The effects of human disturbances on diversity and dynamics of eastern Tanzania miombo arborescent species

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Declaration

I declare that this thesis is my own work, unless specifically acknowledged in the text. It is being submitted for the Degree of Doctor of Philosophy at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other university. The thesis is submitted as a collection of published or submitted papers for publication. All seven papers (two published, one in press, three submitted and one to be submitted) were researched, written and prepared for publication by myself, but as co-authors, my supervisors, Prof. Ed.T.F. Witkowski and Prof. Kevin Balkwill have contributed through their guidance.

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Abstract

This interdisciplinary study makes comparisons between patterns of woody resource abundance (stocks) under contrasting management regimes and describes the effects of human disturbance on plant diversity and population dynamics of miombo woodlands. Socio-economic data were collected from two sampled villages surrounding the Kitulanghalo Forest Reserve in eastern Tanzania, about 150 km west of Dar-es-Salaam. Biophysical data were collected from sixty-four modified-Whittaker nested plots in the reserve and surrounding public lands. Use was also made of the data from permanent sample plots and aerial photographs & landsat images.

The ethnobotanical and utilisation survey indicated that major uses of woody species were for charcoal production (the main commercial activity in the area), firewood, medicine and poles. Commercial production of charcoal results in local wood consumption of 6.01 m^3 $capita^{-1}$ $year^{-1}$ compared to subsistence firewood consumption of only 1.5 m^3 $capita^{-1}$ $year^{-1}$. Shifting cultivation is practiced by 68% of the population. The present level and pattern of harvesting are changing the structure and composition of the vegetation, especially in public lands and are not sustainable. However, the heavy wood utilisation in public lands has minimal effect on floristic composition as indicated by a high Sørensen's similarity of 87.7% between the reserve and public lands.

Multivariate analysis indicated that the linear combinations of physiographic variables (most of which are associated with human disturbance) significantly influence the pattern of tree harvesting, and species composition at the community level. The decrease in plant density through harvesting or self-thinning (natural mortality) in public lands is accompanied by enhanced wood productivity, hence growth rates were higher in public lands compared to the reserve. Ninety percent of harvested woody species in public lands resprouted hence management under coppice rotation as a silvicultural system is recommended.

Common property regimes and local institutional capacities are weak and need to be strengthened before local people are given the full responsibility of managing the public lands and assisting in policing the forest reserve. This calls for government institutions to provide and motivate for an enabling environment in order to ensure equity and sustainable development of natural resources.

This thesis is dedicated to my wife Veneranda for all her love and patience.

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Table of Contents

CHAPTER 1

Introduction

1.1 Background

The Miombo (Zambezian) woodland is the dominant savanna vegetation type in eastern and central Africa. The open, often annually burnt, deciduous woodlands are rich in grasses and dominated by the arborescent genera *Brachystegia* and *Julbernardia* (both Fabaceae, subfamily Caesalpinioideae). There is an increasing interest in utilisation, biodiversity and dynamics of miombo woodland which is reflected by various studies, most of which are synthesized in Campbell (1996) and Mistry (2000). However, most of these studies are not inter-disciplinary. An exception is Rodgers (1979) who studied vegetation pattern and utilization of miombo woodlands by seven species of large grazing herbivores in the Selous Game Reserve, south eastern Tanzania. Another shortfall of these studies is that they do not make comparisons of spatial variation between protected areas and communal lands, except for Vermeulen (1996) in miombo woodlands in Zimbabwe. The present study not only makes comparisons between a protected area and public lands, but also investigates different human disturbance gradients in each of the two management regimes. Thus, the study reveals the patterns of woody resource abundance (stocks) under contrasting management regimes and highlights the effects of human disturbance on biodiversity and population dynamics of the species under study.

Tanzania is the largest country in East Africa with an area of about 88.4 million ha (excluding islands). The population was about 25 million people in 1990 (URT, 1991). Growing at the rate of 2.8% per annum, the population in 2000 is estimated to be 33 million people. About 80% of the population live in rural areas, mostly in about 8000 villages. Agriculture is the mainstay of the economy providing about 45% of GNP and 80% of employment (URT, 1991).

Nearly 50% of the Tanzanian area (more than 44 million ha) is covered by some type of forest vegetation (although often classified as woodlands)(Table 1.1). In terms of legal status of the land, 30% of the forested land is designated as forest reserves (legally protected) under the management of central government while the remaining 70% is forest in public (communal) lands under management of local (provincial) governments.

Table 1.1 Land use patterns in Tanzania (arranged in order of their magnitude).

Land category	Area (million ha)	% cover
Woodlands (mostly miombo)	42.9	48.5
Bushland, grassland, thicket	36.2	40.9
Permanent cultivated land	6.2	7.0
Other uses (urban, roads, rocky, swampy, etc.)	1.6	1.8
Closed forests	1.4	1.6
Plantation	0.2	0.1
Mangrove forests	0.08	0.1
Total land cover	88.4	100.0

Source: Ahlbäck (1995).

Of the 13 million ha of legally protected forests which have been established and officially gazetted, nearly 90% comprise miombo woodlands (Temu, 1979). These woodlands are however marginally managed due to lack of funds and insufficient staff. Forests / woodlands on public lands are without any formal management or legal protection although they provide the bulk of the country's forest-based needs. Most miombo woodlands also occur in public lands.

Although miombo woodlands are the most extensive vegetation type in Africa south of the equator (White, 1983) and in Tanzania in particular (Table 1.1), most professional attention in the last decades has focussed on the establishment of industrial plantations and tree planting campaigns (MNRT, 1989). Thus very few precise data are currently available on the dynamics of miombo woodlands and their response to disturbances.

1.2 Conceptual study model

This inter-disciplinary study entails a holistic approach which integrates information from anthropology, ecology, botany and economics. Any multiple use approach for sustainable management must be ecologically sound, economically viable and socially desirable. The study is an endeavour to investigate the interaction between social, biological and physical processes in resource management. The study hypothesises that current human disturbances which are invariably a result of resource use have an impact on standing wood stocks, biodiversity and dynamics of miombo woodlands (Figure 1.1 a). Resource use, in turn, is governed by both direct and indirect, positive and negative socio-economic factors. The direct negative factor is over-exploitation of resources whereas the indirect negative factors are the underlying causes for over-exploitation which are population growth, commercialisation of the resources and infrastructural development (Figure 1.1 b). The direct positive factor is resource protection, while the indirect positive factor is application of indigenous management systems (Figure 1.1 b). From a largely ecological viewpoint, woodland stocks, biodiversity and dynamics are perceived to be controlled by the physical aspects of soils, climate and other physiographic attributes (Figure 1.1 c). However, over the last two decades, ecologists have increasingly recognised the considerable importance of studying human disturbances as an integral part of the environment (Costanza *et al.*, 1990).

1.3 Inter-disciplinary resource conservation in context.

There are strong interactions between ecological, economic and social systems because natural resources are crucial to human welfare, hence the importance of the emerging field of ecological economics (Costanza, 1991). Human economics can only be understood in the context of ecological systems (Costanza, 1991) which are far too complex to be described by any single measure (Ludwig *et al.*, 1993). Such observations lead inevitably to the conclusion that humanity will only benefit by managing ecological systems sustainably (Hansen, 1997).

Sustainability concepts are increasingly important to policy-makers around the world, but it is not easy to devise better development models because poverty is a major cause of habitat and biodiversity loss in developing countries (Young and Solbrig, 1993; McNeely *et al.*, 1995). Thus, actions to alleviate the loss of biodiversity must also address the socio-economic causes of poverty.

Human activities are not necessarily incompatible with the maintenance of biodiversity, however some important components of biodiversity are most likely to prosper in areas that are remote from human influence while others are associated with conditions provided by humans (McNeely *et al.*, 1995). This study is intended to investigate the responses of miombo woodlands to harvesting in protected and public lands and promote sustainable methods of harvesting arborescent plants.

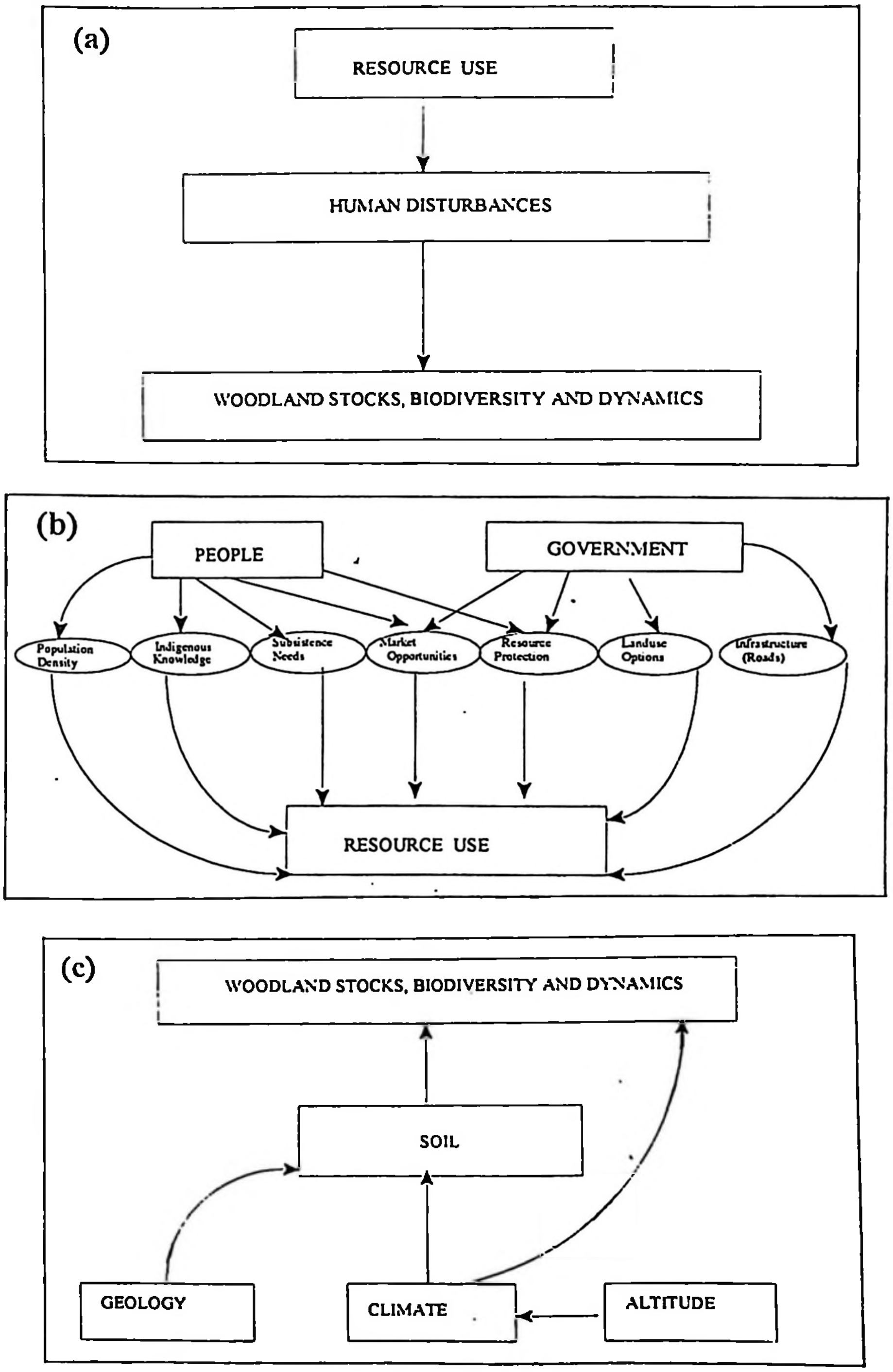

Figure 1.1 Schematic presentations of conceptual interactions between: (a) human resource use, disturbances and biological parameters, (b) socio-economic parameters and resource use and (c) biological and physical parameters in miombo woodlands of eastern Tanzania.

As the world economic, political and social systems developed, most of the traditional conservation practices were rejected and new ones emerged, including practices such as proclamation of nature reserves or laws to protect endangered species (Koppes, 1988). These approaches view conservation as the responsibility of the state apparatus, often to be practiced in isolation from economic driving forces and through the exclusion of extractive human uses and management (Koppes. 1988). On the other hand, natural resources in developing countries must simultaneously provide raw materials for the larger economy and meet the subsistence needs of the growing rural population (Shackleton and Shackleton, 2000). Limited research has been done in miombo woodlands on how property rights affect the use and protection of natural resources and how to integrate indigenous knowledge, innovations and management practices (Matose and Wily, 1996). This study partially fills this gap by identifying potential strengths and weaknesses of local institutions as custodians of renewable natural resources.

1.4 Indigenous knowledge and resource management

Ethno-ecology is a multi-disciplinary endeavour which is increasingly used to encompass all studies which describe local people's perceptions and interactions with the natural environment, including plants and animals, land-forms, forest types, soils and much else (Martin, 1995). It includes subdisciplines such as ethno-botany, ethno-entomology, ethno-zoology and ethno-pharmacology. Ethno-botany for example, is a branch of ethno-ecology concerned with local people's perception of attributes and identification of plants in terms of morphology, physiology and species and their associated uses (Martin, 1995). Today, very few self-confident communities articulate fully the indigenous knowledge that was passed on through past generations. However, in many other societies, the 'forced march' towards industrialisation, political integration and cultural homogenisation has led to attenuation or elimination of local practices (Posey, 1993; Luoga, 1995).

The increased pressure on biological resources arises because of increasing human populations, commercialisation of resources, changing consumption patterns, increased consumption per person and new technologies (Young and Solbrig, 1993;

McNeely *et al.*, 1995). These factors also affect indigenous societies and their natural environment to the point that traditional technologies and social systems are generally dismissed as backward and irrational, despite the possibility of greater ecological soundness and sustainability than many of their modern counterparts (Shiva, 1993). Indigenous management practices remain viable only as long as (a) local communities continue to have substantial levels of dependence on resources garnered from their immediate vicinity, (b) they have full control over the local resource base and (c) they retain a sufficiently high level of internal cohesion (Ostrom, 1990). These conditions are no longer fulfilled when (a) outside state or corporate bodies establish control over natural resources (b) local resources become a source of cash income and (c) local communities lose their traditional social organisation (Ostrom, 1990). Thus, indigenous knowledge has several limitations and it cannot be manipulated independently of the socio-political and economic structures within which it occurs.

Both indigenous and modern systems of knowledge are not static. These systems must therefore have inherent capacities for absorbing relevant new knowledge from inside and outside. A combination of professional and indigenous forest management systems can draw on the strength of both systems to provide for sustainable use and management of resources (Posey, 1993).

1.5 Environmental economics

Many conventional economists ignore natural systems and resources while many of the crucial questions at the ecology-society interface involve economics (Ehrlich, 1989). A society can have an ever-increasing standard of living, measured by monetary income and yet an ever diminishing quality of life (Cobb, 1989). One strength of environmental economics is that it attempts to represent the full set of goods and services which can help us to improve our ability to address previously unforeseen, but not unforeseeable consequences of our actions (Perrings, 1995). For example, resource harvesting is the safety net that allows many households to survive in areas of poor agricultural potential, high human population density and low employment opportunities (Shackleton and Shackleton, 2000). The implication of this is not well documented in the environment of African savannas.

The key to sustainable management does not lie in technical aspects alone, but in realistic approaches that are based on an understanding of the diverse perceptions of the value of resources by the various user groups which determine their fate (Budowski, 1995). Economics has developed various techniques to capture direct use values, indirect use values and option values. Techniques for reflecting the non-use values involving bequest, cultural and heritage attributes are in the early stages of development and they include contingent valuation and opportunity cost methods (Pearce, 1993; Turner *et al.*, 1994; Costanza *et al.*, 1995).

Environmental economists are also concerned about biodiversity precisely because market prices are unreliable indicators of social costs (Perrings, 1995). Loss of biodiversity may lead to loss of ecosystem resilience because the value of biodiversity lies in its role in the provision of ecological services (Perrings, 1995). A major challenge is thus to evaluate the biological consequences of economic activities and to develop appropriate models for the sustainable use of natural resources.

1.6 Biodiversity and ecosystem function

Natural capital provides human beings with material and non-material flows of goods and services (Neumayer, 1998). Biodiversity, a distinctive feature of natural capital can be divided into three components: composition, structure and function (Lamont, 1995). A major challenge for ecologists is to quantify to what extent ecosystem functioning is affected by a change in ecosystem composition and structure (Lamont, 1995).

In order to contribute to resource-use policy and management, ecosystem function has to be defined in terms of human use or interest and the relationship between biodiversity and function has to be examined in the context of specific functions (Walker *et al.*, 1999). For the global-change functions of concern, the set of ecosystem functions would include carbon and nitrogen cycling (C stock, C fluxes and N fluxes) and water budget between trophic levels and the abiotic environment (Lamont, 1995; Walker *et al.*, 1999). The capacity of the ecosystem to endure extreme disturbances is an important test of ecosystem function and is a measure of fundamental ecosystem resistance and resilience (Woodward, 1993) as major switches in functional groups, such as from forest to grassland, can have substantial effects on ecosystem properties (Hobbie *et al.*, 1993).

Ecosystem management, often on a landscape scale, is a proposed solution to problems of single-species (indicator or umbrella) management (Grumbine, 1994), but it has limitations of varying definitions, undefined limits and its focus on processes (e.g., nutrient cycling) (Woodward, 1993; Tracy and Brussard, 1994). The recognition that some ecosystems have keystone species, whose activities govern the well-being of many other species, suggests an approach which may unite the best features of single-species and ecosystem management (Simberloff, 1998). However, very little is known about keystone species in the ecosystem and the experiments that lead to their identification are often very difficult (Bond, 1993; Simberloff, 1998). It is easier to quantify the relatively static components of biodiversity, namely composition and structure than the dynamic functional component, hence the use of changes in structure and composition as a surrogate for changes in function. For example, biomass is an expression of light captured and thus a good measure of energy and carbon content (Lamont, 1995).

1.7 Disturbance regimes

The dynamic nature of biological resources is attributed to the disturbance regime of the ecosystem (Whitmore, 1989; Pickett *et al.*, 1992; Silvertown and Lovett-Doust, 1993; Risser, 1995). Several disturbance and community organisation theories which influence the structure and dynamics of vegetation have been well documented in the ecological literature (Connell, 1978; Pickett and White, 1985; Turner *et al.*, 1993). It is important however to determine which theories are pertinent in savanna (miombo) woodlands where they are yet to be tested. Disturbances are major sources of both temporal and spatial heterogeneity in the structure and dynamics of naturally occurring communities (Sousa, 1984). In relating disturbance to biodiversity at community level, it is important to know which species are favoured and which ones are disfavoured by disturbance (Bazzaz, 1983). The requirement of disturbance for the continued existence of certain species in a community shows that disturbances are ecologically significant (Pickett and White, 1985). Biological resources have the important character of being renewable, so with proper management they can be used sustainably. However when the levels of human use of biological resources exceed their capacity for renewal, the diversity and productivity of the system in which they occur may be reduced.

1.7.1 Intermediate disturbance hypothesis

The 'intermediate disturbance hypothesis' refers to a situation where disturbances renew resources at a rate or intensity sufficient to allow continued recruitment and persistence of species that would otherwise be excluded (Connell, 1978; Huston, 1979; Abugov, 1982; Pickett and White, 1985, Hobbie *et al.*, 1993). It is stated that periodic or recurrent disturbance at this intermediate level perpetuates both pioneer and primary species. Under these conditions, species with different life history strategies are able to co-exist and consequently high levels of species richness are maintained. If the frequency / intensity of disturbance increases beyond the intermediate level, only colonising species with high growth or dispersal rates, pioneer species and mid-seral species are able to co-exist. This represents lower species diversity. On the other hand, if the disturbance decreases beyond the intermediate level, only the highly competitive 'climax' species which are better at maintaining resources would exist and equilibrium would eventually be attained. Other less competitive species would be excluded and consequently species richness would be maintained at a low level.

Although the intermediate disturbance hypothesis is widely supported, it has its limitations: (i) the hypothesis does not specify which community and ecosystem parameters will behave in the expected way (Pickett and White,1985), (ii) the concept of maximum level of disturbance is a relative term and needs to be explicit according to the goals of a study (Pickett and White, 1985) and (iii) it assumes deterministic equilibrium for the trends in species richness rather than mechanisms based on stochastic processes, patch dynamics and non equilibrium states (Picket and White, 1985; Auerbach and Shmida, 1987; Turner *et al.*, 1993).

