the decision to pay out meager revenue, time and land for planting trees has been roughly an imprudent retort to most of the small-scale farmers, taken without contemplation of other alternatives and the consequences of existing market and policy failures (Ahlbäck 1995, Bakengesa 1997).

The current forest management move is to designate the main responsibility of forest management to local stakeholders i.e. the villagers and village governments. A forest component, with a programmatic approach, was approved in December 2002 for a five-year period. The programme, called Participatory Forest Management (PFM) is contributing to a comprehensive reform of Tanzania's forest administration and management, which places new emphasis on participatory management systems of natural and other forests. In Tanzania, PFM has become the most important approach within the forestry sector following its inclusion in the National Forest Policy in 1998 and the Forest Act of 2002 and Land Act of 1999.

The move towards PFM has been derived from two factors: firstly, recognition that neither central government nor local governments have the human and material capacity to manage the nation's forest resources in a sustainable way without the support of poor communities living close to the forest. Secondly, there has been a political will to decentralize government functions to the lowest levels of government. The PFM attempts to secure and improve the livelihoods of local people dependent on forest resources. Hobley (1996) observed that livelihood enhancement is by involving all key stakeholders in the process of forest management, understanding their needs and situations, allowing them to influence decisions and receive benefits and increasing transparency and consequently curb the current high deforestation rate.

4 Collaborative Forest Management: a Paradigm Take-Over of Management of Miombo Woodlands in Tanzania

Early attempt to solve environmental problems without local people involvement have achieved very little success. Today the role community in the management of natural resources has become a key component in development programs (Kajembe and Mgoo 1999). Since 1998 the Government has changed forest policy from central government oriented to participatory management were communities around were given mandate to manage the forests on behalf or under joint management. Various Community Based Forest Management models (CBFM) been established with success such as Duru-haitemba (CBFM), Urumwa (CBFM) in Tabora, Mgori Joint Forest Management (JFM) in Singida. However, under JFM and CBFM the legal ownership of land remains with the Government. Village committees are co-managers of the forest and are entitled to shares in forest products. Forest protection committees control access to the forests and manage them. These local community institutions are said to proving more effective than State Forest Departments in managing the forest. Regenerating forests now provide more medicinal, fibre, fodder, and dry fuelwood and food products for rural people, whose livelihoods are thereby improved. For example, Abdallah and Sauer (2007) compared species diversity of three forest management regimes: forests under general land, community based management in Iringa region. The study revealed that most of the species were observed in forests with lowest Shannon-Weaver Index (1.5) (see also Table 1) and with uneven relative abundances (general land forests and family forests). However, the forests under family and general lands revealed the lowest volume and basal area (11.1 m^3/ha and 2.5 m^2/ha respectively) compared to forests under community based management (20.0 m^3/ha and 4.3 m^2/ha respectively).

Further economic efficiency of small-scale farmers where correletated with species diversity of places where forest management regimes where they collect firedwood for tobacco curing. The correlation coefficients indicate that a higher economic efficiency of small-scale tobacco production is associated with higher species diversity in the surrounding forest area. Since species diversity is not a direct input for tobacco production, however, it could be suggested that a more efficient use of firewood (energy saving) for tobacco curing as well as a more efficient use of land would lower the rate of biodiversity loss. In other words, reducing shift cultivation/forest clearing for new tobacco plots could reduce the rate of change of miombo woodlands to other land use.

The coefficients further indicate that CBFM has a positive impact on the species diversity of the respective forest resources. Hence community based institutional arrangements significantly would contribute to the conservation of the forests in Tanzania. This indicates the need for replication of such arrangements to other types of forest management such as those in general lands and families. This supports the view of PFM and decentralization of forest management in the country i.e. continue to transfer the control over the woodland resources to the community level because local communities are successful in curbing free-riding behaviour and in sustainably managing the resource (Dewees 1994, Ruttan 1998, Ostrom 1999, Trawick 2001, Milinski and Semmann 2002). Since forests with lower diversity indices occur in the general lands (non gazetted), which lack proper management, and harvesting is done without close supervision due to absence of or weak property rights, households producing tobacco at the expense of these forests could lead to inefficient scores. This is because forests under general lands rarely motivate conservation efforts. According to Ostrom (1999) general lands forests do not have property right, appropriators gain property rights only to what they harvest. However, the appropriators usually make no effort to conserve the resource. Frequently, the appropriators act independently and do not communicate or coordinate their activities in any way, hence these predict over-harvesting.

However, both CBFM and JFM in Tanzania are still in experimental stage. Although efforts for scaling-up JFM and CBFM in Tanzania are underway, but private sectors, donors and government efforts to provide benefits on an equivalent scale from non-forest sources and an essential supplement to agriculture are naïve. Therefore chances for poverty reduction and forest conservation reconciliation are rare.

Table 1. Forests and institutional arrangements.

Village	Forest name	Management regime	Area (ha)	Use	H'
Kiwere	Kidundakyave Village Forest Reserve	CBFM	1 985	Two zones: 1) zone of utilization (firewood for tobacco and home use, charcoal, timber, etc.) 2) protection zone.	3.4
Itagutwa	Total of 63 family based forests	Family management	699	406 ha used for cultivation (10% of this is used for tobacco production, the remaining is used for maize, sunflower, pigeon peas, beans etc.) 288 ha are reserved.	1.7
Kitapilimwa	Total of 17 family forests	General forest	436	121 ha are used for cultivation (25% of this is used for tobacco production, the remaining is used for maize, sunflower, pigeon peas, beans etc.) 776 ha are reserved.	1.5
Mfyome	Mfyome Village Forest Reserve	CBFM	2456	Two zones: 1) zone of utilization (firewood for tobacco and home use, charcoal, timber, etc.) 2. Reserved zone.	2.4
Mgera	A total of 30 family forests	Family management	1781	81 ha are used for cultivation (10% of this is used for tobacco production, the remaining is for maize, sunflower, pigeon peas, beans etc.) 1 700 ha are not under utilization.	1.5

n.a. = no forest inventory as the forests are not under utilization, H′= Species Diversity Index
Source: Abdallah and Sauer (2007)

5 Participatory Forest Management Constraint

While many villages are participating in PFM across the country, relatively few have formalized their forest management in line with the Forest Act of 2002. This requires that villagers have an approved management plan or signed Joint Management Agreement for their forest land. The introduction of PFM is currently hampered by the cost and time taken to transfer management right to non-government stakeholders and currently only 1% of the total forest reserve area is under this form of management. For example, it is estimated that a single PFM may even take up to 4 years to realize, and cost between US$50,000 – 100,000 to implement, depending on the size and the location of the forest. Clearly more work is needed to improve the economic efficiency of the PFM process and to streamline the actual implementation process.

FBD (2006) revealed that revenues reported from areas under JFM, particularly in catchment forests, remain particularly low. One important source of revenue from village forest management is fines levied by the village council on those found undertaking unauthorized activities in the forest. However, as law enforcement efforts by local communities increase and as illegal activities drop, revenue from fines decreases. This sometimes acts as a disincentive to local forest management as fines often represents one of the only sources of revenue to local communities from catchment forests.

The accelerated retrenchment during the 1990s, often to comply with structural adjustment policies, occurred together with the realization that centrist management strategies need reformulation. Erosion of the legitimacy of local institutions is one of the PFM constraints. Local institutions have no real authority to decide on the management of forest resources. Another challenge is with regard to the stratified communities. Interests of some actors are represented only inadequately. Lack of political will at the centre to give powers to communities and grassroots organizations is also a challenge to CBFM initiatives. It is also important that benefits must be significant if the community is to go to the trouble of establishing and enforcing the rules about resource use. This begs the question on whether community based forest management programmes/projects have sufficient value to stimulate community participation. This remains a puzzle! Rural communities are undergoing rapid social, economic, and political change, as the development and modernization process spreads and deepens. Even if effective and viable user groups exist or can be put in place today, will they survive and persist in the face of modernization pressures? Much more need to be known about the institutional context in which users now find themselves and the type of support that will increase the probability of sustainable management of our forest resources (Kajembe et al. 2000).

In some PFM projects often the interests of women are forgotten. In addition to this, conversion of general lands into JFM or CBFM restricts access to land and other natural resources by women (Rani Undated). Realities that could work against CBFM or JFM include, among others, difficulty in recognizing the most appropriate community members for programme participation, e.g. men or women (Little 1994). Women are often excluded from community organizations or committees that manage natural resources, even when the projects are intended to benefit them (IFAD Undated).

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Tanzania's Forest Policy and Its Practical Achievements with Respect to Community Based Forest Management in MITMIOMBO

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Implementation of the Forest Policy of 1998 and Forest Act of 2002 resulted in decreased illegal harvesting of forest resources, encroachment, fire incidences and unregulated activities such as charcoal burning and timber harvesting. The implementation also improved livelihood of communities living near the forests and biodiversity i.e. increased stocking and number of species both flora and fauna. It further improved management of forests (forests under Participatory Forest Management, PFM, are managed following management plans) Moreover the implementation increased area of forest reserves by 2 047 824 hectares, increased household income through initiated income-generating activities, which diversified the economy thus reducing poverty. More important is that the implementation resulted into increased awareness on PFM, which resulted into positive attitude of communities towards PFM. This strategy should be scaled up due to its success in the 25 districts. However, during the implementation some problems were encountered. These include delays in assisting communities to prepare management plans of their village land forest reserves and in signing of management plans and lack of enough forest staff to assist communities to implement PFM, lack of enough equipment and solid integration of PFM with the local governments' plans to ensure its sustainability. It is important that solutions to the encountered problems be work out by all stakeholders.

1 Introduction

In Tanzania, forests have historically been managed centrally through Forest and Beekeeping Division (FBD) under the Ministry of Natural Resources and Tourism (MNRT). This type of management was characterized by extensive state control without involvement of local community. The system have interfered too much on the local scene and undermined the traditional institutions, hence prevented them from playing their role in regulating resource use (Maganga 1993).

The main problem with centrally managed forests was that resources were thinly spread to the extent that the management of the resource was difficult. This kind of forest management has resulted into forest degradation and deforestation through illegal activities and increased human pressure on the resources (MNRT 1998a, Wily and Dewees 2001). Deforestation resulted into decrease of area under forest cover. For example before independence, the forest cover was more than 50%, which gradually decreased to 45% in late 1970s, to about 41% in mid 1990s and to about 36% in late 1990s (Luoga et al. 2000).

Currently, the forest sector in Tanzania administratively operates under three parallel structures, Forestry and Beekeeping division under the Ministry of Natural Resources and Tourism, the Regional Secretariat which is foreseer of all natural resources in the region, and Local Government Authority which predominantly owned and managed the local government forest reserves (MNRT 1998a).

The sector contributes 92% of fuel energy, protects watersheds for power generation, serve as source of water for irrigation, conserve soil and add nutrients to the soils for agricultural production (URT 2001, MNRT 1998a). Furthermore, forestry sub sector's contribution to the Gross Domestic Product (GDP) is 2–3.4% per annum (URT 2001). For example the foreign exchange earnings from forestry sector in year 2000 was USD 6.9 million derived from sales of various forest and beekeeping products which was an increase of 32.7% compared to year 1999.

Following the Forest Policy of 1998, the government of Tanzania, in pursuit of the dual objectives of arresting forest degradation and furthering development, officially supported devolution of ownership and management responsibilities over some forest resources to local communities under Participatory Forest Management (PFM) approaches (MNRT 1998b, Wily and Dewees 2001).

2 Forest Policy, Legal and Institution Framework

2.1 Forest Policy 1998

The overall goal of the Forest Policy of 1998 is to enhance the contribution of the forest sector to sustainable development of Tanzania and conservation and management of her natural resources for the benefit of present and future generations. In practice this means that forests have to be managed in terms of socio-economic, ecological and cultural sustainability or, in other words, in accordance with principles of multi-functionality and equitable benefits and responsibility sharing.

The Forest Policy of 1998 contains two important statements in support of PFM. The two statements are:

Policy statement number 5
To enable sustainable management of forests on public lands, clear ownership for all forests and trees on those lands will be defined. The allocation of forests and their management responsibility to villages, private individuals or to the government will be promoted. Central, local and village governments may demarcate and establish forests reserves.

Policy statement number 39
Local communities will be encouraged to participate in forestry activities. Clearly defined forestland and tree tenure rights will be instituted for local communities, including both men and women.
The Forest Policy also recognizes the role of the private sector in management of forest resources. In this new policy, the responsibility of managing forest resources will be left in the hands of specialized agencies and the private sector, the central government responsibility will be the manage-

ment of forest reserves of national strategic importance. Emphasis has been given to joint forest management between the central government, specialized executive agencies, the private sector or the local government (MNRT 1998b).

Implementation of PFM will not only involve the National Forest Policy of 1998, but also the Local Government Reform (1998), Gender Policy of 2001 and the Land Policy of 1995. Other important policies considered in the implementation of PFM including the Beekeeping Policy of 1998, Fisheries Policy of 1997, Mineral Policy of 1998, Agriculture Policy of 1997, Wildlife Policy of 1998 and Water Policy of 2002.

2.2 Legal and Institutional Framework

Legal framework in support of PFM in Tanzania is revealed in the Forest Act No. 14 of 2002, Land and Village Land Acts of 1999, the Local Government Laws (Miscellaneous Amendments Act No. 6 of 1999) and the Poverty Reduction Strategy Paper (PRSP) of 2000 and National Strategy for Growth and Reduction of Poverty of 2004. Apart from Forest and Land Acts, implementation of PFM will be influenced by a number of legislation and laws from relevant sectors such as Wildlife Act, Beekeeping Act, Fisheries Act and legislations in agricultural sector (MNRT 2002). The Forest Act No. 14 of 2002 supports PFM as it categorizes national, local authority, village and private forestland and makes full provision for actors in each of these categories to declare forest reserves.

According to MNRT (2002), at the central government level, FBD has taken keen interest in PFM strategies and has developed among others the guidelines for Community Based Forest Management (CBFM). FBD is not responsible for implementing PFM activities. District councils have critical role to play in facilitating planning and implementation of forest management activities including PFM. Districts provide technical assistance and capacity building for implementing PFM activities on the ground. Through local government reform programme, district councils will be able to increase their capability to support PFM activities. Villages are the lowest level of the governance system. Village Governments perform executive and legislative powers together with other responsibilities and duties, including forest management (MNRT 2002).

3 Forest Resource Degradation

Forest degradation can be defined as impoverishment of standing woody material mainly caused by human activities such as over-grazing, over-exploitation (for woodfuel in particular), repeated fires, or due to attacks by insects, diseases, plant parasites or other natural causes such as cyclones. Very often degradation does not show up so much in decrease of woody vegetation but rather as a gradual reduction in biomass, changes in species composition and soil degradation (Milledge and Kaale 2003).

Tanzania is among the countries in the world experiencing high deforestation rates ranging from 130 000 ha to 500 000 ha per annum (MNRT 2001c). The high deforestation rate is ascribed to both direct and underlying or indirect factors. The direct agents of deforestation are: settlement and agricultural expansion, commercial charcoal and fuel wood production, overgrazing, uncontrolled fires, shifting cultivation and illegal logging (Kaoneka 1990, MNRT 2001c).

The indirect or underlying causes of deforestation are rapid and uncontrolled population growth, poverty, market failures, absence of proper definition of property rights and security of tenure and general policy failures (Kaoneka 1990). The major environmental issues in Tanzania related to forestry include uncontrolled deforestation, weak concession and revenue collection systems, lack of unclear cost and benefit sharing system, inadequate involvement of local communities, lack of sufficient staff and information on forest resources, inefficient utilization of resources and a preference for a narrow range of forest plant species in terms of utilization. As such, the forest institutions in Tanzania are faced with the challenge of managing forests in a way that is sustainable and supportive to rural livelihoods.

Moreover, for a long time the protection of forests in Tanzania has traditionally been implemented by restriction based on the pricing policy (Mariki 2001). This did not work due to the so-called market failures. First the prices were too low to cover even the management costs. Second the prices did not apply to non-market forest products. Third the prices did not cost out the replacement cost and environmental management. Therefore the price was not a rational parameter to regulate the utilization of forest resources.

4 Sustainable Forest Management and People's Livelihood

Sustainable Forest Management (SFM) may be defined as management to maintain and enhance the long-term health of the forest ecosystems while providing ecological, economic, social and cultural opportunities for the benefit of the present and future generations (FAO 1999). In other words it is the stewardship and use of forests and forest land in such a way and rate, that maintains biodiversity, productivity, regeneration capacity, vitality and potential to fulfill, now and in the future, relevant ecological, economic and social functions, and that does not impact negatively on other ecosystems (Davis and Johnson 1987).

In short, sustainable forest management should balance the needs of people and communities with the ecological values. The concept of sustainable forest management includes an environmental dimension that aims at perpetual maintenance of the resources: an economic dimension that involves people in decision-making process concerning forest management and the distribution of forest benefits.

Livelihoods connote the activities, entitlements and assets by which people make a living. Assets in this particular context are defined as not only natural/biological (land, water, common property resource, flora and fauna) but also social (community, family social networks), economic (job, savings, credit), political (participation, empowerment), human (education, labour, health, nutrition) and physical (road, markets, clinics, schools, bridges) (Chambers 1987, Carney 1998). The access to use and interaction among these assets serves as the foundation of a livelihood system. General contributions to overall household well being as well as distinct and heterogeneous adaptive and coping strategies that are pursued at an intra household level also form a livelihood system. A last component of the livelihood equation is sustainability issue. A livelihood is sustainable if it can cope with, recover from and adapt to stresses and shocks, maintain and enhance its capabilities and assets, and enhance opportunities for the next generation (Roe 1998).

5 Forest with Respect to Poverty Reduction

Forest resources contribute directly to livelihoods and can complement other key components of poverty reduction (e.g. food production, education and primary health care). The challenge is to support specific changes that will lead to a greater role for forest and tree resources in the livelihoods of the poor. Forests and trees can provide commercial opportunities and employment for the poor. In addition, they are often central to the development of good local governance (MNRT 2001b). A people-centred approach can increase the impact of forests and trees in reducing poverty. According to FAO (2000) benefits to local livelihoods from people-centred forestry include:

- Rights to access, control and use of forest and tree resources
- More say in decisions over use and management of forest resources
- Reduced vulnerability, not only through secure forest resources but also political empowerment
- Income from forest goods and services
- Improved governance through more effective local institutions
- Partnership to enhance capacities
- Direct benefits from environmental services.

6 Participatory Forest Management (PFM in Tanzania)

PFM refers to processes and mechanisms that enable people who have a direct stake in forest resources to be part of decision-making in all aspects of forest management, from managing resources to formulating and implementing institutional frameworks (DANIDA 2002). It is based on set of rights and privileges recognized by the government and widely accepted by resource users and characterized by sharing power instead of just benefits and assuming owner/user rights of forests (URT 2003).

PFM is a strategy to achieve sustainable forest management by encouraging the management or co-management of forest and woodland resources by the communities living closest to the resources, supported by a range of other stakeholders drawn from local government, civil society and the private sector. It may be developed in unreserved forests in the village or general land or national forest reserves or forest reserves owned by local authorities at district level. It may apply to forests that are either rich or poor in biodiversity, intact or degraded, large or small, moist montane or dry woodlands or mangrove forests or even commercial plantations.

Objective of PFM regime may be protection or production or combination of the two. Its focus is improved rural livelihood and reduced poverty. Operationally, it is comprised of CBFM and Joint Forest Management (JFM) (DANIDA 2002). In CBFM a village, or a group or private forest reserve is declared and ultimately gazetted by villagers or a group or private people. Other frameworks covered in the PFM approach include the JFM where local communities or Non-Governmental Organizations (NGOs) are involved in the management and conservation of government forest reserves. These forests are managed with appropriate user rights and incentives (MNRT 1998b).

PFM approaches are well linked to other macro-economic policies of addressing poverty reduction. For example, recent efforts to tackle poverty are quite pragmatic but have still to be pursued under relatively decentralized policy initiatives. These include the Tanzania Development Vision 2025 which is a principal vision of the country to alleviate the widespread poverty by improving socio-economic opportunities, ensuring good governance, transparency, improved and redefined public sector performance, with emphasize on appropriate balance between public and private institutions by year 2025. The National Poverty Reduction Strategy Papers (PRSP) of 2000 and 2004 are other medium-term strategy for poverty reduction. Another initiative is the Tanzania Assistance Strategy (TAS) which is a medium-term national strategy encompassing joint efforts of government and the international community in improving the living standard of Tanzanians (URT 2000).

The country, like several other African states, has suffered from inefficient governance. The above mentioned recent policy approaches in Tanzania try to address these problems of weak governance by emphasizing a shift towards decentralization and devolution of government power to district and local government levels. Such devolution of power is expected to have positive effects on more effective and sustainable management of natural resources at district and local community level.

It is widely agreed that PFM may benefit Tanzania by arresting forest degradation and supporting the development and empowerment of rural communities (MNRT 2001b, Wily 2000, Petersen and Sandhovel 2001, Wily and Dewees 2001).

It has been recognized that the government alone is not able to protect and manage forest resources sustainably. Community involvement in forest management through PFM as well as clarification of ownership and user rights is seen as a possible solution (MNRT 2002).

PFM denotes the devolving of the entire management responsibility of forest resources to local communities by CBFM. It also denotes a joint agreement between concerned parties to manage national and local government forest reserves with adjacent communities by JFM.

The government support PFM activities in various areas of the country through various donor agencies. These donor agencies include DANIDA, NORAD, FINIDA and World Bank. Nevertheless, flourishing implementations and scaling up of PFM is delayed by limited capability among both practitioners as well as decision-makers. Ngaga et al. (2003) reported that the capacity of local governments to implement the Forest Policy of 1998 and the Forest Act of 2002 is very low both in terms of human and financial resources. There is thus an insistent prerequisite to address issues pertaining to capacity building at ministerial, district and village levels.

7 Districts and Villages Practicing CBFM in the Country

In Tanzania there are about twenty regions and about 1082 villages implementing CBFM on 2,05 million hectares of forestland (MNRT 2006). Table 1 presents regions, number of districts and villages and areas of forest reserves under CBFM. Table 2 gives an overview of CBFM in mainland Tanzania. There is a national programme to support PFM in all rural districts and the Government has issued formal guidelines for assisting communities to bring either reserved or currently unreserved forests under community based management (MNRT 2001a).

Table 1. Regions, number of districts and villages and areas of forest reserves under CBFM in mainland Tanzania. VLFR = Village Land Forest Reserves.

Regions	Number of Districts	No. of Villages	No. of VLFR	Gazetted VLFR	Total Area (ha)
Tanga	4	94	22	1	12 391
Morogoro	3	38	2	0	173 431
Iringa	6	101	60	29	162 039
Mbeya	3	37	0	0	44 700
Lindi	4	31	7	0	284 7826
Tabora	3	22	22	0	111 925
Kigoma	3	32	9	0	22 530
Kilimanjaro	1	53	3	0	553
Mwanza	1	101	14	0	17730
Shinyanga	3	345	45	0	401 122
Mara	2	45	37	0	4 887
Manyara	2	55	28	0	209 494
Arusha	1	9	2	0	2 150
Pwani	6	30	15	3	50 872
Kagera	1	15	8	0	15 450
Ruvuma	0	0	0	0	0
Mtwara	1	25	9	0	73 121
Dodoma	2	2	12	0	24 421
Singida	1	35	4	0	376 400
Rukwa	1	14	14	0	59 882
Total	34	560	96	33	2 047 824

Table 2. Overview of Community Based Forest Management in Mainland Tanzania.

Number of villages with CBFM established or in process	1 082
Area of forest covered by CBFM arrangements	2 047 824 hectares
Number of declared Village Land Forest Reserves	313
Number of gazetted Village LAnf Forest Reserves	33
Number of districts where CBFM is implemented	48
Primary forest types where CBFM has been promoted	Miombo, coastal and acacia woodlands
Percentage of forest classified as unreserved in 1991 that is now covered with CBFM arrangement	10%
Percentage of villages engaged in CBFM activities	10.3%

8 Benefits of PFM

Implementation of PFM in some districts of Tanzania has resulted into the following benefits:

- Decreased illegal harvesting of forest resources
- Decreased encroachment
- Decreased fire incidences
- Decreased unregulated activities such as charcoal burning and timber harvesting

- Improved biodiversity
- Increased number of species both flora and fauna
- Increased stocking
- Improvement of livelihood of communities
- Increased area of forest reserves by 2.05 million hectares
- Increased game numbers
- Improved management of forests (Forests under PFM are managed following management plans)
- Improved water flow from water sources or streams
- Increased household income through initiated income-generating activities. which diversified the economy thus reducing poverty
- Increased awareness on PFM. which resulted into positive attitude of communities towards PFM.

9 Problems of PFM

The following are some problems encountered in the implementation of PFM:

- Delays in assisting communities to prepare management plans of their Village land forest reserves
- Delays in signing of management plans
- Relative low revenues especially from catchment forests
- Lack of enough forest staff to assist communities to implement PFM
- Lack of enough equipment
- Lack of solid integration of CBFM with the Local Governments' plans to ensure sustainability.

10 Conclusions

Experience of few years indicates that CBFM is an important strategy for the management of forests in Tanzania. In many districts implementation of CBFM is a success story. However, there are some problems encountered during implementation. Stakeholders should find solutions to the problems encountered. The benefits of CBFM outweigh the encountered problems. Therefore the strategy should be scaled up to include all districts in the country with a prerequisite to build capacity at ministerial, district and village levels.

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General ecological features of miombo woodlands and considerations for utilization and 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. Dry season fire is the other main determinant for succession of vegetation and soils in a stand-age time perspective. Soils, again, has a wide range in mineral properties, but the organic content is typically low with low nitrogen availability as a result of the frequent fires. Major environmental considerations for the use of miombo include the management of soil quality, water quantity & quality, fire, biodiversity and structural and functional changes induced by climate change. Organic matter, water and fire is discussed in general and as affect of moimbo forest management. In general it is 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.

1 Background

The understanding and wise management of miombo woodlands is crucial to a large part of Africa. It gives the livelihood to millions and is a distinct and unique biome. This review aims to give a basic description of miombo ecology and input to a scientifically based discussion on future uses and management of these complex woodlands and how to make more research to enlighten this discussion.

2 Defining Miombo

Miombo woodland is a significant biome covering about 10% of the African landmass (ca 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 is the dominant forest component of Angola, Zambia, Tanzania, Malawi, Mozambique and Zimbabwe (Fig. 1). 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 et al. (1986)

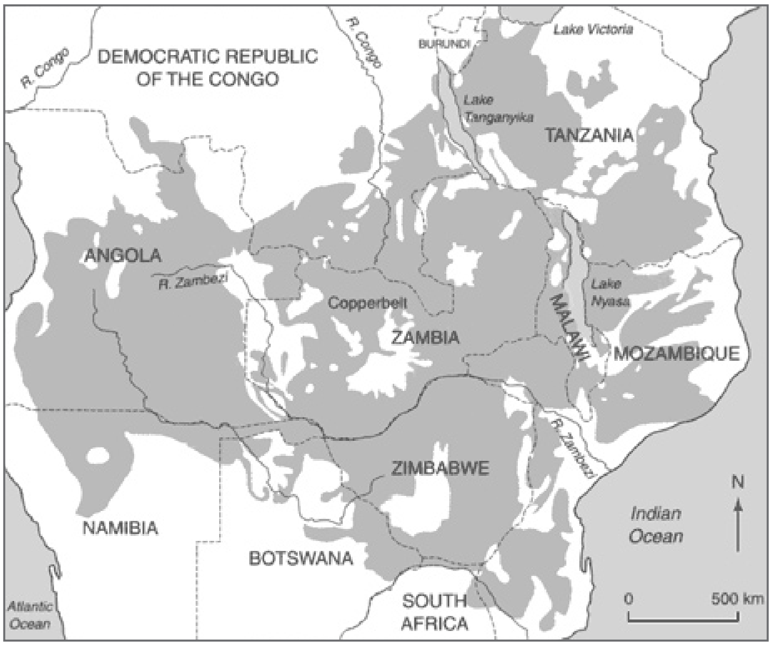


Figure 1. Distribution of miombo woodlands.

gave a useful definition; ”Those tropical and some near tropical ecosystems characterised by continuous herbaceous cover consisting mostly of heliophilous C4 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 eco-zones have for long time had 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).

3 Edaphic Determinants

3.1 Climate

Climate semi-aridity is the main edaphic determinant. Rain input is typically unimodally distributed (Fig. 2). However, high ranges (annual rainfall 55–1200 mm; length of dry season 3–7 months; mean annual temperature range 15–25 ºC, Frost 1996) give way to division of 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.

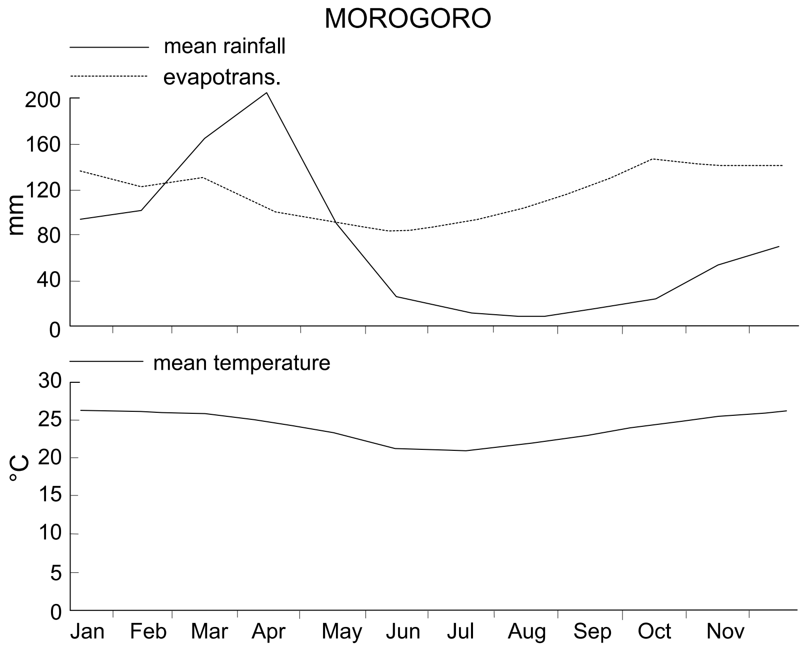


Figure 2. Typical intermediate miombo monthly rainfall, potential evapotranspiration and temperature with unimodal rainfall distribution (Morogoro, Tanzania, source FAO 1984).

3.2 Geology and Soils

Apart from sections of inselbergs or enscarpments 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 (Table 1, 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)

Table 1. Typical miombo top soil chemical properties and nitrogen contents of senescent leaves of N-fixing and non N-fixing miombo trees. After Frost (1996).

Top soil contents	mean	range
CEC me 100g-1	7.6	1.8–25.1
Tot. exch. bases me 100g-1	4.7	0.3–20.8
Base sat. %	57.6	3–100
Exch. Ca %	2.7	0–15
Exch. K %	0.3	0–2.3
Extract P ppm	13.4	0–54
Carbon %	1.4	0.3–3.8
Nitrogen %	0.10	0.02–0.62
pH (H2O)	5.6	4.2–6.9
Senescent leaves		
Non N fix N %		0.6–1.8
N fix. N %		1.9–4.7

Top soil organic content is typically low (Frost 1996; Walker and Desanker 2004). Nitrogen availability is low as a result of the frequent fires and relatively slow decomposition from high acidity (Table 1).

3.3 Root Symbiosis

The strong dominance by *Caesalpinioideae* in miombo has not been fully understood, but a 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).

3.4 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 has probably been part of fire impact for millennia (Clark and van Zinderen Bakker 1964). 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).

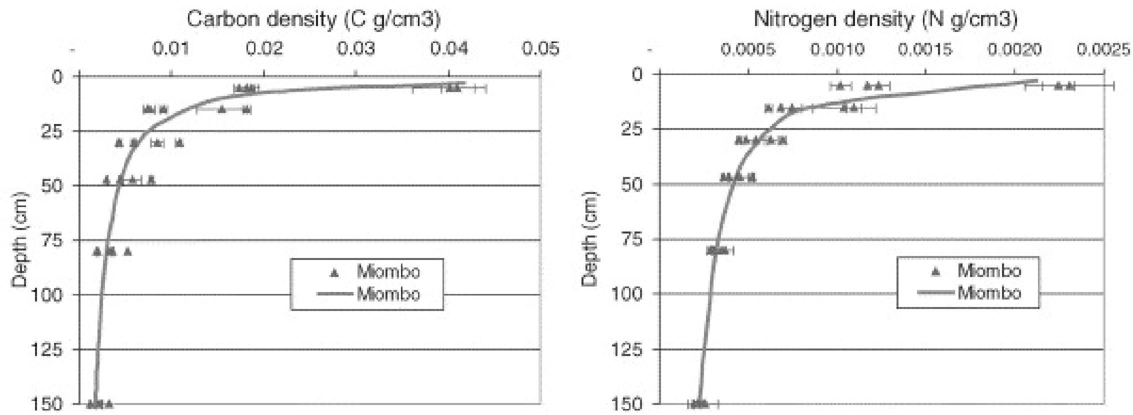
4 Environmental considerations for use and management

4.1 Soil and Fertility Management

Management of organic material in soils is crucial for 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. 3). In the nutrient poor miombo soils top soil nutrient contents correlate closely with the soil organic matter contents (Fig. 3).

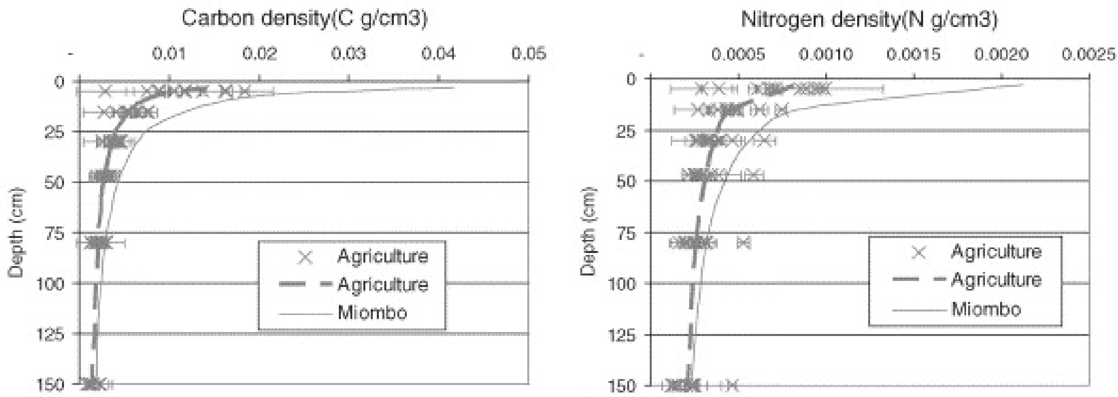
Soil organic matter also determines top soil physical properties. The soil structure determines water infiltrability and thereby to a large extent the fate of potential surface runoff, erosion and groundwater recharge/dry season streamflow (Bruijnzeel 1990, Malmer et al. 2005).

Soil organic matter management includes limiting biomass removal by grazing and harvest and/or bringing back organic matter in various forms as well as ensuring continued site biomass production by cultivation or by effective secondary succession (Malmer et al. 2005, Chidumayo and Kwibisa 2003).



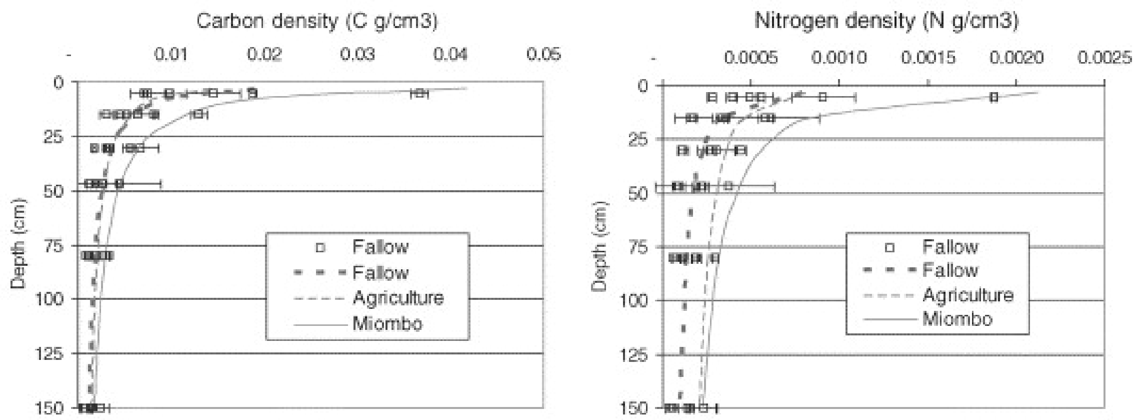
Miombo
log C density = -0.995+(-0.807*log cm) R^2= 0.83

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 3. Land use type regression of carbon and nitrogen density with depth (Bars denote SE, after Walker and Desanker, 2004)).

4.2 Water Quality and Quantity

Projected water demand and supply for Africa is problematic (Fig. 4). The role of forests for groundwater recharge is under long term scientific and policy debate (Bruijnzeel 2004). Tree based land use and reforestation improves soil quality, importantly infiltrability (cf. above), but good data for various tropical ecosystems is lacking (Ilstedt et al. in press). On the other hand regenerating forest is highly water demanding. Especially fast growing tree plantations of exotic tree species have been pointed out (Fig. 5). Recently it has also been confirmed that also indigenous first succession species are also highly water demanding (Fetene and Beck 2004). Under these circumstances expected increased groundwater recharge and stream dry season flows may be missing due to increased water use. In contrast to most modern tree plantations, or large tracts of secondary regrowth, natural mosaics of old growth forest and patches of regeneration probably in a suitable way distribute the high water demand over the landscape in a less dramatic way.

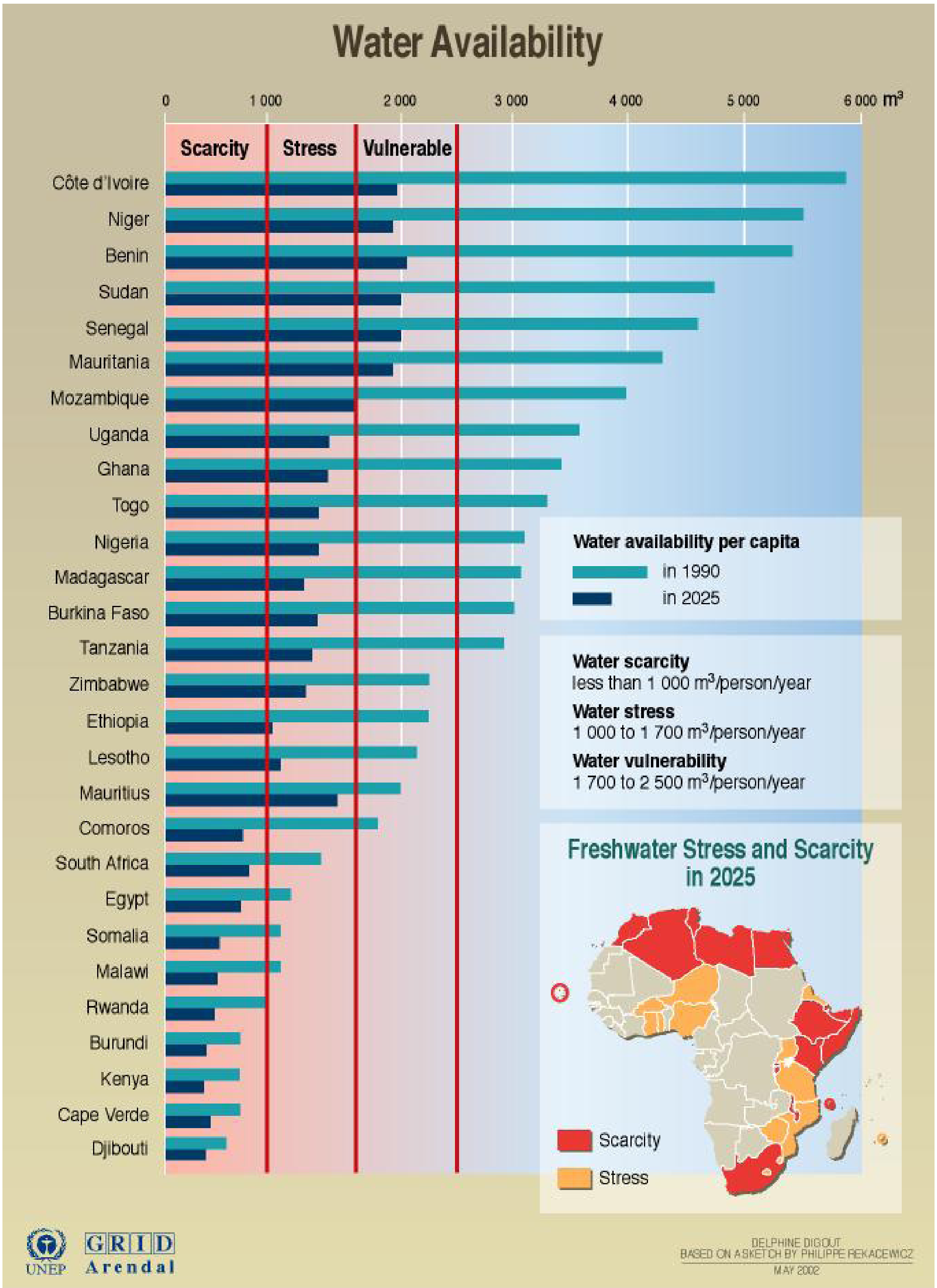
Studies of water use by miombo woodland is virtually non existent. Studies of soil physical properties as well as water use of complex miombo stands would be desirable both for the understanding of this important biome as well as for the understanding of modern, tropical and complex landscapes with various land use.

4.3 Fire Management

Typical Miombo fires are mostly swift and instrumental in forming regeneration and structural patterns. However, late dry season fire and fire in stands protected from fire (with higher fuel load) may be problematic for soil quality development and mature trees. All around the tropics increasing fires promotes fire climax successions and soil deterioration (Malmer et al. 2005, Chidumayo and Kwibisa 2003). This has fostered a general negative policy formation against the use of fire. Among the negative side of fire use is the losses of carbon and nitrogen to the atmosphere, reduced soil protection after fire, effects on water and air quality and successively deteriorating soil structure and fertility with repeated fire. However, in dry season ecosystems, controlled early dry season fires reduces the risk of devastating fires when biomass is allowed to accumulate for longer times (Fig. 6). Fire also releases nutrients tied up in less decomposable organic matter and prepares soil for seed germination. Many tree species seeds are dependant on fire for germination. In a long term perspective of management of complex miombo stands, fire will have to be handled by prescribed fire or by fire prevention or possibly by the combination of both. However, applied research and trials are urgently needed.

5 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.



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

Figure 4. Predicted water availability in African countries.

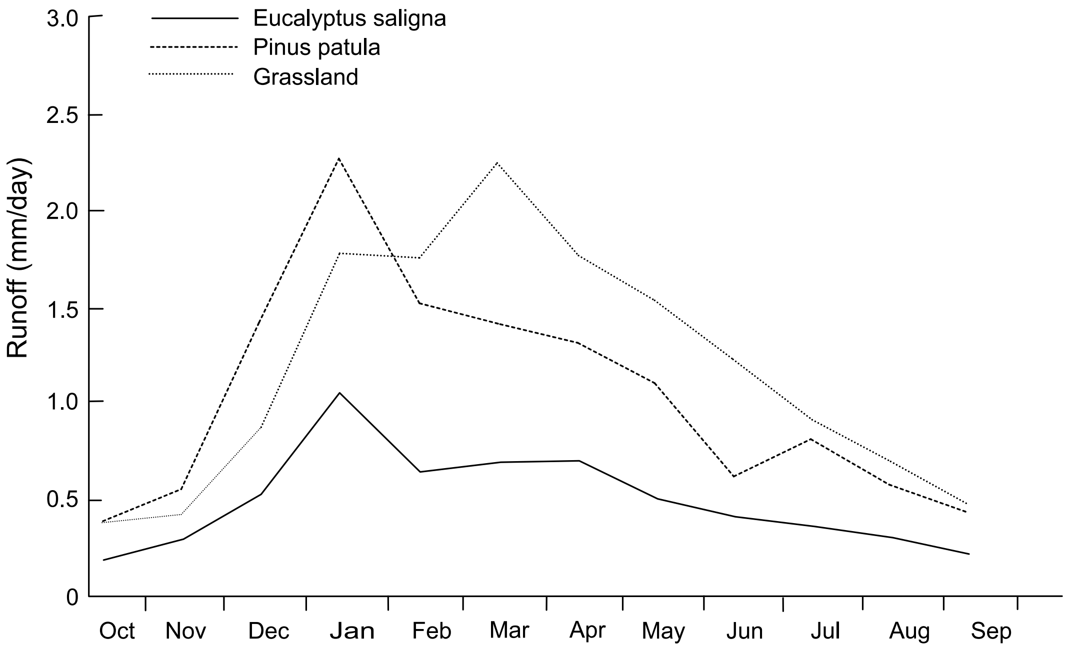


Figure 5. Lower monthly mean daily runoff by eucalypt plantation compared to pine plantation and grassland in Sao Hill, Tanzania 1981 – 1989 (Mhando, 1991)

Figure 6. High biomass accumulation in fire protected plot in dry forest woodland in central Burkina Faso.

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Stand Structure and Tree Species Composition of Tanzania Miombo Woodlands: A Case Study from Miombo Woodlands of Community Based Forest Management in Iringa District

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Species structure and composition of miombo woodland is presented. Forty permanent sample plots were established in forests practicing Community Based Forest Management at Nyangoro, Kitonga and Udekwa Village Forest Reserves in 2002 and remeasured in 2005/06. Two blocks of 0.24 ha were established at Nyangoro and Udekwa and one block of 0.64 ha at Udekwa. The blocks were divided into 20 m x 20 m plots. All trees of greater than 4.5 cm (in 20 m x 20 m plots) in diameter at breast height (dbh) were remeasured for dbh, crown radius (Cr) (four direction at right angles to each other), height to the living branch (Hc) and total height (HC). In 10m x 10m saplings were measured for dbh and Ht while seedlings were measured only for Ht in (5 m x 5 m). The data was analysed for structure (diameter distribution, basal area, crown radius and biodiversity indices) and for species composition (number of species, species relative frequency, density, dominance and importance value index). Structure described by diameter distribution was inverse J-shaped. Inverse J-shape can be used to monitor and assess sustainability. Diameter distribution being inverse J-shaped, Weibull, Johnson B and Beta function can be used to model it. The basal area of stands at three sites ranged from 15.0–15.6 m^2/ha while volume ranged from 63.6–65.7 m^3/ha. The best equation for predicting crown radius which in turn can be used to estimate canopy cover was: $Cr = 1.48 + 0.103\ dbh + 0.326\ Ht^2 + 0.227 Hc^2$. The crown radius equation constructed can be used to estimate canopy cover at three sites. Species diversity index and Shannon Weiner's index were higher at Udekwa Village Forest Reserve than at the other village Forest Reserves indicating that Forest Reserves of Udekwa had stable structure. For year 2002 there were 43, 57 and 60 species at Nyangoro, Kitonga and Udekwa and increased to 47, 60, and 63 for year 2005 respectively. The relative frequency of *Julbernadia globiflora* decreased at Kitonga and Udekwa and increased at Nyangoro while relative density increased for all sites. For relative dominance only Kitonga had decrease. The importance value index followed the same trend. For other species there existed also intermingled changes.

1 Introduction

According to the national land covers and land use reconnaissance carried out in 1996 miombo woodlands cover 374 356 km^2 or 93.2% of total forest area of Tanzania (Mnangwone 1999) (Table 1).

Table 1. Forested area of Tanzania mainland.

Forest type	Area km^2	Percent %
Closed Forests	24 313	6.1
Miombo woodlands	374 356	93.2
Mangroves	1 569	0.4
Plantations	1 349	0.3
Total	401 587	100.0

These woodlands are major source of woodfuel, construction poles, food (game, meat, fruits, honey etc.) and traditional medicines. Miombo also support agriculture farming (e.g. tobacco growers use energy from miombo for processing their tobacco).

There is growing concern about deforestation of miombo woodlands in Tanzania. Among the principal causes of the problem are charcoal production, declining fallow periods in shifting cultivation, grazing and wildfires. The miombo woodland is one of the most extensive and importance vegetation types in Tanzania. This miombo woodland flora is well known in Tanzania but the origin of their differences within and between stands is unclear and may be caused by geomorphic evolution of landscape (Cole 1986 in Frost 1996), edaphic factors, principally soil moisture and soil nutrients (Astle 1969, Campell et al. 1988 in Frost 1996), effect of fire (Lawton 1979, in Frost 1996), wildlife impacts and past land use (past history), interaction of available soil nutrients and root symbosis (Hogberg 1986), successional status (Backeus et al. 2006), competitive interaction and other anthropogenic disturbances. Very few studies of stand structure in miombo woondlands in Tanzania has been conducted (Table 2).

Table 2. Studies of stand structure conducted in miombo woodlands in Tanzania.

Range of Variables	Author
Density 74–1041 individuals /ha	Isango 2004, Backeus et al. 2006
Basal area 8–16.7 m^2/ha	Backeus et al. 2006, Boaler and Sciwale 1966, Tuite 1992
Diameter at breast height 4.5–65 cm	Malimbwi and Temu 1984, Isango 2004, Mbwambo 2000
Shannon Weiner's diversity index (1–2.85)	Tuite 1992, Isango 2004, Malimbwi et al. 1998
Canopy cover 20–75%	Temu 1985, Boaler 1966
Dominant height 15–30 m (plots)	Isango 2004

Iringa District is practicing Community Based Forest Management (CBFM), but unfortunate it is not among the areas covered by these studies (Table 2) and therefore no information is available on stand structure and species composition on its forests. Stand structure and species composition is important in management of multiple forest resource, wildlife, aesthetics, hydrologic recovery, range of forage conditions and as bases for projecting changes in vegetation over time. It is also important for regeneration, growth, mortality, understory development and spread of disturbances (Chen and Bradshaw 1999).

The purpose of this study was to carry out survey to describe quantitatively stand structure and species composition on community based forests in Iringa District. It is from the knowledge of clear understanding of stand structure, species composition and its difference within and between stand that we can be able to recommend the community.

2 Materials and Methods

2.1 Description of Study Areas

The focus of the study was in Iringa rural district covering 27% of miombo woodlands (the area of Iringa rural district is 15 420 km^2) (IRADEP 1986). The study plots were established at Nyangoro, Kitonga and Udekwa in community based forests reserves. The location of site, altitude, forest area, climate, chemical soil properties of the area are shown in Table 3. It is clear that soils from the study area are poor in nutrients as show by C/N ratio which is typical of miombo woodland soils.

Table 3. Characteristics of the study sites and chemical properties of soils at the three studied sites.

Site	Location	Altitude m.a.s.l.	Forest area ha	Mean annual temp ˚C	Mean annual rainfall mm
Nyangoro	35˚ 37’–36˚ 06’ E 7˚ 07’–7˚ 30’S	796–1818	60 000	10–15	565
Kitonga	36˚ 05’–36˚ 15’ E 7˚ 35’–7˚ 45’ S	796–1818	20 000	13.5–24.7	720
Udekwa	36˚ 21’ E 7˚ 44’ S (Plot centre)	1000–1,300	>60 000	18.8	>900

Site	pH H_2O	Mg	Ca	K	P	Al	CEC	N%	C%	C/N
Nyangoro	5.968	0.78	0.71	0.40	4.776	0.036	18.3	0.156	0.898	6.23
Kitonga	5.628	0.14	0.13	0.45	3.506	0.040	8.15	0.142	1.046	6.91
Udekwa	5.738	0.398	0.31	0.60	4.854	0.052	8.63	0.134	1.280	10.50

2.2 Sampling Design

The area was stratified using site related characteristics (soils and climate). For the size of the plots experiences from other miombo woodlands were sought. Lawton (1978) observed that the 20 m x 20 m sample plots were adequate for floristic studies of miombo woodlands and other woodlands in north-eastern Zambia and an increase in sample size resulted in very few new species being recorded. McGregor (1994) used the same size in assessing the pattern and structure of miombo woodlands in peasant farming area of Zimbabwe. This study adapted the size as the smallest size unit in a block when establishing Permanent Sample plots (PSPs) from which the data were collected. Two blocks of 0.24 ha were established at Nyangoro and Kitonga and one block of 0.64 ha at Udekwa. The blocks were divided into subplots of 20 m x 20 m for reasons advanced above and for easy management (Dallmeier1992, Philip 1983). The block corners were established in north-south direction or east-west direction using a compass. The corners of the plots were fixed starting from the centre of the plot outward to minimize measurement errors (Dallmeier 1992). The corners of blocks and plots were marked by big stones and painted white or easy visibility.

2.3 Data Collection

A total of forty PSPs were established in 2002 and assessed in 2005/2006 (40 plots for trees, 40 plots for saplings and 40 plots for seedlings). During data collection all trees greater than 4.5 cm in diameter at breast height (DBH) were measured for dbh and crown width (CR) with diameter tape while, height to first living branch (HC) and total height (HT) was measured with calibrated pole or suunto clinometer as thought appropriate. Species names were identified by an experienced botanist. All variables recorded in each size of plot are as indicated in table 4. CR was measured in four directions at right angles to each other.

Table 4. Distribution of plots according to the type of data collected.

Site	No of Plots	Type of data	Size of plots in meters and Parameters of interest		
			Trees 20 m x 20 m	Saplingss 10 x 10 m	Seedlings 5 m x 5 m
Nyangoro Kitonga Udekwa	12 12 16	Structure and composition	Species name, DBH, HT, HC and CW	DBH and HT	HT

2.4 Data Analysis

2.4.1 Structure of Miombo Woodlands

2.4.1.1 Diameter Distribution

Stand structure can be described as the distribution of species and tree sizes in a forest area (Husch et al. 1982). Structure has been also defined as the distribution of trees by diameter classes (Adam and Ek 1974). Tree data were grouped into 5 cm diameter classes e.g. the class boundaries were 4.5–9.5, 9.5–14.5 cm etc. These gave the frequency of trees in each diameter class. The frequency distribution table was then used to draw bar chart graphs.

2.4.1.2 Basal Area and Volume per Hectare

The basal area for all the trees in each plot was summed and divided by the size of the plot to give basal area per hectare while volume was obtained by using the equation by Frost (1996) which converts basal area/ha to volume/ha (volume $V=6.18* Ba^{0.86}$, where: V=volume/ha (m^3/ha) and Ba=basal area/ha (m^2/ha)

2.4.1.3 Crown Radius and Canopy Cover

The woodlands typically comprise of an upper canopy or umbrella shaped trees and discontinuous understory of shrubs, saplings and seedlings. The upper canopy or umbrella shaped forms canopy cover. In this study canopy cover is predicted from crown radius and is important for stratifications of forests, for estimation of volume when combined with height and for predicting amount of forage in land range.

The following models were tried for fitting the data:

$CR = \alpha + \beta\ DBH$

$CR = \alpha + \beta_1\ DBH + \beta_2 HT$

$CR = \alpha + \beta_1\ DBH + \beta_2\ HT + \beta_3\ HC$

$CR = \alpha + \beta_1\ DBH + \beta_2\ HT + \beta_3\ HC + \beta_4\ DBH^2$

$CR = \alpha + \beta_1\ DBH + \beta_2\ HC^2 + \beta_3\ HT^2$

$CR = \alpha + \beta_1\ DBH + \beta_2\ HC^2 + \beta_3\ HT^2 + \beta_4\ HT$

Where:

CR = mean crown radius (m)
DBH = diameter at breast height (m)
HT = total height
HC = height to crown radius
α, β_i = constants

DBH was used in all of the models because previous studies by Dawkin (1963) and others have reported that this is the most correlated variable with crown radius in tropical species (e.g. miombo woodland species).