1.7.2 Patch dynamics

The concept of patch dynamics is applied more generally in situations where the disturbance regimes are not stable and therefore the landscape is not in equilibrium (Romme and Knight, 1981). There is a critical distinction between an opening, called a gap, in a forest canopy and the area it influences, called a patch. There is a similar and equally important distinction in a sparsely wooded savanna between the tree crown and its zone of influence, called a tree dominated patch In terms of patch dynamics, the fundamental differences between tree fall gaps and savanna trees is in the rapidity of their births and deaths. Most forest gaps form, develop and disappear relatively quickly (10–30 years), whereas savanna trees germinate, grow and persist for more than a 100 years (Belsky and Canham, 1994). As a result isolated savanna trees constitute a more permanent element of the landscape. Patch dynamics have widely been assumed to be essential for the maintenance of species diversity in old growth forests. Most forest species, including shade tolerant trees, shrubs and herbs, respond positively to tree gaps (Denslow, 1987; Canham, 1988; Dirzo *et al.*, 1992). The existence of trees in the form of tree clumps is common in some savanna types such as those in Texas and Venezuela (San-José *et al.* 1991) but not in the African savannas where the distribution of trees is more scattered (Mistry, 2000). Thus difficulties in testing patch dynamics in African savannas.

1.7.3 Landscape dynamics and gradient analysis

The intermediate disturbance hypothesis and patch dynamics are most appropriate at fine-scales and do not specify a particular context that may enhance or constrain disturbance impacts in a given situation (Pickett and White, 1985; Delcourt and Delcourt, 1988; Natasha *et al.*, 1990). Turner *et al.* (1993) extended a broader view of landscape dynamics which considers the spatial-temporal scales of disturbance as most concerns over conservation biology and resource management are related to landscape use (Delcourt and Delcourt, 1988; Wiens *et al.*, 1993; Pickett and Cadenasso, 1995). Many landscapes are affected by multiple disturbances which occur at different spatial and temporal scales and which may interact (Canham and Loucks, 1984). Ecological patterns and land-cover changes are more predictable at a landscape scale because the effects of local heterogeneity are averaged out at broader scales (Wiens, 1989; Pickett and Cadenasso, 1995). Where disturbance interval is long relative to recovery time and a small proportion of the landscape is affected, the system is stable and exhibits low variance over time. Where disturbance interval is comparable to recovery interval and a large proportion of the landscape is affected, the system is stable but exhibits large variance and where disturbance interval becomes much shorter than recovery time and a large proportion of the landscape is affected, the system may become unstable and shift into a different trajectory (Turner *et al.*, 1993). Thus from an ecological perspective, landscape dynamics offers a broader way to consider environmental heterogeneity or patchness in spatially explicit terms.

The limitation of disturbance hypotheses also led to the formulation of the 'individualistic response hypothesis' which asserts that the distribution of any plant species is a product of its own physiological requirements and tolerances, modified by the availability of resources that are subjected to competitive utilisation by associated species (Gauch, 1985). Gradients in plant abundance associated with physical gradients may be different for each species, creating a vegetation mosaic of populations integrated across the landscape (Cody, 1989; Patten and Robbin, 1995).

1.8 Community organisation theory

There are different theories pertaining to community structure and organisation and one of these is the island biogeography theory which was developed largely by MacArthur and Wilson (1967) and Martin (1981) and states that the species richness of an island is directly related to its size and distance from the mainland. Preston (1962) showed that a curvilinear relationship holds between the number of species (S) and the area of an island (A). $S = CA^z$ or $S = log\, C + z\, log\, A$, where c and z are constants.

Several studies have attempted to apply species area curves to the large mammal fauna of the African savanna in order to predict the possible long term consequences of the isolation of reserves by the development of surrounding areas (e.g., Western and Ssemakula, 1981; East, 1981). These studies found little or no evidence of a relationship between the number of species and reserve size. This is because the reserve creation is constrained by social and economic factors and their effects on land availability rather than ecological factors (Western and Ssemakula, 1981). The increasing demand for land and rapidly growing human population in the African savanna region (Young and Solbrig, 1993) signifies the threat of land degradation. The complete degradation of the matrix surrounding a forest reserve suggests that the assessment of long term species losses following isolation is important in miombo woodlands.

1.9 Human disturbances in miombo woodlands

Miombo woodlands are viewed to be sub-climax to semi-evergreen forests and are maintained by fires (Trapnell, 1959; Kielland-Lund, 1990a), exploitation by people (Frost, 1996; Mistry, 2000) and wildlife (Lawton, 1978). Human disturbances in miombo woodlands differ from one place to another depending on their type, intensity and frequency. For example, Zambian miombo woodlands are more affected by the agricultural practices of local shifting cultivators than bush fires (Stromgaard, 1985). In Zimbabwe browsing by livestock severely reduces coppice regrowth particularly of *Julbernardia globiflora* (Benth.) Troupin in the initial stages (Grundy, 1995). Wood harvesting for charcoal production in Zambia and Tanzania is not selective for particular girth classes and species (Chidumayo, 1991; Monela *et al.*, 1993).

Another concern about clearing of miombo woodlands for cultivation, increasing levels of extraction of products and the occurrence of annual fires, is the resultant loss of biodiversity. A study by Stromgaad (1986) in abandoned shifting cultivation plots indicates that the diversity of woody species was lowest initially as some of the species were eliminated by clearing. Stromgaad (1986) reports further that the abundance of dominant miombo species declined during succession, whereas the abundance of *Combretum* species increased.

1.10 Problem statement and motivation

Sustainable management of natural resources is geared towards conservation of the resource so as to meet the present and future needs of growing populations (WCED, 1987). Sustainability requires an effective commitment to develop appropriate indicators for measuring performance and guiding management through implementation of best practices across involved sectors (Sattler *et al.*, 1997). Sustainable conservation strategies are based on two principles: (i) integration of commercial and conservation philosophies in a perpetual management of resources and (ii) conservation management of the reserve system needs to be integrated with management of land outside the reserve system (Shea *et al.*, 1997). Most natural resource problems are human problems that have been created under a variety of political, social and economic systems (Ludwig *et al.*, 1993). In miombo woodlands, other than Zimbabwe (McGregor, 1995; Campbell *et al.*, 1997; Campbell *et al.*, 2000; Kundhlande *et al.*, 2000) there are few comprehensive studies on the quantities and direct and indirect values of the resources extracted. Gradient analysis by the use of ordination techniques has been limited in miombo woodlands (Rodgers, 1979; Frost, 1996). This study helps to fill these gaps.

1.11 Aim and objectives

The aim of this study was to investigate the impacts of human resource utilisation on plant diversity and persistence of miombo arborescent species in the forest reserve and public lands. The specific objectives of the study were:

1. To undertake an ethno-botanical and utilisation survey of trees used for subsistence and commercial purposes;
2. To determine the value of charcoal production and its full cost through cost benefit analysis (CBA);
3. To determine the effects of wood harvesting on stocks in protected and public lands;
4. To determine and compare diversity and distribution of tree species in protected and public lands;
5. To gain an understanding of the population dynamics of selected preferred species under contrasting management regimes; and
6. To explore the effects of government intervention and the role of local institutions in the sustainable management of woodlands.

1.12 Structure of the thesis

The thesis comprises three distinct parts with 9 chapters. Each of chapters 2–8 comprises a paper that has been published in or submitted to an internationally recognised scientific journal. Presenting a thesis as a collection of papers for publication inevitably results in some repetition, particularly in the sections dealing with the study area and methods.

The first part of the thesis, comprising three chapters (2, 3 and 4) concerns socio-economic aspects. Chapter 2 covers mainly the ethnobotanical aspects of woody species and it ascertains local people's knowledge and reliance on woody resources as a first step towards the development of sustainable resource conservation. Chapter 3 deals with resource economics. This chapter assigns monetary values to the commercial production of charcoal (the main commercial activity in the area) through cost benefit analysis (CBA). Chapter 4 fills the gap left by the two preceding chapters by quantifying wood used for subsistence purposes and determining the other types of economic pursuits and land uses in the area. This chapter is inter-disciplinary as it deals with the interactions between local communities, markets, the socio-political environment and the resource base.

The second part of the thesis deals with the bio-physical aspects of the woodland stocks, biodiversity and dynamics of preferred species and it comprises three chapters (5, 6 and 7). Chapter 5 compares harvested and standing wood stocks in two contrasting management regimes, protected and public lands. The chapter also investigates different human disturbance gradients from probable disturbance foci. Chapter 6 relates wood harvesting to woody species richness and diversity. The chapter also determines the underlying environmental gradients (including human disturbances) at the community level. Chapter 7 aims at formulating silvicultural prescriptions for miombo woodlands. The chapter examines the regeneration of the four most preferred species and describes their population dynamics over three years (1992–1995) in relatively undisturbed miombo within a forest reserve and regrowth miombo in public woodlands.

The third part of the thesis gives overall recommendations on sustainable management and it constitutes two chapters (8 and 9). Chapter 8 depicts the land-use

/ land-cover changes in the area and ascertains the local people's ownership rights, knowledge and institutional capacity as prerequisites for the sustainable management of natural resources in miombo woodlands. Chapter 9 is a synthesis that integrates the three major parts of the thesis. The chapter outlines the knowledge this study has contributed. In addition, this last chapter indicates areas for future research, i.e what additional knowledge is required to provide even better management practices for the area.

CHAPTER 2

Differential utilisation and ethnobotany of trees in Kitulanghalo Forest Reserve and surrounding communal lands, eastern Tanzània.

Economic Botany 2000, 54:328–343

2.1 Abstract

This study documents the utilisation aspects and distribution of ethnobotanical knowledge of the local people of Morogoro, Tanzania, as a first step towards sustainable utilisation and conservation of tropical woodlands. A total of 133 arborescent species in 31 families was identified of which 69% had a variety of uses. These uses were classified into 12 categories and major uses were charcoal, firewood, medicine and poles. Most tree species have occasional uses, but a few are exceptionally useful and thus their levels of utilisation may far exceed their regeneration and production. The questionnaire survey indicated that 62% of the respondents agreed that traditional medical services were more available than modern services. Utilisation surveys indicated that wooden poles are the building material used in 98% of the dwellings and storage structures, wild foods were useful for food security especially during drought years, and high quality timber trees have been depleted in the forest because of earlier exploitation by pit-sawing. The distribution of ethnobotanical knowledge indicated that much of the relevant ethnobotanic and utilisation information was held by more aged members of the society and hence there is a clear need to capture this knowledge before it is lost. This study has shown that resources are defined by use and culture, and some components of ethnobotanical knowledge have potential for the sustainable management of miombo woodlands.

Key words: Indigenous knowledge, miombo woodlands, participatory rural appraisal, Tanzania, tree use values.

2.2 INTRODUCTION

The uses and ethnobotanical aspects of plants in Tanzania have not been adequately documented and in terms of conservation, it is important to determine which species are used and whether over-utilisation may be occurring. On a global level, 80% of the world's population is believed to rely to some extent on medicinal plants, but little is known about the abundance and distribution of these plants or the effect of timber harvesting on medicinal plant populations (Caniago and Siebert, 1998). About 80% of Tanzanians, some 24 million people, live in rural areas where forest resources are central to their livelihood (URT, 1991). In terms of legal status, 30% of the forested land is designated as forest reserve (protected) while the remaining 70% is public land. Public lands are communal and available for use; they are regarded as common property, whereas in the reserves, utilisation is restricted by the issuing of licences. Most of the forested land comprises miombo woodland which covers nearly 3 million km^2 of central and eastern Africa, and provides food, fuel, construction materials and medicines (Liengme, 1983; Campbell and du Toit, 1988; Gauslaa, 1989; Grundy *et al.*, 1993; Clarke, *et al.*, 1996). Miombo woodland is a distinctive type of African savanna dominated by the arborescent genera *Brachystegia* and *Julbernardia* (both Caesalpinioideae).

Quantitative techniques in ethnobotany have been used to compare the uses and importance of different plant species and families. Familial use value analysis indicates which families are important in providing subsistence or commercial resources for timber or other uses (Phillips and Gentry, 1993). These values are important in setting priorities for conservation of useful families (Prance *et al.*, 1987; Phillips and Gentry, 1993). The ordinal ranking system (Prance *et al.*,1987) distinguishes between major and minor uses and is an improvement over the simple percentage useful calculations.

The overall aim of this study is to ascertain the local people's knowledge of and reliance on woody resources as a first step towards sustainable resource conservation. The decreased availability of certain important species in northern Tanzania for example, is reported to have been caused by high utilisation pressure in recent decades (Smith *et al.*, 1996). This study records the disappearing indigenous knowledge (Luoga, 1995). The objectives of the study were to: identify tree species which are recognised as resources by local communities; undertake a local quantitative valuation of the uses of arborescent resources; document the indigenous knowledge that is associated with the utilisation of resources; and assess how ethnobotanical knowledge is distributed among the human population with respect to age, education and gender.

2.3 Study area

The study was conducted in the Kitulanghalo Forest Reserve and the villages and public (communal) lands surrounding the reserve. The area is located about 50 km east of Morogoro Municipality on the road to Dar-es-Salaam, which is about 150 km further east (Figure 2.1).

There are two main local tribes in the study area namely 'Kwere' and 'Zigua'. Three villages are in proximity to the reserve with their hamlets scattered in the two villages, Lubungo and Gwata, are traditional settlements while Maseyu was formed by the resettlement scheme of the mid-1970's, when people were moved from scattered settlements north of the reserve and concentrated near the highway which runs from Dar-es-Salaam to Lusaka, Zambia (Figure 2.1). Most local people are subsistence farmers. Major subsistence crops include maize, sorghum, beans (*Phaseolus vulgaris*) and cassava. Sesame and cotton were previously grown as cash crops but there is no market for these at present. The major type of vegetation is open miombo woodland dominated by the tree species *Julbernadia globiflora, Brachystegia boehmii* and *Pterocarpus rotundifolius* (authors listed in Appendix 1). The most common smaller trees and shrubs are *Combretum* spp., *Diplorynchus condylocarpon* and *Dichrostachys cinerea.* spp. The undergrowth is dominated by a heliophilous grass layer and forbs. Dominant grass species include *Hyparrhenia* spp., *Themeda triandra* and *Panicum maximum* and most common forbs are *Indigofera* spp.

Patches of semi-evergreen forest (Kielland-Lund,1990a) are more conspicuous in the western part of the reserve along the base of Kitulanghalo Hill where the tree layer is dominated by *Manilkara sulcata* and *Scodophloeus fischeri*. Common smaller trees are *Cola clavata* and *Strychnos henningsii*. No cattle are herded in the area because of the prevalence of tsetse flies transmitting nagana (sleeping sickness).

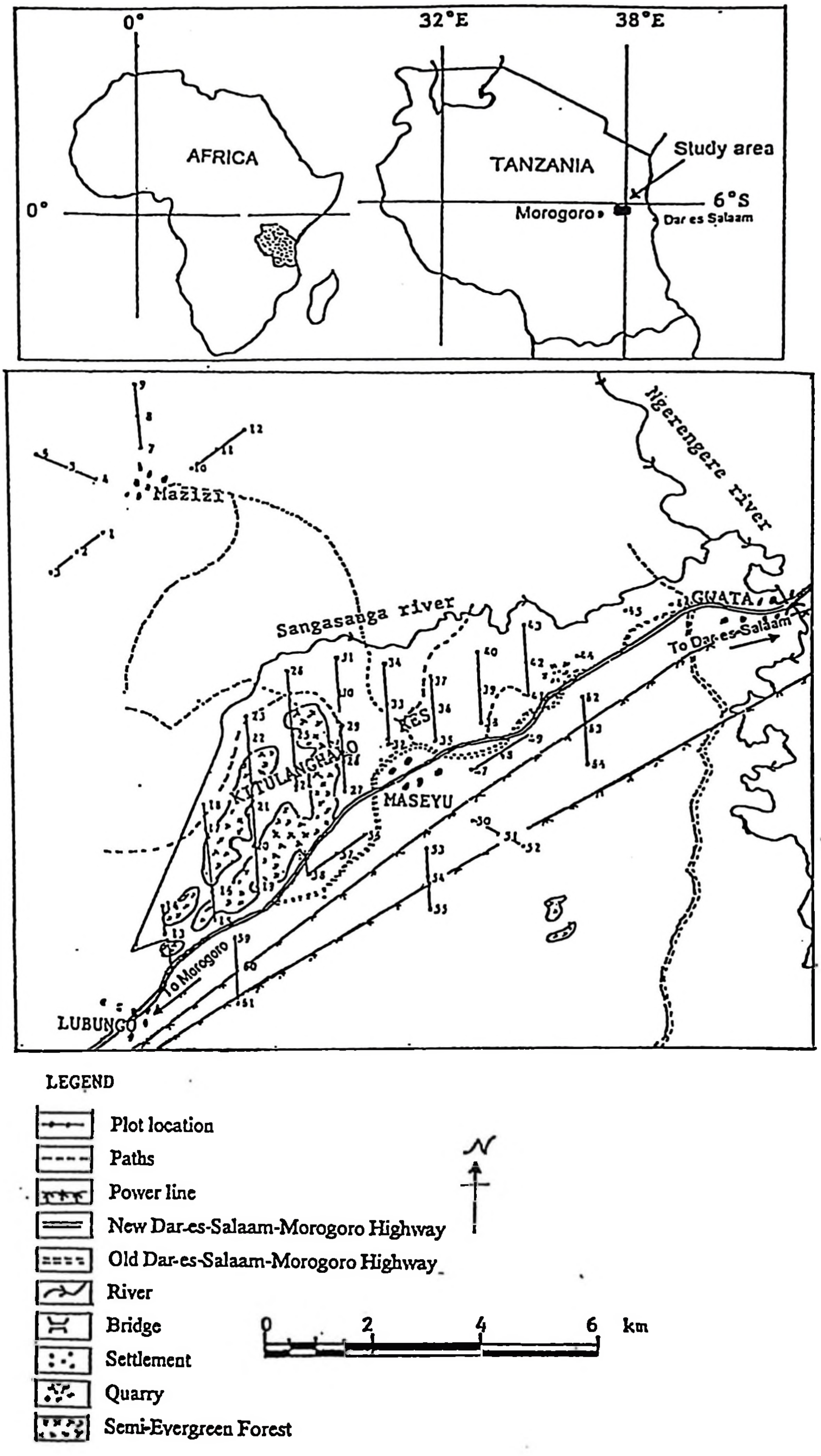

Figure 2.1 The location of plots in the Kitulanghalo Forest Reserve and surrounding public lands, Morogoro, Tanzania.

2.4 METHODS

Data were collected over 4 months (May 1997 and November1997 to January 1998 using participatory rural appraisal (PRA), structured and semi-structured interviews and field plots. PRA techniques are useful in the valuation of savanna resources (Campbell *et al.*, 1997), being participatory in nature and allowing farmers to apply their indigenous knowledge, experience and capacity to share information (FAO, 1990). PRA techniques were applied to 30 participants in each of the two villages of Gwata and Maseyu in May 1997. This initial phase was very important to build rapport with the farmers and hence formed the basis for subsequent surveys. Visual methods used included participatory resource mapping, transect walks, time lines and chronologies, matrix scoring, pair-wise ranking, seasonal calendars, wealth ranking and the use of ven (pie) diagrams (FAO, 1990; Campbell *et al.*, 1995).

The questionnaire was tested on 10 people in Lubungo village in order to ascertain the pertinence of the questions, after which minor modifications were made. Structured questionnaire interviews were then administered to 80 households in 8 hamlets of two villages, Gwata and Maseyu. This represents a sampling intensity of 8%. There are 1012 households within the study area, 13% of which are female-headed. The total population of the three villages surrounding the reserve is 4640 people with an average of about five people per household. The selection of households to be interviewed was done systematically in order to obtain a representative sample in terms of wealth, gender and age classes. For example, the sample comprised 67 male-headed and 13 female-headed households. Unstructured and group interviews which are the most widely used methods of data collection in cultural anthropology (Martin, 1995), were used to obtain information on ethnobotany and utilisation from key informants who were traditional healers (n = 4), charcoal burners (n = 8), village headmen (n = 3) and craftsmen (n = 5).

Data from interviews were analysed using both descriptive and inferential statistics. The best fit of linear, natural ln, exponential or power in regression analyses were presented in order to establish the influence of age and education (independent variables) on ethnobotanical knowledge, as represented by responses on the number of tree species used for firewood, charcoal, medicines, construction, household items, food and other miscellaneous uses. Differences in response in relation to gender were analysed by nonparametric (Mann-Whitney) tests.