2.4.1.4 Biodiversity indices

Indices for species structure were calculated in 2005 and compared with those calculated in 2002 to detect if there was any change in structure. The following formulas were used for different indices:

Species diversity index (SDI) (Kohli et al. 1996) (1)

$$SDI = -\sum_{=i}^{s} \log_{10}(P_i)/\log_{10}(1/S)$$

Where:

S = the number of species at that site
$P_i = n_i/N$
n_i = total number of individuals in the i^{th} species
N = total number of individual of all species

Shannon Weiner's diversity index (SD) (Kent and Coker 1992): (2)

$$SD = -\sum_{=i}^{s} P_i \ln P_i$$

Where:

S, P_i, n_i, and N as in equation (1)

Equitability (Evenness) was calculated as: (3)

$E = SD/SD_{Max}$

Where:

$SD_{Max} = \log_{10}(S)$

For species richness (SR) or variety indices was calculated following the method of Margalef (1958a) in Odum (1971):

$SR = (S – 1)/(\log_{10} N)$ Odum (1971) (4)

Where:

SR = species richness, S and N as equation (1).

2.4.2 Composition of Miombo Woodlands

Composition is the assemblage of plant species that characterize the vegetation (Martin 1996). The composition of miombo woodlands appears to be relatively uniform over large regions suggesting a broad similarity in key environmental conditions (Frost 1996). The most common measure of composition is richness (the number of different species) and abundance (the number of individuals per species found in specified area). Species richness can be documented by calculating its relative density (RD). RD does not show the distribution of species which is shown by relative frequency (RF). The abundance is calculated as relative dominance (RDo). The formulas used to calculate RD, RF, RDo and the importance value index (IVI) are as follows (Balslev et al. 1987, in Dallmeier 1992, Sabogal 1992):

RD = (number of individuals of a species)/(total number of individuals of all species) x 100,
RF = (frequency of one species)/sum of all frequencies) x 100,
RDo = (combined Ba of single species)/ (total Ba of all species x 100) and
IVI = sum of (RF+RD+RDo)/3

3 Results and Discussion

3.1 Structure of Miombo Woodlands

3.1.1 Diameter Class Distribution

The diameter class distribution of miombo woodland stands confirm to De iocourt's q factor procedure (inverse J-distribution) with stems frequencies decreasing with increase in diameter at breast height for all three sites (Fig.1). The figure indicates that stands are developing and regeneration in the forest is present. Looking very critically at Nyangoro the histogram shows a reduction in the number of stems in diameter class 1, 2, and 5 in 2005 due death, harvesting of trees and upgrowth. The reduction of stems at Udekwa is caused by mortality.

At Nyangoro 64% and 31% of trees fell within the 4.5–14.5 cm and 14.5–19.5 cm in 2002 while 62% and 34% fell within 4.5–14.5 and 14.5–19.5 cm in 2005. At Kitonga 46.3% and 45.7% fell within 4.5–14.5 and 14.5–19.5 cm in 2002 and 28.3% and 29% fell within 4.5–14.5 and 14.5–19.5 cm in 2005. For Udekwa and for more details see Appendices 1 and 2. Generally there is better growth at Kitonga than at other sites as indicated by the movement of trees in various diameters. Evidence in recent years has revealed some unanticipated difficulties and complications in the use of inverse J-distribution even if it is accepted to be a tool for management of uneven aged forests like miombo woodlands:

- The negative exponential model assume equal mortality rates among size classes, which Goff and West (1975) in O'Hara and Milner (1994) regarded as biologically unrealistic
- Simulation by various models suggest that there are other sustainable distribution besides the negative exponential (Goodburn and Lorimer1999)
- The method is difficult to apply on the ground.

This gives caution in the use of inverse J-distribution as stock control in management.

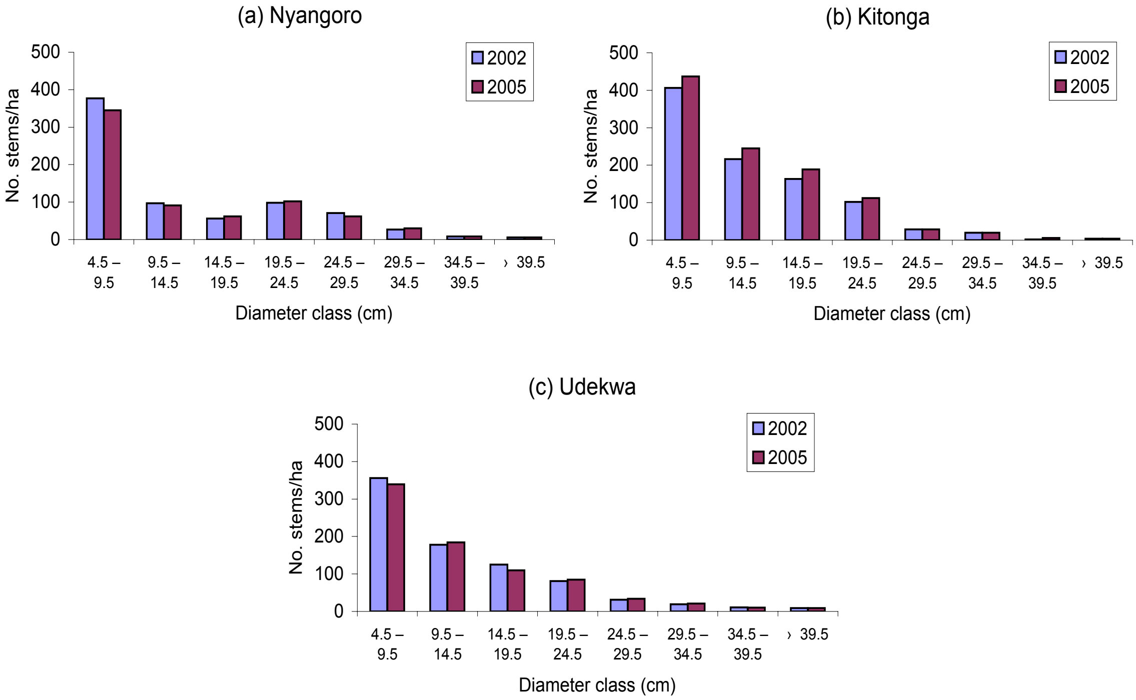

Figure1. Diameter distribution of stems at Nyangoro, Kitonga and Udekwa in Iringa District, Tanzania.

3.1.2 Basal Area and Volume

The stand density of miombo woodlands varied between 700–1038 stems/ha. The basal area varied between 15.04–15.63 m^2/ha while the volume varied between 63.6–65.7 m^3/ha. The basal area is within the range of other studies in Tanzania (Boaler and Sciwale 1966, Backeus et al. 2006) (13.8–16.7 m^2/ha). Nyangoro in Table 5 had a volume of 65.7m^3/ha this value being higher than that obtained by Luoga (2000) at Kitulanghalo Forest Reserve (54.07 m^3/ha). The difference may be due to species composition, genetic and site difference. Kitonga had the highest number of seedlings when compared to the other two sites of study. This shows that Kitonga has more bright future than the other two sites.

Table 5. Stands structure of Nyangoro, Kitonga and Udekwa in Iringa, Tanzania.

Stands	Nyangoro		Kitonga		Udekwa	
variables	2002	2005	2002	2005	2002	2005
m^2/ha	15.48	15.63	15.63	15.40	15.04	15.50
m^3/ha	65.2	65.7	65.7	64.9	63.6	65.3
Stems/ha	740	700	938	1038	801	783
*Seedlings/ha	24 466	20 000	93 600	90 000	34 850	36 000

* seedlings are for various species (trees and non trees)

3.1.3 Crown Radius and Canopy Cover

The best model for predicting crown radius was equation 6 by having lowest standard error, high adjusted coefficient of determination (R^2) and normal distribution of residuals as shown in Table 6 and Fig. 2. From this study it is clear that crown radius can be predicted from diameter at breast height, total height and height to the crown base.

Table 6. Regression equations for combined miombo woodland species.

Equation n_o.	Regression equation	R^2	Std Error
1	CR = 0.431 + 0.149 DBH	0.65	0.772
2	CR = 0.073 + 0.113 DBH + 0.136 HT	0.67	0.752
3	CR = 0.005 + 0.108 DBH + 0.224 HT + 0.203 HC	0.69	0.719
4	CR = 0.228 + 0.050 DBH + 0.240 HT + 0.188 HC + 0.002 DBH	0.70	0.714
5	CR = 0.489 + 0.0979 DBH + 0.166 HT^2 + 0.283 HC^2	0.71	0.699
6	CR = 1.480 + 0.103 DBH + 0.326 HT^2 + 0.227 HC^2 + 0.277 HT	0.72	0.691

3.1.4 Biodiversity Indices

The other measures of structure are indices of biodiversity: higher values of diversity indicate greater stability of community structure (Narayan et al. 1994, in Kohli et al. 1996). Species diversity index (SDI) and Shannon Weiner diversity index (SD) were higher at Udekwa (SDI=75.9; SD=1.29) followed by Kitonga (SDI=69.6; SD=1.32) and Nyangoro (Table 7), indicating that Udekwa has a more stable vegetation than Kitonga. The same trend is observed in the indices of richness and evenness thus confirming that the vegetation community of Udekwa is stable when compared to the other two sites.

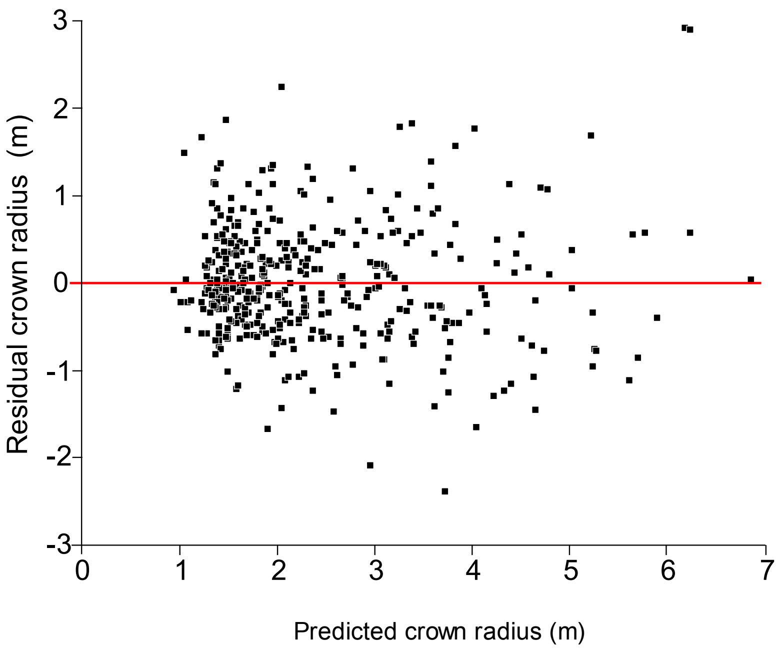

Figure 2. Distribution of residuals, model 6 in Table 6.

Table 7. Species diversity index (SDI), Shannon Weiner diversity index (SD), species richness (SR) and species evenness (E) at indicated sites in Iringa, Tanzania.

Number of	species		SDI		SD		SR		E	
Site\Years	2002	2005	2002	2005	2002	2005	2002	2005	2002	2005
Nyangoro	43	47	-	50.2	1.42	1.50	29.7	16.5	0.82	0.91
Kitonga	57	60	-	69.6	1.32	1.32	31.5	21.1	0.75	0.76
Udekwa	60	63	-	75.9	1.31	1.29	35.7	23.5	0.72	0.72

3.2 Composition of Species

A total of 43, 57 and 60 species were enumerated at Nyangoro, Kitonga and Udekwa respectively in 2002 while in 2005 species increased to 47, 60 and 63, respectively (Table 7). A total of 81 species were registered in 2005 for three sites (Appendix 2). The variation within and between communities vary widely as noted by (Frost 1996) and in Tanzania it is shown by various studies: Mbwambo (2000) enumerated a total of 34 species in miombo woodlands adjacent to five villages in Tabora. Backeus (2006) 86 species around Ihombwa village in Mikumi Division, Kilosa District. Malimbwi et al. (1998) enumerated 95 and Luoga (2000) enumerated 79 species in same Forest Reserve of Kitulanghalo while Tuite (1992) in Ihowanza in Mufindi enumerated 102 species.

There has been a change of relative density, dominance and frequency from year 2002 to 2005. Looking at Table 8 the relative frequency of *Julbernadia globiflora* decreased by 0.20% for Kitonga and increased by 0.24% for Nyangoro and decreased by 0.05 percent for Udekwa. As regards relative density, there was an increase for all sites, 0.58% for Kitonga, 0.24% for Nyangoro and 2.67% for Udekwa. For relative dominance, there was decrease of 29.69 percent for Kitonga, and an increase of 65.43% for Nyang'oro and 250.4% for Udekwa. The decrease of relative dominance at Kitonga is due poaching of trees. For Udekwa high increase was due the high basal area increase compared with other species. Important value index (IVI) for *J. globiflora* from 2002 to 2005 decreased by 20.35% and increased at Kitonga and Udekwa by 6.87% and 37.72% respectively. There is little change for frequency and relative density indicating that there is little expansion of *J. globiflora.* For the changes of other species see Table 8.

Table 8. Relative frequency, density, dominance, and importance value index at Kitonga, Nyangoro and Udekwa in Iringa, Tanzania.

Species name	Index	Kitonga		Nyangoro		Udekwa	
		2002	2005	2002	2005	2002	2005
Julbernadia globiflora	RF (1)	8.96	8.76	5.34	5.56	9.09	9.04
	RD (2)	26.27	26.85	5.62	5.86	26.02	28.69
	RDo (3)	34.16	13.42	11.67	77.10	35.17	285.57
	IVI (4)	69.38 (1)	49.03 (1)	22.63 (3)	29.5 (5)	70.28 (1)	108.00 (1)
Brachystegia spiciformis	1			-	-	6.82	7.50
	2			-	-	10.10	20.52
	3			-	-	29.86	120.01
	4			-	-	46.77 (2)	70.25 (2)
Brachystegia bussei	1	-	-	8.4	7.94	-	-
	2	-	-	16.01	16.96	-	-
	3	-	-	42.46	223.68	-	-
	4	-	-	66.87 (1)	82.83 (1)	-	-
Dalbergia nitidula	1	5.22	5.84	7.63	8.73	7.95	7.91
	2	4.42	4.47	9.27	9.65	8.16	8.86
	3	2.91	3.85	2.22	127.21	2.70	88.19
	4	12.55 (4)	14.16 (6)	19.13 (4)	48.53 (2)	18.81 (4)	35.00 (4)
Cucumis molle	1	4.48	4.38	-		7.39	6.78
	2	2.43	2.46	-		7.96	9.70
	3	2.37	3.172	-		4.14	96.59
	4	9.28 (7)	10.15 (9)	-		19.49 (3)	37.70 (3)

*Numbers in brackets under Nyangoro, Kitonga and Udekwa show the position in its importance value.

4 Conclusions

Before sustainable management strategies can be instituted to any forest it is essential to know and understand the structure and composition of forest. This helps to manage it successfully.

Diameter distribution in miombo woodlands stands are inverse J-shape curve. Weibull, Johnson B and Beta function can be used to model diameter distribution in addition to the used negative exponential function of De Liocourt. Although De Liocourt's principle biologically is unrealistic it is accepted as a management tool for uneven aged forests, this calls for more advanced stand structures models to be developed. Inversed J-shape and histogram charts can be used to monitor and assess sustainability.

The number of species in studied areas of in miombo woodlands in Tanzania vary from 79–95 while the Shannon diversity index vary from 1–2.527. There is little change in relative frequency and density when compared to relative dominance and importance value index in miombo woodlands. Both species structure and composition are sensitive to environmental impacts (pressure) thus they can be used as indicators for destruction of forests. This study found that crown radius could be predicted from diameter at breast height, total height and height to the crown base. If inventory data exists, at the studied sites these models represent a fast and efficient method of estimating crown radius which in turn can be used to estimate canopy cover without requiring additional field measurements.

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Appendix 1. Diameter distribution of trees at Nyangoro, Kitonga and Udekwa in Iringa Tanzania.

Class No	Diameter Range cm	Nyangoro No trees/ha		Kitonga No trees/ha		Udekwa No trees/ha	
		2002	2005	2002	2005	2002	2005
1	4.5 – 9.5	377	345	406	437	356	339
2	9.5 – 14.5	97	91	216	245	178	184
3	14.5 – 19.5	56	62	163	189	125	110
4	19.5 – 24.5	98	102	102	112	81	85
5	24.5 – 29.5	71	62	29	29	31	34
6	29.5 – 34.5	27	30	20	20	19	21
7	34.5 – 39.5	8	8	2	6	11	10
	› 39.5	6	6	4	4	9	9
	Total	734	700	938	1038	801	783

Appendex 2. List of species in three sites of community based forest reserves in Iringa District.

Albizia tanganyikensis
Albizia amara
Allophylus africanus
Brachystegia allenii
B. longifolia
B. microphylla
B. mosambisciensis
B. spiciformis
B. utilis
B.boehmii
B.bussei
B.manga
Bauhinia petersiana
Boscia sp.
Bridelia cathartica
Burkea africana
Combretum molle
Combretum zeyheri
Cassia pertisiana
Sp. of *Celastraceae*
Clerodendrum myricoides
Cussonia sp.
Dichrostachys cinerea
Diplorhynchus condylocarpon
Dalbergia nitidula
Disospyrus fischeri
Euphorbia candelabrum
Euphorbia cuneata
Euphorbia abyssinica
Ehretia acuminata
Euphorbia candledrum
Euphorbia tirucalli
Ethryna abyssinica
Eudea divinorum
Family of Rubiaceae
Faurea saligna
Ficus natalensis
Flueggea virosa
Grewia bicolor
Hydrothelphusa madagascariensis
Julbernardia globiflora
Lannea edulis
Lannea schimperi
Lannea schweinfurthii
Maerua sp.
Maerua triphylla
Markhamia lutea
Markhamia obtusifolia
Monotes africanum
Monotes elagans
Mundelea cericea
Ochna mossambicensis
Ochna holstii
Ochna macrocalyx
Ochna off-ovata
Ochna rotundifolia
Ochna sp.
Ormocarpum kirkii
Ozoroa insignis
Pterocarpus angolensis
Pseudolachnostylis maprouneifolia
Papilionaceal family
Pappea capensis
Pavetta gardenifolia
Prunus sp.
Pterocarpus sp.
Rhus sp.
Rhus natalennsis
Strochynos sp.
Strochynos potatorum
Swarzia madagascariensis
Terminalia stenostachya
Tapiphylum burnetti
Tarrena
Tarrena graveolens
Vangueriopsis
Vernonia sp.
Xeroderris sp.
Ximenia caffra
Xmenia americana
Zanthoxylum chalybeum

Total species 81

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Trees to Promote in the Management of Miombo Woodlands in Tanzania: Species, Sizes and Qualities

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Miombo woodlands occupy the greater portion of the Zambezian phytocorion. This ecosystem is largely characterized by the three closely related genera of *Brachystegia*, *Julbernadia* and *Isoberlinia,* from the legume family Caesalpinaceae. Nineteen species of *Brachystegia* and three species of *Julbernadia globiflora*, *J. paniculata* and Isoberlinina *angolenisis* occur in miombo as dominants with some canopy associates such as *Pterocarpus angolensis, P. tinoctorius, Afzelia quanzensis, Albizia* spp., and *Pericopsis angolensis*. The miombo are also rich in medicinal and indigenous fruit trees. In the miombo woodlands of Tanzania is where a large proportion on the population derives products and services for their livelihood. Tree sizes and quality are important factors in allocating different tree species into different uses. The choice of a species also depends on the type of use such as timber, construction poles, charcoal, firewood, floorings, furniture, carvings, medicinal etc. The choice of the species to promote in the management of the miombo woodlands will depend on the stand structure, density and diversity of the species at that particular time. As the woodland improves, the number of species will increase and so do the range of species to promote.

1 Introduction

Miombo woodlands occupy the grater portion of the Zambezian phytocorion. In Tanzania miombo is the most important type of savanna woodland (Gauslaa 1988). It occurs at altitudes from near sea level to about 1,600 m, with annual rainfall ranging from 500 mm to 1 200 mm (Jeffers and Boaler 1966). Miombo constitutes the largest single vegetation type in the country, forming nearly 90% of the total forest area or 13% of the land area corresponding to 309 320 km^2 (URT 1998). Two types of miombo are recognised in Tanzania, namely relatively dry and wet miombo woodlands. The relatively dry miombo woodland covers extensive areas of Shinyanga, Kigoma, Tabora, Rukwa, Mbeya and Iringa regions and wet miombo occupies the south-eastern regions (Millington et al. 1994). Miombo in Tanzania consists of two main layers, the tree canopy and the herb or ground layer, plus an under-wood layer of smaller trees. In some places a shrub layer also exists (Jeffers and Boaler 1966). This ecosystem is largely characterized by the three closely related genera of *Brachystegia*, *Julbernadia* and *Isoberlinia,* from the legume family *Caesalpinaceae*. Nineteen species of *Brachystegia* and three species of *Julbernadia globiflora*, *J. paniculata* and *Isoberlinia angolenisis* occur in miombo as dominants with some canopy associates such as *Pterocarpus angolensis, P. tinctorius, Afzelia quanzensis, Albizia* spp. and *Pericopsis angolensis*. Of the Tanzanian woodlands, miombo contains more of the commercially exploitable timber, and more than thirty years ago had an estimated 15 exploitable trees per km^2 (Temu 1979). The best miombo stands are capable of yielding 35–80 m^3 per ha, although the trees are generally small, rarely exceeding 60 cm diameter at breast height. The Tanzanian miombo woodlands are among the best sources of some economically important tree species, namely *Pterocarpus angolensis, Afzelia quanzensis, Swartzia madagascariensis, Isoberlinia* spp. and *Brachystegia spiciformis*. They supply logs to the sawmilling industry and small scale pitsawyers (Temu 1979). These woodlands are also known for their high quality honey production in the beekeeping industry and as habitats for many wild animals and birds (Temu 1979). From the aforesaid it is evident that a number of goods and services are obtained from miombo woodlands. These influence management objectives or goals. Such goals may include production of: timber, fuelwood, poles, fruit, herbal medicine; it may also focus on: biodiversity conservation (flora and fauna), soil enrichment/ rehabilitation, protection of water catchments, aesthetics, etc. This diversity in management goals is likely to be user category, and location specific. The net effect is the need for a common agreement and or harmonization of management objectives as means to forestall potential user conflicts.

2 Promotion objectives and suitable species

The communities around miombo woodlands have knowledge of the importance of their woodland resources and put different species to different uses, with some overlap where a species has multiple uses. Mbwambo (2000) observed strong preference for suitable species for building poles in villages surrounding Urumwa Forest Reserve. Due to the scarcity of suitable timber tree species in the Urumwa Forest Reserve low quality species such as *Sterculia quinqueloba* are used. For firewood live trees are cut and dried, however any combustible material is used. The fact that the villagers choose particular miombo trees for different purposes is an indication of some kind of local knowledge and management.

2.1 Timber products

An impressive list of the uses of Tanzanian Timbers is provided by Bryce (1967). Desirable characteristics for various uses are summarized Table 1.. Tree sizes and quality are important factors in allocating different tree species into different uses. The Forest Act No. 14 of 2002 classifies all trees with diameter over-bark at breast height (1.3 m) greater than 20 cm as saw logs. Diameters between 5 and 20 cm are suitable for poles. Diameter classes for poles are given as; Class I: 15–20 cm, Class II: 10–14.9 cm, Class III: 5–9.9 cm and Class IV: below 5 cm. These classes have different prices (URT 2002).

Table 1. Abridged list of uses of Tanzania Miombo timbers.

End use	Desirable Characteristics	Example
Artificial limbs	Light weight, easy working non- splintering	*Pterocarpus angolensis*
Batons (Police)	Moderately high density and impact strength	*Acacia nigrescens* *Pericopsis angolensis*
Bearings, slides	Hardness and even wear An oil texture advantageous	*Delbergia melanoxylon* *Pericopsis angolensis*
Benchs, laboratory	Furniture-grade woods, impermeable and resistant to acid corrosion	*Afzelia quanzensis*
Boat building		
- Frame		*Pterocarpus angolensis* *Pterocarpus angolensis*
- Ribs		*Tamarindus indica*
- Keels, keels on, hog		*Afzelia quanzensis* *Brachylaena huillensis* *Tamarindus indica*
- Stem		*Pericopsia angolensis*
- Floors, engine beds		*Acacia nigrescens*
- Planking		*pericopsis angolensis*
		Afzelia quanzensis
- Decking		*Pterocarpus angolensis*
- Internal fittings		*Afzelia quanzesis*
		Pterocarpus angolensis
Boxes and crates	Pale colour, low density good nailing properties printability, low cost	*Sclerccarya birrea* *Vitex* spp.
Bridge timbers	High compressive and bending strength, durability resistance to weathering	*Acacia nigrescens* *Julbernadia globifora*
Building timbers		*Julbernadia globiflora*
- Durable		*Combretum schummanii* *Sterculia quinqueloba*
- Non- durable		*Brachystegia spiciformis* *Sclerocarya birrea*
Carvings	Good appearance, fine and uniform texture, working cleanly with handtools	*Brachylaena huillensis* *Dalbergia melanoxylon* *Pterocarpus angolensis* *Slerocarya birrea* *Swartzia madagascariensis*
Casks, tanks and vats	Impermeable wood, straight grain, knot free, easy to machine and bend, taint free	*Afzelia quanzensis*
	High density with high proportion of fixed carbon	*Brachystegia spiciformis*

End use	Desirable Characteristics	Example
Charcoal		*Branchystegia bochmii* *Swartzia madagascariensis* *Julbernadia globiflora* *Tamarindus indica*
Coffins	Durability, good appearance, easy to work with and polish	*Pterocarpus angolensis* *Pterocarpus chrysothrix*
	Straight grained, medium density, turning smoothly stable in service	*Pterocarpus angolensis* *Afzelia quanzensis*
Draining boards	Straight grain, fine texture, impermeable, good appearance, moderately hard, free from tannin, wearing smoothly stable in service	*Afzelia quanzensis*
Floor and Pedistrian Traffic - Heavy duty: Corridors, fixed traffic lanes in schools, barracks, post – of-fices assembly halls, etc		*Pterocarpus angolensis* *Sterculia quinfuelob* *Combretum schumanii*
- Medium duty: Classrooms, hotels, banks offices, libraries etc.		*Acacia nigrescens* *Brachylaena huillensis*
Floor for Industrial Traffic - Heavy duty: Heavy; trucking with impact sorting sheds, workshops, warehouses etc.		*Brachylaena huillensis* *Brachystegia spiciformis* *Pterocarpus angolensis*
Floors for special purpose - Decorative - Small movement		*Brachystegia*
- Resistance to chemicals		*Afzelia quanzensis*
- Resilience (gymnasium/dancing floors)		*Acacia* spp.
Fuelwood	High density, little oil/resin content, low in water solubles	*Branchylaena huillensis* *Combretum schumanii*
Furniture	Attractive but subdued figure, stability in service, easy working durable, taking a high polish of choice	
- Top quality		*Pterocarpus angolensis* *Afzelia quanzensis* *Pterocarpus chrysothrix*
- Low grade		*Sterculia quinqueloba* *Combretum schumanii*
Handles, knife		*Combretum schumanii* *Dalbergia melonoxylon*
Joinery	Good colour, figure, stability easy working, and good finishing	*Afzelia quanzensis* *Pterocarpus angolensis* *Pterocarus chrysothrix*
- High grade		*Combretum schumanii*
- other grades		*Sterculia quinqueloba*
Mallets	Hard and heavy woods, preferably with interlocked grain for high resistance to splitting, with fine texture, turning cleanly	*Acacia nigrescens* *Combretum schumanii*

End use	Desirable Characteristics	Example
Marine timbers	Need be naturally durable if not preservative impregnation mandatory	*Acacia nigrescens*
Mining timber	Strength properties of naturaldurable/impregnated timber need be above average	*Acacia nigrescens* *Brachystegia spiciformis* *Julbernadia globiflora*
Mouldings	Medium to high density fine and uniform texture machining cleanly to a smooth finish	*Afzelia quanzensis*
Musical Instruments	Fine texture, high density stability, oilness, take of screw threads clenly, dark colour and good finish.	*Combretum schumanii* *Dalbergia melanoxylon* *Swartzia madagascariensis*
Paddles	Light weight, warping free, adequate strength	*Pterocarpus angolensis* *Faidherbia albida*
Panelling	Colour, figure, stability in service	*Pterocarpus angolensis*
Planes, wood working	Medium density and hardness, warping free wearing smoothly easy to machine	*Afzelia quanzensis*
Marine (conforming to B.S. 1088:1957		*Afzelia quanzensis* *Pterocarpus angolensis*
Rollers, pulley sheaves	Hardness, high resistance even wear	*Acacia nigrescens* *Brachystegia boehmii*
Rulers	White colour, straight grain, machining to a smooth finish hard, taking engraving clearly	*Brachylaena huillensis*
Screws	Hard timber, dense with fine and uniform texture working cleanly to give strong, undamaged edges	*Dalbergia melonoxylon* *Combretum schumanii*
Shingles	Light weight, durable, impermeable warping free, fissile, resistant to weathering.	*Dalbergia melonoxylon*
Shuttering (concrete formwork)	Light weight, low shrinkage, little warp, non absorptive, easy nailing.	*Faidherbia albida*
Sleepers	Dense, resistant to mechanical breakdown, holds spikes firmly stable in service and resistant to weathering	*Acacia nigrescens*
Tent pegs	Durable, hard with interlocked grain	*Acacia nigrescens* *Brachystegia spiciformis* *Julbernadia globiflora*
Turney	Hard, with fine texture and straight grain	*Dalbergia melanoxylon* *Brachylaena huillensis* *Tamarindus indica*
Veneers	Pronounced figure, attractive appearance, good drying and glucing properties	*Swartzia madagascariensis* *Pterocarpus angolensis*

Table 1 lists some 20 different uses for *Pterocarpus angolensis*. Timber tree species such as *Afzelia quanzensis* has eight different uses. Going by numbers, it is tempting to recommend that tree species having a big array of uses deserve promotion. However, this needs to be viewed with caution because the ultimate selection depends on a priority accorded to a given use. Also worth noting is the rotation length for miombo timber tree species. Fire tends to prolong growth periods. Reduction of fire intensity and or elimination accelerates growth.

2.2 Other Uses

Fruits, poles, herbal medicine and apiculture are among key miombo products and form part of community socio-economic activities in the miombo ecosystem. For fruit trees the key consideration is growth size and fruit shelf life. Important miombo fruit trees include *Azanza garckeana, Belanites aegyptiaca, Borassus aethiopum, Tamarindus indica, Uapaca kirkiana, Vitex* spp etc. (Ruffo et al. 2002). In Tabora region for example, the most frequently used and available indigenous fruit tree species include *Annona senegalensis, Berchemia bicolor, Flacourtia indica, Grewia bicolor, Grewia* sp.*, Hexalobus monopetalus, Parinari curatellifolia, Phyllanthus engleri, Popowia obovata, Strychnos cocculoides, S. spinosa, Tamarindus indica, Vangueriopsis lansiflora, Vitex doniana, V. mombassae, Ximenia africana* and *X. americana* (Mbwambo 2000).

Desirable pole characteristics include durability, insect (damage) resistance sapwood/heartwood ratio, preservative treatment, splitting, and strength. Mbwambo (2000) recorded suitable pole species for Tabora villages that included *Albizia antunesiana, Combretum collium, C. molle, C. zeyheri, Dalbergia melanoxylon, D. nitidula, Erythrophloem africanum, Pericopsis angolensis, Pterocarpus tinctorius* and *Terminalia sericea.*

Herbal medicine is frequently influenced by the plant part used, place of origin, and storability as these contribute to the concentration of active ingredients and consequently herbal efficicacy. Work by Derry et al. (1999) amply testifies that generalizations might be misleading because herbal preference tends to be location specific. Interestingly, almost all miombo trees and shrubs have wither widespread and or local use. However, *Securidaca longipedunculata, Zanha africana, Cassia abbreviate, Entanda abyssinica* and *Terminalia sericea* are among top priority herbs in Shinyanga. According to Mbwambo (2000) other miombo species with medicinal properties found in the central western Tanzania include: *Afzelia quanzensis, Cassipourea insignis, Combretum collium, C. molle, C. zeyheri, Dichrostachys cinerea, Erythrina abyssinica, Fagara mekeri, Ozoroa insignis, Popowia obovata, Pterocarpus angolensis, P. tinctorius, Schrebera koiloneura, Tamarindus indica, Vitex mombassae* and *Xylopia antunesii.* It is worth noting that some species are both for timber (*Afzelia quanzensis, Pterocarpus angolensis* and *P. tinctorius),* fruits *(Tamarindus indica* and *Vitex mombassae*) and that their promotion must take into consideration their multiple uses. Tree species preferences for medicinal use depend on the knowledge of the user and the number of cures each species offers.

Plants oftenly used by bees as fodder need a high concentration of nectar and or pollen, and propolis. Miombo species suitable for apiculture are: *Julbernadia globiflora, Brachystegia spiciformis, Combretum* spp*. Tamarindus indica, Adansonia digitata, Ficus sycommorus and Albizia* spp. (Kihwele 2001).

3 Management Pathways

The foregoing shows that miombo trees meet an array of needs. If management objective seeks to satisfy such needs to their totality that might be well above the ecosystem's resilience.

Forest use plans specifically tailored to meet key needs from sections of miombo forests seem to be one of the feasible management options. Such zonation may call for Joint Forest Management interventions to make it work. There is also need to produce some of miombo products out of those forests. This can be achieved by domestication. Already fruit tree domestication involving

Uapaca kirkiana and *Strychnos cocculoides* has been undertaken by ICRAF and the results are inspiring. Equally encouraging is the domestication of *Prunus africana* as a medicinal plant; and by the same token *Pterocarpus angolensis, Afzelia quanzensis* among others as timber species.

4 Conclusion

Trees to promote for use in the miombo woodlands depends on management goals and community priorities sometimes influenced to some extent by indigenous knowledge. Where important timber tree species have become scarce in the rural areas due to over-exploitation communities frequently use less durable alternative species. Other uses such as poles, charcoal, firewood, indigenous fruits, beekeeping and medicines need to be put on board when planning for trees to promote. Tree sizes and quality are more important for uses such as timber and poles, and of less importance to other uses. The choice of the species to promote in the management of the miombo woodlands will depend on the stand structure, density and diversity of the species at that particular time. As the woodland improves, the number of species will increase and so do the range of species to promote. Due to multiple uses of the miombo woodlands therefore, the choice of species, sizes and qualities to promote in the management is not a simple model.

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Balancing Wood and Non-Wood Products in Miombo Woodlands

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In most of the sub-Saharan countries including Tanzania, Mozambique, Malawi, Zimbabwe and Zambia, more than 80% of rural people are poor and traditionally rely on existing non-wood goods and services provided by miombo. These woodlands are among the most threatened of the tropical ecosystems. There is a need of investigating the importance of miombo ecosystem, their threats and the governments concerned to ensure sustainable and equitable use of these dwindling resources. This paper gives an overview of the roles played by miombo in the provision of both wood and non-wood products and how the utilization can be balanced for sustainability. It is evident that there has been limited research on miombo productivity and the impact of management on non-timber product supplies. This needs immediate attention in order to address the demand-supply situation. Also sustainable use of trees and shrubs is an integral part of balancing variable products and uses in miombo woodlands. Conservation of miombo while raising the living standard can be enhanced through controlled harvesting, improved domestication and utilization and commercialization of trees and their products.

1 Introduction

To-date, much less attention has been paid to the widespread changes occurring in tropical dry forest and woodland ecosystems (Myers 1980, Houghton 1990, Houghton and Skole 1990) on which a majority of rural people in tropical countries depend for their livelihoods (Campbell 1987, Janzen 1988, Packam 1993, Desanker et al. 1997, FBD 1999, FAO 1999). In most of the sub-Saharan countries including Tanzania, Mozambique, Malawi, Zimbabwe and Zambia, FAO (1999) observed that more than 80% of rural people are poor and traditionally rely on existing non-wood goods and services. Moreover, FAO (1996) statistics show that forest fringe dwellers in Mozambique draw 93% of their livelihoods from the forests.

Makonda and Ishengoma (1997), Makonda et al. (1997, 1998a, 1998b) and Kessy (1998) highlighted the need of investigating the importance of forest products to the daily life of local communities in their struggle to make ends meet that sometimes threaten the forests. The economies in the miombo ecoregions are largely dependent on agriculture through poor household farmers (World Bank 1994). The nutrient-poor soils in the miombo woodlands, however, limit agricultural potential in these areas (Moyo et al. 1993). As a result, the share of the population below the national poverty line in this ecoregion has been ranging between 51 and 91% (World Bank 1996).

According to Brown and Lugo (1982) and Solomon et al. (1993), the largest area of these ecosystems is situated in Africa and about half of it is miombo. In Tanzania, woodlands cover 39.6% of the land area (FBD 1999) with potential to deliver many varieties of forest products (Mziray 1999).

Miombo woodlands can be divided into wet and dry types (White 1983), wet miombo being located on eastern Angola, northern Zambia, south western Tanzania and central Malawi with annual rainfall of exceeding 1 000 mm. Canopy height in this type is greater than 15 m. The dry miombo type is found in Zimbabwe, central Tanzania, and the southern areas of Mozambique, Malawi and Zambia, with annual rainfall of less than 1 000 mm. The canopy height in the dry type is less than 15 m (Bridges 1990).

Due to the high rate of deforestation accompanied with low land productivity (Desanker et al. 1995, Frost 1996, Chidumayo 1997) and poor land use in the miombo ecosystem, there is a need of the governments in the concerned countries to ensure sustainable and equitable use of these resources. Janzen (1988) lamented that miombos are among the most threatened of the tropical ecosystems.

This paper gives an overview of the roles played by miombo in the provision of both wood and non-wood products and how the utilization can be balanced for sustainability.

2 Products and Uses of Miombo Woodlands

Desanker et al. (1997) estimated 39 million people to be directly deriving their livelihoods from miombo woodlands, in seven countries. These countries are Tanzania, Mozambique, Malawi, Zambia, Angola, Democratic Republic of Congo and Zimbabwe. These authors estimated further that around 15 million urban inhabitants depend on products harvested from these trees, including food, fibre, firewood, charcoal, poles and withies.

2.1 Wood Products

Miombo woodlands have been providing large quantities of urban and agro-industrial fuel. In Tanzania for example the industries using much fuel include tobacco curing, salt mining, tea curing, brick burning and fish smoking (FBD 1999). Table 1 shows the trend of increasing fuel wood consumption in Tanzania between 1992 and 1996, which is an indicator of growth in population.

As documented by FBD (1999), fuel wood is becoming scarcer with time, making much of it entering the market economy. Malimbwi et al. (2000) noted that charcoal has attracted farmers to abandon farming in order to trade in this commodity. In central parts of Tanzania, up to 70% of cash income of most of the villagers comes from charcoal production.

Several authors have acknowledged the role played by miombo woodlands as chief source of hardwood timbers throughout eastern, central and southern Africa (Humbert 1959, Bryce 1967, White 1983, Phillipson 1994, Ishengoma et al. 1997, 1998, Richter and Dallwitz 2000, Mackenzie 2005).

Table 1. Per capita fuelwood consumption in Tanzania by various sectors (MTcap^{-1}year^{-1}).

Year	1992	1993	1994	1995	1996
Household	0.766	0.785	0.777	0.771	0.834
Industries	0.093	0.101	0.110	0.120	0.130
Others	0.046	0.048	0.051	0.059	0.063
TOTAL	0.935	0.934	0.938	0.950	1.027

Source: FAO (1999) in FBD (1999)

2.2 Non-Wood Forest Products

2.2.1 Products

There is increasing recognition of the value of non-timber forest products from miombo including food (fruits, vegetables, fungi, roots, tubers, game meat and insects), medicine, essential oils, bees wax and honey, gum, tannins, latex, dyes, fibres, fodder and conservation functions.

Many authors have documented the role of wild foods in improving nutrition and increasing food security particularly in poor rural areas and during famine periods (FAO 1992a, 1992b, 2001, MNRT 1998, FBD 1999). In pronounced severe food shortage in Tanzania for example, wild vegetables either supplement or substitute staple foods, common in parts of Iringa, Dodoma, Singida and Morogoro (FBD 1999, Mvungi 2001). The common vegetables during the period include *Zanthoxylum chalybeum, Adansonia digitata, Bidens pilosa* and *Sesamum* spp.

Fruits are used as food, beverages, and sources of essential oils for cooking. The main fruits include *Adansonia digitata*, *Allanblackia* spp., *Parinari* spp., *Azanza garckeana*, *Uapaca kirkiana*, *Vitex* spp., *Strychnos cocculoides* and *Tamarindus indica*.

Flying termites (Kumbikumbi in Kiswahili), green grasshoppers (Senene in Kiswahili), mushrooms and bush meat are important protein sources in miombo woodlands where animal husbandry is not possible (Karmann 1998, FBD 1999). These are traded in local markets either fresh or after being fried, dried or salted.

The miombo ecosystems have high potential of producing mushrooms; over 34 edible species have been identified in Tanzania (Härkonen et al. 1995), 53 in the Democratic Republic of Congo (Lawton 1995) and 60 in Malawi (FAO 2000).

Tanzania produces about 138 000 tonnes of honey and 9 200 tones of bees' wax per year an industry which takes place in miombo woodlands (FBD 1999). Most of the honey and bees wax produced is consumed locally and only small amounts are exported to Germany, Japan, United Kingdom and the United Arab Emirates. Dewees (1996) in FBD (1999) highlighted that beekeeping and honey hunting in the miombo woodlands of Tanzania could be an especially lucrative business.

The non-wood forest products from miombo are therefore important as they form alternative sources of livelihood, contribute to poverty alleviation through generation of income, and provide food and improved nutrition, medicine and a range of products and foreign exchange earnings.

Research done in six communities in Tanzania by CIFOR (1999) found that farmers were deriving up to 58% of their cash income from the sale of honey, charcoal, fuel wood, wild fruits and vegetables. O'ktingati and Monela (1990) concluded that the value of non-timber forest products contribution to the existing low value of woodlands in Tanzania can have quite a substantial addition to the national economy.

2.2.2 Services

A number of services are derived from miombo including agriculture and grazing, water catchment, climate amelioration and carbon sequestration.

In Handeni Tanga for example, observed that people consider miombo woodland first of all as a resource for agriculture and cattle grazing (Karmann 1998). Such services have also been well documented by Desanker et al. (1997) for the miombo ecosystems of central Africa.

It is important to note that the headwaters of several major southern and central African river systems lie in the miombo region. Examples of these rivers and countries in which they occur are: River Zambezi (Zimbabwe and Zambia), River Kafue and Lualaba (Zambia), River Okavango (Angola and Namibia), River Ruaha, Rufiji and Ruvuma (Tanzania), River Save (Zimbabwe and Mozambique) and River Congo (Democratic Republic of Congo).

The miombo ecosystems regulate climate, operating through both the hydrological and carbon cycles (Brown and Lugo 1982, Solomon et al. 1993). The vegetation partitions radiant energy into different components thereby regulating the climate system. Vegetation is also a major source of carbon dioxide and methane which are themselves radiatively reflective particulates.

3 Balancing Variable Products and Uses in Miombo Woodlands

The diversity of the wood and non-wood products from miombo have been extensively recorded, however, very little quantitative information is known on the extent of their use, including actual and potential supplies which is key to sustainable utilization.

Using tree and shrub resources sustainably is an integral part of balancing variable products and uses in miombo woodlands. Conservation of miombo while raising the living standard can be enhanced through controlled harvesting, improved domestication and utilization and commercialization of trees and their products.

About 60% of the woodlands in Tanzania, however, do not have any legal status, as noted by Mnzava (1991). It is in these woodlands where a lot of uncontrolled wood harvesting and charcoal production takes place. According to UN (1994) as cited by FBD (1999), fuelwood is the second major cause of deforestation throughout the developing world.

In this way, FAO (2001) estimated Tanzania to be losing 92 000 ha/year (0.2%) of its forest land through deforestation. In Malawi, particularly Zomba area, Desanker et al. (1997) observed that the miombo woodlands had been very degraded by tobacco companies for fuel.

In these countries, charcoal is being produced from traditional earth kilns which are so wasteful as billets are not properly seasoned before carbonization starts and attention of operators to the kiln during carbonization is very inconsistent. The recovery rate is only 30% by weight compared to

60% when using metal kilns (Emrich 1985).

The demand for fuel wood and charcoal continue to rise while growth of trees and shrubs (inputs) occur at a slower rate. In Tanzania, in 1988 there was a deficit of about 21 million m^3/year (the human population was about 23 million), to-date when the population stands at about 37 million, the deficit is even wider than ever as it is directly proportional to population increase and aggravated by deforestation. Similar observations were made elsewhere by Campbell et al. (1996).

Such changes in land cover are likely to have caused a variety of impacts on the river regimes and water quality as observed by Mumeka (1986) for River Lualaba and McFarlane and Whitlow (1990) elsewhere. For the past five years, Tanzania has been experiencing problems in hydroelectricity generation due to shortages of water in the dams.

Marketing of miombo products can be considered as an incentive for the conservation of the woodlands (Dewees and Scherr 1996). Fruit trees that have potential to provide food security and to alleviate poverty and malnutrition have been overlooked by science, and their potential left untapped.

Though for example, Tanzania is the richest in *Sclerocarya birrea* trees in Southern Africa, they are not significantly used (FBD 1999) but harvested for timber and veneer. This is a commercially very important tree in South Africa, for distillery of famous liquor known as "Amarula". In their study concerning domestication of wild species in Zimbabwe, Gumbo et al. (1990) revealed *Sclerocarya birrea* was the most preferred followed by *Azanza garckeana* and *Parinari curatellifolia*.

In Malawi and Zambia, Packam (1993) noted that farmers were already being encouraged to use miombo fruits in their range of products, such as the *Uapaca kirkiana* fruit processing for commercial sale. Establishment of woodlots or plantations using miombo species to carter for wood and non-wood forest products has the potentials of relieving miombo from pressures.

In comparison with honey hunting in which the revenue from bee-keeping is higher, with a small capital outlay required, Karmann (1998) was optimistic that the higher profits of beekeeping might encourage people to use resources in an environmentally friendly manner.

When considering destructive harvesting, however, expanding the markets would become even more risky. Several authors have calculated the damages of miombo woodlands due to bark harvesting and Karmann (1998) concluded that its use can only be justifiable in the utilization of the whole tree. For subsistence economies, Karmann (1998) recommended a strengthened use of NWFP with establishment of collaborative processing and marketing to favour the marketing possibilities of all product samples.

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Land Rehabilitation Experiences from West Pokot, Kenya

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In the bottom of Rift Valley in West Pokot District in Kenya Vi Agroforestry Project has been rehabilitating land since the mid 1980s. These areas had serious problems with overgrazing and erosion. There were virtually no ground cover and no regeneration of trees. Some experiences from this land rehabilitation are: It is necessary to have participatory discussions with local users (farmers/cattle owners). If employment is created, employ locally and let the community influence who gets employed. Fencing – exclosure of grazing animals – is essential. Water harvesting, collecting water for planted/sowed trees were done. Most tree species could be sown. Activities started on communal land, i.e. school compounds, church compounds, not on land for common grazing. Results gave good tree survival and impressive natural grass regeneration. The increased grass production could be utilised during limited periods of time and/or by limited number of cattle. When the land was privatised – this method of fencing spread rapidly to most individual farmers, since the good example was already there.

1 Participation

After initial contacts with local leaders a Participatory Rural Appraisal (PRA) was conducted with all involved stakeholders and local farmers/pastoralists. The local farmers/pastoralists decided together with the project on activities to be carried out. In the early days, 1980s and early 1990s, this concerned mostly areas of common use but designated for a special purpose, e.g. school compounds or church compounds. Later, after a governmental privatisation of land, it became more focused on individual farms. Intensive extension and dissemination of agreed upon methods and techniques, and the knowledge behind, were the key to the success. Also the fact that many good examples form "the early days" existed, e.g. school compounds, facilitated a rapid adoption of new methods and techniques among individual farmers. In the beginning of the project there was a need for hiring of local labour. This was done locally, which created respect and a positive attitude from local people. Extensionists employed needs a good educational background, but also good local knowledge on both natural and social conditions.

2 Fencing – Exclosure of Grazers

Fencing to keep grazing animals out during an establishing phase is essential. Fences were constructed with local material, twigs and branches from trees, and constructed with local labour. Once the tree seedlings are established and the grass has regenerated naturally, the grazing should be controlled, e.g. by cut and carry systems, by allowing limited grazing in time and number of animals.

3 Water Harvesting

In order to give tree seedlings a good start, water harvesting structures were established and trees planted or sowed immediately below. During rain events these structures often filled up with water, making it available for the seedlings for extended time. Water harvesting structures eventually filled up with soil, but not until trees were fully established and erosion checked by trees and grass. The structures were also constructed with local labour.

4 From School Compounds and Communal Land to Private Farms

The plantations started on communal lands like school and church compounds. A few years after the government of Kenya started to demarcate private land in the area. Farmers got private ownership with clear boundaries between neighbours. Very many farmers took up the example set by the project with fencing of their (or part of their) private land. Many also established water harvesting structures and planted/sowed trees.

5 Results

Tree establishment was very good. But even more impressive was the natural regeneration of grasses in this seriously eroded area. The only scientific quantification in the area (Nyberg and Högberg 1995) concludes the soil C increased in the plantations and that most of the new C came from the increased growth of grasses. The adoption of the methodologies among farmers, on their private farms, has been great and greatly influenced by the intensive extension by the Vi Agroforestry Project and by the successful examples established early by the project. The livelihood for many families has greatly improved. Through soil and water conservation, grazing control and good agroforestry bananas can now be grown where they could not even be thought of before.

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Bananas in West Pokot.

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Structure and Management of Complex Stands – Key Features and Study Methodology

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In even-aged single species plantation forests, it is sometimes sufficient to analyze and predict growth and yield in terms of simple stand attributes. Generally, diameter distributions and stem volume prediction is usually involved for deal with dimensions and timber products. In the management of indigenous multiple-species forests with complex structures and dynamics, the information needs are more intricate. Tree and species interaction, multiple layers and clustered spatial distributions, treatments, regeneration and other factors tend to constitute a system of mutual interactions which must be attended to in management for specific objectives. Some of the basic features, in all probability relevant for studies in miombo woodlands too, are introduced and demonstrated in terms of two studies in mixed uneven-aged stands. Outlines for potential applications in project activities are discussed.

1 Introduction

Given the vast extent of the ecosystems and their importance in rural livelihood and local economies (Campbell 1996), and articles by Hamza and Kimwer, Makonda and Gillah, Monela and Abdallah in this publication), remarkably little research efforts have been focused on the structure, dynamics, and management of the miombo woodlands of Africa. Uncontrolled, often illegal use, and over-exploitation of the resources has resulted in rapid deterioration in many areas. Economic, social, and ecological sustainability of the ecosystems is endangered. Current experience in Tanzania and elsewhere indicates that participatory management strategies have the potential of providing means to decelerate and even reverse the adverse developments (articles by Hamza and Kimwer, Lulandala and Chitiki, Makonda and Gillah, Nyberg, in this publication). The challenges are huge of course. 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 (Makonda and Gillah, Nshubemuki and Mbwambo, in this publication). Furthermore, the silvicultural information base for the development of feasible management regimes is often underdeveloped for Tanzanian (Nshubemuki and Mbwambo, in this publication) and other miombo areas (e.g. Chidumayo and Frost 1996, Musokonyi 1998).

Many extension efforts still tend to focus on disseminating technical tree-planting packages, while the true potential of miombo woodlands could probably be harnessed and developed in a much more cost-effective way through the utilization and management of the existing indigenous stands. Similarly, the approaches used to develop the management regimes for the plantation forests with their uniform structures, dynamics, and management regimes (e.g. Pukkala 1998, Valkonen et al. 2000) certainly would not work for the complex miombo stands. In miombo woodlands, analysis methods capable of accounting for the inherent and human-induced variability within the stands are needed. 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. Primary examples of successfulness of such applications are presented by Nshubebuki and Mbwambo, and Isango (in this publication).

The purpose of this paper is to introduce some approaches and methodologies of silvicultural and forest growth and yield research that could constitute effective tools for research and management in the structurally complex miombo stands. They generally consist of intensive measurements on permanent, semi-permanent, or temporary sample plots, including elaborate measurements on structurally and functionally important tree dimensions, tree growth, and regeneration. The 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.

The analyses are more or less related to modeling. Simulation for interpolation and prediction are often applied. The results can be communicated through computer illustration of the results of the analyses in terms of alternative treatments within the limitations of the data. One case study (Piirto and Valkonen 2005) with indigenous uneven-aged stands of Monterey pine (*Pinus radiata* D. Don) are used to demonstrate the methodologies and applications in this paper. The study was based on sample plots measured just once. Tree increment data was acquired through coring, and the regeneration survey represented just one point in time. Therefore, results from another regeneration data set from Finland (Ollikainen 2001), based on repeated measurements during a longer period, are also introduced.

2 Analysis Framework

The purpose of the research on complex stands usually is to provide tools for analyzing the stand dynamics both in great detail and as a system of mutual interdependencies:

1. What kind of stand structures and species compositions do the stands currently display?
2. How are trees of different species and sizes surviving, growing, and developing in stem form and wood products in the stands?
3. How much regeneration of different species is currently present ?
4. How much regeneration is established annually, how much of it survives, and how do the surviving individuals develop?
5. What kind of treatments would best promote the development of desirable trees (species, sizes, forms, products)?
6. What kind of management would be best in promoting the desired balance of wood and non-wood products, benefits and values on a sustainable basis?

It is comprehensible that such elements constitute a system where none of the elements is independent of the others. The basic elements at the top of the list can be, and usually are, initially analyzed one by one, providing the basic insight to the key constituent parts. However, as the issues become more complex and comprehensive down the list, the role of more general and flexible in terms of models tends become greater.

3 Stand Structure

Stand structure has three main components: species composition, tree size distribution, and spatial distribution. They are generally interdependent in terms of the ecological properties of trees, site, management, and other factors. The current stand structure is a product of past development. Numerical analysis tools may often provide useful information on selected features in detail. They involve different types of diversity and dispersion indices and spatial analyses, often utilizing geostatistics. A comprehensive insight in the essential attributes related to management goals is more useful for practical purposes. The number, proportion, and social and spatial status of individual trees of species, forms and sizes is the primary issue. There is also a link to considerations on what kind of growing environments would be best for the desirable trees to regenerate and develop.

Examples of tree size (diameter) and species distributions in the Monterey pine study are shown in Fig. 1. Note that Monterey pine was the central species to promote in this case. Other species were considered to have mainly adverse influences through competition for resources and growing space. Also note that only continuous-cover management is permitted in the area by regional forestry statutes.

Fig. 1A shows a typical complex, mixed structure where both Monterey pine, Douglas fir *(Pseudotsuga menziesii var. menziesii* (Mirbel) Franco), and broadleaf species consisting mainly of shade-tolerant oaks like Coast live oak (*Quercus agrifolia* Nee) and Shreve oak (*Quercus parvula var. shrevei* C. H. Muller). Lots of large and mid-size pine and Douglas fir is present, but the numerous small diameter classes are becoming dominated by the oaks. Since the primary goal with overwhelming priority is the sustainability of Monterey pine in the stand, structures like the one displayed in Fig. 1B would be much more favorable. In the lack of wildfires and management, many parts of the forest are becoming like in Fig. 1C, where Monterey pine is no longer capable of sustaining its presence due to broadleaf invasion resulting in complete canopy coverage and intense shading.