To determine the type of wood used in building structures, 18 new unplastered wooden structures of different sizes were selected and all the poles of different kinds in each structure were counted and the species identified.

Sample plots of 20 x 50 m (0.1 ha) were used to collect both utilisation and ethnobotanical data. A systematic allocation of plots along transect lines was applied; 34 in the forest reserve and 30 in public lands (Figure 2.1). Of the plots in the public lands, 12 were placed north and 18 south of the reserve. All species encountered in the plots were enumerated and their uses discussed with 5 experienced local elders (men) who were available throughout the field work period.

The use value analysis was performed on all the arborescent species (trees and shrubs) to determine the utility of the resources. In the analysis, uses were categorised into three classes, no use, minor use and major use and the use value scores assigned to these classes were 0, 0.5 and 1 respectively (Prance *et al.*, 1987). To minimise the investigator's value judgements associated with this method (Phillips and Gentry, 1993), information from plot surveys in the forest was corroborated with information gathered from PRA, questionnaires, and informal surveys. The familial use value was determined to evaluate the importance of different plant families to the ethnic people and was calculated as the average of the use values of the species belonging to that family (Prance *et al.*, 1978; Phillips and Gentry, 1993).

2.5 RESULTS AND DISCUSSION

2.5.1 Identification of tree species by their local names

A total of 133 species of trees and shrubs was encountered during the PRA and in the sample plots (Appendix 1). Six pairs of species, each within the same genus share the same local name (Appendix 1); one drawback of local names. The importance of trees in local culture is shown by 98% of the trees being identified by the local people by local names. In addition, several villages and townships in the district are named after common tree species: 'Maseyu' (*Xerophyta spekei*), 'Mikese' (*Acacia seyal*), 'Mkuyuni' (*Ficus spp.*) and 'Mkambalani' (*Acacia nigrescens*).

2.5.2 Recognition of tree species as resources

The recognition of plant species by the local people is utilitarian in nature. Sixty nine percent (69%) of the species in the area have uses (Appendix 1). This figure is comparable to Kenya (Medley, 1993) , but is lower than the 80% reported in Amazonian studies (Prance *et al.*, 1987; Anderson and Posey, 1989). From the use value analysis, 12 direct uses were recognised of which charcoal had the highest contribution to the total use (18.3%), followed by firewood (16.8%) and medicines (15.7%) (Table 2.1). Most species used to make charcoal are in the families/sub-families Caesalpinioideae, Combretaceae, Mimosoideae and Papilionoideae (Appendix 1), which together account for 76% of the total use values for charcoal (Table 2.1). *Julbernardia globiflora*, *Brachystegia boehmii* and *Grewia bicolor* have the highest total use values, each with a score of 4 (Appendix 1).

Only 13 of the 37 families recorded have use values greater than 1, while the species in six families, namely Araliacea, Labiatae, Moraceae, Olacaceae, Rhamnaceae and Vitaceae, have use values of zero (Table 2.1). Because each is represented by a single species, the families Bombacaceae (*Adansonia digitata*) and Loganiaceae (*Strychnos spinosa*) have the higest familial use values of 2.5 and highest average of three uses per species (Table 2.1). This indicates that the intensive and multiple uses are focussed on few species/families which stand out as being particularly useful, a result which has also been reported by Phillips and Gentry (1993). However, the impact of species' uses depends on whether the utilisation is destructive or nondestructive. For example, *A. digitata* is used for rituals, fruits and fibres, and thus does not involve the cutting of branches or the tree trunk, whereas *S. spinosa* is used for charcoal, firewood and building poles, which are destructive uses. This suggests that the family Loganiaceae, with only one species but multiple destructive uses could be threatened with local extinction if the species is over-utilised. *A. digitata* has similar uses in Zimbabwe (Mandondo, in press) indicating an overlap of ethno knowledge, which occurs in various ethnic groups of people across the ecological ranges of plant species (Smith *et al.*, 1996).

Sclerocarya birrea subsp. *caffra*, *Sterculia africana* and *Sterculia appendiculata* are also valued in the study area for traditional worship as they are associated with ancestral sacrifices and traditionally were not harvested. Despite the traditional value of *Sclerocarya birrea* subsp. *caffra*, it was found that it is now harvested due to a partial commercialisation of its wood for timber and handcrafts. *Pseudolachnostylis maprouneifolia* is considered a sacred tree by the immigrant tribes from southern Tanzania, and other trees which are associated with certain ritual beliefs are *Turraea stuhlmanii*, *Grewia bicolor*, *Erythrina abyssinica*, *Maytenus senegalensis* and *Ehretia amoeana*. This respect and consequent preservation of certain tree species indicates that some indigenous practices have an impact in terms of conservation, although low utilisation may also relate to lack of markets. No place in the forest is spared specifically for spiritual purposes, although Kitulanghalo Hill in the reserve, was formerly used as a holy shrine for traditional ceremonies.

Such practices are now conducted less frequently and take place around selected sacred baobab trees or in burial places. The village elders admit that most of the traditional values have been greatly diluted, but a special respect is still maintained for burial places ('maziara'). All burial places are preserved under either natural or planted tree cover and even dry wood is not supposed to be collected. In Zimbabwe, burial places are also mostly kept under dense cover of mature trees (Mandondo in press). In other parts of Tanzania, there are small pockets of 'traditional forest reserves' which are managed under traditional jurisdiction (Luoga, 1995).

2.5.3 Utilisation of resources

2.5.3.1 Fuel wood

A broader range of species is used for charcoal and firewood than for other uses (Appendix 1) resulting in higher use values for these than for other uses (Table 2.1). Generally the collection of firewood is not a major cause of deforestation as dead branches, naturally dying trees and unused material from trees that are harvested for other purposes are collected. However, the household survey revealed that 10% of the respondents are local brewers and collect live as well as dead wood, as live wood prolongs the fuel burning time. Live wood is also used for brewing and brick burning in other miombo areas (Mazambani, 1993). The most commonly collected species are *Combretum* spp. followed by *Julbernardia globiflora*. *Bridelia cathartica* is avoided because it produces a pungent smell when burnt and *Boscia salicifolia* and

Dalbergia melanoxylon are avoided for cultural reasons.

Pair-wise comparisons in PRA revealed that firewood shortage ranked least among the villagers' problems in both villages (Table 2.2). The abundance of fuel wood is also reflected in the short fuel wood expeditions of only 54 minutes per day compared with five hours in north east Tanzania (Fleuret and Fleuret, 1978). Thus, firewood is still abundant in the area.

Table 2.1 Familial use values of arborescent species in Kitulanghalo Forest Reserve and surrounding public lands (Uses: Ca = Carving, Cha = Charcoal, Fi = Firewood, Fo = Food, Li = Live fence, Me = Medicine, Mi = Miscellaneous, Po = Poles, Ri = Rituals, Ro = Rope fibre, Ti = Timber, Wi = Withies).

No.	Family	No. of spp. *	Ca	Cha	Fi	Fo	Li	Me	Mi	Po	Ri	Ro	Ti	Wi	Total	Familial **	Uses/spp. ***
1	Anacardiaceae	5	0.5	0.5	0	0	0.5	1.5	1	0	1	0	0.5	0	5.5	1.1	1.4
2	Annonaceae	2	0	0	0	1	0	0	0	0	0	0	0	0	1	0.5	0.5
3	Apocynaceae	3	0	0.5	0.5	0	0	0	0	0	0	0	0	0	1	0.3	0.3
4	Araliacea	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0
5	Bignoniaceae	4	0	0	1	0	0	1	1	2	0	0	0	2	7	1.8	1.3
6	Bombacaceae	1	0	0	0	1	0	0	0	0	1	0.5	0	0	2.5	2.5	3.0
7	Boraginaceae	1	0	0	0	0	0	0	0	0	0.5	0	0	0	0.5	0.5	1.0
8	Burseraceae	3	0	0	0	0	1	0.5	0	0	0	0	0	0	1.5	0.5	0.3
9	Caesalpinioideae	13	0	5.5	5.5	1	0	1	1	5	0	2	3	0.5	24.5	1.9	0.7
10	Capparaceae	2	0	0	0	1	0	1	0	0	0	0	0	0	2	1.0	1.0
11	Celastraceae	2	0	0	0	0	0	0	0	0	1	0	0	0	1	0.5	0.5
12	Combretaceae	9	0	7	7	0	0	1	0	3.5	0	0	0	0	18.5	2.1	0.4
13	Compositae	1	0	0	0	0	0	1	0	0	0	0	0	0	1	1.0	1.0
14	Ebenaceae	5	0	0.5	0.5	1	0	0.5	2	1.5	0	0	0.5	1	7.5	1.5	1.6
15	Erythroxylaceae	1	0	0	0	0	0	0	0	1	0	0	0	1	2	2.0	2.0
16	Euphorbiaceae	9	0	2	1.5	0.5	0	1.5	1.5	2	1	0	0.5	0	10.5	1.2	0.9
17	Labiatae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0
18	Loganiaceae	1	0	1	1	0	0	0	0	0.5	0	0	0	0	2.5	2.5	3.0
19	Meliaceae	2	0	0	0	0	0	1	0	0	1	0	0	0	2	1.0	1.0
20	Mimosoideae	13	0	5.5	4	0	0	5	1	2	0	0	0.5	0	18	1.4	0.5
21	Moraceae	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0
22	Ochnaceae	4	0	0.5	0	0	0	1	1	0	1	0	0	0	3.5	1.0	1.0
23	Olacaceae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0
24	Palmae	1	0	0	0	0	0	0	1	0	0	0	0	0	1	1.0	1.0
25	Papilionoideae	13	1	5	5	0.5	0	3	1	4	1	0	1.5	1	23	1.8	0.8
26	Rhamnaceae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0
27	Rubiaceae	11	0	1	0	1	0	1	2	0	0	0	0	1	6	0.5	0.5
28	Rutaceae	2	0	0	0	1	0	0.5	0	0.5	0	0	0	0	2	1.0	1.5
29	Salvadoraceae	1	0	0	0	0	0	0	1	0	0	0	0	0	1	1.0	1.0
30	Sapindaceae	4	0	1	1	1	0	1	0	0.5	0	0	0	1	5.5	1.4	1.5
31	Simaroubaceae	1	0	0	0	0	0	1	0	0	0	0	0	0	1	1.0	1.0
32	Sterculiaceae	5	0	0.5	0.5	0	0	1	0	1	0	1	0	0.5	4.5	0.9	1.2
33	Tiliaceae	3	0	0	0.5	2	0	1	0.5	1	1	0	0	1	7	2.3	2.3
34	Umbelliferae	1	0	0	0	0	0	1	0	0	0	0	0	0	1	1.0	1.0
35	Velloziaceae	1	0	0	0	0	0	0	1	0	0	0	0	0	1	1.0	1.0
36	Verbenaceae	2	0	0	0	1	0	1	0	0	0	0	0	0	2	1.0	1.0
37	Vitaceae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0
TOTAL		133	1.5	30.5	28	12	1.5	26.5	15	24.5	8.5	3.5	6.5	9	167		
Percentage of total use value			0.9	18.3	16.8	7.2	0.9	15.7	8.9	14.6	5.1	2.1	3.9	5.4	100		

Total use values for individual species are shown in Appendix 1

* All species of the family present in the area, whether they are used or not

** Total use value for the family, divided by number of all species in the family

*** All uses of the family, divided by number of all species in the family

Table 2.2 Participatory rural appraisal (PRA) ranking results of socio-economic problems in Maseyu and Gwata villages, Morogoro, Tanzania.

Problem		*Ranks		
		Maseyu village (n=30)	Gwata Village (n=30)	Average
1	Lack of dispensary	1	1	1
2	Vermin damaging mature crops	3	3	3
3	Poor farming tools	2	5	3.5
4	Lack of safe water	5	2	3.5
5	No reliable transport	4	6	5
6	Lack of milling machine	8	4	6
7	Shortage of wooden building poles	6	7	6.5
8	Shortage of firewood	7	8	7.5

*The rank of 1 indicates the greatest importance of the social problem to the villagers.

2.5.3.2 Medicines

A total of 35 tree species with medicinal properties was recorded, 83% of which were harvested from roots (Table 2.3). Species of the family Mimosoideae were the most used for remedies, representing nearly 23% of all medicinal trees (Table 2.3). The questionnaire survey showed that 62% of the respondents agreed that traditional medical services were more available than modern services because there were no government dispensaries in any of the villages. Cash expenditure for medical care in Maseyu Village, where there was no dispensary, was US\$ 2.9 ± 0.388 per month per household, significantly lower (t = 1.537, p = 0.065, df = 43) than US\$ 3.5 ± 0.627 in Gwata Village where there was a private prison's dispensary. PRA results indentified lack of dispensaries as a key problem for the people (Table 2.2) and hence the greater dependence on traditional medicines. This indicates that trees from miombo woodlands make a large contribution to medicines.

2.5.3.3 Building poles

On average each household had 4 structures of which at least one was a granary and the other three were dwellings (questionnaire surveys). At least one dwelling was located at a farm and was occupied by a few members of the family for at least four months a year while protecting crops from vermin before harvesting (seasonal calendars drawn during PRA). The necessity for each family to have an extra dwelling at the farm is shown by the vermin problem being ranked third in both villages out of eight problems (PRA) (Table 2.2). The extra dwellings increase the requirement for wooden building poles, although the people do not acknowledge that wooden building poles are in limited supply (Table 2.2). Wooden poles form the main structural material for 98% of the houses, where a rectangular architectural design uses four types of poles namely 'mijengo' (wall erecting poles), 'miamba' (beam poles), 'pau' (roofing poles) and 'fito' (withies/cross joint members) (Figure 2.2). The walls and floors are then plastered with mud, while the roof is thatched with grass. About 17 different species were used for wall erecting poles but the preferred species were *Spirostachys africana* (28%), *Dombeya rotundifolia* (17%) and *Julbernardia globiflora* (12%). For beam poles,13 species were recorded, the common ones being *Diospyros consolatae* (18%), *Spirostachys africana* (15%), *Dombeya rotundifolia* (14%) and *Terminalia sericea* (14%). Seventeen species were used for roofing poles, including *Markhamia zanzibarica* (23%) and *Millettia usaremensis* (18%), both of which are forest species, and *Combretum* spp. (12%). A total of 15 species was used for withies, mainly *Millettia usaremensis* (29%), *Diospyros consolatae* (14%) and *Markhamia sanzibarica* (13%). The importance of *Diospyros* spp. for construction material concurs with other studies in Tanzania (Hall and Rodgers, 1986) and Kenya (Medley, 1993).

Various views about utilisation of poles include the selection of building materials because of their resistance against bio-degraders, their availability and cultural taboos. *Spirostachys africana* for example, is the most favoured species for poles because it is termite-resistant, but high levels of utilisation in the past might have reduced its availability, consequently more use is made of *Julbernardia globiflora* and *Combretum* spp., which were formerly not commonly used for poles. *Boscia salicifolia, Suregada zanzibariensis, Ehretia amoena, Deinbollia borbonica* and *Allophylus rubifolius* are not used for construction purposes due to cultural taboos. In other areas of Africa, building poles are also selected based on their resistence and availability (Campbell and Du Toit, 1988; Cunningham, 1993).

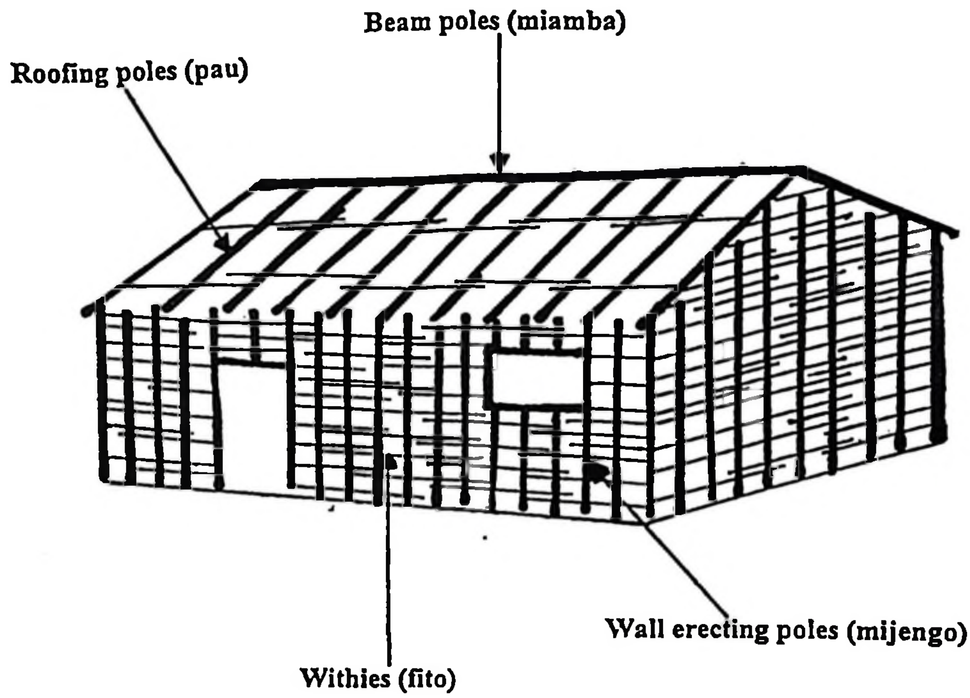

Figure 2.3 Architectural design of traditional houses showing different categories of poles.

2.5.3.4 Food

Maerua triphylla has edible roots (tubers) that provide food security, especially during drought years. Three arborescent species produce edible leaves (vegetables): *Zanthoxylum chalybeum*, *Ormocarpum kirkii*, and *Zanha africana*. Nine species bear edible fruits: *Flueggea virosa*, *Allophylus rubifolius*, *Heinsia crinita*, *Diospyros zombensis*, *Grewia bicolor*, *Vangueria infausta*, *Annona senegalensis*, *Tamarindus indica* and *Ximenia caffra*. The importance of the woodlands in the provision of food may be considerably underestimated because herbaceous plants which have high nutrient and vitâmin vàlues (Wehmeyer *et al.*, 1969) were not included in this study.

Table 2.3 Tree species with medicinal properties and associated indications in kitulanghalo forest reserve and surrounding public lands.

No.	Species	Family	Remedy for	Plant part used
1	*Acacia goetzei ssp. goetzei*	Mimosoideae	Cough, chest pain	Bark
2	*Acacia nilotica*	Mimosoideae	Diarrhoea, women menstrual pain, hernia	Roots
3	*Acacia robusta*	Mimosoideae	Stomach disorders, worms, baby delivery	Roots
4	*Acacia polyacantha*	Mimosoideae	Fever	Roots
5	*Albizia anthelmintica*	Mimosoideae	Cough, chest pain	Bark
6	*Albizia harveyi*	Mimosoideae	Worms, stomach disorders	Roots, Leaves
7	*Albizia petersiana*	Mimosoideae	Stomach disorders, worms	Roots
8	*Bridelia cathartica*	Euphorbiaceae	Anemia	Roots
9	*Cassia abbreviata*	Caesalpinioideae	Hernia	Bark, roots
10	*Cassia afrofistula*	Caesalpinioideae	Pneumonia, malaria, hernia	Roots, bark
11	*Clerodendrum glabrum*	Verbenaceae	Worms, male libido	Roots
12	*Combretum molle*	Combretaceae	Hernia	Roots
13	*Combretum zeyheri*	Combretaceae	Baby delivery, hernia	Roots
14	*Commiphora africana*	Burseraceae	Mammary glands, hernia	Roots
15	*Dalbergia melanoxylon*	Papilionoideae	Hernia, worms, stomach disorders	Roots, leaves
16	*Deinbolia borbonica*	Sapindaceae	Heart problems	Roots
17	*Dichrostachys cinerea*	Mimosoideae	Snake bites, diarrhea, male libido	Leaves, bark, roots
18	*Diospyros mossambicensis*	Ebenaceae	Toothache	Roots
19	*Diplorhynchus condylocarpon*	Apocynaceae	Hernia, stomach disorders, male libido	Roots
20	*Dombeya rotundifolia*	Sterculiaceae	Constipation, baby delivery	Roots
21	*Ehretia amoena*	Boraginaceae	Worms	Roots
22	*Erythrina abyssinica*	Papilionoideae	Yellow fever	Roots
23	*Flueggea virosa*	Euphorbiaceae	Fever, stomach disorders, hernia	Roots
24	*Grewia forbesii*	Tiliaceae	Headache, worms, headaches	Roots
25	*Harissonia abyssinica*	Simaroubaceae	Diarrhoea, hernia	Roots

Table 2.3 continued

No.	Species	Family	Remedy for	Plant part used
26	*Lannea schimperi*	Anacardiaceae	Yellow fever, baby delivery	Roots
27	*Lannea schweinfurthii*	Anacardiaceae	Wounds and ulcers	Roots
28	*Ochna leptoclada*	Ochnaceae	Stomach disorders, hernia	Roots
29	*Ochna macrocalyx*	Ochnaceae	Stomach disorders	Roots
30	*Pteleopsis myrtifolia*	Combretaceae	Chest pain	Bark, leaves
31	*Spirostachys africana*	Euphorbiaceae	Purgative	Bark
32	*Steganotaenia araliacea*	Umbelliferae	Tissue inflamation	Bark, roots
33	*Xeroderris stuhlmannii*	Papilionoideae	Stomach disorders	Leaves
34	*Zanha africana*	Sapindaceae	Male potency and libido	Roots
35	*Zanthoxylum chalybeum*	Rutaceae	Yellow fever, hernia	Leaves, roots, bark

2.5.3.5 Timber

High quality timber tree species that were previously available in the area were *Pterocarpus angolensis* and *Afzelia quanzensis* but most of these species have been depleted in the forest because of earlier exploitation by pit-sawing (Nduwamungu, 1996) resulting in a diversification to secondary or non-merchantable tree species such as *Sterculia quinqueloba*. *Pterocarpus angolensis* is also reported to be rapidly dwindling in other parts of the country (Mbwambo *et al.*, 1995) and elsewhere in miombo woodlands (Mushove, 1993; Clarke *et al.*, 1996).

2.5.3.6 Miscellaneous uses

Most other uses of trees in the area are technological and highly species-specific (Table 2.4). Only one species was mentioned for each of the following products: mats (*Hyphaenae coriacea*), bows (*Grewia bicolor*), drums (*Lannea schimperi*), beer fermentation (*Kigelia africana*) and hair combs (*Diospyros kirkii*) (Table 2.4).

2.5.4 Distribution of ethnobotanical knowledge with respect to age, education and gender

Most young people from the villages have more years of formal education than old people, but education level was either unrelated to tree knowledge (all regressions had $r^2 < 0.1$), or tended to be negatively related (all slopes were negative). Older people (>35 years) tend to know more uses than young people (Table 2.5) and ethnobotanical knowledge was positively correlated with age for number of medicinal species ($r^2 = 0.44$, $p < 0.0001$, $df = 79$, linear fit) and total species for all uses ($r^2 = 0.19$, $p < 0.0001$, $df = 79$, linear fit). This points to a generation gap in terms of the source of education, as well as a lack of application to daily life in modern formal education. A large and growing gap in ethno-medical knowledge between the youth and the older generation has also been reported in Zimbabwe (Mukamuri, 1997) and Indonesia (Caniago and Siebert, 1998). A similar generation gap exists in Mexico, where informants' ages predicted in part their knowledge for numbers of species for medicinal uses ($r^2 = 0.52$, $p = 0.001$) and all uses ($r^2 = 0.392$, $p = 0.003$) (Phillips and Gentry, 1993).

Table 2.4 Miscellaneous ethnobotanical uses of tree products in villages surrounding Kitulanghalo Forest Reserve, Morogoro, Tanzania.

Products / Uses	Tree or shrub species
1. Traditional chairs (vigoda)	*Pterocarpus angolensis, Afzelia quanzensis, Xeroderris stuhlmannii* and *Sclerocarya birrea* ssp. *caffra*
2. Traditional beds (made of poles and ropes)	Poles from *Diospyros kirkii, Strychnos spinosa* and *Scrodophleous fischeri*; ropes from *Sterculia africana, Adansonia digitata, Brachystegia boehmii* and sisal
3. Mortar (kinu)	*Afzelia quanzensis, Xeroderris stuhmannii*
4. Pestle (mchi)	*Scrodophleous fischeri, Diospyros consolatae* and *Dalbergia melanoxylon*
5. Paints (for decorating mats and baskets)	Roots of *Euclea divinorum*, sap of *Xeroderris stuhlmannii* and *Pterocarpus angolensis.*
6. Bows	*Grewia bicolor*
7. Arrows	*Diospyros* sp., *Scrodophleus fischeri, Grewia bicolor, Acacia nigrescens* and *Spirostachys africana*
8. Tooth and other types of brushes	Fibres of *Dobera loranthifolia* and *Xerophyta spekei*
9. Mats, baskets and brooms	Leaves of *Hyphaenae coriacea*
10. Glue	Sap of *Diplorhynchus condylocarpon* and *Euphorbia candelabrum*
11. Drums	*Lannea schimperi*
12. Gun handles	*Ochna holstii*
13. Beer fermentation catalyst	Fruits of *Kigelia africana*
14. Hair combs	*Diospyros kirkii*

Generally men tended to know more tree species for particular uses than women (Table 2.5; Figure 2.3), although statistically significant differences were only found for charcoal production ($z = 2.131, p = 0.033$, df = 78) and miscellaneous uses ($z = 2.306, p = 0.021, df = 78$) most of which are produced by men. This is in contrast to studies in Indonesia (Caniago and Siebert, 1998) and Amazon (Lewis and Lewis, 1990) where women were frequently more knowledgeable about herbaceous and non-forest plants than men. These differences indicate a gender specialization of labour that traditionally men work on arborescent plants while women mostly collect herbaceous plants.

Table 2.5 Number of trees known to be used for medicines and all uses among 80 local people living around Kitulanghalo Forest Reserve, Morogoro, Tanzania.

Gender and age groups	No. of respondents	Medicinal trees (mean ± SE)	Range (Min–Max)	Trees for all uses (mean ± SE)	Range (Min–Max)
All men	67	4 ±0.240	0–9	30 ±1.037	8–54
All women	13	3 ±0.599	0–8	26 ±3.054	2–46
People older than 35	64	4 ±0.242	0–9	31 ±1.013	13–54
People younger than 35	16	2 ±0.370	0–4	23 ±2.382	2–39
Men older than 35	54	4 ±0.255	1–9	31 ±1.082	13–54
Men younger than 35	13	2 ±0.389	0–4	24 ±2.373	8–39
Women older than 35	10	3 ±0.712	0–8	29 ±2.867	14–46
Women younger than 35	3	2 ±1.202	0–4	16 ±7.126	2–26

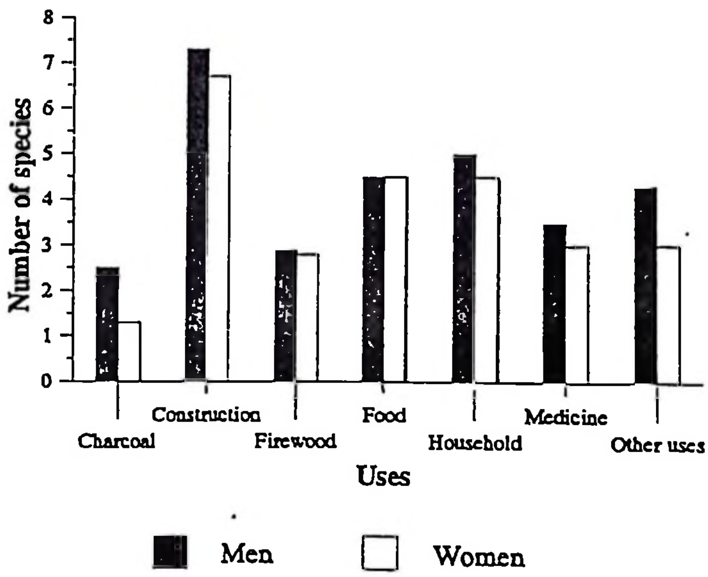

Figure 2.3 Comparison of number of trees known to be used for different purposes by men and women in villages surrounding Kitulanghalo Forest Reserve, Morogoro Tanzania.

2.6 CONCLUSION

This study has shown that resources are defined by use and culture, and some components of ethnobotanical knowledge have potential for the sustainable management of miombo woodlands. However, much of the relevant information is held only by more aged members of the society, thus there is also a clear need to capture the ethnobotanical and utilisation knowledge before it is lost. Most tree species have occasional uses, but a few species are exceptionally useful and thus their levels of utilisation may far exceed their regeneration and production and this will form the basis of future publications.

CHAPTER 3

Economics of charcoal production in miombo woodlands of eastern Tanzania: Some hidden costs associated with commercialisation of the resources.

Ecological Economics 2000, In Press.

3.1 Abstract

This paper assigns monetary values to commercial production of charcoal (using traditional earth kilns) in the miombo woodlands surrounding Kitulanghalo Forest Reserve in eastern Tanzania, through cost-benefit analysis (CBA). Charcoal is the most commercialised resource in the study area and the net present value (NPV) for the charcoal business over a 15-year period was US$ 511 ha^{-1}. The profit from charcoal production is attributable to very low capital outlays, 'free' own labour, 'free' raw materials, lack of concern about associated external costs and high demand for charcoal. When the cost of labour, raw materials and opportunity costs were considered, the NPV value was negative (US$ -868 ha^{-1}), indicating that profit realization is accomplished at the expense of other potential uses of the woodlands. The estimated local wood consumption for charcoal of 6.01 m^3 $capita^{-1}$ $year^{-1}$ is very high compared to subsistence firewood consumption of 1.5 m^3 $capita^{-1}$ $year^{-1}$. The estimated area cleared for charcoal production locally was 1671 ha $year^{-1}$ which was about 13% of surrounding easily accessible communal woodlands in the area (< 5 km from settlements and < 10 km from the Dar-es-Salaam–Morogoro highway) which were estimated to cover 13 350 ha. This shows that although commercialisation of wood resources provides tangible monetary benefits to rural communities, it also contributes to the resource depletion that will ultimately threaten their long-term survival. We recommend some policy interventions in order to safeguard the resources.

Key words. Cost benefit analysis, net present value, opportunity cost, wood fuel.

3.2 INTRODUCTION

The fuelwood crisis in most Southern African Development Cooperation (SADC) countries has been highlighted since 1980 (International Institute for Environment and Development, 1980), but it continues unabated (Monela *et al.*, 1993; Kaale, 1995). About 90% of the total energy consumption (biomass, petroleum, electricity and coal) of Tanzania is fuelwood, compared with only 14% in South Africa (SADC, 1993). Most of the fuelwood is obtained from miombo woodlands, which are dry tropical woodlands covering nearly 3 million km^2 in Africa and inhabited by > 40 million people (Clarke *et al.*, 1996). The demand for fuelwood is rising due to the relatively high cost of electricity and petroleum-based fuels (e.g., paraffin) as well as the rapid human population growth, particularly in urban areas (Deudney and Flavin, 1983).

In Dar-es-Salaam, Tanzania, the consumption of charcoal was positively related to its price, and price-elasticity-of-demand for charcoal was also positive (Shechambo, 1986). The main reason for this market trend is that charcoal is a complementary commodity, as it requires metal or ceramic stoves for it to be consumed. These stoves are cheap, affordable and readily available in the market as compared to electric and gas cookers (Shechambo, 1986; Luoga *et al.*, 2000a). The impact of the commercial charcoal industry on the vegetation around urban areas in miombo woodland has been relatively well documented (Mashalla, 1979; MNRT,1989; Chidumayo, 1991; Monela *et al.*, 1993). In Tanzania, the areas neighboring Dar-es-Salaam are particularly badly affected (MNRT,1989; Monela *et al.*, 1993).

In resource economics, the economic definitions of 'benefits' and 'costs' have been expanded (Pearce, 1993). Total economic value (TEV) comprises actual use values and non-use values, with the latter describing option and existence values. Direct use values are conceptually fairly straightforward, but are not necessarily easy to measure in economic terms (Pearce, 1993), while non-use values are normally difficult to determine (Turner *et al.*, 1994; Costanza *et al.*, 1995). The approaches used to determine non-use values are often based on willingness-to-pay (WTP) techniques (Turner *et al.*, 1994), but these techniques are only used reliably in situations where it is possible to impute a value to the unpriced goods or services (Tobias and Mendelsohn, 1991; North and Griffin, 1993; Goulder and Kennedy, 1997) and are almost impractical to apply in most ethnobotanical studies as the questions are probably too hypothetical to elicit consistent responses from rural people (Martin, 1995; Clarke *et al.*, 1996).

Informal trading in savanna (e.g., miombo) woodland products is more economically rewarding near cities (Monela *et al.*, 1993) and along main roads (Campbell *et al.*, 1997) than in villages because of very limited market opportunities due to lower purchasing power in rural areas. The primary value of savanna woodlands lies in domestic and subsistence uses within households (Shackeleton, 1993; Campbell *et al.*, 1997; Luoga *et al.*, 2000a; Shackleton and Shackleton, 2000) and hence finding suitable prices as a basis for valuation is often difficult because of the nature of a subsistence economy. Local people have twelve types of uses for trees in miombo woodlands of eastern Tanzania, which are charcoal, firewood, poles, timber, medicine, withies, food, fibre, live fences, carving, spiritual and other technological uses (Luoga *et al.*,2000b). Of these, charcoal production had the highest use value (accounting for 18.4% of total use value) and was followed by firewood (16.6%) (Luoga *et al.*, 2000b). Prices of forest products in such local economies are frequently determined through surveys (Campbell *et al.*, 1997) unlike products in industrialised economies, where there are readily available reported price data. However, for the commercial products derived from ecosystems, the market prices represent only the marginal values of the products which are less than actual values (Goulder and Kennedy, 1997). Miombo woodlands also perform vital ecosystem services such as carbon sequestration, nutrient cycling and watershed protection (Scholes, 1996).

This study assigns monetary values to commercial charcoal production using traditional earth kilns and determines the importance of the industry to the economies of the local producers through cost-benefit analysis (CBA). When CBA is undertaken from a societal perspective, several other factors may need to be included. Firstly, there is the need to take into account external costs and benefits; secondly, adjustments may be needed in the market prices of inputs and outputs to account for price distortions; and thirdly, consideration and estimation of any forward and backward links to the primary (charcoal production) industry (Abaza, 1993; Dosman and Luckert, 1998).

Specifically, this study focuses on answering two major questions in public miombo woodlands surrounding the Kitulanghalo Forest Reserve: 1) What is the value of charcoal production (the main commercial activity in the area) from the producers' point of view? And 2) Is the full cost of charcoal production being acknowledged?

3.3 STUDY AREA

The study site is about 50 km east of Morogoro and 150 km west of Dar-es-Salaam and comprises public (communal) lands surrounding the Kitulanghalo Forest Reserve. The public lands comprise settlements, open woodlands and cultivated land. The area is bisected by the Dar-es-Salaam–Morogoro highway which marks most of the southern boundary of the reserve and is the main transportation route for forest products to urban and commercial centres such as Dar-es-Salaam and Morogoro (Figure 3.1).

One thousand and twelve households with a total population of 4640 people live in three villages: Lubungo, Maseyu and Gwata, of which the surrounding woodlands are important for subsistence purposes and as a source of income, as the majority of the local people obtain construction materials, fuel wood and medicines from them (Luoga *et al.*,2000b). The public lands which are easily accessible to the people (< 5 km from settlements, and < 10 km from the Dar-es-Salaam–Morogoro highway) are estimated to cover about 16 500 ha, out of which 3150 ha comprise permanent cultivation and settlements and 13 350 ha open woodlands.

The climate of the area is tropical and subhumid (Kielland-Lund, 1990a). Mean annual rainfall is about 900 mm which is seasonally distributed providing a wet season from November to May and a dry season from June to October. The annual mean temperature is 24.3 °C while the annual minimum and maximum temperatures are 18.6 °C and 28.8 °C respectively. This climate, together with the generally nutrient-poor, well-drained soils supports miombo woodlands and some patches of semi-evergreen forests (Kielland-Lund, 1990a).

There are no longer large wild mammalian herbivores in the area, nor are there cattle due to the presence of tsetse flies (*Glossina* spp.), which transmit sleeping sickness (nagana) to domestic animals. Annual fires are common in the area, although there are no specific data for fire frequency and intensity. The local farming system is characterized by shifting cultivation of food for subsistence consumption and the market. Farm production, which is generally poor, relies on family labour with simple tools and no or very little capital input.

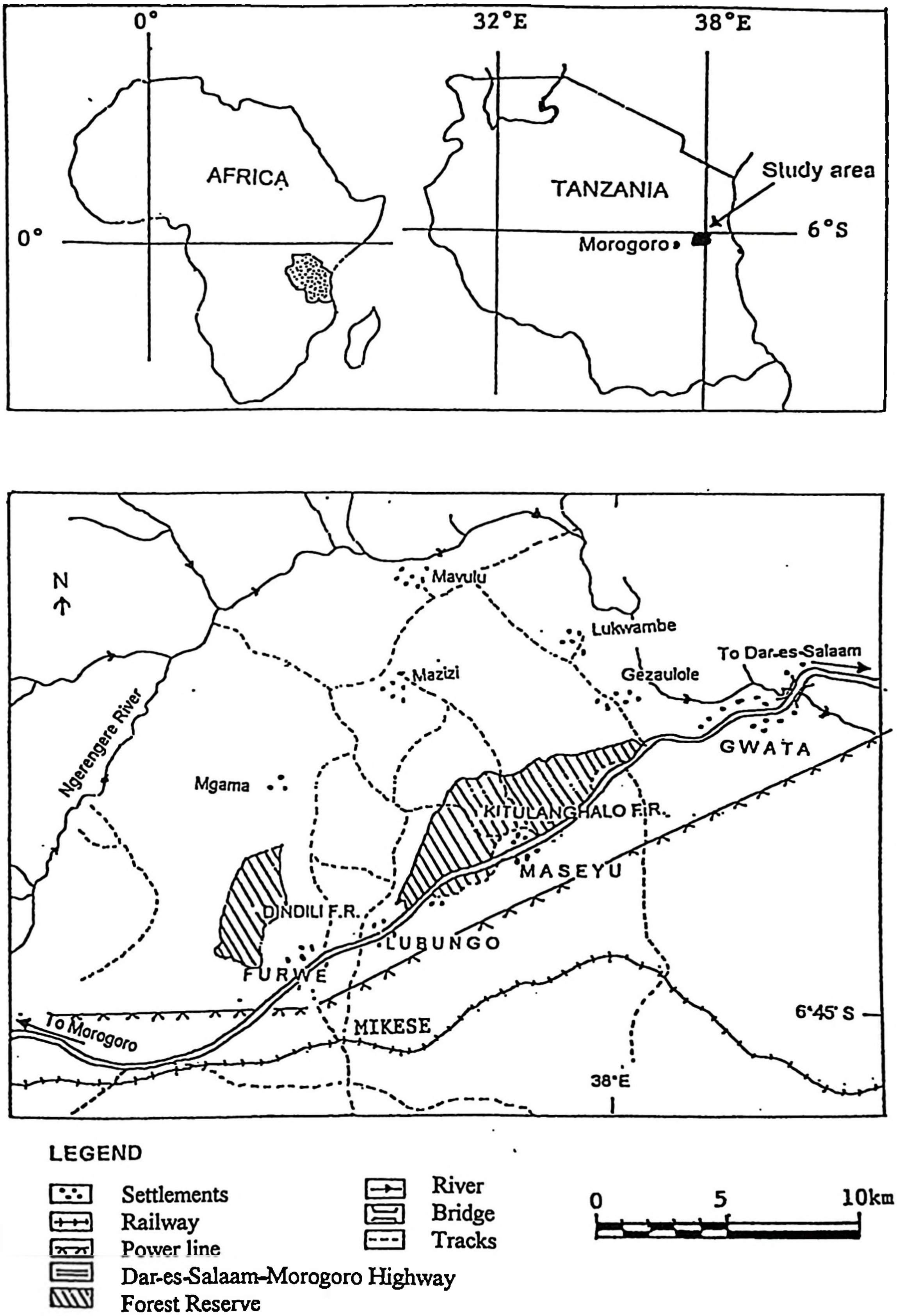

Figure 3.1 The location of Kitulanghalo Forest Reserve and surrounding public lands, Morogoro, Tanzania.