In terms of similar diameter distributions, the spatial distribution of trees of different sizes and species can be important. Fig. 2A illustrates the distribution on the plot shown in Fig. 1A. In this case the spatial distribution is randomly dispersed. In Fig. 2B, a plot with a similar diameter and species distribution, the spatial structure is strongly segregated by species.

In this way, the principal constituents of stand structure can be easily explored and demonstrated for management purposes. Index or geostatistics-based analyses were not considered worthwhile in the example study (Piirto and Valkonen 2005).

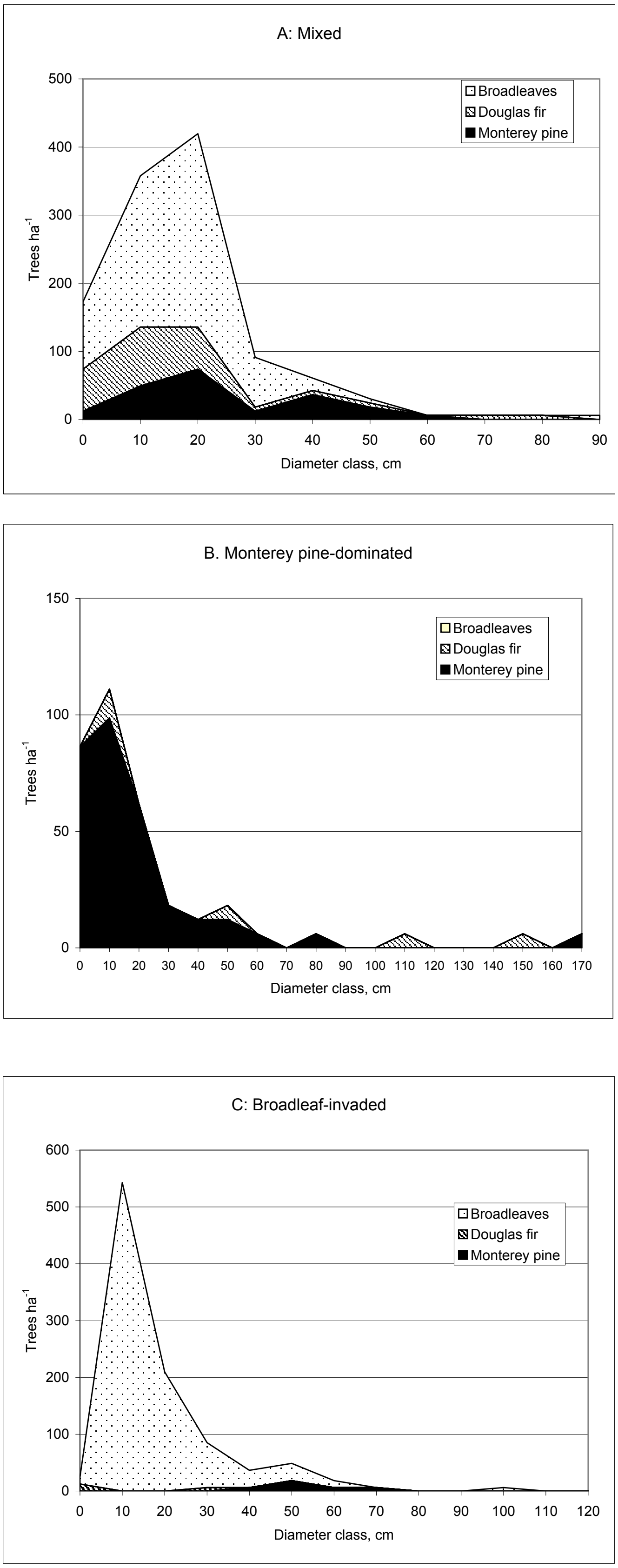

Figure 1. Examples of tree size and species distributions in native uneven-aged Monterey pine stands at Año Nuevo, California (Piirto and Valkonen 2005). Number and species category of trees by 10-cm diameter classes. A: Complex mixed-species structure. B: Almost pure Monterey pine. C: Broadleaf invaded.

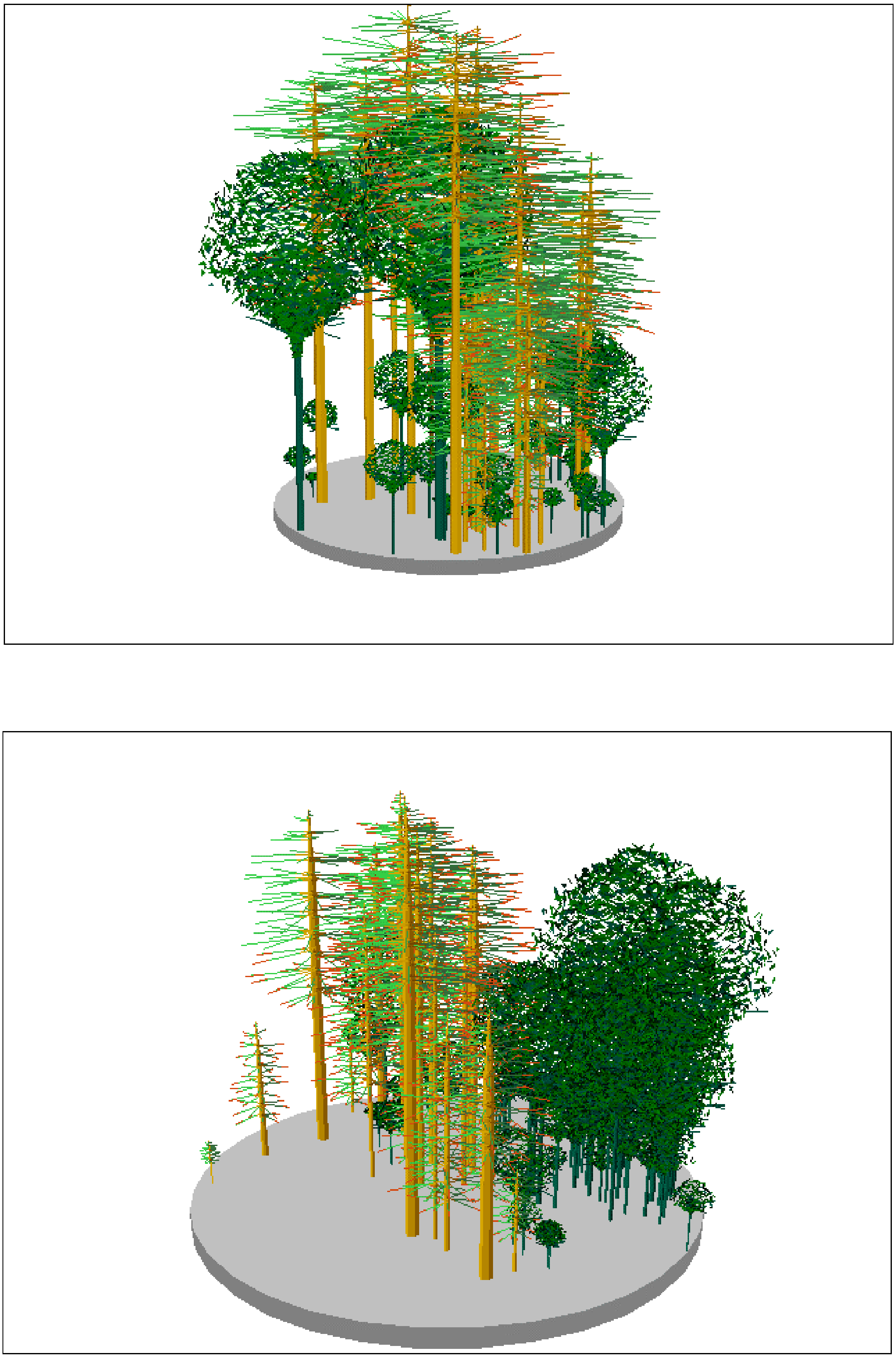

Figure 2. Examples of clearly different spatial distributions in terms of complex mixed-species diameter distributions as in Fig. 1A. Illustrations were produced with the Stand Visualization System by McGaughey (2001).

4 Regeneration

Regeneration is an essential component of the dynamics of structurally complex stands managed with continuous cover systems or regenerated naturally. In many cases, the emergence, survival, and vitality of advance regeneration of desirable species is a valuable asset in such stands. Its emergence and presence can be promoted in ways adapted according to the properties and requirements of the species.

In the Monterey pine study (Piirto and Valkonen 2005), a regeneration survey confirmed prior observations that the number of Monterey pine was critically low in the forest. The average number of seedlings and saplings was 45 ha^{-1}. Very few sample plots any Monterey pine regeneration at all (Auten 2000).

Although the result and the conclusion were clear in this case, one survey assessment is mostly not enough to reveal the dynamics of regeneration in complex stands, particularly when treatments are applied. Long-term monitoring on repeatedly measured sample plots is required. This is illustrated in Fig. 3. The number of Norway spruce seedlings constantly decreased in selection stands in southern Finland. A very abundant seed crop combined with a cool rainy summer resulted in plentiful regeneration in 1990. Average mortality and regeneration rates in the subsequent years then resulted in the decline. A single assessment at the beginning of the observation period would have yielded a grossly exaggerated perception of the regeneration potential in the stands.

Regeneration is most effectively surveyed on small plots distributed throughout the stand or plot area. They can be mapped for coordinates and used for spatial analysis and modeling together with the tree data. Additionally, the spatial distribution is also attended to at the same time. The number of empty (or stocked) plots is an essential parameter in addition to the total number of stems.

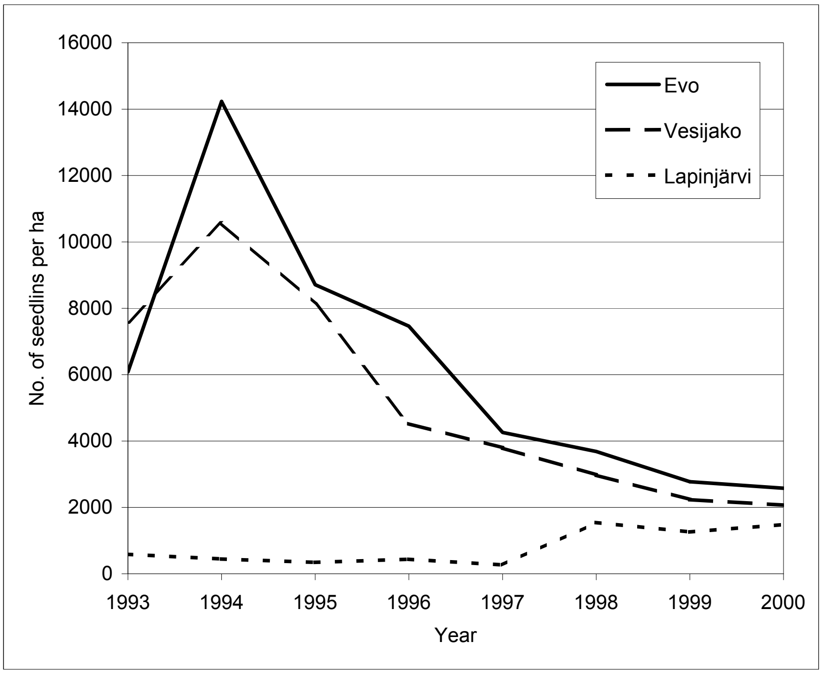

Figure 3. Average number of Norway spruce (Picea abies Karst) seedlings (height 3–10 cm) on the ERIKA sample plots in uneven-aged spruce stands in southern Finland in 1993–2000 (Ollikainen 2001).

5 Tree Growth

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. It constitutes the basis for the selection of trees to remove for revenue and for the promotion of the retained trees.

Fig. 4 shows that the maximum diameter and basal area growth rate for Monterey pine was observed at about 60–90 cm. The largest trees grew very slowly in comparison. Stand density had a very remarkable influence on tree growth. It was concluded that in order to promote Monterey pine, stand densities should be substantially reduced from the current levels (average 50, maximum 70 m^2/ha^{-1}). In addition to remove trees of the undesirable species, some of the largest pine trees could be removed to maximally promote pine growth.

Diameter increment data can be reliably acquired in terms of temporary sample plots through coring – where the trees produce pronounced annual rings. For instance, increment of the broadleaves could not be measured in the absence of rings in the Monterey pine study, despite the fact that the conifers showed distinct annual rings caused by the variation of dry and wet seasons. That is a common obstacle in with tropical conditions and species. Studies with growth bands (Nöjd and Isango 2003, and article by Nöjd in this publication) can offer a solution but through arduous work only.

Tree height data would be useful in studies on stand dynamics, because mutual shading is closely correlated with height differences. However, height increment data is much more difficult to obtain than diameter increment data. Additionally, there is a strong correlation between tree diameter and height within a species that heights can be estimated with sample trees and models (h = f(d)) in most applications.

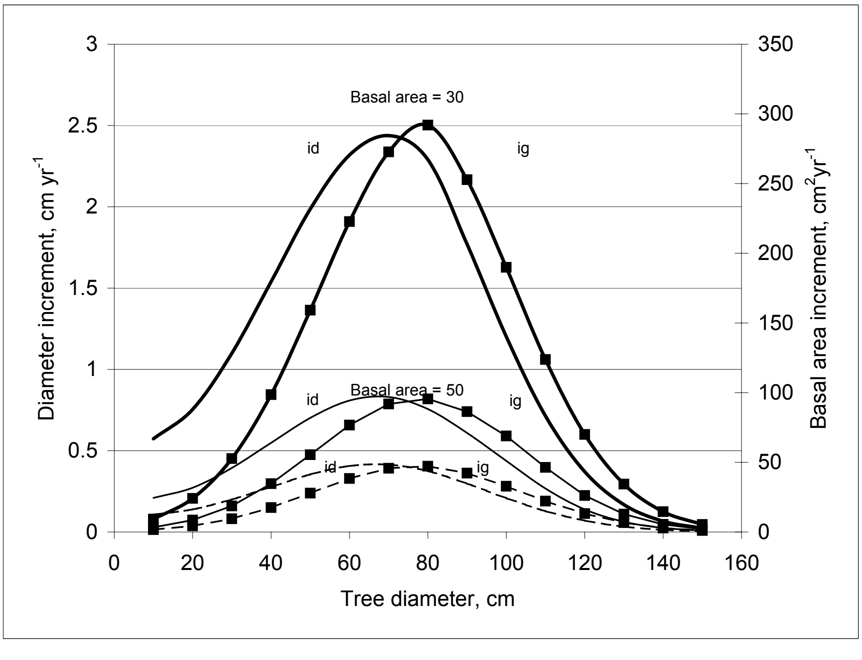

Figure 4. The effect of tree diameter and stand basal area on the diameter and basal area increment of Monterey pine trees (Piirto and Valkonen 2005). Stand basal area 30, 50, and 70 m^2ha^{-1}. id = diameter increment, ig = basal area increment.

6 Models

Modeling 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. 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).

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. This is clearly illustrated in Fig. 4. In model notation, this development can be described with two basic components:

$$\ln(i_g) = b_0 + b_1 d - b_2 d^2$$

Where
i_g = increment of tree basal area
d = tree diameter
$b_{i,\ i=1,n}$ = estimated parameters

ln transformation is often applied to as required case by case, i.e. here in the Monterey pine study (Piirto and Valkonen 2005).

Competition can be described with stand-level parameters (often basal area), or tree level competition measures, or a combination of both:

$$\ln(i_g) = b_0 + b_1 d - b_2 d^2 - b_3 G - b_4 CI$$

Where
G = stand basal area
CI = competition index

A multitude of tree-level competition index formulations is available in research papers. Basically, they attempt to describe the competition pressure that each individual tree is subjected through the presence of other trees in its vicinity. The indexes can be distance-dependent or distance-independent. Basically, a distance-dependent competition index is based on the principle that another tree causes a competition influence that is directly proportional to its size and distance from the subject tree like the very basic formulation of Hegyi (1974) as modified by Biging and Dobbertin (1992) and applied in Piirto and Valkonen (2005):

$$CI_{jm} = \sum_{j \neq m} d_m / d_j \left(s_{jm} + 1\right)$$

Where
CI = competition index for subject tree j, including competitors m
d_j = diameter of subject tree j
d_m = diameter of competitor tree m
s_{jm} = Distance from tree j to tree m

With such a simple formulation and parameters estimated with data from a set of temporary sample plots, results highly relevant to practitioners were produced in the Monterey pine study (Piirto and Valkonen 2005). In the absence of site index curves and applicable site classification systems, site was taken into account with stand-level random parameters. Secondary models were constructed for the prediction of tree height and crown width for illustration purposes. Separate models were constructed for each of the conifer species. As increment data could not be acquired for broadleaves through coring, their increment was predicted with the pine models. To estimate the potential influence of uncertainty in that prediction, sensitivity analyses were performed.

7 Treatments and Simulations

The constructed models can be used to examine various aspects of stand dynamics involving tree growth. Stand development subject to relevant treatments is an obvious application. In the Monterey pine study (Piirto and Valkonen 2005), the models were used to assess the potential benefits of treatment alternatives in the promotion of Monterey pine in the stands. The following treatments were applied to each sample plot:
1. No treatment
2. Group selection: Circular gaps of 24 m diameter (0.045 ha), where all trees were removed, except that small ($d \leq 25$ cm) conifers were retained. The purpose was to promote the growth of small pines and to initiate regeneration.
3. Single tree selection. Some (5–25 ha^{-1}) of the largest ($d > 60$ cm) trees were first removed, then a proportion of the large broadleaves was removed until the same plot basal area was achieved as was established in the gap treatment on that plot. The purpose was to promote existing Monterey pines with the highest growth potential (mid-sized), and to establish more favorable conditions for small pines, pine advance growth, and regeneration.

Fig. 5 illustrates an example of the treatments on one plot. The development of the stand on each plot in each alternative was then simulated for 20 years (i.e. for about one cutting cycle). There was no way to predict regeneration, and its role was ignored. Tree mortality was applied as an empirically defined maximum basal area limit (70 m^2/ha) with random mortality weighted by species.

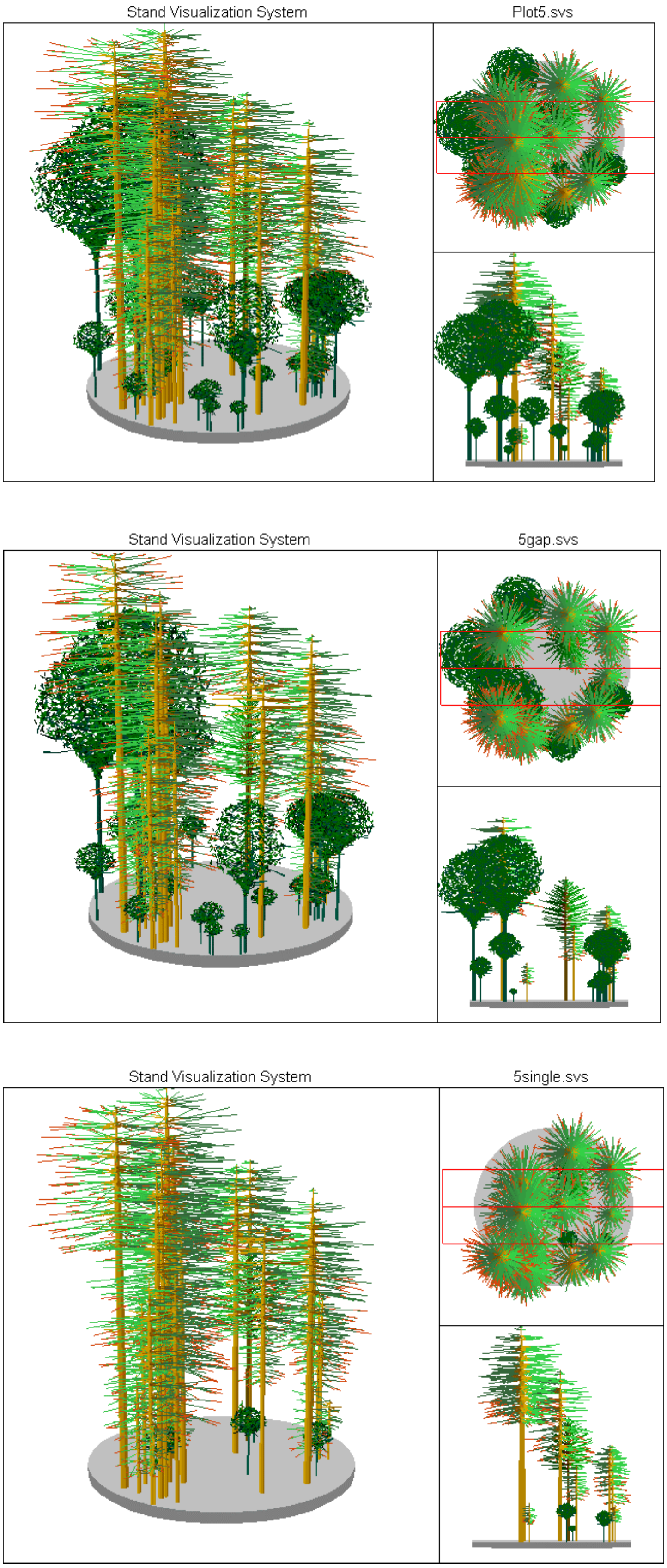

Figure 5. Examples of the treatments on one plot. A: No treatment: B: Group selection. C: Single tree selection. (Piirto and Valkonen 2005). Illustrations with the SVS system by McGaughey (2001).

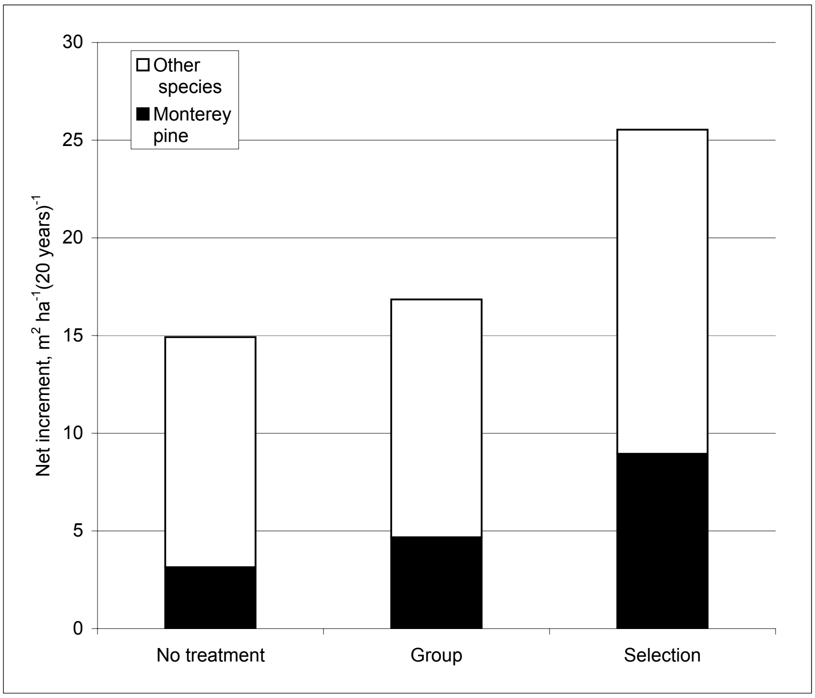

Figure 6. Net basal area increment by treatments and species groups for the 20-year simulation period (Piirto and Valkonen 2005).

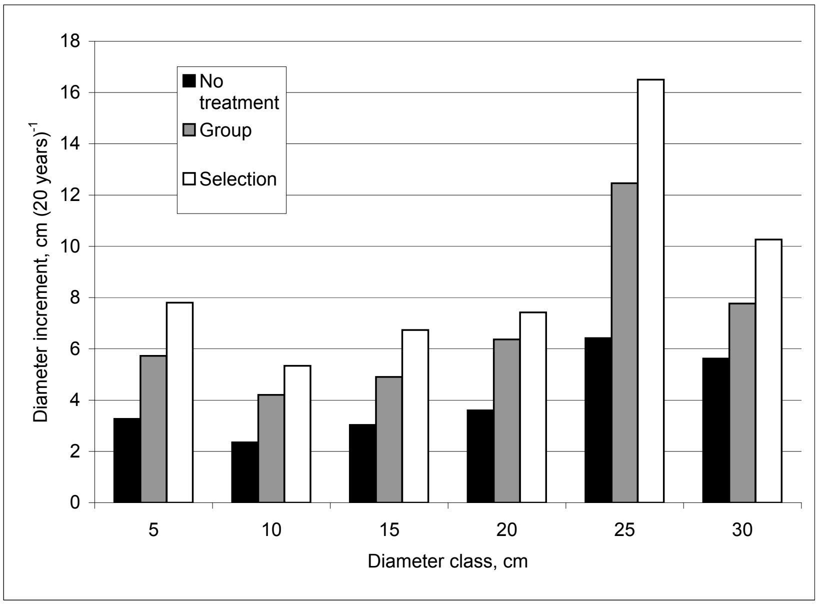

Figure 7. Average diameter increment of small Monterey pine trees by 5-cm diameter classes during the 20-year simulation period by treatments (Piirto and Valkonen 2005).

The basic results in Figs 6 and 7 indicated that group or single tree selection treatments are urgently required to promote Monterey pine in the stands. Single tree selection seemed a little more beneficial to Monterey pine than the group selection treatment. However, the analyses comprised the development of those trees already present in the stands, ignoring regeneration. Given the shade intolerance of Monterey pine, treatments with larger gaps may tend to be more efficient than single-tree or group selection in promoting regeneration. The most effective ways to promote regeneration will be an essential component of optimal treatments, given the critical lack of regeneration in the stands. Regeneration trials with various gap sizes and soil treatments were then initiated in the forests.

8 Conclusions for Analysis on Miombo Stands

The methodology applied in the Monterey pine study (Piirto and Valkonen 2005) must be modified to be applicable to analyses on miombo stands. That study was based on temporary plots, where tree increment data was acquired by coring. Very likely, that is currently not feasible with miombo species. Knowledge and experience on the formation of annual rings is almost totally lacking for them. Consequently, the plots must be at least semi-permanent with the measurements repeated at one-year intervals for at least a few years (3–5) to account for possible variations between years (if any). Of course, even a one-year observation period can yield data for rough initial estimates, but the results may be severely biased if tree increment for that year deviates markedly from the average due to weather conditions or other factors. Tree diameters must be measured with high accuracy to provide high-quality increment data. Growth bands may be useful.

The very large array of species makes the acquisition of relevant tree increment data applicable for general analysis and modeling a much more arduous effort than in mid-latitude forests. A number of observations are required to cover the range of variation of each variable in the model. The ecological and physiological properties and different growth patterns of trees add a multiplicative dimension to the task. Species may be aggregated into groups with more or less similar growth responses, for which a firm basis can be gradually established through accumulation of data and experience.

If accurate tree increment data can be successfully combined with an appropriate measures of competition (i.e. description of how different kinds of trees influence each other), modeling is a very powerful tool in describing the dynamics of stands with complex structures. The basic competition measures should account at least for stand density and tree size distribution. The utilization of spatial indexes is often beneficial, but not necessary. A multitude of different types and formulations of indexes is available for the enterprising researcher to explore and experiment with. A serious problem of the approach is that the evaluation of index performance and reliability of estimates is inherently very difficult (Ojansuu 1995) For instance, basal area of trees larger than the subject tree has often been a very good parameter which takes the relative dominance of trees into account in addition to stand density (Schütz 2001, 2006).

The establishment of regeneration must be accounted for in management systems based on partial cuttings and natural regeneration. Additionally, the development of regeneration, natural or artificial, must be described for any kind of system. The examples given above suffice to demonstrate that long-term observation of the dynamics of regeneration and the factors behind the developments is necessary for reliable prediction and action in practice. Treatments can be applied only when the basic features of the regeneration process are understood. That said, it is understandable that regeneration studies in miombo woodlands are far more intricate than for other types of environments: fires, herbivory, sprout and coppice regeneration, multitude of species, grass and grazing, and climatic and edaphic variations constitute a complex web of interactions which is very difficult to assess and manipulate for desired results.

Simulation with models constructed with empirical data can constitute very powerful tools for forest managers when the data basis is comprehensive (e.g. the Motti simulator in Finland; http://www.metla.fi/metinfo/motti/menu-esittely-en.htm). Simulators with limited data can also be interesting to researchers and practitioners for gaining a preliminary insight to stand structure and dynamics, basic management alternatives and their consequences in a flexible, computerized setting: Users must be made aware of the limitations of the models and the system as a whole – the constructor bears the responsibility for that. In the miombo environment, the type of forest management and silviculture that may optimally promote the goals of the various stakeholders in a specific situation is an extremely complex question, with equally variable applications as solutions. In terms of such a small-scale project as MITMIOMBO, we can only address one or two basic treatment principles on the experimental, leaving a large variety of alternatives aside. But it is not the specific treatments that are on trial and display, but principles and approaches, of which empirical modeling seems one of the most powerful ones despite the formidable challenges.

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Principal Ways to Promote Amelioration of Degraded Miombo Ecosystems in Semi-Arid Tanzania

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Miombo woodlands are representative of a significant type of dry deciduous woodland ecosystem found in semi-arid Tanzania. Management of the miombo woodlands in Tanzania has for many years been based only on timber harvesting regulations such as the allowable cut and minimum diameters. Information on silvicultural treatments is lacking and this has led to over-exploitation of commercially important tree species hence a need to introduce simple and cost effective methods for restoration of degraded miombo woodlands to be researched. Five treatments were applied in disturbed forest reserves of Urumwa and Igombe in Tabora to test their effectiveness in improving structure and species diversity of the woodlands. The applied treatments included: no treatment (control), selective felling, thinning, coppicing, and clearfelling with soil re-working. Species diversity indices were determined and compared for the two sites subjected to five woodland management options. The management options applied influenced species diversity to some extent. There is increasing vegetation heterogeneity with time in treated plots and to some extent to no treatment plots possibly due to reduced disturbances. However these plots require further observations for concrete conclusions and recommendations. Selection of any of these will largely depend on management objectives of a given forest.

1 Background Information

Miombo is an informal term used to describe the indigenous woodlands of central, southern and eastern Africa which are largely characterised by the three closely related genera of *Brachystegia, Julbernardia* and *Isoberlinia,* from the legume family Caesalpinaceae (White 1983). Muyombo in *Kinyamwezi* and *Kisukuma* languages in Tanzania refers to *Brachystegia spiciformis*. The miombo woodlands form part of the Zambezian regional centre of endemism which has about 8 500 species of which about 4 600 are endemic. According to White (1983) 19 species of *Brachystegia* and three species of *Julbernardia globiflora, J. paniculata* and *Isoberlinia angolensis* occur in miombo as dominants. In addition to the dominant tree species, some canopy associates such as *Pterocarpus angolensis* and *Afzelia quanzensis* are valuable timber species (Jeffers and Boaler 1966, Lawton 1979, Lawton 1980, Lawton 1982, Acres et al. 1984). Miombo represents the largest extent of savanna and contiguous woodland type in Africa, even perhaps globally (Frost 1996), and over 75 million people are estimated to live within this biome (WRI 1992). In regions where population pressures are high and arable land resources are limited, miombo woodlands are becoming an increasingly important element in complex systems of rural land use which integrate woodland management with crop and livestock production (Dewees 1996). Two classes of miombo woodland are recognised. First is the relatively dry miombo covering huge areas of central and east Africa between 15º South of the equator with less than 1000 mm annual rainfall. The second class is the wet miombo found in high rainfall areas (more than 1000 mm) with lower seasonality than the relatively dry miombo (White 1983).

1.1 Research on Principal Ways for Amelioration of Degraded Miombo

Management of the miombo woodlands in Tanzania has for many years been based only on timber harvesting regulations such as the allowable cut and minimum diameters. Information on silvicultural treatments is lacking and this has led to over-exploitation of commercially important tree species such as *Pterocarpus angolensis* and *Afzelia quanzensis*. After many years of unsustainable management, a six year bilateral project entitled Forest Resources Management Project (FRMP) was established in Tabora in 1993. The objective of the project was to bring some 400 000 ha of miombo woodlands under improved management. The term improved management in this context needs to be: ecologically and environmentally sound, based on sustainability and self-reliance, built on local knowledge and traditions, cost effective, within the technical capacity of the implementing agents, fit into and strengthen the local institutional structure, promote involvement of local people and built in mechanism for monitoring and evaluation in order to learn and continuously improve the management. Woodland management studies were established in Urumwa and Igombe Forest Reserves by the Tanzania Forestry Research Institute in 1996 to study the influence of stand manipulation techniques and fire on miombo regeneration and species diversity. This paper discusses the preliminary results on the effect of stand manipulation techniques on species diversity in the miombo woodlands of Tabora eight years after.

2 Materials and Methods

2.1 Study Sites

The study plots were laid out in Urumwa Forest Reserve (5º and 5.2ºS and 32.7º and 33ºE) and Igombe Forest Reserve (4º and 5ºS and 32.7º and 33ºE), respectively, about 15 and 30 km from Tabora Municipality. Urumwa and Igombe Forest Reserves cover about 130 and 2040 km^2, respectively.

2.2 Methods

Five 40 × 40 m plots were demarcated in 1996 and replicated twice, in Urumwa and Igombe Forest Reserves. Five treatments, appearing once in each plot were applied including: no treatment (control), selective felling, thinning, coppicing, and clearfelling with soil re-working. Data was collected on species density and number of species available in each plot for the past eight years. Diversity indices; Species diversity index (SDI), Shannon and Wierner index of diversity (H'), Dominance Index (λ), Uniformity Index (J), Species Richness (R) and Evenness (E) were calculated and compared between treatments in each site. The indices were calculated using the following formulae:

Species diversity index (SDI) = $\sum_{i=1}^{s} \log(n_i / N) / \log(1/S)$

Where:
n_i = the number of individuals of each species
N = the total number of plants of all species
S = the total number of species

Shannon-Wiener index H' = $\sum_{i=1}^{s} P_i \ln P_i$

Where
P_i = the proportion of total sample belonging to the ith species (i.e. $P_i = n_i/N$)
Species richness R = (S-1)log (N)
Evenness E = H'/log (S)

The index of dominance (λ) = $\sum_{i=1}^{s} (n_i / N)^2$

The Uniformity Index J = H'/ln(k), where k is the total number of tree species in the sample.

3 Results and Discussion

3.1 Species Diversity

Plant species diversity indices were determined for the two sites subjected to some management options. Eight-year (2004) assessments are presented in Table 2. SDI, H', λ, J, R and E were calculated for each treatment in both sites.

The indices have the following meanings:
SDI: high value indicates high species diversity
H': high value indicates high diversity
λ: high value indicates more or less homogenous vegetation
J: low value indicates high uniformity

SDI (Table 1) was high under no treatment, selective felling and thinning treatments in Urumwa, eight years after trial establishment. More diversity according to SDI was also recorded under thinning, no treatment and cleafelling plots in Igombe. was found to be higher under all treatments in Urumwa and was only recorded to be higher under thinning in Igombe. λ indicated high vegetation heterogeneity under clearfelling and coppice in Urumwa and under thinning in Igombe. J followed similar trend in the two sites. R was higher under no treatment, selective felling, coppice and thinning treatments in Urumwa while in Igombe it was higher under no treatment and thinning only. On the other hand E was high under coppice and cleafelling in Urumwa and under thinning and coppice treatments in Igombe indicating improvement in vegetation stability. According to Kohli et al. (1996), the higher the index of E and R, the more stable will be the vegetation.

Table 1. Species Diversity Index (SDI), Shannon and Wierner diversity index (H'), Dominance Index (λ), Uniformity Index (J), Species Richness (R) and Evenness (E) in Urumwa (U) and Igombe (I) Forest Reserves, Tabora Tanzania at eight years.

Treatment	Site	SDI	H'	λ	J	R	E
Clear felling	U	19.70	2.62	0.09	0.91	9.86	2.09
	I	10.40	1.52	0.31	0.73	4.16	1.68
Coppice	U	19.51	2.65	0.09	0.92	10.47	2.11
	I	15.12	2.18	0.15	0.85	6.83	1.96
Thinning	U	25.91	2.55	0.11	0.83	10.27	1.90
	I	21.50	2.77	0.08	0.92	10.40	2.13
Selective felling	U	28.42	2.60	0.12	0.83	10.72	1.91
	I	16.50	1.65	0.36	0.64	7.44	1.48
No treatment	U	29.10	2.68	0.10	0.83	12.11	1.91
	I	21.36	2.28	0.16	0.71	10.92	1.63

Table 2. Provisional influence of stand manipulation treatments on ecological indices at Urumwa and Igombe Forest Reserves, Tabora Tanzania.

Treatment	Year	Ecological Indices					
		SDI		H'		λ	
		Urumwa	Igombe	Urumwa	Igombe	Urumwa	Igombe
	1997	18.94	4.28	2.23	2.00	1.00	0.79
Clearfelling	1999	21.35	18.92	2.84	1.63	1.24	1.00
	2001	24.93	17.58	2.85	2.25	0.08	0.15
	2004	19.70	10.40	2.62	1.52	0.09	0.31
	1997	9.25	10.49	2.02	1.98	1.00	1.00
Coppice	1999	19.84	22.35	2.19	2.04	1.02	1.00
	2001	23.31	14.71	2.30	1.97	0.15	0.19
	2004	19.51	15.12	2.65	2.18	0.09	0.15
	1997	12.52	8.53	2.54	1.91	1.04	0.43
Thinning	1999	31.58	18.90	2.75	1.50	0.99	1.00
	2001	27.36	20.31	2.47	2.04	0.14	0.20
	2004	25.91	21.50	2.55	2.77	0.11	0.08
	1997	16.14	13.83	2.39	2.20	1.00	1.00
Selective felling	1999	29.48	12.90	2.97	2.13	1.04	1.00
	2001	28.80	16.04	2.72	2.11	0.09	0.15
	2004	28.42	16.50	2.60	1.65	0.12	0.36
	1997	9.36	9.32	2.10	2.30	1.00	1.00
No treatment	1999	21.56	18.23	2.56	2.29	0.89	1.00
	2001	24.26	10.61	2.49	1.81	0.08	0.22
	2004	29.1	21.36	2.68	2.28	0.1	0.16

Assessments for 1997, 1999, 2001 and 2004 are presented in Table 2 for comparison. There is a clear indication on change in diversity indices under different treatments in the two sites.

SDI increased steadily under no treatment in Urumwa and remained relatively stable for other treatments eight years after trial establishment. In the Igombe site, SDI increased steadily under thinning treatments and other treatments recorded reductions in diversity from the intermediate years, but still higher than it was eight years ago. Human disturbance may have contributed much on the decrease in species diversity in these two sites due to cutting of young trees for fibres and as withies for house construction. H' followed similar trends in the two sites. According to Mussanhawe et al. (2000), H' index of diversity alone cannot be used to compare biodiversities of different sites because it is constrained by the number of individuals that occur in both sites and the sample size. J takes into account the number of species at a site and exaggerates the differences when comparing areas with low number of species. There was decrease in values of λ under all treatments in all sites, indicating high diversity and heterogeneity of the vegetation with time. SDI and λ are inversely related (Kohli et al. 1996). Generally thinning selective felling and no treatment gave high species diversity indices in all sites. For no treatment plots the improvement in species diversity may have been contributed by reduced disturbance due to frequent visits to the plots.

4 Conclusions

The eight years results have indicated preliminary response of the vegetation to the treatments applied. Higher diversity observed under different treatments is an indication of increased stability of the vegetation with time through application of different management regimes. There is a clear indication on change in diversity indices under different treatments in the two sites. Stand manipulation techniques have shown potential to improve woody plant species diversity in the miombo woodlands of Tabora. The management options applied has influenced species diversity to some extent for the past eight years. However these results can not be conclusive, as the differences seem not to be treatment specific. The eight years results, however, have indicated preliminary response of the vegetation to the treatments applied. Higher diversity observed under different treatments is an indication of increased stability of the vegetation with time. Samir (1997) observed the tedious nature assessments, which thwarts the number of replications on its little influence on Shannon and Wierner Diversity Index. Selection of the best treatment will largely depend on the goals of any miombo woodland management. Other treatments such as fire and exclusion of herbivores are recommended for further research.

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The Girth Band Method as a Means for Studying Radial Growth at Short Time Scale

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Different types of equipment for studying the short term increment of tree diameter are demonstrated. These include automatic measurement systems consisting of electronic girth bands that record tree circumference changes to within 0.01 mm. When combined to a data logger these can be used for continuous monitoring of tree diameter and even for monitoring the daily oscillations of tree diameter. Manually read girth bands are also able also measure circumference changes with high accuracy (to within 0.1 mm). When read at sufficiently short intervals, they can provide excellent data on the short-term growth of individual trees. The use of girth bands in the MITMIOMBO project is discussed.

1 Introduction

Girth bands are a widely used method for monitoring the increment of tree diameter. Depending on measurement interval, they can be used for studying annual, monthly, daily, or even hourly tree growth. While the measurements are not especially complicated, a fairly large amount of work is required for producing a sufficiently long time series. As a result, our knowledge on the typical growth patterns of forest trees is fragmentary, even for important tree species and for areas with a long tradition of forest research.

Girth bands are mainly used for producing basic knowledge about diameter growth. However, the findings may have practical applications. In tropical conditions, where the basic annual growth pattern is not self-evident, knowing the typical period for diameter growth is helpful in planning experimental studies. Nöjd and Isango (2003) studied the growth of *Pinus patula* at Kiwira, Tanzania at an altitude of 2300 m above sea level. They discovered that the species had a short period of growth cessation during July-August. Thus, in order to accurately monitor annual growth, permanent plots should be remeasured during those months.

Repeated measurements of tree dimensions on permanent experimental plots yield accurate results rather slowly. If results on diameter increment are needed more quickly, girth bands are worth considering.

2 Manual Girth Bands

In its simplest form, girth band is a measurement tape that is fixed permanently around a tree stem. If the readings are taken at sufficiently short intervals, it will yield a time series on the development of tree diameters. This type of manual girth band is inexpensive and easy to use. Technical problems are unlikely, although interference by animals or humans might happen. The accuracy is sufficient for most purposes: changes of tree diameter can be recorded to within 0.1 mm.

The main disadvantage with the manual method is the amount of work: each data recording requires a visit to the forest. In addition, the data has to be entered into a compured manually. The data will seldom have a sufficient time resolution to enable analyzing the daily changes of tree diameters.

3 Automatic Girth Bands

Automatic girth bands are electronic devices, which automatically record changes of tree circumference at regular intervals. They typically reach a somewhat higher accuracy than manual ones, roughly to within 0.01 mm. If needed, a very short measurement interval can be chosen.

In addition to periodic growth, automatic girth bands will yield information about reversible short term changes of tree diameter. Trees generally show a rather regular diurnal pattern: graphed against time, the daily diameter changes resemble a sine wave (Fig. 1). The phenomenon is related to transpiration. The peaks occur during the night, when relative air humidity tends to be high. During the day transpiration tends to be high; thus, the low points of the curve invariably occur during the day.

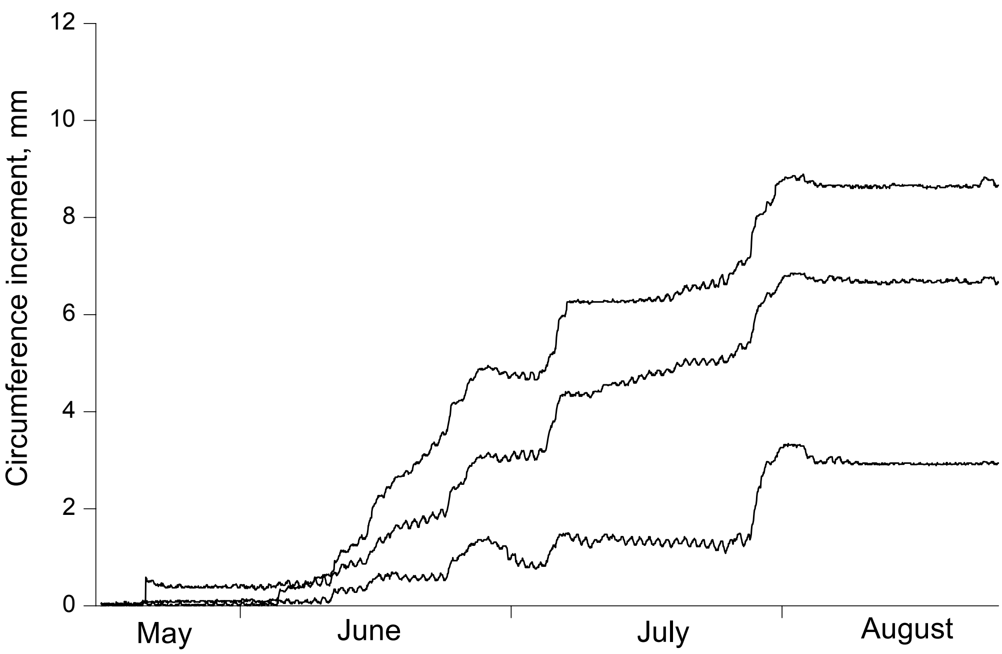

Figure 1. Diameter increment of Scots pine in Southern Finland in 1998. The species has a thick bark, which explains the rather strong swelling, observed during periods of heavy rain. Note the frequent sine-wave type of reversible changes in the growth curves.

Being able to measure the daily shrinkage and swelling, or the absense of it, will add to the value of measurements, especially if basic meteorological data is also available.

Fig. 1 shows a typical annual pattern of circumference increment in the conditions of Finland. After a heavy rain, tree diameters tend to increase rapidly. After such increase, the daily pattern of night-time swelling and day-time shrinking typically disappears for several days. In the more temperate conditions of Germany, a prolonged drought may also cause the daily sine wave pattern to disappear for several weeks during growing season. This type of observations were made during the severe drought of late summer 2003, which also caused severe reductions of annual growth.

Automatic girth bands also have disadvantages. The cost of the equipment is high. One needs a data collector (data logger), which adds substantially to the expenses. A laptop computer is needed for collecting the data in the field. In addition, there are the costs of electric cords and other consumables.

An even more severe handicap are the technical problems that seem to occur frequently. Lightning may cause voltage peaks that damage or totally destroy the data logger. Rodents like to chew the electric chords. In conifers, resin flow may cause the bands to get stuck. Excessive dust can influence the performance of the bands. Human interference can also be a source of problems.

4 Girth Bands in MITMIOMBO

Within the framework of the MITMIOMBO project, girth band measurements serve three important purposes:

- The girth band results will be used for calculating the annual growth of the trees on the permanent plots. The growth of the girth band trees will be generalized to produce a growth estimate for those trees that are not equipped with bands. Comparing diameter and height data from different time points will eventually produce results on annual growth. Given the short duration of the project, this approach would not be sufficiently accurate during the duration of MITMIOMBO.
- Knowing the annual growth pattern will be useful for planning the remeasurement of the experimental plots. At present, we do not know, whether the miombo trees grow continuously in the conditions of Tanzania. If a period of growth cessation (or even a period of slow growth) is discovered, it makes sense to remeasure the permanent plots during that time.
- The response of the sampled tree species to ecological attributes can be studied. Differing reactions to climatic events could be discovered between species. Some species might show a cessation of growth during dry periods, while others might not. The recovery of growth after such events could have a different timing. Obviously, these type of differencies would provide information about the drought sensitivity of the species. The observed growth patterns could also be linked with other phenological events.

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Interaction and Communication with Local Communities, Farmers and Tree Growers and Organizations on the Management of Miombo Woodlands: Experiences and Suggested Applications in MITMIOMBO Project

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The miombo woodlands are used in a diversity of ways that influence biodiversity and ecosystem stability most of which threaten woodland and agro-ecosystem sustainability. Local communities, farmers, tree growers and various organizations are among the key stakeholders in the management of the miombo ecosystem. This paper summarizes some of the results of different stakeholder involvement in the management of miombo woodlands. It highlights some important issues related to stakeholder involvement, the role they play with respect to interaction and communication and the constraints they face in reaching the targets. The results of these approaches can be translated to provide some useful suggestions and guidelines in the management of miombo woodlands elsewhere.

1 Introduction

More than ninety percent of Tanzania's forested area is covered by savanna woodlands. The woodlands show a varying degree of tree cover, and many terms are used to make distinctions, such as "closed woodlands", "open woodlands" and "wooded grasslands". A common term for most woodlands is "miombo woodlands". "Miombo" is a name used by the Wanyamwezi people for the *Brachystegia* trees that are very common in the woodlands, often being dominant or co-dominant with species such as *Julbernardia* and *Acacia*. According to Voss (2000), the miombo woodlands usually feature more or less as scattered trees of low stature (12–18 m.), and the ground is covered with grasses, herbs and (often thorny) scrubs. These woodlands occupy terrains from almost sealevel to 1600 metres above sealevel with annual rainfall between 500 and 1200 mm and mostly with one rainy season. They are widespread on Tanzania's central plateau and are part of a greater "miombo zone" in eastern and southern Africa. Tree species of the miombo woodlands are fire resistant to some degree, and fires occur frequently either induced by humans or naturally. Termite mounds are often found in valleys in the miombo woodlands, harbouring a more succulent vegetation of trees of such genera as *Pterocarpus* and *Dalbergia* presumably due to a higher level of nutrients in the soil created by the insect activity.

The forest resources of present-day Tanzania are the focus of much attention from various directions. Peasants, city dwellers, foresters, state officials, NGOs, private firms, national and foreign development organizations, researchers, the media and the general public all seem to be concerned, in one way or another, about the development and management of the miombo forest resources (Voss 2000). Because of the complexity in the source uses and associated balances, sometimes conflicts arise between the various stakeholders. Thus there is a great need for transparency and effectiveness in communication and interaction between the various stakeholders and other institutions at various levels. The miombo woodlands are among the ecosystems that are subjected to very heavy encroachment by the surrounding communities, especially in the rural areas. In Tanzania, the woodlands are being cleared at a faster rate than the scale that would maintain sustainable yield to meet the various needs of the growing population (Monela et al. 1993, Mangora 2005). One way of reducing pressure on miombo woodlands and promote their conservation is by growing more trees on community and public land to meet the basic community needs for forest products, at the same time saving some parts of the country from a threat of desertification (Nduwamungu et al. 2004). That exercise can not be successful without proper coordination mechanisms between the various resources users. This paper, therefore, summarizes some of the findings by different researchers and gives some highlights on the lessons that can be derived from them.

2 Local Community Involvement in Forest Management

2.1 Joint Forest Management Approach

This case study was conducted by Zahabu (2006) at Kitulangalo area, which is 50 km to the east of Morogoro town on the side of the Morogoro-Dar es Salaam highway. The high level of accessibility to the highway made this area a prime charcoal production area for the supply to the nearby Morogoro municipality and the city of Dar es Salaam. Timber and building poles extraction was another business threat to the forest of that area. The National Forest Department didn't have enough manpower to control the illegal activities such that the area was an open access area. In 1995, part of the forest (about 600 ha) was given to Sokoine University of Agriculture (SUA) to be used for training and research purposes, although protection was the major goal. This part of the forest is under Joint Forest Management (JFM) with Gwata village; the village amongst other villages near to Kitulangalo forest. By JFM it means that the land is still owned by the government, but the management is mainly in the hands of the local communities, following jointly prepared management guidelines. In the year 2000 another 420 ha were demarcated for the village community, and is now called Kimunyu village forest reserve. As a community forest, the land is now the property of the village, which has full responsibility for its management. SUA manages the training forest jointly with the village government through the village environmental committee. The university employs two members from the committee as forest guards.

2.2 Results of an Approach

The result is that, currently there is higher tree stocking in managed forest reserve compared to adjacent unmanaged public land that is under open access management. The improving health of the forest can also be explained from carbon stock viewpoint. In Gwata village, six persons (four women and two men) were trained in mapping and forest inventory techniques according to *Kyoto: Think Global Act Local* project with the help of the two guards employed by the University.

Over the period of one year, management activities have resulted to a considerable tree stock increase (Table 1). Although the number of stems per hectare (N) has decreased, tree volume has increased, and therefore the biomass and corresponding carbon. These results show that community involvement is vital in conservation and management of miombo woodlands.

Table1. Stand parameters of the forest at Kitulangalo.

	Year	N	V (m^3/ha)	Biomass (t/ha)	Carbon (t/ha)	Area (ha)
Training	2005	695	55	35.2	17.2	600
Forest	2006	639	63	39.3	19.3	
Kimunyu	2005	846	78	40.5	19.8	420
	2006	817	88	45.0	22.1	

Source: Zahabu (2006)

Table 2. Estimated local transaction costs for monitoring carbon.

Activities	If carried out only by professionals		If carried out only by local communities with a little assistance from professionals				
				Cost (euro)			
	No. of Days	Cost (euro)	No. of Days	1st Year	2nd Year	3rd Year	4th Year
1. Pilot and inventory planning	3	640	10	2597	1343	525	
2. Field Assessment							
- Kitulangalo SUATFR	10	2475	10	2597	1800	1470	975
- Kimunyu VFR	6	1460	6	1575	1080	915	585
- Without Project Case	5	1210	5	1312	817	653	375
3. Data punching and analysis	10	2250					
4. Consultation fees							
- Inventory specialist	34	6120					
5. Institution fees (10%)		1410					
Total		15565	31	8081	5040	3563	1935

Source: Zahabu (2006)

Measuring biomass stock to determine changing carbon stock like other forest management programmes involves costs. At Kitulangalo the costs involved were recorded. A comparison of costs of carbon assessment by local communities against the professionals revealed that, it costs twice as much to hire professionals for carbon assessment in the village forest studied compared to when you use the local people including the cost of training which is considerable in the first year of assessment. It is expected that the villagers will be able to undertake the same work at progressively lower cost in the preceding years as the costs for training and supervision is reduced (Table 2).

These results provide an evidence that community involvement in management of miombo woodlands, both under Joint Forest Management and in full community forest management, have resulted in a significant reduction in degradation together with significant increases in sequestration of carbon in both types of forest in Kitulangalo.

The local transaction costs, though much lower than costs of professional measurement and monitoring, represent insignificant proportion of the likely financial benefits. However, this margin of profit is particularly important since the other benefits (i.e. financial benefits from such forest management) are small. This is because the government has banned charcoal production and therefore this source of income does not accrue anymore.

This case study provide an evidence that carbon as a "non timber forest product" could offer a real incentive for this community to continue with its forest management activities, and for more communities to become involved in managing their forest taking into account the global effort to mitigate atmospheric carbon.

Concern about miombo woodland management is partly rooted in the growing perception of the importance of these areas to rural households and communities. Because of their high degree of dependence on miombo areas, there is an increasingly widespread view that their long term conservation and management can only be assured if communities are brought more actively into the management process, and if rights of use and access are assured through legislative and policy reform (Dewees 1994). Therefore sustainable management of this ecosystem can only be achieved through proper planning on utilization regimes.

3 Role of Communication and Interaction with Farmers and Tree Growers

The management of miombo woodlands cannot be fully successful without proper involvement of farmers and tree growers in different agro-ecological systems. Miombo being the major source of forest products (i.e. fuel wood and building poles) as well as potential areas for shifting cultivation (Malimbwi et al. 1998) makes it vulnerable to disappearance because of altered ecological processes.

Village afforestation programmes, smallholder forestry and agroforestry practices can provide wood requirements to the rural communities hence reduction of pressure to miombo woodland. One way of achieving this is through *on-farm* and *of-farm* training thus a need for effective communication. Communication and interaction with farmers and tree growers is one of the essential aspects in understanding the constraints the farmers and tree growers face in carrying out tree planting practices that would reduce pressure on miombo woodlands.

Many researchers have reported the importance of farmer training on sustainable conservation and utilization of miombo woodlands. Lusambo (2002) reported on inadequacy of extension education as one of the constraints hindering tree planting and environmental conservation in Tanzania. Likewise, Zahabu (2001) reported the need to assist charcoal makers with training for greater efficiency of charcoal making process as well as sustainable charcoal production and supply from the woodlands.