3.4 METHODS

Unstructured and group interviews were used to obtain information on costs and revenues associated with charcoal production from key informants who were charcoal producers (n = 8, all male residents who were born in the village), charcoal wholesalers (n = 3), village headmen (n = 3), forest guards (n = 3) and the regional forest officer. Ten unburnt charcoal kilns were randomly selected in communal lands and measured to obtain the stacked volume of wood. The solid round wood volume was calculated as 60% of stacked volume (O'Kting'ati, 1984a) and was converted into charcoal weight equivalents, with 8 m^3 of round wood required per tonne of charcoal (Ishengoma, 1982).

CBA was undertaken by calculating the net present value (NPV) of future cash flow from charcoal production on both a per capita (NPV_c) and a per hectare (NPV_h) basis, using costs and revenues which were based on data from the kiln site. The rationale behind using CBA was that the analysis employed economic scarcity values (shadow prices) in estimating costs or benefits as opposed to the use of market prices in a financial analysis (Dixon and Sherman, 1991). Direct costs included raw materials, labour and equipment. The value of round wood as a raw material was obtained through derived demand from tax (royalty) paid by wholesalers for each bag of charcoal bought from a producer.

Labour was assumed to have a shadow price of zero because of persistent unemployment in the area, and the opportunity cost of labour was also very close to zero because there was no commercial farming. However, during cropping seasons charcoal production competes with subsistence farming for family labour. In this case, during sensitivity analysis the shadow wage was set at 100% (US$ 1.67 personday $^{-1}$) and at 50% of the government minimum wage (Peters *et al.*, 1989). Indirect costs were calculated as the opportunity costs of products foregone through charcoal production. Direct benefits consisted of revenues received from charcoal sales, while net revenue was calculated as the difference between annual revenue and cost, i.e. net revenue = revenue - (direct costs + opportunity costs) which was then discounted to calculate the NPV (Little and Mirrlees, 1974; Turner *et al.*, 1994). Through discounting, the assessment of total monetary value not only takes into account the current market value of one year's harvest, but also the present discounted value of future production. The analysis period was 15 years, equivalent to the life span of an axe, which is the key tool in indigenous charcoal production.

$$NPV = \sum_{n=1}^{15} R_t - C_t / (1 + i)^t$$

where NPV is the net present value, R_t is the revenue accrued at time t (t = 1, 2, 3 . . . 15 years), C_t is the cost incurred at time t, and i is the discount rate.

The choice of a discount rate is not necessarily a straightforward decision (Krutilla and Fisher, 1975; Norgaad and Howarth, 1991) but some guiding principles are available (Dixon *et al.*, 1989; Norgaad and Howarth, 1991). In this particular study, a real (effective) discount rate was used (Fredriksson and Persson, 1989) which was derived from commercial bank lending rate and inflation:

$$RDR = (NDR - IR) / (NDR + 1)$$

where RDR is the real discount rate; NDR is the nominal discount rate (22%), i.e. the current (1997) Tanzanian central bank interest rate for short and long term loans; and IR is the inflation rate (17%).

Due to the absence of national price indices for wood products, current (1997) prices in Tanzanian shillings (TAS) were converted into low inflation US$ (US$ 1 = TAS 600), where inflation was assumed to have the same effects on revenue and cost over the analysis period. Sensitivity analyses were carried out to determine how the NPV_h model responded with varying discount rates, costs and revenues.

3.5 RESULTS

3.5.1 Process of charcoal production

The indigenous production of commercial charcoal using earth mound kilns, each of which was owned by an individual household (Figure 3.2) was well developed in the region, with 54% of the local households involved in charcoal production as their main source of livelihood while other households are mainly involved in producing crops (Luoga *et al.*, 2000a). Charcoal production is labour intensive and mainly carried out by household labour (mostly men) although mutual labour sharing is common especially in producing wood as a raw material (felling, crosscutting, piling and stacking of logs) which requires high manual labour inputs.

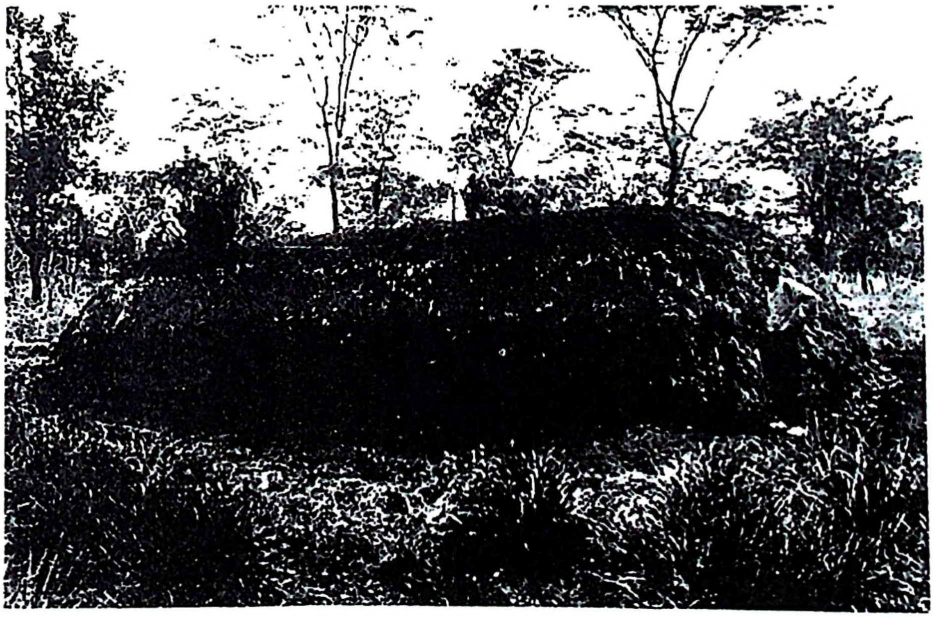

Figure 3.2 Traditional earth kilns in miombo woodlands surrounding Kitulanghalo Forest Reserve, Morogoro, Tanzania.

These initial activities require 54 persondays kiln $^{-1}$ which is more than 50% of the total labour requirement for charcoal production from one traditional earth kiln (Table 3.1). The tools used in charcoal production include an axe, a machete, a hoe, a shovel, a fork and wooden levers. The total initial cost of the tools is only US$ 20.5 (Table 3.1). After felling trees, the logs are crosscut into about 1–2 m long billets, piled into a stack, and then thatched with grass before plastering with earth, except for a small window through which fire is set. Once fire has been established, the window is plugged with earth to ensure controlled partial combustion (carbonization) of logs into charcoal.

Although in theory the harvesters should have obtained permits from the village authorities, this licensing system for local people harvesting from communal lands was not applied. Products harvested for subsistence use were thus tax free but in the case of commercialised resources such as charcoal, licensed wholesalers were normally taxed by the local government according to the number of bags of charcoal purchased from the producers. A single bag of charcoal weighing 35 kg was taxed at US$ 1, although many wholesalers evaded taxes to maximize profits. Administratively, local governments are hierarchically composed of a district, divisions, wards, and villages. Village authorities are assisted by forest guards to collect the fees for the local government from commercialised wood products which fall under their jurisdiction.

3.5.2 Economic Analysis

On average, each household of 5 people constructed a mean of 5 kilns per year with each kiln requiring 10.2 ±2.02 (SE) m^3 of wet wood and having a mean production of 1.28 ±0.26 tonnes of charcoal, the equivalent of 44.2± 8.67 bags of charcoal. Annual productivity for households that were involved in the business was therefore 44.2 bags person $^{-1}$ year $^{-1}$ [(44.2 bags household^{-1} x 5 kilns year^{-1}) / 5 people household^{-1}]. The 1997 nominal price of one bag of charcoal was US$ 2 at the kiln site, hence the gross income from charcoal was US$ 88.40 person $^{-1}$ year $^{-1}$ (US$ 2 bag^{-1} x 44.2 bags person^{-1} year $^{-1}$). The overall wood consumption for charcoal was estimated as 6.01 m^3 capita^{-1} year^{-1} [(10.2 m^3 household^{-1} kiln^{-1} x 5 kilns year^{-1} x 547 households in business / 4640 people (population)], which is very high compared to the recorded firewood consumption of only 1.5 m^3 $capita^{-1}$ $year^{-1}$ (Luoga *et al.*, 2000a).

Table 3.1 Activities, labour requirements and tools involved in traditional charcoal-making in a single kiln in public lands surrounding Kitulanghalo Forest Reserve, Morogoro, Tanzania.

Activity	Person days	Tools		
		Type	Life span (Yrs)	Cost (US$)
Felling and crosscutting trees	28	Axe Machete	15 3	5.8 2.5
Log piling	12	Wooden levers	-	-
Stacking of logs	14	-	-	-
Kiln side plastering	8	Hoe Shovel Fork	5 5 15	3.0 4.2 5.0
Cutting of roofing grass	2	Machete Hoe	- -	-
Roofing with grass and soil	4	Hoe Shovel Fork	- - -	- - -
Unloading the kiln	26	Hoe Shovel Fork	- - -	- - -
Loading the sacks	6	Shovel	-	-
TOTAL	100	-	-	20.5*

*Initial cost of tools.

The wood volume of standing trees in communal lands, where most of the charcoal production is carried out, was 16.7 m^3 ha^{-1} (Luoga *et al.*, submitted a.), hence the estimated area cleared annually was 1671 ha yr^{-1} [(10.2 m^3 $household^{-1}$ $kiln^{-1}$ x 5 kilns^{-1} year^{-1} x 547 households in business) /16.7 m^3 ha^{-1}] .If the standing wood volume of 16.7 m^3 was cleared for charcoal production, it would produce 61 bags of charcoal ha^{-1} [(16.7 m^3 ha^{-1} / 8 m^3 tonne^{-1}) x 29 bags tonne^{-1}], representing an income of US$ 122 ha^{-1} (US$ 2 bag^{-1} x 61 bags ha^{-1}). The value of wood (US$ m^{-3}) was derived from royalties giving US$ 4.35 m^{-3} [(44.2 bags kiln^{-1} /10.2 m^3 kiln^{-1}) x US$ 1 bag^{-1}]. The opportunity costs of other products were not included and with an effective discount rate of 4%, the calculated NPV_c over 15 years was US$ 451 capita^{-1} year^{-1} and the NPV_h was similarly US$ 511 ha^{-1} (Table 3.2). This indicates that the business is profitable from the producers' point of view (Table 3.2). The cost of empty sacks was not included in the calculation because they are normally supplied by the wholesalers or customers and hence do not form part of the cost to the producer.

Sensitivity analyses on an area basis indicated that the profitability of the business was only slightly affected by an increase in the discount rate. The tripling of the discount rate to 12% resulted in a positive NPV_h of US$ 306, indicating that the increase in prime rates had a trivial effect on the profitability of the business (Table 3.3, scenarios 2 and 3). Large variations in NPV_h were obtained when varying the cost of labour (Table 3.3, scenarios 3, 4 and 5) indicating that labour is the main input in charcoal production and hence the profit margin depends very much on the assumptions regarding valuation of labour. The profit margin in charcoal production is also enhanced by charcoal burners not paying tax to the central or local government. When the value for round wood as raw material was assumed to be zero in the model, the NPV_h was positive even when labour was costed at half wage rates (Table 3.3, scenario 6). An increase of US$ 2 to the estimated value of round wood lessened the NPV_h but it remained positive (Table 3.3 scenario 7), indicating that the business would still be profitable if more tax was paid by the charcoal producers.

3.5.3 Some hidden costs of charcoal production

In the use value analysis undertaken in the miombo woodlands of the Kitulanghalo area, 42 species were used for charcoal production, a higher number than for any other use, and the commonly used species were *Combretum molle* Engl & Diels,

Table 3.2 Cost Benefit Analysis (CBA) results of indigenous charcoal production in miombo public lands surrounding the Kitulanghalo Forest Reserve, Morogoro, Tanzania.

Year	Activities	Analysis per capita basis (US$ capita^{-1} yr^{-1})				Analysis per area basis (US$ ha^{-1})			
		Cost C_t	Rev. R_t	Net rev. R_t-C_t	Disc. net rev	Cost C_t	Rev. R_t	Net rev. R_t-C_t	Disc. net rev
0	Purchase of tools (Axe, hoe, machete, fork and shovel)	20.5	0	-20.5	-20.5	20.5	0	-20.5	-20.5
1	Production* and sales of charcoal	44.37	88.4	44.03	42.34	72.65	122	49.35	47.45
2	Production and sales of charcoal	44.37	88.4	44.03	40.71	72.65	122	49.35	45.63
3	Production and sales of charcoal	44.37	88.4	44.03	39.14	72.65	122	49.35	43.87
4	Replacing machete, production and sales of charcoal	46.87	88.4	41.53	35.5	75.15	122	46.85	40.05
5	Production and sales of charcoal	44.37	88.4	44.03	36.19	72.65	122	49.35	40.56
6	Replacing hoe and shovel: Production and sales of charcoal	51.51	88.4	36.83	29.11	79.85	122	42.15	33.31
7	Replacing machete, production and sales of charcoal	46.87	88.4	41.53	31.56	75.15	122	46.85	35.6
8	Production and sales of charcoal	44.37	88.4	44.03	32.17	72.65	122	49.35	36.06
9	Production and sales of charcoal	44.37	88.4	44.03	30.93	72.65	122	49.35	34.67
10	Replacing machete, production and sales of charcoal	46.87	88.4	41.53	28.06	75.15	122	46.85	31.65
11	Replacing hoe and shovel: Production and sales of charcoal	51.51	88.4	36.83	23.92	79.85	122	42.15	27.38
12	Production and sales of charcoal	44.37	88.4	44.03	27.5	72.65	122	49.35	30.82
13	Replacing machete, production and sales of charcoal	46.87	88.4	41.53	24.94	75.15	122	46.85	28.14
14	Production and sales of charcoal	44.37	88.4	44.03	25.43	72.65	122	49.35	28.5
15	Production and sales of charcoal	44.37	88.4	44.03	24.45	72.65	122	49.35	27.42
			NPV_c		451.45		NPV_h		510.6

Basic data: A discount rate of 4%, raw materials (wood) valued at US$ 4.35 m^{-1}, charcoal sold at US$ 2.00 bag^{-1}.

Assumptions: labour has zero value, same annual production over the analysis period of 15 years.

* Includes all activities of charcoal production from felling of trees to loading of bags of charcoal.

Julbernardia globiflora (Benth.) Troupin, *Brachystegia spiciformis* Benth. and *Brachystegia boehmii* Taub (Luoga *et al.*, 2000b). More than 56% of the harvested trees in the study area (ranging between 2.4 cm to 68.6 cm trunk diameter at breast height) were felled for charcoal burning (Luoga *et al.*, submitted a). Other purposes for felling trees were carving, firewood, building poles, fibre and timber. Some of these utilize species which are also harvested for charcoal (Table 3.4), suggesting that charcoal production is associated with negative external costs.

A woodland inventory indicated that there is an average of 27 extractable poles ha^{-1} (Luoga *et al.*,submitted a). Clearing the woodland for charcoal would mean foregoing the poles which are valued at US$ 2.70 ha^{-1} (27 poles ha^{-1} x US$ 0.1 $pole^{-1}$). 2% of live wood was harvested for firewood (Luoga *et al.*, submitted a). With the total annual removal of 6.38 m^3 ha^{-1} (Luoga *et al.*, submitted a), the firewood volume is 0.33 m^3, valued at US$ 3.44 ha^{-1} (0.33 m^3 ha^{-1} x US$ 10.42 m^{-3}).

Important timber and carving trees in the area are *Dalbergia melanoxylon* Guill. & Perr., *Pterocarpus angolensis* DC., *Sclerocarya birrea* ssp. *caffra* Sond. and *Sterculia quinqueloba* Sim. The total standing volume of the above species was 1.85 m^3 ha^{-1} (Luoga *et al.*, submitted a) with an estimated value of US$ 111 ha^{-1} (1.85 m^3 ha^{-1} x US$ 60 m^{-3}). When the opportunity costs of these quantifiable foregone products (US$ 117 ha^{-1}) were included, the NPV_h was US$ -868 (Table 3.3, scenarios 8 and 9), indicating that the business is not profitable. This indicates that the profit realization and employment creation associated with charcoal production are accomplished at the expense of other potential uses of the woodland.

3.6 DISCUSSION

Labour is by far the major input in charcoal production, while items of equipment involve a very low capital outlay, which when costed over their lifetime, can be assumed to be negligible (Table 3.1). By assuming a zero price of labour and free raw materials, Monela *et al.*, (1993) reported an average household income of US$ 177 $year^{-1}$ from charcoal production along the Dar-es-Salaam–Morogoro highway. This profit margin is probably the reason for 54% of the households being involved in charcoal production as their main income-generating activity. The farms in the area, which were traditionally cultivated for cash crops, are reported to have low yields

Table 3.3 Sensitivity analysis for CBA on an area (ha) basis for the input variables of indigenous charcoal production in miombo public lands surrounding the Kitulanghalo Forest Reserve, Morogoro, Tanzania.

Scenarios	MODEL INPUTS						NPV ($US\$ ha^{-1}$)
	Discount rate	Labour	Raw materials	Equipment	Opportunity cost of other products*	Price of charcoal	
1	Real (4%)	Free	Derived demand ($US\$ 4.35 m^{-3}$)	Market rate	Nil	Market rate ($US\$ 2 bag^{-1}$)	510.6
2	Doubie (8%)	Free	Derived demand ($US\$ 4.35 m^{-3}$)	Market rate	Nil	Market rate ($US\$ 2 bag^{-1}$)	388.91
3	Triple (12%)	Free	Derived demand ($US\$ 4.35 m^{-3}$)	Market rate	Nil	Market rate ($US\$ 2 bag^{-1}$)	305.8
4	Real (4%)	Wage rate ($US\$ 1.67 personday^{-1}$)	Derived demand ($US\$ 4.35 m^{-3}$)	Market rate	Nil	Market rate ($US\$ 2 bag^{-1}$)	-1886.86
5	Real (4%)	Half wage rate ($US\$ 0.83 personday^{-1}$)	Derived demand ($US\$ 4.35 m^{-3}$)	Market rate	Nil	Market rate ($US\$ 2 bag^{-1}$)	-680.95
6	Real (4%)	Half wage rate ($US\$ 0.83 personday^{-1}$)	Free	Market rate	Nil	Market rate ($US\$ 2 bag^{-1}$)	110.56
7	Real (4%)	Free	Increased by US$ 2 ($US\$ 6.35 m^{-3}$)	Market rate	Nil	Market rate ($US\$ 2 bag^{-1}$)	139.24
8	Real (4%)	Free	Derived demand ($US\$ 4.35 m^{-3}$)	Market rate	US$ 117.14	Market rate ($US\$ 2 bag^{-1}$)	-867.9
9	Real (4%)	Free	Derived demand ($US\$ 4.35 m^{-3}$)	Market rate	(Half) US$ 58. 57	Market rate ($US\$ 2 bag^{-1}$)	-178.65

* Foregone wood products of timber, carving, firewood and poles (construction wood).

Table 3.4 Percentage of tree species that are used to make charcoal in addition to other uses in Kitulanghalo Forest Reserve and surrounding public lands, Morogoro, Tanzania.

Uses	Number of species	No. of species also used for charcoal	Percentage
Charcoal	42	-	-
Timber	12	11	92
Firewood	36	32	89
Poles	41	29	71
Medicines	35	18	51
Ropes	4	2	50
Carving	2	1	50
Others	18	6	33
Rituals	9	1	11
Food	13	1	8
MEAN ± SE	22.2 ± 5.4	11.2 ±4.1	50.5 ±10.1

Source: Modified from Luoga *et al.*, 2000 b

because of inherently infertile soil, lack of adequate soil moisture (Shayo-Ngowi *et al.*, 1995) and poor tools, as well as lack of markets (Luoga *et al.*,2000b).

The ready and large market for charcoal in Dar-es-Salaam (Mashalla, 1979; Shechambo, 1986; Monela *et al.*, 1993) is another driving force for the involvement of a large number of people in charcoal production. In some areas of the coastal region which are closer to Dar-es-Salaam, farmers were reported to cut down cashew-nut trees (*Anacardium occidentale*) in order to make charcoal (Havnevik, 1983), indicating that the returns from the charcoal industry were higher than cashew-nut farming, an export crop. A bag of charcoal purchased for only US$ 2.00 at the kiln site, was sold at US$ 5.00 in Dar-es-Salaam, indicating a considerable profit margin as most wholesalers use their own transport and hence have low transport costs. Charcoal is reported to be used by more than 80% of urban Tanzanians (Ishengoma, 1982; Shechambo, 1986), although it is normally used together with other energy sources. The most common combination (71% of households) is charcoal and kerosine (Shechambo, 1986).

Adopting a standing wood volume of 45 m^3 ha^{-1} along the Dar-es-Salaam–Morogoro highway, Monela *et al.* (1993) reported an average charcoal production of 36 kilns household $^{-1}$ $year^{-1}$ with a production of 10 bags $kiln^{-1}$ (360 bags $household^{-1}$ $year^{-1}$), while with the current stocking of 16.7 m^3 ha^{-1} the production is 221 bags $household^{-1}$ $year^{-1}$. The decline in charcoal production is probably attributable to increased labour requirements to fell and stack the increasingly more scattered trees. The results of this study have shown further that instead of making small kilns due to decreased wood stocks, charcoal producers now tend to make bigger kilns (44 bags $kiln^{-1}$) in order to attract wholesalers. Normally wholesalers collect charcoal at the kiln sites using their own or sometimes hired transport from Dar-es-Salaam, and the cost of moving their vehicles in the woodland decreases if the charcoal pay-load is collected from fewer points. Small producers who have very few bags of charcoal to sell are sometimes forced to transport their bags to the highway on bicycles.

The motive of personal profit triggers individuals to use common environmental resources more heavily and contribute less to their protection, a concept known as 'externality' which is an extra-market effect that market prices will not reflect as part of the full cost of production (Bernstein, 1981; Costanza *et al.*,1995). The estimated clearing of 1671 ha $year^{-1}$, is about 13% of the easily accessible woodlands in the study area. This result is consistent with a previous study (Monela *et al.* 1993) which reported the clearing of 4354 ha $year^{-1}$ along the Dar-es-Salaam–Morogoro highway, estimated by deriving the amount of wood used for charcoal production from quantities of charcoal transported annually to Dar-es-Salaam. This resource depletion, which is concentrated around homesteads and access roads, will affect the entire local population. In their struggle to survive, poor people are driven to degrade their environment, with long-term negative implications for future production and wealth generation.

However the recovery rate in miombo trees by coppicing is very high unless the plants have been uprooted during the initial disturbance (Frost, 1996). The net primary production (NPP) of trees in the study area is estimated at 3.7 ± 1.3 (SD) tonnes ha^{-1} $year^{-1}$ (Ek, 1994). If this growth is not interrupted by fierce fires, the harvested areas will take less than 5 years to regain the pre-harvest stock of 13.8 ± 1.4

(SE) tonnes ha^{-1} (Luoga *et al.*, submitted a). However this biomass would comprise mostly saplings of 3-6 m high (Frost, 1996), indicating that the main impact of charcoal production is the change in vegetation structure from woodlands to bushlands. Annual fires are common in the study area, although there are no specific data for fire frequency and intensity. It has been reported that most smaller trees of < 4 cm diameter at breast height (DBH) are not resistant to the fires (Kielland-Lund, 1990b), so that fires also affect the recruitment of trees. The local NPP of 3.7 tonnes $ha^{-1} year^{-1}$ (about 4.35 $m^3 ha^{-1} year^{-1}$) indicates that the removal of wood of 6.38 $m^3 ha^{-1} year^{-1}$ (Luoga *et al.*,submitted a) is not sustainable. The sustainable amount of charcoal that could be harvested in order to correspond with the NPP would be 15.5 bags ha^{-1} [(4.35 $m^3 ha^{-1}$ / 8 $m^3 tonne^{-1}$) x 1000 kg $tonne^{-1}$ / 35 kg bag^{1}].

In areas that are cleared for charcoal production, subsistence farming (shifting cultivation) is practiced in the more fertile (arable) patches, where the land is cultivated for about 6 years before it is left fallow for about 4 years (Luoga *et al.*, 2000a). This fallow period is too short for the woodland trees to regain their original stem diameters, thus subsistence farming is another cause of land cover change. The negative impacts of land cover changes on biodiversity and ecosystem function in miombo woodlands have not been well studied (Frost, 1996), but generally when miombo woodlands are harvested, there is a release of carbon from soil and biomass of about 0.2 Pg of C $year^{-1}$, a change in energy exchange at the land surface and a decrease in the formation of rain-generating convective storms. Similarly if about 3 million km^2 of miombo woodlands were managed to maximize carbon storage, a total of 6–10 Pg of C could be sequestrated (Scholes, 1996). These ecological functions of trees are difficult to express in monetary terms. In Kenya, the NPV of land set aside in parks, reserves and forests appeared to be very low compared to the opportunity costs of the land for other economically productive activities because the ecosystem functions of the trees could not be quantified due to a paucity of data (Norton-Griffiths and Southey, 1994). Sustainable resource conservation has benefits that extend far beyond the profits of commercial resource use. Thus the actual impact of over-utilisation of environmental resources is underrated because both tangible and intangible negative externalities are not accounted for.

As the area of woodland decreases, so the marginal value of each tree will increase (Goulder and Kennedy, 1997) as trees are commercial products, and demand will begin to exceed supply. The non-specificity and vast extent of harvesting for charcoal results in loss of other potential products from woodlands and highlights the possibility of undermining the ecological functions of the woodlands, both of which raise a number of policy issues relevant to the rational use of resources. One feasible option would be to introduce a fee of about US$ 2 m^{-3} of round wood to charcoal producers, paid to the village authorities and used for policing the resources. The decrease in profit margin (Table 3.3 scenario 7) will not only increase the charcoal producers' perceived value of wood, but when accompanied with initiating alternative means of generating income, will motivate some people to engage in other activities and hence reduce pressure on woodlands.

Another important policy issue is that of property rights. Although the communal woodlands (where most of the charcoal is produced) are locally governed by a fairly well defined group of villages, the motive of profit maximisation from charcoal encourages individuals to overuse common resources. Commercial use of the resources often leads to depletion, corresponding to Hotteling's model of resource use which maintains that biological resources which are not increasing in value as fast as the rate of interest are normally exploited and revenues put into other markets (Costanza *et al.*,1997). Sustainable forest utilisation is based on the creation of boundary and authority rules determining who can use resources under what conditions (Katerere *et al.*, 1999). In order to maintain tree cover in the study area, the degraded communal woodlands near the settlements and highway should best be used for collection of subsistence wood resources which have been shown to be sustainable (Luoga *et al.*,2000a). According to Katerere *et al.* (1999) common property regimes in rural settings are not strong and they need to be supported so that they can bring together a variety of sectors involved in woodland management, with government institutions providing a broader enabling environment.

3.7 CONCLUSIONS

The realised profit margin in traditional charcoal production is attributable to: very low capital outlays; own labor which is apparently free; free raw materials; a high demand for charcoal; lack of concern for negative externalities and lack of alternative ıcome-generating activities. Although commercialisation of wood resources rovides tangible monetary benefits to rural communities, it also contributes to nvironmental degradation that will ultimately threaten the long-term survival of these ommunities. The common property regime seems to be weak in enforcing control ıechanisms to check overuse of resources, and hence needs to be strengthened.

CHAPTER 4

Subsistence use of wood products and shifting cultivation within a miombo woodland of eastern Tanzania, with some notes on commercial uses.

South African Journal of Botany 2000, 66: 72–85

4.1 Abstract

This study categorizes different subsistence and commercial uses of resources and quantifies the amount of wood used for firewood and building poles within an eastern Tanzanian miombo woodland site. Data from questionnaire surveys were collected from 80 households sampled from two villages. Firewood was used solely at the subsistence level by 96% of the population, with a per capita consumption of 1.5 ± 0.17 (SE) m^3 $year^{-1}$, whereas building poles were not only used at subsistence level but were partly commercialised in the informal market. Per capita consumption of wood for building poles was 0.138 ± 0.01 m^3 $year^{-1}$, based on an average house life-span of eight years. Timber and charcoal production were the most commercialised resources. Shifting cultivation, which is undertaken in the majority of the areas cleared for charcoal, is practiced by 68% of the population while permanent cropping is practiced by 32% of the population. Both farming systems predominantly comprise mono-cropping and mixed-cropping of cereals with bean crops. Shifting cultivation changes vegetation structure from woodlands to bushlands because of a short fallow period of only four years after continuous farming for about six years. Current levels of subsistence use of firewood and poles appear to be sustainable, but levels of shifting cultivation are not. However, selection of favoured species for building poles often leads to over-exploitation, especially when these species are inherently scarce.

Key words. Building poles, firewood, human use, miombo woodlands, sustainable use.

4.2 INTRODUCTION

The African savannas have been foci of global attention since the 1970's, but very few studies have been undertaken within an integrated framework which combines economic, social and environmental considerations (Solbrig and Young, 1993). Savannas are viewed as non-equilibrium ecosystems within which people form an integral part and the levels of human investment in capital, labour and knowledge are the major determinants of the behaviour of managed savanna systems (Solbrig. 1993). Miombo woodlands, a specific type of savanna characterised by deciduous arborescent species (dominated by the genera *Brachystegia* and *Julbernardia*) and grasses, are the most extensive vegetation type in Africa south of the equator. These dry tropical woodlands, covering nearly 3 million km^2 are home to over 40 million people and are the sources of products that serve the basic needs of an additional 15 million urban people (Campbell *et al.*, 1996). In miombo woodlands, the number of products traded in the formal sector, and therefore recorded in official statistics, is much smaller than the number traded in the informal sector, although little can be said about the value of such trade (Brigham *et al.*, 1996).

The miombo woodlands of Tanzania, occupy nearly 40% of the total area of the country and fall into two tenurial categories: woodland in protected areas (reserves) managed by the central government, and woodlands in communal areas (public lands) managed by local governments. Apart from using miombo woodlands for farming, local people have twelve types of uses for trees in these woodlands of eastern Tanzania, which are charcoal, firewood, poles, timber, medicine, withies, food, ropes (fibre), live fences, carving, rituals and other technological uses (Luoga *et al.*; 2000b). Among these uses, charcoal production had the highest use value accounting for 18.4%, followed by firewood (16.6%) and medicine (15.7%) (Luoga *et al.*, 2000b).

This paper is part of a trans-disciplinary study dealing with the interactions between local communities, the natural resource base, markets and the socio-political environment. Luoga *et al.* (2000b) ascertained the local people's knowledge of and reliance on woody resources as a first step towards sustainable resource conservation. In addition, Luoga *et al.* (in press) assigned monetary values to local charcoal production (the most reliable cash-generating activity in the area) and determined the importance of the charcoal industry to the economies of the local producers through cost-benefit analysis (CBA). This paper, fills a gap left by the other two by quantifying wood use for subsistence purposes and determining the types of economic pursuits and land uses in the study area.

4.3 METHODS

4.3.1 Study Area

The study area comprises the Kitulanghalo Forest Reserve (2452 ha) and surrounding public lands and lies between 6°34'S–6°45'S and 37°53'E–38°04'E. The total population of the three villages (Lubungo, Maseyu and Gwata) is about 4640 people in 1012 households, with an average of about 5 people per household. The area is about 50 km east of Morogoro and 150 km west of Dar-es-Salaam on the Dar-es-Salaam–Morogoro highway, which is the major means of transport for the people and forest products to urban and commercial centres such as Dar-es-Salaam and Morogoro (Figure 4.1).

The vegetation of the area has been described by Kielland-Lund (1990a). It comprises open miombo woodland dominated by trees of *Julbernadia globiflora* (Benth.) Troupin and *Combretum* spp. The area also has patches of semi-evergreen forest dominated by *Manilkara sulcata* (Engl.) Dubard and *Scodophloeus fischeri* (Taab.) Léon.

The annual rainfall is 900 mm, which is seasonally distributed providing a wet season from November to May and dry season from June to October. The annual mean temperature is 24.3°C while the annual minimum and maximum temperatures are 18.6°C and 28.8 °C respectively. This climate supports a regular rain-fed cropping regime, the main crops being maize, sorghum and peas. There are no large wild herbivores in the area, nor are there cattle due to the presence of tsetse flies (*Glossina* spp.), which transmit nagana (sleeping sickness) to domestic animals.

4.3.2 Data collection

Structured questionnaire interviews (Appendix 2) were administered to 80 households in 8 hamlets of two villages, Gwata and Maseyu in November and December 1997. This sample size represents a sampling intensity of 8%.

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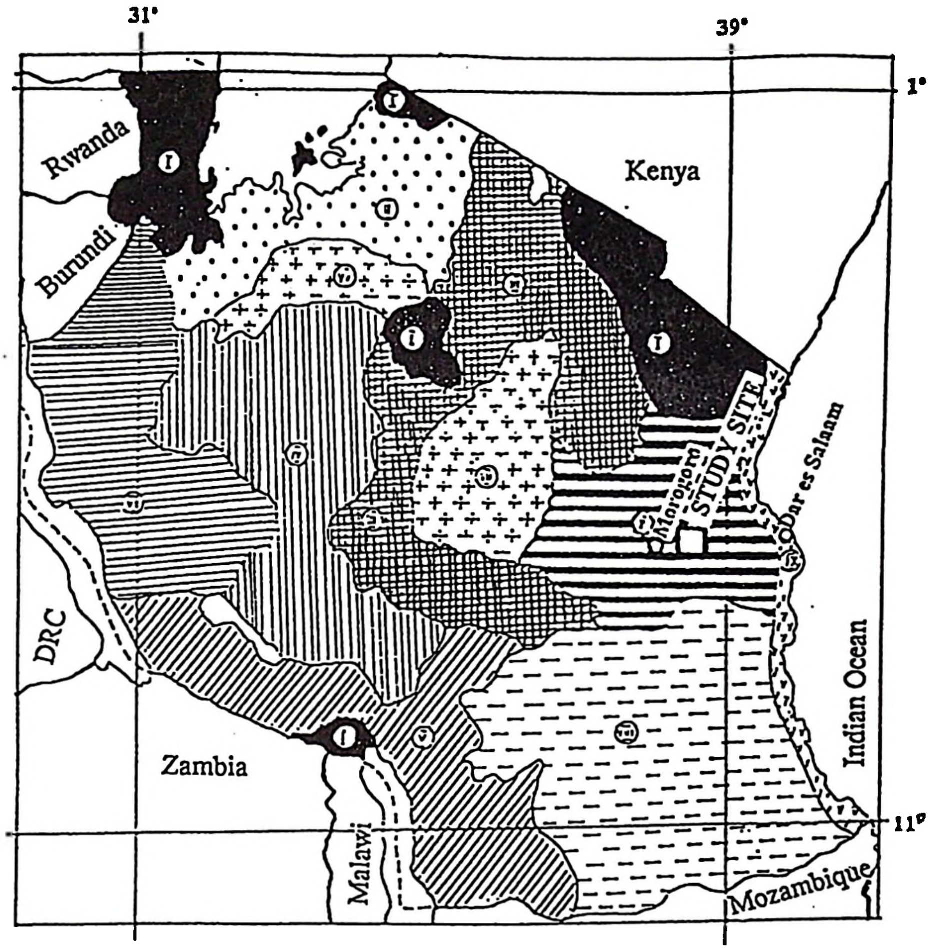

Zone

- I Commercial/subsistence farming under very high population pressure.
- II Overgrazing and farming cotton.
- III Overgrazing and migratory pastoralists.
- IV Extensive tobbaco farming and curing.
- V Commercial. maize.
- VI Immigrants and refugees from Rwanda Burundi and Dem. Rep. of Congo.
- VII Degraded land due to drought and grazing pressure.
- VIII Scarcely populated areas with relative abundance of wood supplies.
- IX Fish smoking,shrimp farming and salt production in mangrove ecosystem.
- X Commercial fuelwood and shifting cultivation.

Figure 4.1 Land use classification in Tanzania showing the area of commercial fuelwood deforestation, other land uses and the study area (Modified from MNRT, 1989).

The selection of households to be interviewed was made systematically in order to obtain a representative sample in terms of wealth, gender and age classes, e.g. the sample comprised 67 male-headed and 13 female-headed households which is nearly proportional to13% of total households that are female-headed. The respondents were the heads of households and the questionnaire covered broad social and economic perspectives of the households in regard to the use of tree products and land of the surrounding woodlands (refer to Appendix 2). Unstructured and group interviews were used to obtain information on utilisation from key informants who were traditional healers (n = 4), charcoal burners (n = 8), village headmen (n = 3) and craftsmen (n = 5). Data from interviews were analysed using descriptive and inferential statistics and content analysis.

To determine the amount of wood used in building structures, 18 new unplastered wooden structures of different sizes were selected and all the poles of different categories in each structure were counted. Five poles of each category were measured for length and mid-diameter (Grundy *et al.*, 1993).

4.4 RESULTS

4.4.1 Subsistence use of resources

Firewood collection and harvesting of poles for construction were the main subsistence products of the trees in the study area. The woodland was also important in subsistence farming where the cultivation of food crops goes along with collection of other food materials of fruits, edible tubers and leaves from the woodlands. *Tamarindus indica* L., a popular fruit tree, bears fruits which are sometimes used locally to make beverages. Edible mushrooms, which are common in other parts of miombo woodlands (Harkonen, 1997), do not occur in this area.

4.4.1.1 Firewood

Ninety-six percent of the respondents used firewood for domestic fuel and 4% used charcoal. Firewood was used for night lighting by 25% of the households, whereas a large proportion (75%) used kerosine lanterns. Each household used about 162 ± 11(SE) headloads of firewood per year, each weighing 29.2 ± 1.4 (SE) kg, and having a volume of 0.048 ± 0.002 m^3. The annual per capita firewood consumption was thus 1.5 ± 0.17 m^3 $year^{-1}$.

4.4.1.2 Building poles

Building poles were used both at a subsistence level and as a commercial commodity in the informal market. The surveyed houses had a mean size of 20.2 ± 3 (SE) m^2 floor area (n = 18), ranging from 8 m^2 to 48.2 m^2. On average a house was built of 309 ± 35 (SE) poles in the ratio of 1 : 17 : 25 : 34 for beams, roofing poles, wall erecting poles, and withies respectively (Figure 4. 2, Table 4.1). Harvesting of poles for house construction was very selective in terms of diameter (refer to similarity of dimensions within each category in Table 4.1). The durability of poles and hence the longevity of houses ranged from three to fifteen years depending on the natural resistance of the poles to termites and other bio-degraders. With an average household size of five people, four houses per household, and average house life span of eight years, the per capita consumption of construction wood was 0.138 ± 0.01 (SE) m^3 $year^{-1}$. *Spirostachys africana* Sond. is the species from which durable poles with the greatest commercial potential were produced. The price of one *S. africana* pole of about 12 cm diameter and 3 m long was US$ 0.20 at the felling site. Other species for walling and beam poles were sold locally at US$ 0.05 per pole while the thin withies were sold for US$ 0.02 each.

Table 4.1 Number and dimensions (mean ± SE) of different categories of building poles in houses surrounding Kitulanghalo Forest Reserve, Morogoro, Tanzania.

Pole Category	Number per house	Length (m)	Diameter (cm)	Volume per pole (m^3)	Volume per house (m^3)*
Wall erecting (n = 90)	98±8.77	2.47±0.049	7.12±0.138	0.01±0.0004	0.99±0.101 (73)
Beam (n = 47)	4±0.50	4.23±0.121	6.82±0.152	0.016±0.0008	0.063±0.008 (5)
Roofing (n = 90)	70±9.83	2.43±0.040	3.79±0.064	0.0028±0001	0.229±0.035 (17)
Withies (n = 90)	136±25.4	2.92±0.060	1.51±0.035	0.0006±0.003	0.068±0.012 (5)
TOTAL	309±34.7				1.377±0.316

* Figures in brackets indicate percentage contribution by volume of each pole category to the total volume of poles.

4.4.1.3 Shifting cultivation

The farming techniques used were shifting cultivation, which was practised by 68% of the population and permanent cropping (32%) through mono-cropping or mixed cropping (Figure 4.3). Except for rice, which was exclusively cultivated as a mono-crop in permanent plots within a few scattered water-logged areas known locally as "mbuga", other crops were grown in either permanent or "shifting" plots. Maize and sorghum were the main food crops and were grown by almost the entire population (95% of households grew maize and 93% sorghum) through mono-cropping or mixed with other crops especially peas (*Vigna unguiculata* (L.) and *Vigna radiata* (L.)) which were the major source of protein and grown by 82% of the population. Other crops were sesame (59%) and cassava (30%), while cotton which had once been a major mono-crop grown for cash, was no longer cultivated because of high input costs and unreliable markets. Shifting cultivation mostly occurred in the cleared areas after charcoal production, but only on the more fertile soils. With shifting cultivation, after the removal of the big trees for making charcoal, the smaller trees, unused branches, litter and grass were collected into small heaps or spread evenly on the surface and burnt to form ash to fertilise the soil (slash and burn). The land is then cultivated for 6 ± 0.13 (SE) consecutive years and then left fallow for 4 ± 0.27 (SE) years before it is recultivated.