A study carried out by Nduwamungu et al. (2004) revealed that tree planting is positively correlated to farm size and level of education. Therefore farmers and tree growers need more training on the better methods of raising trees from the nursery stage up to the field condition including all necessary tending operations. Gender and age were also found to have effect in tree planting. Men headed households tended to have more planted trees than females headed households. Moreover, middle age households plated more trees than younger and older households. Lack of sufficient seedlings has also been reported to be one of the constraints in carrying out village afforestation (Nduwamungu et al. 2004, Lusambo 2002).

Research can play a useful role in the societal discourse provided that it can accept that it produces results which are relevant for the society, learn from other groups of society and be able to communicate with actors who are in a better position to effect change (Herweg et al. unpublished). Therefore research works on sustainable management of miombo woodlands should always consider the opinions of those stakeholders (i.e. farmers, tree growers and eventual users of planted trees) and take them into account throughout the entire research work. Through communication and interactions the constraints of farmers and tree growers in tree planting programmes can better be understood and plans can be developed to tackle the problems. Therefore there is a great need for communication and interaction between other stakeholders including forestry experts with farmers and tree growers to enhance management of miombo woodlands. The MITMIOMBO program, therefore, should lead the way in that direction.

4 Participation of NGOs and CBOs

NGOs are non-governmental organizations, run by people who in theory are independent of government. According to Walubengo and Obare (1996), NGOs work at two levels: at the community level, they are small informal organizations, often invisible to the outsiders. They hardly receive external support. These Community Based Organizations (CBOs) remain outside formal structures. Some examples of CBOs are women groups, youth groups, farmers groups, village development committees, water users associations, forest users groups, farmers groups, pastoralists groups and self-help groups. Generally speaking, the activities of CBOs are limited to the local level and hardly have any influence on the national political process. The second level of NGO intervention is at higher level: national or international. These provide services to communities directly or through CBOs and other NGOs. They offer a variety of services, some very specialized. Some are purely charity or service organizations, while others look for a more political role.

The NGO community in East Africa faces a severe challenge in the management of natural resources and yet many of NGOs and CBOs have the institutional capacity to face these challenges with confidence. As the role of NGOs and CBOs is to support social welfare and development of the people especially the rural poor, it is necessary that they build enough capacity to operate effectively and to cope with emerging problems of trade liberalization. As already pointed out, the natural resources are under greater utilization pressure. This pressure cannot only be felt in the rural communities but also in other areas. This is attributed by political and social changes worldwide. Enhancing the capacity of NGOs and CBOs could be very useful in the efforts of sustainable management of miombo woodlands under a proper coordination following principles of stakeholder analysis.

5 Role of Forestry Extension

One of the crucial aspects in achieving the desired outputs in sustainable management of miombo woodlands is through proper extension services. Forest extension is an important tool in helping people obtain the products and services they need from trees and to better manage remaining natural forests. The basic tasks of forest extension are to work with researchers, farmers and communities to help generate appropriate technologies, built up individual and community abilities to develop themselves, and help to diffuse the technology to others.

In order for the extension programmes to work effectively the following should be the key issues to focus on:

1. To whom should extension be focused?
   Communities, institutions and individuals within or without public forestlands are the focus of extension programmes. Small-scale farmers and the landless are the highest priority of both individual and communal forest extension.
2. How should technology be extended?
   Participation is a key to successful extension. Participatory methods should be used from problem identification, examination of alternative solutions, project implementation and monitoring and evaluation. Mass communication, demonstrations, cross-farm visits and brochures are some of the forest extension methods often used. Meetings (Workshops) among the researchers, extensionists and beneficiaries are important to promote continuous and effective communication, ensuring appropriate technology keeps pace with change. Learning from past experiences through analysis of success and failures are important part of these meetings.
3. Who should do extension work?
   Forest employees (experts) are responsible for carrying out forest extension services and will depend on an increase in both their quality and quantity. Because of the limited resources the government has, forest officials may collaborate with other government agencies and non-government organizations.
4. What should be extended?
   Technology, which can provide economic, social and ecological benefits to successful extension.

Forest extension is an important tool in the effort to provide people with what they need from trees and forests and to better manage remaining forests. Participatory extension methods are the most effective methods of carrying out extension activities.

6 Concluding Remarks

Sustainable management of miombo woodlands requires an understanding of the linkages that exist among different stakeholders in terms of their interests. Such understanding requires a critical analysis of the roles the stakeholders play. Communication and interaction among the stakeholders is the proper way of understanding the common interests among themselves that will lead to establishment of a common understanding on sustainable management of miombo woodlands.

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Principal Ecological Issues with Significance in the Management and Restoration of Tanzanian Miombo Woodlands

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1 What are Miombo Woodlands?

Miombo woodlands are a woody vegetation type normally dominated by the woody species of the *Fabaceae* family in the subfamily *Caescdpinioicleae*, particularly of the genera *Brachystegia*, *Julbernardia* and *Isoberlinia*.

On the African continent, these woodlands cover a total area of about 2.8 million km^2 that extends a central belt from Tanzania to the Democratic Republic of the Congo, on the northern part through Angola, Zambia, Malawi, Zimbabwe, and Mozambique in the south. On a global scale, the ecology of miombo ecosystems is closely related to that of the Cerrado of South America,. the dipterocarp woodlands of south-east Asia and the monsoonal tallgrass eucalypt woodlands of northern Australia.

In Tanzania, forests and woodlands cover about 34,6 million hectares of which 90% (approximately 31 million ha) are miombo woodlands, occupying mainly the western, southern, central and eastern zones.

2 Ecological Features Charecterizing the Miombo Woodlands in Tanzania

The miombo woodlands occupy the subtropical regions characterized by low and often intermittent rainfall (i.e. 700–1400 mm annually), high temperatures (i.e. 8–23°C) with increasingly extended dry periods (i.e 5–7 months per year). The miombo soils are generally infertile with low cation exchange capacities – the uplands are predominantly alfisols, oxisols and ultisols and the bottomlands are predominantly gleysols and vertisols. Most of the trees are deciduous but produce new leaves before the rains, thus, drawing on substantial internal reserves. The woodlands are characteristically uniform over the broad regions, comprising of an upper canopy of umbrella-shaped trees, occasionally with a scattered layer of subcanopy trees and a discontinuous understorey of shrubs and saplings with a patchy herbaceous layer of grasses, forbs and soffrutices. This uniformity reflects the remarkably similar physiognomy of the dominant canopy trees – broad-leafed, thornless – of the subfamily *Caealpinioidecre* of the family *Fahaceue*. The grasses mainly comprise species in the family *Andropogomeae*.

Differences in structure and species composition occur along rainfall gradients. The wetter miombo (i.e. mean annual rainfall > 1000 mm) cover the south-western parts of Tanzania with tree canopy height > 15 m. The dry miombo occur in central Tanzania (i.e. mean annual rainfall < 1000 mm) with tree canopy < 15 m in height.

Woody plants make up more than 95% of total plant biomass in mature woodlands but grasses predominate in dambos (swamps). The dominant tree genera are all ectomycorrhizal.

The biomass of, and consumption by, indigenous large herbivorous mammals is generally low. Consumption by herbivorous invertebrates is generally low though episodic outbreaks occur every few years.

While a smaller percentage of the woodlands is reserved and protected, most of them remain public with free access by everybody. Miombo ecosystems are surrounded by continually escalating poverty stricken human populations with high dependence on the forests for the direct and indirect benefits e.g. farmland, various wood and non-wood forest products (firewood, charcoal, building poles, timber, fruits, medicines, vegetables, honey, mushrooms, water etc.), meat and other animal products from livestock and wildlife. They do also have unique environmental and biodiversity values. Fire is of annual recurrence and has become very important, both as an ecological factor and as a management tool.

3 Principal Issues of Significance in the Management and Restoration of Miombo Woodlands

The climatic and edaphic conditions limit the level of development and productivity of the woodlands. The deciduous and ectomycorrhizal nature of the trees promotes nutrient cycling and absorption. Dry-season leaf-litter fall, and dry herbaceous layer promote recurrent annual fires. Prescribed burning or controlled grazing could help to reduce fire incidences and associated devastations.

The low level of protection, permitted free access, the escalating human and animal populations around the miombo woodlands and their high capacities to provide a diversity of goods and services cause severe deforestation and environmental degradation. Communities continue to covert forests into farms through most wasteful shifting cultivation. Community dependence on wood and non-wood products and services from forests.

These exists limited free access into the forests by gazettement of public land forests and enforcement of laws and bylaws. Forest conservation programmes are ex-situ directed and community focused through species domestication and agroforestry management. Institutionalizing of various forest product controls e.g. products' certification, products' pricing based on actual value, judicious application of sustained yield management principles.

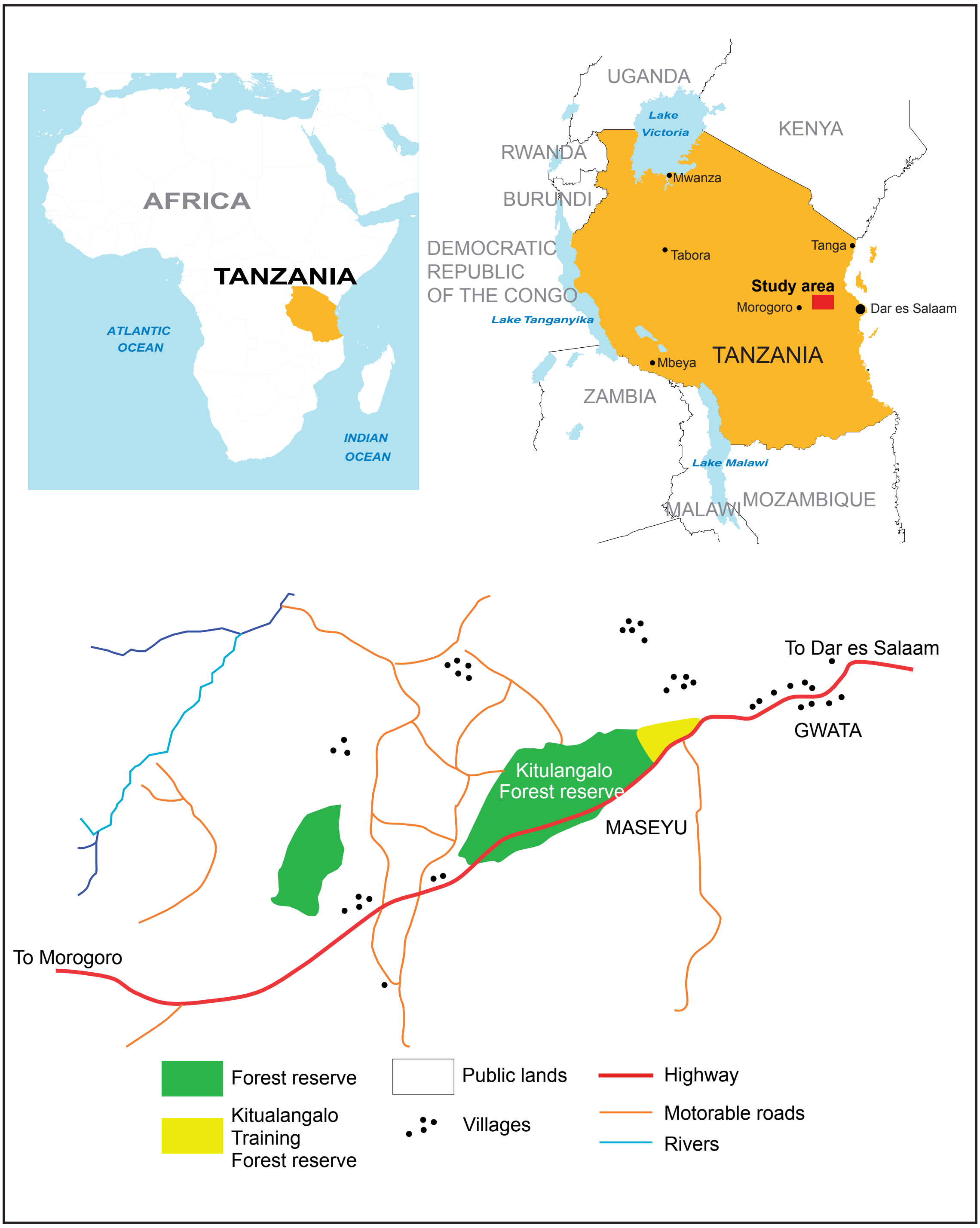

Figure 1. The location of the Kitulangalo area.

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The role of herbivores in the ecosystem and management of miombo woodlands

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Savanna biome including miombo woodland has great importance for human economy. Savanna biomes are characterized by dynamic changes between grassland and woodland. Therefore it is very important to understand the importance of different ecological factors regulating these dynamic systems. The research on relative importance of rainfall, fire and herbivores was reviewed. Rainfall was found to be the main regulating factor for woody cover. The maximum woody cover increased linearly up to 650 mm of annual rainfall, but areas with higher rainfall had maximum woody cover of 80 %. Under the 650 mm limit, the woodland-grassland dynamics was regulated by fire and herbivores. The importance of fire and herbivores depended on the environmental variation and interactions between them.

1 Introduction

Miombo woodland (savanna) is globally an important ecosystem which has great importance for human economy (e.g. Sankaran et al. 2006). Characteristic to savanna biome is the temporally changing woodland and grassland dynamics. To manage these woodlands in a sustainable manner the understanding of dynamic changes in savanna biome has great importance. Changes in rainfall, fire and abundance of herbivores have been emphasized as the leading ecological factors determining the dynamics of woodland/grassland (e.g. Kellman and Tackaberry 1997). However, the relative importance and possible interactions among these factors are poorly understood. The purpose of this paper is to review the role of herbivores in the behind this dynamic alteration between woodland and grassland and in the management of miombo woodland. Special attention will be put on the ecological interactions among herbivores, their host plant and their abiotic environment. The possible influence of herbivores on the species richness and diversity woody plants will be discussed.

2 Rainfall, Fire and Herbivory in Determining the Structure of Savanna Ecosystem

The primary factors determining the coexistence of trees and grass in savannas, including miombo woodlands, remain largely unrevealed. In a long term the same environment can change from grassland into woodland and vice versa. Most likely the vegetation changing between tree and grass savanna types can not be predicted by a simple model. Although savanna as a biome is spatially large and research efforts to reveal the origin and age of them has been done for decades, the processes behind the origin and age of savannas are not well understood (see references in Jeltsch et al. 2000). In general, the most speculated determinants of savanna biome are the availability of resources (water, nutrients) and environmental disturbance, like fire and herbivory. It is highly likely that these factors are all important in determining the structure of a savanna, and it might be a mistake to overlook the importance of the interactions between these factors.

The relative importance of fire, rainfall and herbivory were evaluated in extensive study by Sankaran et al. (2006). They used data from 854 sites across Africa. They found that Mean Annual Precipitation (MAP) explained the maximum percentage of woody cover in the area with less than 650 mm of MAP. Thus, in these dry or semi-dry areas the maximum woody cover was constrained by MAP and increased linearly with increasing MAP. If the MAP was more that 650 mm the regulation of maximum woody cover was released from the strict constriction set by MAP. They defined savannas with less than 650 mm rainfall as “stable” areas where rainfall determines the interactions between woody cover and grasses, while fire, herbivory and soil properties play only a regulatory role by interact to reduce woody cover below the MAP-controlled upper bound. Above a MAP of 650mm, savannas are called ‘unstable’ systems in which MAP is sufficient for woody canopy closure. Disturbances (fire, herbivory) are required for the coexistence of trees and grass in these “unstable” systems. Based on their model one can hypothesize that changes in annual rainfall will considerably affect the distribution and dynamics of the savannas.

In disturbance driven, i.e. unstable, savannas (MAP above 650 mm) fire was found to be more important regulator of woody cover than herbivory (Sankaran et al. 2006). High fire frequency correlated with low woody cover. But in sandy savannas this correlation was absent. Although effects of herbivory on woody cover were less apparent, grazers tended to enhance woody cover and browsers and mixed feeders to depress it.

3 Browsing Intensity, Species Richness and Diversity of Plants

It has been documented that browsing has very constant influence on species richness and diversity in many different biomes, although evidence for this assumption in miombo woodlands is limited (e.g. Begon et al. 2006). In general, browsing seems to cause increase in species richness: some amount of browsing enhances plant species coexistence if compared to situation with no browsing or grazing at all (Mwentera et al. 1997, Proulx and Mazumder 1998). It has also been documented that above certain limit browsing intensity decreases plant species richness. Heavy intensity of browsing lowers the species richness of plants.

Browsing has contrasting influences in the nutrient-rich or nutrient-poor habitats or ecosystems (Proulx and Mazumder 1998, see also Begon et al. 2006 for review). In non-enriched or nutrient-poor ecosystems browsing does not enhance plant species richness. In contrast, in enriched or nutrient-rich ecosystems browsing causes plant species richness to increase with increasing browsing intensity. Thus the interaction between soil fertility and browsing intensity is remarkable and is important to integrate into the studies of herbivory in miombo woodlands.

4 Domestic versus Natural Herbivores

Studying the differences of effects browsing effects by natural and/or domestic herbivores has been shown to be complicated. Most studies are correlative and conclusions are difficult to draw since other possible factors explaining the observed patterns between the domestic and natural herbivores were not measured. However, it is highly likely that even closely related herbivore species have different preferences for plant species due to their spatial, temporal, and dietary differences (see references in Richardson-Kageler 2004) thus having different impacts on the vegetation and the ecosystem as a whole (Stuart-Hill 1992). It would be expected that as a consequence of these impacts the plant communities would have differing assemblages of species.

Experimental testing of above mentioned hypothesis is difficult. Most commonly studied populations are isolated and distant from each other, the densities are not known or they differ vastly, biotic (habitat differences since differing browsing/grazing history) and/or abiotic characteristics (rainfall, soil fertility) also are not consistent. Therefore the needs for replicated experimental studies on the influences of browsers in sustainable densities in miombo woodland are high.

One of the best fully comparative experimental studies used the methods of randomly located fences between domestic and natural herbivores (Richardson-Kageler 2003, 2004). Densities of herbivores were at sustainable level and the time for experimentation was sufficient, being over ten years for all comparisons. In addition the study had a very good coverage of savanna woodlands in Zimbabwe.

At sustainable stocking rates the differences in the species richness of woody plant species between areas browsed by domestic and natural herbivores were found to be relatively small (Richardson-Kageler 2004). However, the study indicated that the abundance of plant species changed depending on their functional group, spinescence, leaf longevity, fruit types and dispersal type. Having found differences in the abundances of plant functional groups Richardson-Kageler (2003, 2004) conclude that the time needed to change woody plant species richness is hundreds of years compared to the time needed to change woody plant abundances which is merely decades.

5 Herbivory on Seedling

Generally herbivore impacts on seedlings are not well known (Shaw et al. 2002), but mammals are emphasized to cause high mortality on seedlings and saplings (Dublin 1995, Sinclair 1995). There are very few studies on invertebrates and rodents (Shaw et al. 2002). The relative role of the different herbivores is important to know in survival and establishing of seedling and saplings. Shaw et al. (2002) demonstrated well that when mammalian herbivory and trampling where experimentally excluded seedlings suffered high mortality caused by invertebrate and rodent herbivory. This effect was difficult to recognize while seedling were under the feeding pressure of larger mammals. This mean that in practice removing mammals which seems to cause high mortality do not really help seedling since other herbivores are causing equal amounts of mortality. Shaw et al. (2002) also found that invertebrates were more important than rodents causing compensatory mortality among seedlings. The population densities of rodents and invertebrates have high temporal variation and thus, one can assume high temporal variation in the impacts compared to mammalian herbivores.

6 Historical Evidence on the Effects of Browsing on Woody Plants

If it is assumed that herbivores have a big impact on the establishment of seedlings this should mean that the structure of forest stand should reflect the population crashes of the major browsing herbivores. Even-aged stands of many tree species are found in East and Southern Africa (Prins and van der Jeugd 1993). Fire may play a role (Norton-Griffiths 1979) but many *Acacia* saplings, and older trees, are resistant to fire (Prins and van der Jeugd 1993). Occasions of fire are frequent and when compared with the frequencies of the even aged forest stands these occasions are more common and therefore can not alone explain the pattern.

The major rinderpest epidemics of impala in years 1880, 1961, 1977 and 1984 correlated with the ages of the even aged forest stands of *Acacia* in Manyara national park (Prins and van der Jeugd 1993). Thus, the seedlings in these specific years survived very well, formed even aged stands which will then exist in the landscape for ten or even hundreds of years. From the plants' point of view the windows for successful seedling establishing and survival are rare and more or less random, unpredictable phenomena.

7 Study Methods of Browsing Effects

There are many difficulties in carrying out experimental studies with larger herbivores in order to prove their possible effects on environment. Probably the most common way of study is enclosure method. In this type of experiment browsers and/or grazers are excluded from certain area and similar areas are randomly set as controls. In these studies the problem has been inproper replication of enclosures and controls, as well as too short study periods in order to the effects to be realized. Another method which tries to superimpose the enclosure method is the use of fenced areas and compare situation developed both site of fence, e.g. browsed and non-browsed comparisons, or domestic and natural herbivore comparisons. In this method one needs to presume that the environments on the both sites of fence were similar and random in the beginning of experiment. This assumption is difficult to prove, especially if randomization is not used when the experiment was constructed. Using this kind of natural experiment is usually quite problematic.

Species richness, diversity and sometimes also dominance of plants have been analyzed in enclosure studies. In most cases the plant community level multivariate methods would have given more complete picture of vegetation. These more sophisticated methods would uncover also correlated changes in the vegetation, and in general would reveal minor changes in vegetation.

8 Herbivory and the Evolution of Miombo Trees

According to the general hypothesis of plant-herbivore interactions herbivore pressure on plants drives their evolution into having a variety of defensive traits against herbivores. Rules of natural selection state that the benefit must be greater than the costs if a defensive trait is to be favored.

Several factors determine the response of a plant to herbivory. Such include plant intrinsic factors, e.g. growth rate, and abiotic factors like availability of nutrients and water. In addition, important biotic factors determine these responses. Biotic factors can be divided into competition (both between and within species, even between shoots within an individual) and obviously intensity, frequency and timing of damage. On woody plants, large herbivores usually utilize shoots and leaves, which are removed through twig-biting, leaf-picking or leaf-stripping (Bergström 1992), and plant responses are usually divided into the plants' ability to compensate for lost tissues and the effect the damage has on structural or chemical defenses. In addition to within plant responses, the plants may rely on mutualistic relations such as ants protecting them.

The simplest way to respond to herbivory is to tolerate herbivory by growing new tissues fast to replace the lost tissues. In savanna ecosystems this is especially true for grasses. Although fast-growing plants are assumed to have less need for actual defenses, rapid regrowth may not be enough to prevent mortality or growth retardation due to browsing or grazing, especially in the juvenile phase of the plant (Bryant et al. 1983). Compensatory growth has been well documented in the temperate zone (e. g. Danell et al. 1994, 1997, Lehtilä et al. 2000), and also reported to exist in various woody plants in savanna ecosystem for *Combretum apiculatum* (Bergström et al. 2000), *Acacia nigrescens* and *A. tortilis* (du Toit et al. 1990), and in *A. erubescens* (Dangerfield and Modukanele 1996). For species living with frequent fires growth in height may be especially important. However, after a severe loss of tissue, several studies have reported a reduction in growth of shoots and height (e.g. Heichel and Turner 1984, Marquis 1992, Hjältén et al. 1993, Bergström and Danell 1995), while others record increased branching and total shoot length (Torres et al. 1980, Alados et al. 1996).

The next obvious trait to defend oneself is to have some mechanical defenses, such as thick cuticula and/or different types of spines, spikes and thorns. These defenses are extremely common in savanna ecosystems. Longer spines have been reported from areas with herbivores than from areas that without (Rohner and Ward 1997, Young and Okello 1998), and trees subjected to simulated browsing have responded in increased spine length (Young et al. 2003). *Acacia* species especially are protected by thorns. Juvenile individuals, assumed to be more prone to browsing, have been reported to have longer, more closely situated thorns (Brooks and Owen Smith 1994, Rohner and Ward 1997). Thorns are also longer within the reach of browsers compared to those above the limit for browsing (Young 1987, Milewski et al. 1991, Young and Okello 1998)

The chemical composition of regrown plant tissues is also likely to be altered by removal of them. New refoliated leaves are younger in age, which in itself may imply lower amounts of poorly digestable fibres and tannins compared to mature leaves. In addition, removal of tissues alters plant's carbon nutrient balance, which in turn induces changes in concentrations of nutrients and secondary metabolites such as condensed tannins, phenolics, terpenes and alkaloids (Tuomi et al. 1984, Fowler and Lawton 1985, Haukioja and Honkanen 1997), all of which have been shown to affect herbivores (e.g. Faeth 1992, Alados et al. 1992). However, chemical responses are dependend on biological characteristics of plant species (such as growth phase) and abiotic conditions, most importantly available resources, thus the variation in chemical responses is enormous.

Some plants have evolved symbiotic relationships with ants to avoid feeding on their tissues. In order to rely on the protection provided by ants, the trees have to offer something for their symbiotic partner. Many trees have extra-floral nectaries from which the ants may feed and others provide shelters for the ants to live in. These traits are extremely common in the tropics throughout the world. According to Madden and Young (1992) *Acacia drepanolobium* trees taller than 1.3

m are more likely to be occupied by aggressive ants in the genus *Crematogaster* than are shorter trees. Within plant the ants are concentrated on shoot tips, the plant parts preferred by giraffes. Trees with relatively more foliage have more swarming ants than trees with less foliage. Giraffe calves exhibit a strong sensitivity to *Crematogaster* ants inhabiting *A. drepanolobium*, feeding for significantly shorter periods on trees with a greater number of aggressive ants. In addition, the thorns of *A. drepanolobium* are significantly shorter than are the thorns of *A. seyal*, a species without symbiotic ants, a pattern that may indicate a trade-off between ants and thorns as defenses.

9 Impact of Large Herbivores on Miombo Woodland Vegetation

The impact of large herbivores in dynamics of woodland-grassland savanna has been discussed based on the 1970–80s elephant hypothesis which suggests that high elephant density prevents the increase of woodlands in African savanna ecosystems. This hypothesis still holds its position as the main explaining factor keeping the savannas in grass state, with the additional effect by other large herbivores and fire. However, when elephant densities are not extremely high, the elephants seem to play a mere regulatory role by altering species composition of plant cover.

Elephants seem to favor certain food-plants but are still relatively robust in their food selection. In South-Africa's Tembe Elephant Park and adjacent uninhabited areas species turnover rate was higher, and the densities of elephant favored food plants was lower when elephants were included (Guldemond and van Aarde 2007). Thus the composition of species assemblage was different. However, at community level, elephants had no apparent effect on woodland specific abundance-incidences and rank-abundance relationships of woody plants (Guldemond and van Aarde 2007). Similar result on the effects of other large herbivores was reported by Burke (1997) on the effect of large grazers in Namibia. There was a change in floristic composition in two decades of grazing. Richardson-Kageler (2003, 2004) also found differences in plant abundances in areas with and without large browsing herbivores. Cumming et al. (1997) studied the effect of elephant herbivory on woody plants, ants and birds in Zimbabwe. They found that woodland birds and ants had significantly lower species richness where elephants had removed the tree canopy. The tree species richness was not different as a whole, but when tree species were compared as height classes, there was a clear decrease in woody plant species richness over 3 m tall. This may have affected the community as a whole.

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Principle Socio-Economic Issues in Utilization of Miombo Woodlands in Tanzania

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The dynamics of miombo woodlands are essentially driven by among others socio-economic activities. Socio-economic activities in miombo woodlands vary depending local conditions, culture, and market. In poor developing economies majority of rural population are poverty stricken, and natural resources outskirting them act as safety net for their wellbeing in most of time. Socio-economic issues have close connection with miombo woodland development as well as rural development. However, many important gaps remain in our understanding of the influence of socio-economic factors and the available policy options and their impact on the development of miombo woodlands. The aim of this paper is to review principle socio-economic issues in utilization of miombo woodlands of selected areas in Tanzania focusing on Tabora and Iringa regions which are typical miombo areas. Main socio-economic activities in these areas were subsistence food and cash crops; livestock keeping, beekeeping, and charcoal making. Unsustainable operations/harvests for most livelihood activities were the main socio-economic issue influencing the miombo woodlands. Proper land use planning and restoration of the degraded area is crucial. Marketing and channel of distribution need to be established for various socio-economic products from miombo. Also, it is important to emphasize on efficiency utilization of inputs from miombo.

1 Introduction

The dynamics of miombo woodlands are essentially driven by among others socio-economic activities. Socio-economic activities in Miombo woodlands vary depending local conditions, culture, and market. Different communities act differently depending on climate, beliefs, taboos, education and wealth (poor or rich). Well educated and wealthier societies (mostly industrialized countries) and their socio-economic activities are differently compared to poor, less educated societies in developing countries (Kilahama 2006). In poor developing economies majority of rural population are poverty stricken, and natural resources outskirting them act as safety net for their wellbeing in most of time. Forests are not only the source of a variety of food that supplements what rural households obtain from agriculture, but also as income. For example 70% of cash incomes of most of villagers in central Tanzania come from charcoal production (Monela et al. 2000). A study in Sierra Leone showed that firewood provides the first cash income from land cleared for rice production (Cunningham 1996). Subsequent fuelwood collection for the market is concentrated during the peak of agriculture period, providing cash income in a period when food supplies have dwindled and new crops are only just being harvested (Wollenberg and Inges 1998). Socio-economic issues have close connection with miombo woodland development as well as rural development. However, many important gaps remain in our understanding of the influence of socio-economic factors and the available policy options and their impact on the development of miombo woodlands.

The aim of this paper is to review principle socio-economic issues in utilization of miombo woodlands of selected areas in Tanzania. The study focused on two areas: Iringa district and villages outskiting urumwa forest reserve in Tabora region. The main methodologies for data collection were literature review, personal communication and field observations.

2 Economic Activities in Miombo Woodlands

The economy of Iringa district and Tabora region like many parts of Africa and particularly in East Africa depend on subsistence and cash crops; livestock keeping, beekeeping, and charcoal making. About 70% of the surveyed households in Iringa and Tabora were subsistence farmers, with 21% beekeepers and 18% others which include employed (such as teachers, nurses, and village officers), petty traders, traditional healers, charcoal makers, and pitsawyers. 29% (Abdallah 2001) and 12% (Abdallah and Sauer 2007) of villages surveyed in Tabora and Iringa districts were engaged in tobacco production. Livestock keeping in both study areas was mainly a pastoral activity.

Relatively there is variation in income of the households from one year to another. This depends very much from the availability of rainfall, material inputs (like fertilizers) and markets. The sources of income of most of the villages surveyed are from tobacco cultivation, food crops, forest products and casual labour. Although income can be sometimes being obtained from both food crops (averaged to TAS 76,000 per year) some households are specialized in forest products collections and casual labour.

2.1 Socio-Economic Importance of Tobacco as among Principle Activities in Miombo Areas

90% of all tobacco in Tanzania is produced from miombo woodlands. It is a leading cash-generating crop (39.1%) followed by tomato in Iringa district and Tabora region. Food crops such as maize, sunflower and groundnuts were mentioned to be sources of cash but they were only used for that purposes when households get excess harvests or during urgent situation. Marketing, pricing and channels of distribution of paprika (especially in Iringa district) that was grown experimentally by 3% of the households were found to be at the infancy stage.

The socio-economic influence of tobacco farming extends beyond the immediate interest of the farmer, reaching out to the farming communities and beyond – affecting the economies of entire nations. In Tanzania, the tobacco sector has the largest agro-processing industries in the country i.e. Tanzania Cigarettes Co (TCC) and J. T. International, adding a substantial value to domestic raw material (tobacco) and a significant contributor to Tanzania's social and economic development. For example, in 2004, TCC alone contributed USD 60 million, equivalent to about 5% of the Government development budget for 2004/05 (FAO 2003).

Tobacco alone contributed about 15% of all revenue generated in Iringa municipality in the year 2004. In addition, tobacco was also seen as a steady and increasingly flowing source of government tax revenue relative to other traditional export crops. Figs. 1 and 2 show tobacco cess collected compared with other sources of revenues in the Iringa municipality. Fig. 2 shows that revenues from tobacco were increasing and it was higher than revenues accruing from forest products. Other sources of revenue referred to by the municipality/council including taxes from beer shops and beverages, shops and all other sources of revenue in the municipality.

However, quantitative efficiency analysis in Iringa district revealed a mean technical efficiency of about 62% (constant return to scale model) and 86% (variable return to scale model) (Abdallah and Sauer 2007) implying that the tobacco-growing households need to decrease their input usage by 38% and 14% respectively to be on the technical frontier. Different production efficiency measures show a significant positive effect of the curing technology. Also, there was a strong positive correlation between the tobacco production efficiency and species diversity. Moreover, environmental cost-benefit analysis of tobacco production revealed a negative NPV, suggesting that small-scale tobacco growing on miombo woodlands would not be economically viable under current practices.

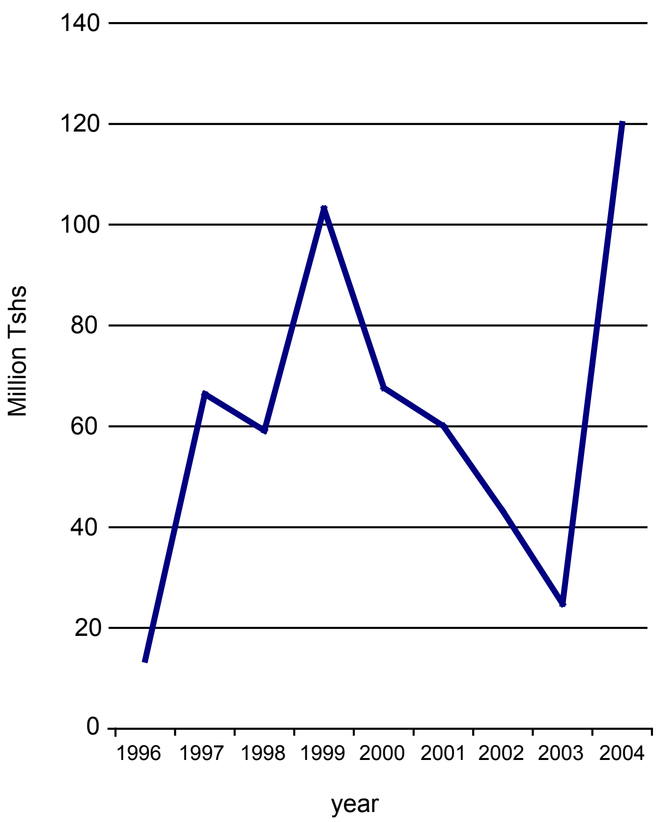

Figure 1. Amount of tobacco cess collected by Iringa district.

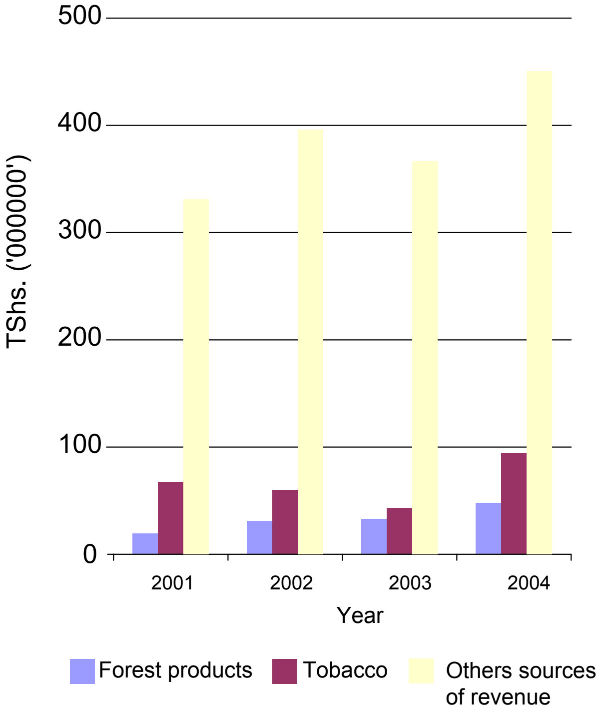

Figure 2. Forest resources utilization as important socio-economic activities.

2.2 Honey and Beeswax

Most of honey in Tanzania is produced from miombo. Tanzania has a capacity of producing 15,800 tonnes of honey and 9,200 tonnes of beeswax per year. However, presently Tanzania is producing about 4,860 tonnes and 324 tonnes of honey and beeswax respectively which is only 0.27% of the available capacity. The honey can be bought between TAS 500 to 1000/kg and beeswax can also be bought between 1500 and 3000 per kg. In the foreign market, honey and beeswax receive price of USD 1–2.5/kg of honey and USD 2–4/kg of beeswax. According to Crafter and Awimbo (1997), in 1988 honey and beeswax (3.8% of the entire forest produce) contributed about TAS 1100 million to the economy of Tanzania. However, production of honey and bees' products is characterized by remarkable fluctuations due to fluctuating rainfall condition in the main bee-keeping areas. Lack of control of local market may also account for this serious trend.

The market of honey in Tabora is good due to the presence of Beekeepers Cooperative Society in Kipalapala. Honey and beeswax collectors sell their products to this cooperative society and products are sold to foreign countries. In Iringa the situation is different. Honey collectors sell their products as they find market.

Areas suitable for keeping bees are the riverbanks and where there are high *Brachystegia glaberrima* trees. About 53% of the respondents revealed that *Julbernadia globiflora*, and *Brachystegia* spp. were the best nectar producing trees. Others were *Brachystegia spiciformis* and *Zanthoxylum chalybeum*. Minja and Kiwere reported that the presence of bee's forsge species such as *Dombeya burgessiae*, *Maesa lanceolata*, *Diospyros whyteana*, *Uapaca kirkiana*, *Vitex mombassae* and *Mysalicifolia* spp. supports significantly honey industry.

There are two seasons for honey harvest, the first one from June to September and the second from October to December. It is due to these reasons when varieties are often extracted. In June the honey obtained is sweeter compared to that obtained in October to December and its combs are reddish in colour. On the other hand the combs of the other season are mostly light in colour. One hive (1.6 m length) can yield about 16 litres/year and 1.4 kg of beeswax per year. One beekeeper can have up to 1993 beehives. An individual can earn up to TAS 1 149 900/year from honey and TAS 338 136/year from beeswax (which is about 53% of cash contributed to the households engaging in beekeeping). However, beekeeping activities in the area were still under traditional technology. The study showed that equipment used in these activities are axes, knife, fire and chopping tool. Collection of honey by using fire destroys large areas of miombo woodlands and grassland each year.

Solid wood and bark beehives are the main types of beehives used in the study are. The solid wood beehive was the main beehive used (75%) compared to those made from barks. But according to Abdallah (2001) about 30% of all trees used to make beehives are dead or dying because of ring barking. The highly favoured species (67%) for solid wood beehives making were stems of *Pterocarpus angolensis* and *Sterculia quingueloba*. These trees are cut down into small billets of about 1.6 m. Caved area is made in these billets so as to create places where combs and bees can stay.

2.3 Firewood and Charcoal for Income Generation

Charcoal making is crucial activity in miombo woodlands. Species frequently used are such as *Pterocarpus angolensis*, *Afzelia quanzesis*, *Brachystegia* and *Julbernadia* spp. in Tabora. Charcoal production venture is growing high because it is taken as part time job to supplement farmers' income. The incentives from the already existing markets in cities and towns encourage charcoal production as a full-time income generating work. A traditional kiln in Tabora can take an average volume of 13.96 m^3 of billets of various tree species to produce 20 to 30 charcoal bags each weighing 40 to 55 kg depending on species used. Charcoal making is increasingly becoming a lucrative business. The main market is urban areas. A bag of charcoal in Morogoro is valued at TAS 12,000 while in Dar es Salaam is at 20,000. Charcoal makers can generate a profit of up to TAS 8000 from one bag of charcoal. The business is forecasted to continue in unforeseeable future, partially due to stagnant in technological development and inability of many consumers to switch over to alternative energy sources. The current method of charcoal production by using traditional earth kilns has been preferred by most Tanzanians as they need very little skill and low capital investment. But, traditional conversion of wood to charcoal wastes as much as 70% of wood caloric value, thus accelerating pressure in destruction of miombo woodlands.

Firewood is not sold in village, but it receives a very thin market in urban centres. In villages only those engaging in local brewing are the ones who can afford buying firewood. A headload of firewood can sell at a range of TAS 200–300. People are motivated to harvest firewood from natural forests where it is freely obtained so as to earn cash especially in slack season.

3 Pastoralism: Empirical Evidence from Dry Miombo Woodlands in Kilosa District

Tanzania is third in Africa in livestock numbers after Sudan and Ethiopia. Although, livestock play diverse economic and social roles in the in Tanzania, but such number of herd do not translate into productivity improvement that could result in the well being of the livestock keepers. This is probably because most of livestock (90%) is traditionally kept i.e. pastoralism mode of production. Pastoralists are nomadic herders moving with big number of livestock in order to access to disperse, ecologically specialized and seasonally varied grazing lands and watering points, to provide for the distinct foraging needs of different livestock species. This grazing habit requires extensive space and reliable source of water, which is scarce in semi-areas especially in dry seasons. Therefore targets for grazing become wet area, 'dampos' or *mbuga* as due to availability of basic requirements such as water and forage. Unfortunately, wet areas in dry zones are the main source of people's livelihoods. People depend on these sites for food and cash crop production through flood irrigation and water for domestic purposes. The co-existence, and sometimes overlapping, of the different land use systems and the population increase has resulted in strained relationships between cultivators and pastoralists. The continuing land use conflicts (Table 1) suggests that the interventions that were introduced to resolve the resource use conflicts are ineffectual, or the underlying causes of resource conflicts are not well known.

Table 1. Number of farmer-herder conflicts dealt with by the Kilosa.

Year	Cases dealt with by the police	Cases forwarded to the magistrate
2000	55	27
2001	39	22
2002	43	18
2003	57	29
2004	45	15
2005	59	23
Total	298	134

Source: Benjaminsen et al. (2007)

For example, in Kilosa district the performance of the conflict resolution committees are poor and inefficient, the resource use conflicts leads to sporadic fighting and killings in the district. The government intervened by evicting all pastoralists from cultivators' villages to settlements designated for pastoralists alongside with the establishment of village conflict resolution committees. Unfortunately the areas designated for pastoralism experience periodic water shortages especially during the dry season (Mchomvu 2001). More important these pastoralists designated areas they lack basic services such as water ponds, clinics, dips (Table 2). Therefore pastoralists have to move and settle either nearby or inside farming villages.

Table 2. Number of various services in the pastoral designated villages of Kilosa District.

Pastoral designated villages	Clinics	Schools[1]	Dips[2]	Water ponds[1]
Twatwatwa	0	2	1	2
Mabwegere	0	1	0	2
Mfirisi	0	0	1	0
Ngaiti	0	1	0	0
Kiduhi	0	1	1	1
Kwambe	0	1	1	1
Godes-Msovelo	0	0	0	0
Madoto-Mkwale	0	1	0	0

Benjaminsen et al. (2007)

1. Costs of establishing schools and dams for watering cattle are shared between the local people and the government.
2. These cattle dips are organised and funded by the pastoralists themselves and not provided by the government.

Therefore when grasses are even scarcer, cattle begin to go to farms in search for left-over maize/rice stalks. If migration is to be entertained, there is a possibility of big conflicts given the fact that in one of the villages alone (Twatwatwa village) there is about 35% of all the indigenous cattle in the district.

The major reasons for this are draught which is caused by low rainfall as a result of changing climate and lack of enough and good structure for water harvesting. Extensive and inappropriate water use for irrigation at the upper slopes of the rivers, lack of water systems for domestic use was also noted to contribute to water shortage especially in pastoralist villages. Migration of animals and or humans to water points is the major adoption mechanism of the most pastoralists. Searching for forage is a year-round seasonal cattle movement practice to areas with extensive pastures. Some cattle are moved towards Wami River searching for water and grass.

Problems of soil compaction, draught and environmental degradation were also pointed out to be caused by livestock trampling, low rainfall and charcoal making (Fig. 3). It was learned that livestock feeding in farms after harvesting and or when passing to water sources cause a considerable compaction to the soils. It was further noted that trespassing animals in farms may occur before removal of crops leading to crop damage. While 50% of the farmers solve emerging conflicts through village conflict resolution committees, 30% of the farmers report to the police where estimates are made in collaboration with the district agricultural/livestock officer for compensation, 16% guard farms throughout with 4% taking no action.

4 Conclusions and Recommendations

Various main socio-economic activities have influences on the management of miombo woodlands. Proper land use planning and restoration of the degraded area is crucial. Technological improvements in the forest products processing will increase efficiency in the use of raw materials from forests developing and adoption of the new technologies for the production of woodfuels. Most efficient combustion devices and improved system for planning, management and organization of wood energy system will make the woodfuel considerably most cost competitive energy source. Marketing and channel of distribution need to be established for various socio-economic products from miombo.

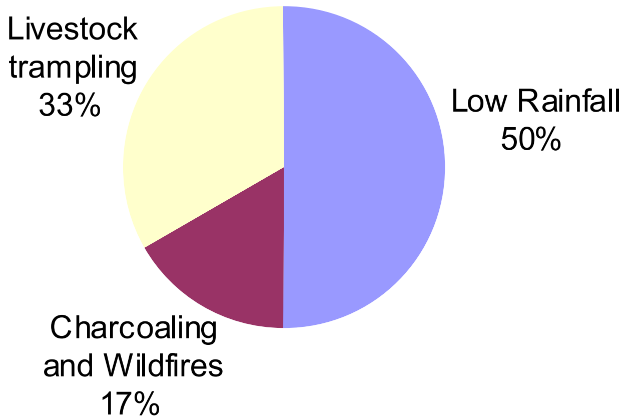

Figure 3. Causes of drought and general environmental destruction in Kilosa district.

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Soil Carbon and Water Dynamics during Regeneration of Indigenous Semi-Arid Miombo Woodlands in Tanzania

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MITMIOMBO focuses on developing methods for the management of indigenous forests of semi-arid Africa. It is a relatively short (two years) pilot project. The project principally aims at creating possibilities for future cooperation in research on the structure, development, and management of semi-arid forest and woodland ecosystems utilizing indigenous tree species and natural regeneration. One of the objectives is to establish a set of permanent experimental research plots in Tanzania to serve as a staging ground for demonstration and application of research methodologies. This application is for a soil science project that would be closely linked to MITMIOMBO; in cooperation with MITMIOMBO partners and utilising MITMIOMBO experimental plots. The aim of the present application is to make a pilot study and to be able to prepare an application for a full research project in 2007 from SAREC and/or from EU (FP7) as a part of a larger continuation of the MITMIOMBO project.

1 Project plan

I plan to do some initial sampling for a pilot project that I hope will lead to application that is met by approval by Sida. This project will use some of the same plots as MITMIOMBO, but also sampling from cultivated areas. The purpose is to see the cultural influence on soil carbon and water infiltration and to see the effects of MITMIOMBO treatments on those parameters. I hope to carry out the following activities in the field.

- To carry out a pilot study of ^{13}C distribution in soil profiles. This would give information on the historical dynamics of C_3 or C_4 plant dominance, i.e. describe the changes (natural or human induced) in dominance of tree and grass dominance within an area. This will also be coupled with measures of soil respiration with a portable Infrared Gas Analyser (IRGA).
- To carry out base-line soil sampling of larger/more areas that are included in the MITMIOMBO project. The availability of these samples would enable us to investigate soil C and N changes induced by project activities in the future.
- To carry out similar base-line measurements of infiltration rates. The recent debate on reforestation/afforestation consuming too much water and draining wells and streams highlights

the need for real data on water infiltration in a semi-arid tropical forest system undergoing regeneration. This work will be initiated now and continued by some of the Tanzanian partners.

We intend to use the data generated from this project in C-modelling. Isotopic data would yield information on contributions from trees/bushes and grasses respectively. Models are needed to understand C-dynamics on larger scales, i.e. at the landscape, regional and global scales, models, however, need measured data for their initial development and subsequent validation. The duration of the larger future research project, for which we will submit a proposal in 2007, extends beyond the present MITMIOMBO project, but is not dependant on the continuation of MITMIOMBO. It will however, maintain the research contacts and cooperation established within the MITMIOMBO project.

2 Justification

The miombo is the most extensive tropical woodland formation of Africa with particular ecological and economic importance covering some 2.7 million km^2 (Kanschik and Becker 2001). Modern man has lived in the miombo woodlands for at least 55 000 years and has, through cultivation, grazing and burning, played a key role in the modification and transformation of the landscape in miombo woodlands (Cidumayo and Kwibisa 2003). In the miombo woodlands some 50–80% of the total system's carbon stocks are found in the top 1.5 m belowground. Deforestation and rapid population growth have led to reduced fallow periods and widespread land degradation. The impact of land use conversion on below ground carbon and nitrogen stocks have not been examined extensively in the past (Walker and Desanker 2004). Walker and Desanker (2004) found carbon levels of 1.2 to 3.7% in miombo top soils in Malawi, while carbon levels in agricultural land in the same area varied from 0.35 to 1.2%. To understand the potential of different ecosystems and changes in land-use to sequester C into the soil it is important to follow an induced change from the start. We aim to monitor changes in soil C and N during regeneration of woodlands initiated by the MITMIOMBO project.

Initial sampling of soils for later analyses will be done and/or initiated during the planning trip. Sampling may also be made on sites presently under different land-use management, e.g. woodlands, grazing lands and agricultural fields.

Models are needed to be able to understand C-dynamics on larger scales, i.e. for landscapes, regions and globally (Smith 2004, Polyakov and Lal 2004). However, models need measured input data and/or to be verified/validated to measured data. We intend to use generated data in C-modelling.

There is an on-going scientific debate on the effect of afforestation and reforestation on water availability. Positive effects of afforestation/reforestation have been questioned with the argument that they consume too much water and, hence, drain streams and wells. In some recent publications (Jackson et al. 2005, Farley et al. 2005, Hayward 2005) there have been gross simplifications and invalid generalisations based on biased geographical data and monoculture plantation of exotic species. These simplifications and generalisations have been further exaggerated in the popular press, e.g. with headlines like "Down with Trees" in the Economist (Anon 2005a) and "Trees Consume the Water of the World" in a major Swedish daily newspaper (Anon 2005b). In the light of this debate it would be very valuable to include real data on water infiltration in a semi-arid tropical forest regeneration project. We proposed to do that.

Initial sampling of water infiltration will be done and/or initiated during the planning trip. Sampling may also be made on sites presently under different land-use management, e.g. woodlands, grazing lands and agricultural fields.

Isotopic analyses of the soil C can give information on the origin of the C and hence describe the historical dynamics of C_3 or C_4 plant dominance, i.e. describe the dynamics (natural or human induced) of tree and grass dominance of the area. This has been done for forest – savanna dynamics (Mariotti and Peterschmitt 1994, Desjardin et al. 1996), for historical shifts in land-use (Eshetu and Högberg 2000, Vitorello et al. 1989) and to analyse the effects of individual trees (Nyberg and Högberg 1995, Jonsson et al. 1999). In miombo woodland with a cultural history this would be very adequate and interesting. A pilot study of ^{13}C of soil profiles to address this is suggested.

Sampling and analyses for this pilot study is included in this application. Sampling stratification and replication will be enough to, if the results reveal interesting historical dynamics, to merit for publication in a international scientific journal.

3 Cooperation

Research contacts and cooperation are established now within the MITMIOMBO project. The future research project is to be planned for to last beyond the present MITMIOMBO project. It is, however, not depending on a continuation/prolongation of the MITMIOMBO. It will mean cooperation with the same researchers and utilising the experimental plots established during this phase, with or without a MITMIOMBO continuation.

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Introduction of the MITMIOMBO Project

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Project Title

MITMIOMBO – Management of Indigenous Tree Species for Ecosystem Restoration and Wood Production in Semi-arid Miombo Woodlands in Eastern Africa
(A EU FP6 INCO/SSA project)

Background

Management of native woodlands with 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 East and South Africa. Woodlands can provide a multitude of wood and non-wood products like timber, firewood, charcoal, beekeeping, fruit, grazing, shading, ecosystem protection, cultural values etc. For instance, about 90% of the energy consumption in Tanzania is derived from wood, mostly from overexploited indigenous woodlands.

Despite the very large extent of the semiarid miombo woodlands in Tanzania (45 million hectares, or 90% of forested land) and Eastern and Southern Africa as a whole (270 million hectares), their utilization has exceeded sustainable levels in many places. Having depleted the resources of the most valuable timber species, for example, people and communities have had to turn to species with less favorable wood properties for their construction needs. Unregulated charcoal production has resulted in extensive lack of wood in many areas.

Without effective regulation, management, and participatory measures, the deterioration of the ecosystems and depletion the forest resource, and poverty and rural depopulation will continue and accelerate in the future. Participatory forest management regimes, such as Community-Based Forest Management and Joint Forest Management, have been initiated with success on about 2 million hectares and around 10% of villages in Tanzania.

Sustainable management of native and non-native trees, woodlots, and forests with the intensive involvement of local communities seems to be a key alternative. Women in particular have shown great interest in establishing and managing tree crops and stands. Given their extent and intensity of use, remarkably little emphasis in research and development efforts have been directed on the silviculture and management of miombo woodlands. Past research end development efforts in forestry and forest ecosystem management in the area have primarily been pursued in terms of the plantation approach.

The knowledge basis for the management of indigenous forests is very limited. The stand structure, species composition, tending and dynamics of indigenous forests and woodlands are much more complicated than those of plantations of exotic tree species, and advanced survey, as well as experimental, analytical (statistical, and simulation) methods are required in order to produce reliable research results and concrete recommendations. 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 miombo woodlands.

Objectives and Activities

The first primary objective is to coach Tanzanian researchers in the application of state-of-the-art research methods for addressing management challenges involving indigenous stands with complex structures and dynamics. After the project, groups of researchers participating in the project will be able to design and implement such studies on their own and to pursue fruitful cooperation with European colleagues in the future. The major objectives subordinate to the primary objective are:

1. To communicate general principles and previous applications of state-of-the-art research methods for stands with complex structures and dynamics in terms of papers presented at two project meetings and specific workshops by smaller groups. The primary approach is modeling and simulation based on empirical data sets from permanent sample plots.
2. To establish and manage a set of permanent experimental research plots in the Kitulangalo Forest Reserve near Morogoro, Tanzania to serve as a staging ground for demonstration and application of research methodologies appropriate for complex stand structures and dynamics, natural regeneration, seasonal growth variation of trees in the area, and pest problems as tree – herbivore interactions.
3. To exchange experiences between researchers on the research methods by direct joint application to design and establishment of the experiments, data analysis, and work towards conclusion relevant to practice in terms of exchange visits (two persons for 1-3 months each) and workshops.
4. To initiate and promote cooperation with researchers in other East and South African countries on the project themes by inviting them to participate in selected activities for communicating the working concept, scientific substance, and results, utilizing the permanent plots for demonstration.

The second primary objective is to pursue interaction and dissemination of knowledge between local communities, farmers, and potential tree growers, local extension workers, and researchers on practical management issues of indigenous stands. Communities in the vicinity of the demonstration plots will be involved.

The third primary objective is to promote the exchange of knowledge and experience between researchers from Tanzania, Europe, and other East African countries on the objectives, methods, and potential benefits of the management of semiarid forest ecosystems. The connections and working relationships that form a network for future cooperation on the subject will be established and strengthened through involvement in this pilot project and participation in its activities.

The project participants humbly acknowledge that the kind of forest management and silviculture that may optimally promote the goals of the various stakeholders in a specific situation is an extremely complex question, with equally variable applications as solutions in the vast domain of miombo woodlands. The inherent limitations of such a small-scale project must be apparent to anyone. We can only apply and demonstrate one or two basic treatment principles on location, leaving a large variety of alternatives aside. On the other hand, it is not the specific treatments that are on trial and display, but principles and approaches. In that sense, the power of research and researchers in generating knowledge and providing tools for making wise decisions in the future is one of the major things that we want to emphasize with the project.

Contractors

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)

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