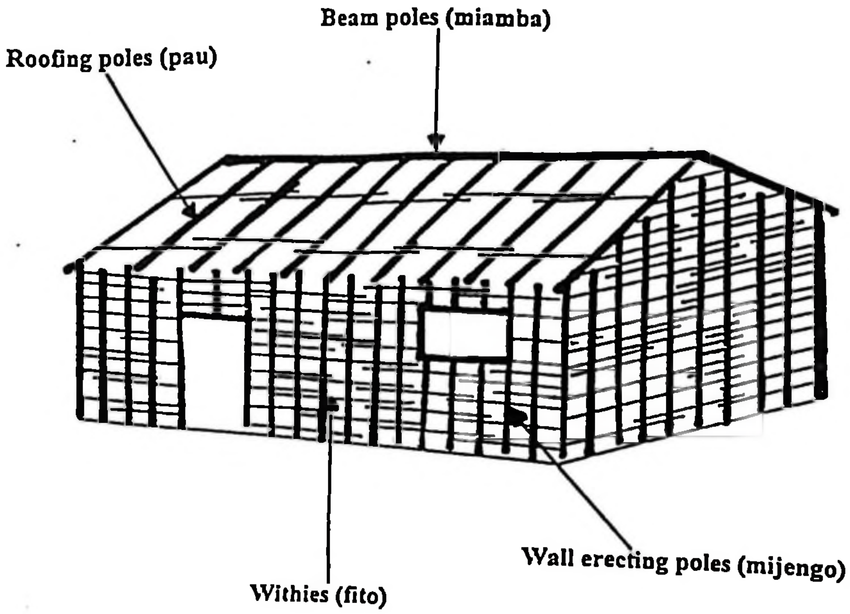

Figure 4.2 Architectural design of traditional houses showing different categories of poles in villages surrounding Kitulanghalo Forest Reserve, eastern Tanzania.

The average farm size (excluding the fallow lands) was 4.25 ± 0.31 (SE) ha household^{-1}. Cash intensive inputs like chemical fertilisers, chemical pesticides, machinery and improved seed varieties are not used. Less than 3% of the people were able to buy inorganic fertilisers to improve the soil.

4.4.2 Commercialised resources

Timber (for furniture and construction purposes) and charcoal were the commercialised resources in the area. Wood carving, which is reported to be an important economic activity elsewhere in the miombo region (Brigham *et al.*, 1996) and South Africa (Shackleton, 1996) is not popular in the area because the people have no traditional expertise in wood-working. Beekeeping, another alternative to diversify sources of income, is not practiced.

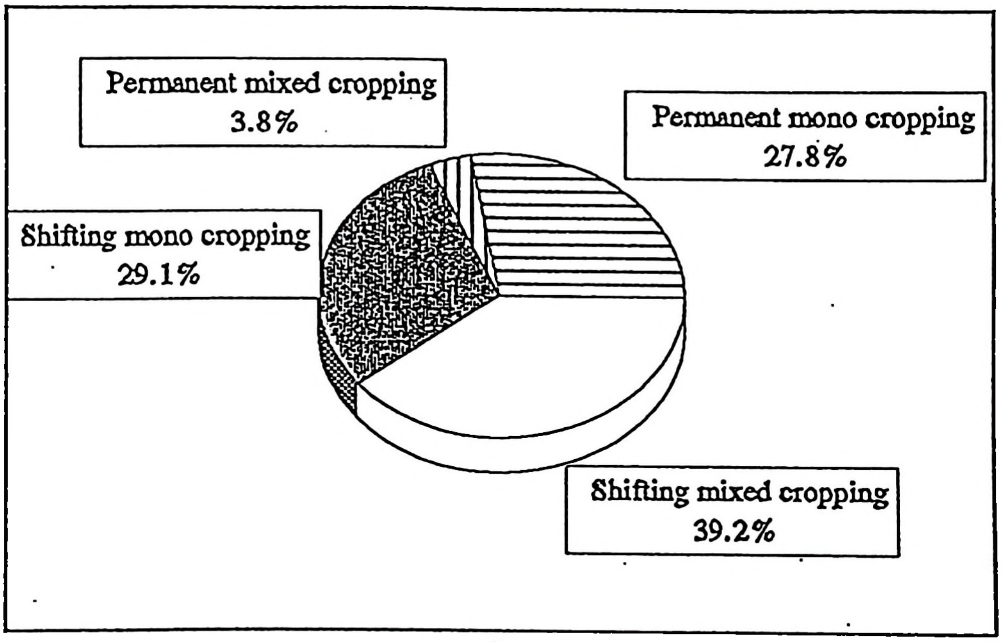

Figure 4.3 Farming systems of the local people on a per household basis in miombo woodlands surrounding Kitulanghalo Forest Reserve, eastern Tanzania.

4.4.2.1 Timber

A plank of sawn timber of *Pterocarpus angolensis* DC. or *Afzelia quanzensis* Welw. measuring 5 cm x 15 cm x 3.6 m was sold at US$ 2.70 at the sawing site. The household survey revealed that most of the door and window frames and shutters of older houses were made of these species indicating that formerly these timbers were relatively readily available. Very few local people can now afford to buy the valuable timber as most of it is purchased at the sawing site by carpenters and timber dealers from Morogoro Municipality.

4.4.2.2 Charcoal

Charcoal was produced chiefly for the markets in the urban areas of Dar-es-Salaam and Morogoro and was the most reliable cash-generating activity (Luoga *et al.*, in press). Money obtained from charcoal sales was used for clothing, youth education, medical services and food (animal protein). Fifty-four percent of the households are involved in charcoal production, but the participants moved in and out of the business as conditions warrant. At least seven migrant households, which came from other regions in the country with low economic potentials, were registered annually as villagers in the two study villages and were producing charcoal. Although this proportion is only about 1% of the population, the migrants tend to be more active in charcoal production than the locals. One crew of two migrants was found to use fire as a means to fell trees, especially *Acacia nigrescens* Oliver, a practice which was not used by local producers (Figure 4.4). This practice has caused some uncontrolled wildfires.

Figure 4.4 The use of fire for felling *Acacia nigrescens* Oliver in miombo woodlands surrounding Kitulanghalo Forest Reserve, eastern Tanzania.

In the study area, charcoal was produced exclusively in earth kilns, each of which was owned by an individual household. Earth kilns can be made either by digging a pit in which the logs are packed, or covering a mound of logs with soil. Carbonation takes place under a limited supply of air after ignition A sack of charcoal weighing about 35 kg was sold at the rate of US$ 2.00 at a kiln site, US$ 2.50 at the Dar-es-Salaam–Morogoro highway, and at about US$ 5.00 to the urban end users (Luoga *et al.*, in press). The urban end users buy their charcoal from retail traders who in turn buy from wholesalers or from producers. The marketing of charcoal therefore forms a complex network creating employment for many people (Figure 4.5)

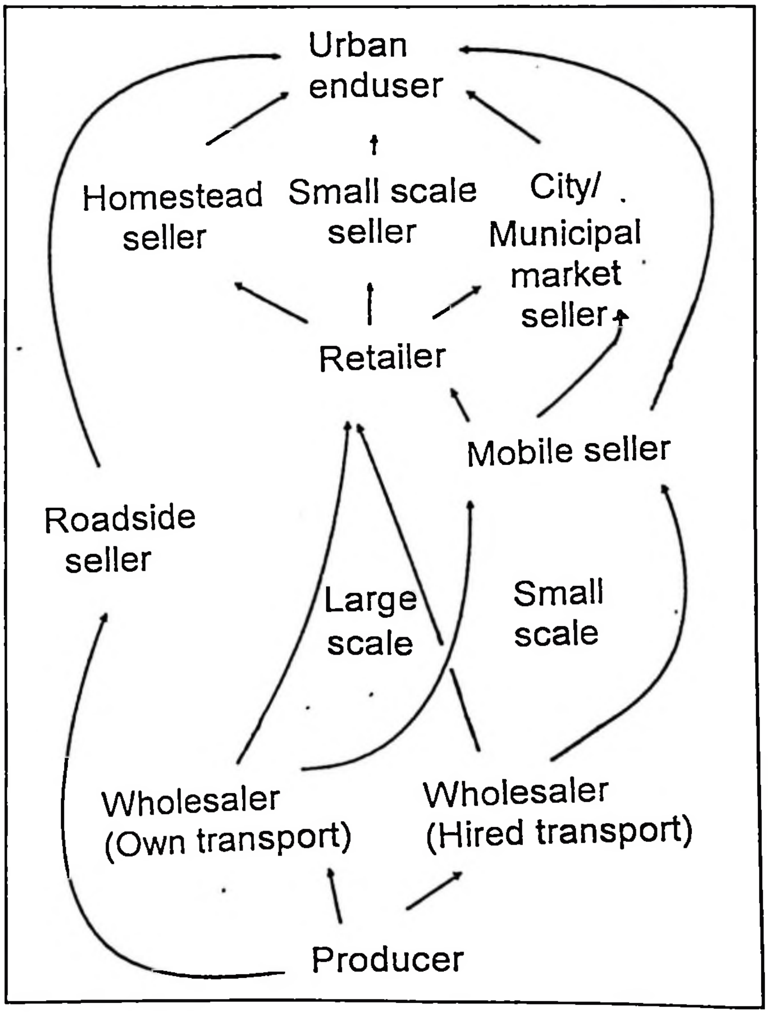

Figure 4.5 The market chain for charcoal from a producer in miombo woodlands surrounding Kitulanghalo Forest Reserve, eastern Tanzania to an urban end-user. (modified from Brigham *et al.* 1996)

4.5 DISCUSSION

4.5.1 Subsistence use of wood resources

The per capita consumption of firewood (1.5 m^3 $year^{-1}$) falls within the range of reported annual per capita fuelwood consumption of 1–2 m^3 in rural areas of Tanzania (Nkonoki, 1981; FAO, 1984) indicating the similarity in levels of use of firewood for subsistence purposes. A few localised areas in the country had higher levels of consumption (≥2 m^3 per capita per year) because of additional rural 'industries' such as tobacco curing, brick burning, tea drying, fish smoking and local brewing, all of which use fuelwood (Mnzava, 1981).

The observed per capita pole consumption of 0.138 m^3 $year^{-1}$ is nearly 4x higher than that of 0.038m^3 $year^{-1}$ which has been cited in Uganda (Cunningham, 1993). The highest recorded per capita consumption of construction wood in Africa is 1.5 m^3 $year^{-1}$ used by the Owambo people in northern Namibia, who normally construct strong wood enclosures around homesteads to protect cattle (Cunningham, 1993), a practice not undertaken in Uganda or in the study area. The favoured pole species, *S. africana,* is now becoming popular not only in rural areas but also in urban centres where it is also used to make fences and to cover sewage pits. The species, like other members of the family Euphorbiaceae, is termite resistant because of the high levels of toxic substances (Vedcourt and Trump, 1969). The commercialisation of *S. africana* poles probably accounts for the observed limited supply in the woodland.

The volume of wood used for the subsistence purposes of fuel and housing was about 1.64 m^3 per capita per year. The total annual consumption in 1997 was estimated to be 7 610 m^3 $year^{-1}$ of wood (1.64 m^3 per capita per year x 4640 people). With a mean annual increment of 4.35 ± 1.3 (SD) m^3 ha^{-1}, determined from miombo woodlands of the study area (Ek, 1994) and an estimated accessible area of 13 350 ha (excluding permanent cultivation and settlements) of communal lands, the sustained yield which could be harvested without reducing the resource base would be 58 072 m^3 $year^{-1}$ of wood (4.35 m^3 ha^{-1} $year^{-1}$ x 13 350 ha). Thus the subsistence but essential to life daily uses have low levels of utilisation, with low impacts on the resources and hence are sustainable if considered independently.

4.5.2 Shifting cultivation

The major problems with most tropical soils are low pH, and low fertility, particularly for phosphorus and nitrogen (Solbrig, 1993), but the post-fire ash deposition through slash and burn raises soil pH and increases fertility for a short period. Human alteration of natural landscapes is not new as people began to transform their surroundings with the adoption of agriculture and the domestication of animals some 10 000 years ago (Solbrig and Young, 1993). However, shifting cultivation in miombo woodlands remains sustainable only when the population density is less than 4 people km^{-2} (Chidumayo, 1987a). With this low population density, the fallow period would be long enough (≥20 years) for woodland fertility to be restored. The population density in the study area is estimated at 22 people km^{-2} (URT, 1995) leading to short fallows of only 4 ± 0.27 (SE) years, hence the practice is not sustainable.

The lack of domestic livestock such as cattle and goats (typical of other communal areas without tsetse flies) resulted historically in greater consumption of animal protein from wild game and virtually all wild mammalian herbivores have been depleted in response to increased human density. The main source of protein now is from cultivated or collected plant material. The absence of cattle also results in a lack of draught power for ploughing, leading to a relatively small average farm size of only 4.25 ± 0.31 (SE) ha per household.

4.5.3 Commercialised resources

Following the high price of high quality timber, most people now utilise lesser known timber species for household items, which are *Sterculia quinqueloba* Sim, *Xeroderris stuhlmannii* (Taub.) Mendonca & Sousa and *Sclerocarya birrea* ssp. *caffra* Sond. (Luoga *et al.*, 2000b). Wood of the latter is also used in Zimbabwe to make handcrafts, carts, furniture and household items (Grundy *et al.*, 1993), unlike in communal lands of South Africa, where the trees are nurtured for several uses including 'marula' fruits.

Charcoal production is the main activity in the area because of the ready market in nearby urban centres. Charcoal is the preferred household fuel in urban areas for the following reasons (Dennis *et al.*, 1980; Ishengoma, 1982; Shechambo, 1986; Monela *et al.*,1993):

- its calorific value is about 7420 kcal kg^{-1} compared to firewood with a calorific value of 3500 kcal kg^{-1};
- it is lighter than wood and hence easier to transport;
- it burns steadily and without smoke and therefore can be used indoors with minimum inconvenience;
- charcoal stoves are cheap and affordable;
- it does not deteriorate with time;
- it occupies less space and therefore is easier to store, ideal for urban living quarters where space is normally scarce; and
- it is more reliable than electricity, which is subject to frequent power cuts.

A trend of local people moving temporarily out of the charcoal business, which occurs mostly during the rainy season when people devote their labour to farming activities has been reported in other places in the miombo region (Brigham *et al.*, 1996). The use of fires as a felling tool by 'outsiders' who were involved in charcoal production in the area can mean that they have more effective ways of felling trees, or that they may have a different attitude to sustainability, possibly because they feel no ownership of the resources and are likely to move elsewhere when the resources are depleted.

Steel and brick charcoal kilns, which have high efficiency (Booth, 1981), are not used in miombo woodlands because charcoal producers have no access to investment capital to buy them nor the technological expertise to manage them. In Europe on the other hand, steel kilns are used because of the high returns on the charcoal market, ready availability of cheap steel, good transport facilities and greater access to investment and operating capital (Booth, 1981).

4.5.4 Potential impacts of present levels of resource use

Ninety percent of the above ground biomass of woody plants is suitable for charcoal production by the earth kiln method in miombo woodlands (Chidumayo,1991). Monela *et al.* (1993) estimated that the total area cleared annually for charcoal production for Dar-es-Salaam city alone is 4354 ha $year^{-1}$. Apart from Dar-es-Salaam, mainland Tanzania has another 19 urban regional (provincial) centres and more than a hundred district hubs all of which depend on charcoal as their main source of household energy. Miombo woodlands, which are the main source of fuelwood, are estimated to cover nearly 34 million ha. However most of the woodlands have been degraded by a variety of land uses (Figure 4.1), resulting in dwindling fuelwood supplies (Kaale, 1995). Degraded woodlands surround all large population centres with charcoal having to be transported from increasingly distant sites (Chidumayo, 1991; Monela *et al.*, 1993). The bio-energy programme of the Tanzanian Forestry Action Plan (MNRT, 1989) attempted to rationalize the demand for charcoal by encouraging urban people to use improved clay charcoal cooking stoves which use less fuel, but most people still use conventional metal stoves which are readily available (Monela *et al.*, 1993).

The ecological effects of the slash and burn farming system is the change of land cover from woodlands to bushlands because of the short fallow period of only 4 years. This shows the strong link between environmental degradation and marginalisation of a human population, the first being the manifestation of the second. Incurring costs in reducing land degradation must be the aim of any rational land use policy as nobody consciously tries to degrade land, but it is an inevitable consequence of use (Solbrig and Young, 1993). Thus the problem of deforestation and land degradation is a complex one, requiring concerted trans-disciplinary studies.

4.5.5 Diversification of uses and the rural economy

Although current levels of subsistence use of wood have been shown to be sustainable, selection of favoured species for building poles often leads to over-exploitation of scarce species. For example *S. africana* has been depleted in Owamboland, northern Namibia (Cunningham, 1993). In order to protect highly favoured species in the study area, there is a need to diversify to other species. Alternatively, the commercial exploitation of these species, has to be limited, an action which needs policy intervention.

Tanzania has four potential alternative energy sources which can be utilised in urban areas: coal, kerosine, hydro-electric power and gas (industrial, natural and bio-gas) (Mnzava, 1981). As a long-term strategy, the country's energy policy should explore the possibility of diversifying to these alternative sources of energy as the continual use of charcoal as the main urban domestic fuel will result in the progressive disappearance of the miombo woodlands.

Wood carving, beekeeping and fruit processing are other feasible activities which could be introduced in the area to diversify the economy and hence reduce pressure on the woodland. The local market for carvings could be reliable because of the presence of the Dar-es-Salaam–Morogoro highway, which most tourists visiting the eastern and southern national parks use. However, the study area has little potential for tourism as it has no wild game or attractive physical features. Miombo woodlands are renowned for having a high potential for beekeeping as the trees flower at different times of the year. Ecologically, beekeeping is advantageous to the woodlands as bees are efficient pollinating agents. *Tamarindus indica* and *Adansonia digitata* fruits from Tanzania are sometimes exported to the Middle East for making beverages (Chihongo, 1995) but this does not happen in the study area. Thus, there is a clear need to sensitize people to the potential for venturing into other non-traditional activities.

4.6 CONCLUSION

Current levels of subsistence use of firewood and poles appear to be sustainable, but levels of shifting cultivation are not. However, selection of favoured species for building poles often leads to over-exploitation, especially when these species are inherently scarce. Unless farming practices are improved, or people are exposed to other income generating activities, people will persist with shifting cultivation and commercial exploitation of woodland resources at the expense of the environment and their future security. Rural people may be responsible for damaging the environment, but it is their marginalisation and the urban demand which triggers the whole process.

CHAPTER 5

Harvested and standing wood stocks in protected and communal miombo woodlands of eastern Tanzania.

Submitted to *Forest Ecology and Management*.

5.1 Abstract

Miombo (Zambezian savanna) woodlands in protected and public (communal) lands of eastern Tanzania were examined to compare standing and harvested wood stocks and investigate different human disturbance gradients between the two utilisation / management regimes. The standing volume in the forest reserve was 47 ± 3.38 (SE) m^3 ha^{-1} and the total removal volume (calculated from stumps) was 7.1 ± 1.18 m^3 ha^{-1}. In the public lands, the standing volume was only 16.7 ± 2.26 m^3 ha^{-1} and the total removal volume was 9.6 ± 2.58 m^3 ha^{-1}. Harvesting intensity decreased with increasing distance from village settlements and reserve boundaries but the pattern had no significant overall impact on standing stocks of wood. The Dar-es-Salaam – Morogoro highway, which bisects the study area is the major axis of disturbance. Multivariate analysis indicated that the linear combinations of physiographic variables significantly influence the pattern of tree harvesting. Commercial harvesting for charcoal overrides patterns from other harvesting purposes because of economic incentive and the wide range of species and size classes harvested. The estimated annual wood removal of 6.38 ± 2.39 m^3 ha^{-1} in public lands exceeds the reported mean annual increment in the study area of 4.35 m^3 ha^{-1} $year^{-1}$. Thus present patterns of harvesting are changing the structure and composition of the vegetation, especially in the communal areas and are not sustainable. This will increase pressure for harvesting in reserves.

Key words: Disturbance gradients, human utilization, miombo woodlands, multivariate ordination.

5.2 INTRODUCTION

It is mainly the physical agents such as floods, fires, drought and wind which are most often associated with the term disturbance, but biological and anthropogenic processes can also act as agents of disturbance (White, 1979). The dynamics of miombo woodlands are largely affected by people through clearance of land for cultivation (slash and burn), subsequent abandonment, selective harvesting of trees for different purposes and initiation of fires (Frost, 1996). Miombo woodlands are open, annually burnt, deciduous, rich in grasses and dominated by the arborescent genera *Brachystegia* and *Julbernardia* (both Caesalpinioideae) (Lind and Morrison, 1974). In Tanzania these woodlands cover most of the public (communal) lands and forest reserves (protected).

Charcoal production for the market requires large volumes of wood, is the main source of income in eastern Tanzania (Monela *et al.*, 1993; Luoga *et al.*, in press) and can result in severe local disturbance of woodlands. In a few Tanzanian forest reserves, pole cutting intensity was high, accounting for the removal of half or even more of the available stems and affecting both lower storey and emergent species (Hall and Rodgers, 1986). Miombo woodlands of Zambia are more affected by the agricultural practices of local shifting cultivators than other anthropogenic disturbances (Stromgaard, 1985) and in Zimbabwe, browsing by livestock severely reduces coppice regrowth particularly of *Julbernardia globiflora* (Benth.) Troupin, at least in the initial stages (Grundy, 1995). In another study in miombo woodlands of Zimbabwe, human disturbances in communal lands were more pronounced near human settlements and decreased with distance from them (Vermeulen, 1996). Thus, human disturbances differ in type, intensity and frequency from one place to another.

This study not only makes comparisons between a protected area and public lands, but also investigates different human disturbance gradients from probable disturbance foci in each of two blocks representing two utilisation/management regimes.

5.3 METHODS

5.3.1 Study site

The study site is about 50 km east of Morogoro and 150 km west of Dar-es-Salaam and comprises the Kitulanghalo Forest Reserve and surrounding public lands which comprise settlements, cultivated land and open woodlands (Figure 5.1).

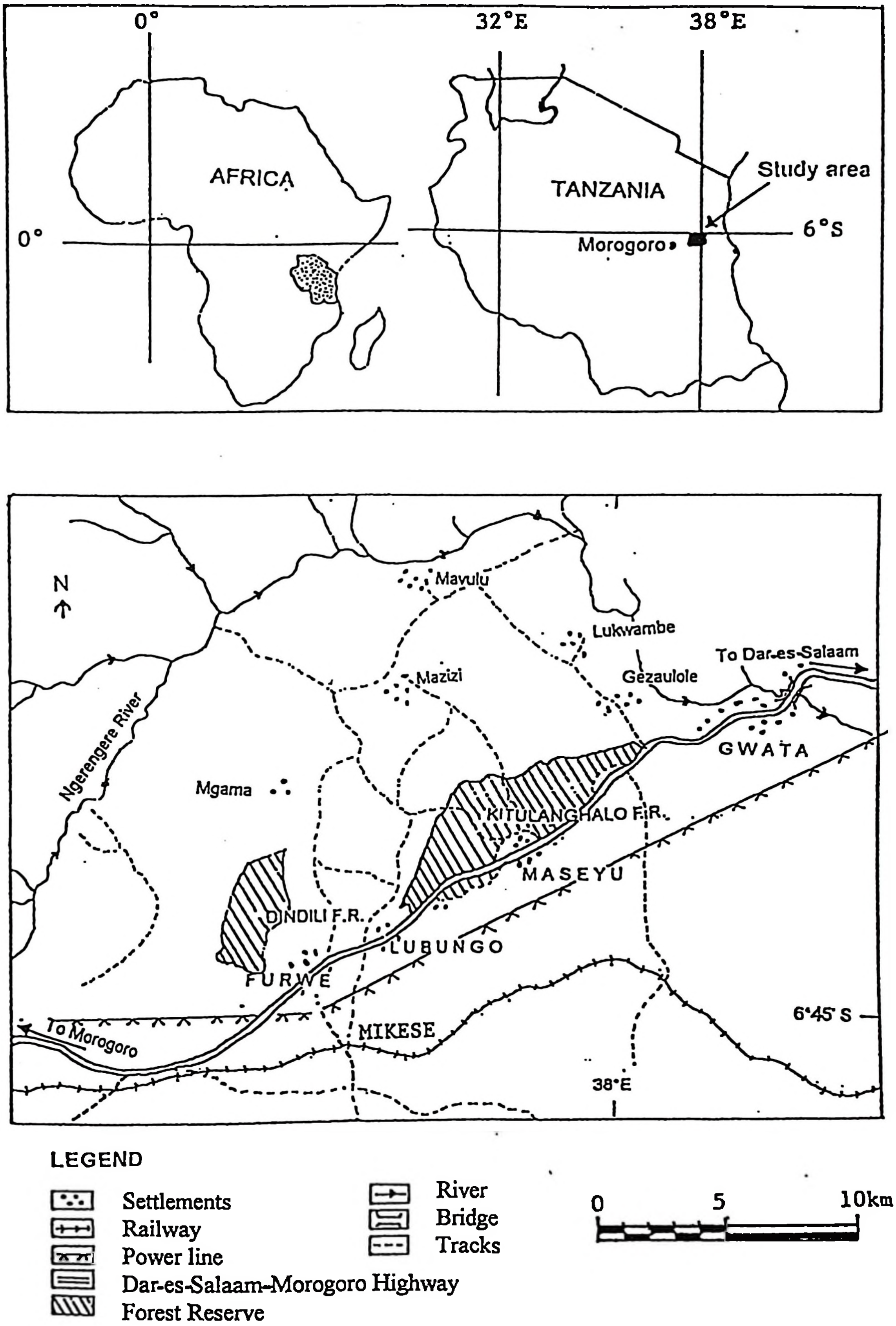

Figure 5.1 The location of Kitulanghalo Forest Reserve and surrounding public lands, Morogoro, Tanzania.

The reserve covers an area of 2452 ha and includes Kitulanghalo Hill (06°41' S, 37°75' E), which reaches about 800 m.a.s.l. The reserve was officially declared and gazetted in June 1955 as a 'productive reserve' indicating a primary objective of forest production (Fottland, 1996), with utilisation controlled through the issuing of licences. In 1985 the reserve, which also serves as a water catchment, was closed for any utilisation although illegal harvesting has continued (Nduwamungu, 1996).

The climate of the area is tropical and subhumid (Kielland-Lund, 1990a). Mean annual rainfall is about 900 mm which is seasonally distributed providing a wet season from November to May and a dry season from June to October. The annual mean temperature is 24.3 °C while the annual minimum and maximum temperatures are 18.6 °C and 28.8 °C respectively. This climate, together with the generally nutrient poor, well drained soils supports miombo woodlands and some patches of semi-evergreen forests (Kielland-Lund, 1990a).

The area has no large wild herbivores and cattle due to the presence of tsetse flies (*Glossina* spp.), which transmit sleeping sickness (nagana) to domestic animals and humans. Annual fires are common in the area, although there are no specific data for fire frequency and intensity.

The study area is bisected by the Dar-es-Salaam – Morogoro highway which marks most of the southern boundary of the reserve and is the main transportation route for forest products to urban/commercial centres such as Dar-es-Salaam and Morogoro. Several tracks crisscross both the reserve and public lands and are used as extraction routes for forest products to the highway.

5.3.2 Field data collection

Sixty-four 50 X 20 m plots were surveyed, thirty-four in the forest reserve and thirty in public lands. Plots were systematically allocated with the long axis along transect lines at intervals of 300 m (edge), 900 m (intermediate) and 1500 m (far) to cover gradients of stand characteristics with increasing distance from probable disturbance centres. Of the thirty plots in public lands, twelve were placed about 10 km north of the highway radiating from Mazizi village and the other eighteen plots were laid in the southern block around Maseyu village (Figure 5.2).

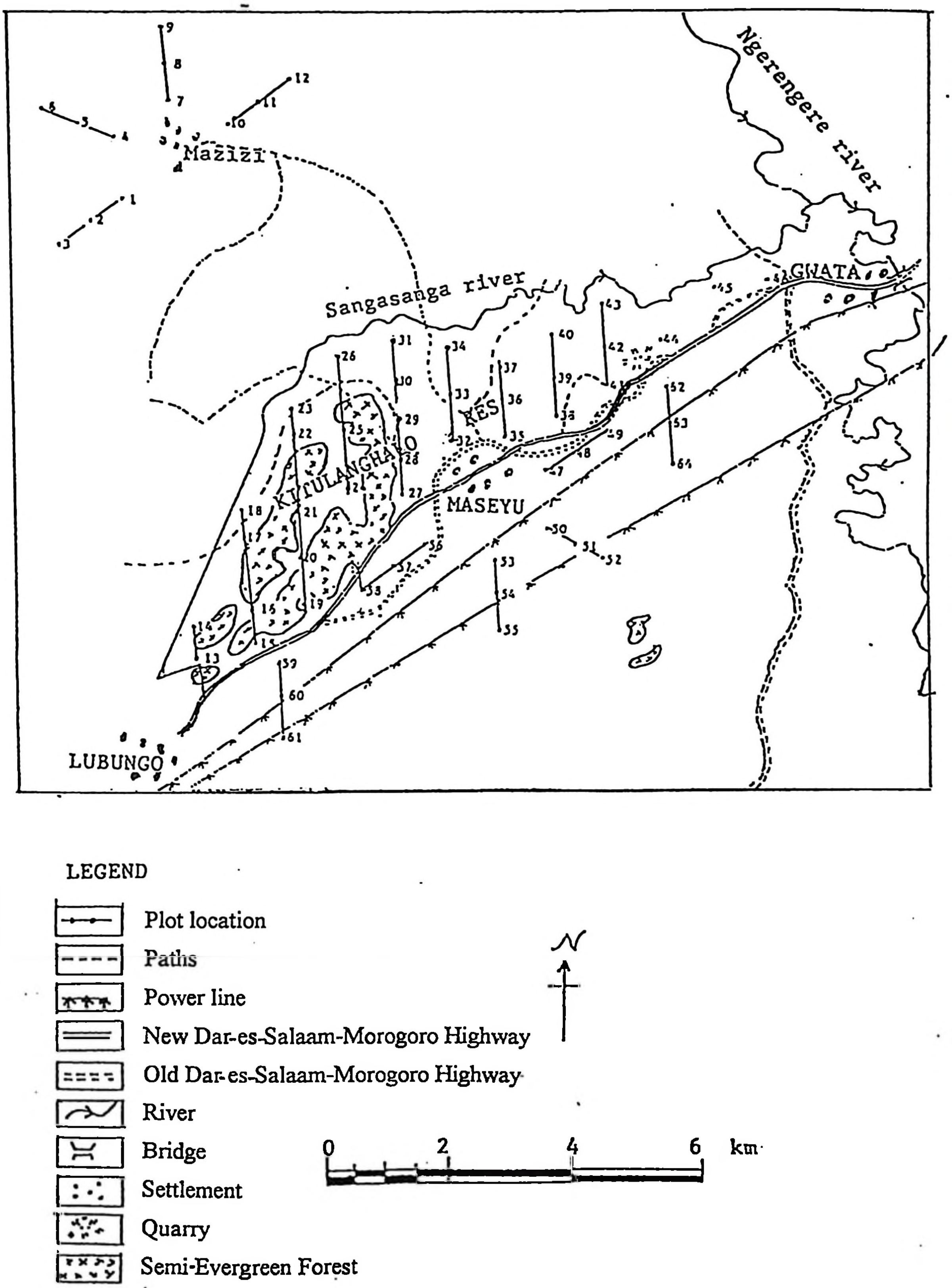

Figure 5.2 Position of plots in Kitulanghalo Forest Reserve and surrounding public lands, Morogoro, Tanzania.

Within the plots, all trees of diameter at breast height (DBH) > 4 cm were identified and basal diameter (BD in cm), diameter at breast height (DBH in cm) and height (m) were measured. This minimum diameter was selected because most smaller trees are not resistant to annual fires in miombo woodlands (Kielland-Lund, 1990b).

There were no records for harvested wood in both the reserve and public land and hence the number of felled trees was recorded from stumps. 'Newly' harvested (stumps harvested within the last year) and 'old' harvested stumps (stumps harvested more than a year previously) were recorded. The distinction between two ages of stumps was established by the colour and freshness of exposed wood, the size of sprouts/coppices and the presence of fire scorch on exposed wood. In each case, basal diameter of the stumps was measured, the species identified and the purpose of removal established with the aid of four local elders well acquainted with ethnobotany and aspects of woodland utilisation. The criteria used for identification of the harvested species were coppice growth, wood and bark characteristics and symmetry of the stump. The following criteria were used to determine the reason for harvesting: species, size, symmetry, stump height, presence of fire scorch, and proximity of charcoal kiln or sawing platform to the stump.

The following parameters were recorded from each plot: altitude, slope, grass cover (% of ground surface) and maximum grass height (cm). Most of these variables were analysed by multivariate analysis and were used as surrogates of potential fire intensity. Grass cover (estimated as a percentage of the total area of a quadrat) and grass height (cm) were measured from ten 2 x 0.5 m quadrats in each plot (Stohlgren *et al.*, 1995).

5.3.4 Estimation of harvested and standing wood stocks

Stand basal area is the best indicator of harvestable wood volume in indigenous forests (Endean, 1967). Using data from different miombo sites, Frost (1996) found that stand volume (V) could be expressed as a function of stand basal area (BA) using the equation:

$V(m^3/ha) = 6.18BA\ (m^2/ha)^{0.86}\ \ (r^2 = 0.89,\ p<0.001)$. -------------------------------- (1)

Equation 1 was used to establish volume of removed wood for different species, and compared with the standing stocks.

In determination of firewood, all dry wood of suitable sizes which could be collected from the plots was weighed. The number of stems suitable for extractable construction poles was also recorded from each plot. Available wood biomass and total volume of the standing trees was calculated using functions previously developed for miombo woodlands at Kitulanghalo Forest Reserve (Malimbwi *et al.*, 1994).

$B = 0.06\ dbh^{2.012}\ h^{0.7}$------------------------------ (2)

$V = 0.0001\ dbh^{2.032}\ h^{0.659}$----------------------------(3)

Where; B = biomass (kg) of a tree, V = volume (m^3) of a tree, dbh = diameter at breast height and h = total height. DBH of the felled trees could be estimated from measured basal diameter (BD) using the established equation from this study:

$DBH = -1.003+0.87BD$ ($r^2 = 0.98$, $p<0.0001$)-------------------------------------- (4)

5.3.5 Statistical analyses

Student *t*-tests were used to compare differences in stocks between land uses. Regression analyses (the best fit of either linear, natural ln, exponential or power) were performed in order to determine the impact of distance from focal disturbance points (independent variables) on harvesting intensity and standing wood resource parameters (dependent variables). Gradient analysis was also carried out by use of ordination techniques namely Principle Component Analysis (PCA) and Canonical Correspondence Analysis (CCA), by using the CANOCO computer program (ter Braak, 1988). Ordination analyses were performed on the number of tree stumps harvested for different purposes, in relation to physiographic variables measured in 64 plots distributed in the forest reserve and public land. Physiographic factors which may affect the pattern of harvesting are distance from the highway, distance from village settlements, distance from reserve boundaries, distance from nearest extraction track, altitude and slope. Monte Carlo permutation was then used to test whether the linear combination of measured physiographic variables has a statistically significant influence on the harvesting patterns.

5.4 RESULTS

5.4.1 Wood harvesting

Tree removals represented a basal area of 1.28 ±0.24 (SE) $m^2\ ha^{-1}$ in the forest reserve compared with 4.03 ±0.68 $m^2\ ha^{-1}$ in the public lands (Table 5.1). The volume of newly felled trees was 1.12 ± 0.19 m^3 ha^{-1} in the forest reserve compared with 6.38 ± 2.39 m^3 ha^{-1} in public lands (Table 5.1). The road (track) network reflects harvesting activities as the tracks are used for vehicular access to collect forest products. The mean distance of plots from the nearest track was considerably shorter in the public lands than in the forest reserve (Table 5.2). Thus, although the utilisation (total number of old and new stumps, basal area and volume) in public lands was more than three times that in the reserve, the reserve was not being effectively conserved as illegal harvesting is occurring. as the tracks are used for vehicular access to collect forest products. The mean distance of plots from the nearest track was considerably shorter in the public lands than in the forest reserve (Table 5.2). Thus, although the utilisation (total number of old and new stumps, basal area and volume) in public lands was more than three times that in the reserve, the reserve was not being effectively conserved as illegal harvesting is occurring.

Harvesting intensity tended to decline with increasing distance from the village or forest reserve boundaries ($r^2 =$ 0.19 and 0.16 for 'old' and 'all stumps' respectively in public lands (ln fits), with all other r^2 < 0.1 irrespective of the model used). Charcoal alone contributed 56.4% of the total tree removal in public lands and also 54.6% in the reserve (Table 5.3) and 91% of all harvested tree species. There was no difference in total number of stumps harvested for charcoal compared to non-charcoal ($\chi^2_1 = 0.0154$, $p = 0.901$) in the reserve and public lands. Very few stumps (0.45%) were removed for timber sawing in both the public land and forest reserve (Table 5.3), but trees harvested for timber have the biggest mean diameters while the widest range of DBH 2.4 – 68.6 cm was recorded from trees harvested for charcoal in public lands (Table 5.4). Thus, charcoal production is the major reason for tree felling in the study area, with little species and size selection, suggesting that harvesting for charcoal invariably results in virtual clear-felling of the woodland around the kiln site.

The total volume of harvested wood ('new' and 'old' stumps) in public lands was 19.6 ± 2.6 m^3 ha^{-1}, compared with 7.1 ± 1.2 m^3 ha^{-1} in the forest reserve, while the standing volume was 16.7 ± 2.6 m^3 ha^{-1} in public lands and 47.0 ± 3.4 m^3 ha^{-1} in the forest reserve (Figure 5.3, Table 5.5). These figures represent removal/standing (R/S) stock ratios of 1.18 in public lands and 0.15 in the reserve. The species with the largest volume of felled individuals in public lands was *Julbernardia globiflora* (Benth.)

Troupin (27.9%), followed by *Combretum molle* Engl. & Diels (13.2%), while in the reserve *C. molle* ranked first in removal volume (20.7 %) followed by *J. globiflora* (16.4%) (Table 5.5).

Table 5.1 Comparison of harvesting intensity (number of stumps, basal area and volume; mean ± SE) between the Kitulanghalo Forest Reserve and surrounding public lands in miombo woodland, Morogoro, Tanzania ('new' stumps harvested within the last year; 'old' stumps harvested more than a year previously).

Removals	Parameters	Reserve (n=34)	Public Land (n=30)	Statistical parameters	
				t	*p*
New	Stumps (no. ha^{-1})	5.00±3.18	47.00±17.58	2.386	0.0100
	Basal area (m^2 ha^{-1})	0.14±0.54	1.38±0.54	2.045	0.0220
	Volume (m^3 ha^{-1})	1.12±0.68	6.38±2.39	2.162	0.0170
Old	Stumps (no. ha^{-1})	50.00±8.55	135.00±22.28	3.562	0.0001
	Basal area (m^2 ha^{-1})	1.04±0.19	2.61±0.51	2.892	0.0026
	Volume (m^3 ha^{-1})	5.98±0.86	13.24±2.18	3.707	0.0001
All	Stumps (no. ha^{-1})	55.00±8.96	182.00±24.19	4.936	<0.0001
	Basal area (m^2 ha^{-1})	1.28±0.24	4.03±0.64	4.237	<0.0001
	Volume (m^3 ha^{-1})	7.11±1.18	19.62±2.58	4.365	<0.0001

Table 5.2 Comparison of physical and ground cover parameters (mean ± SE) between the Kitulanghalo Forest Reserve and surrounding public lands in miombo woodland, Morogoro, Tanzania.

Parameters	Reserve (n=34)	Public Lands (n=30)	Statistical parameters	
			t	*p*
Altitude (m.a.s.l.)	334±13	329±10	0.30	0.381 (NS)
Slope (°)	14±2	10±1	2.10	0.020
Distance from boundary (m)	706±79	900±91	1.62	0.055 (NS)
Distance from highway (m)	1309±154	4597±820	4.18	<0.001
Distance from the nearest extraction track (m)	382±70	139±29	3.06	0.002
Grass height (cm)	83±5	67±4	2.84	0.030
Grass cover (% of plot size)	57±3	64±2	1.95	0.028

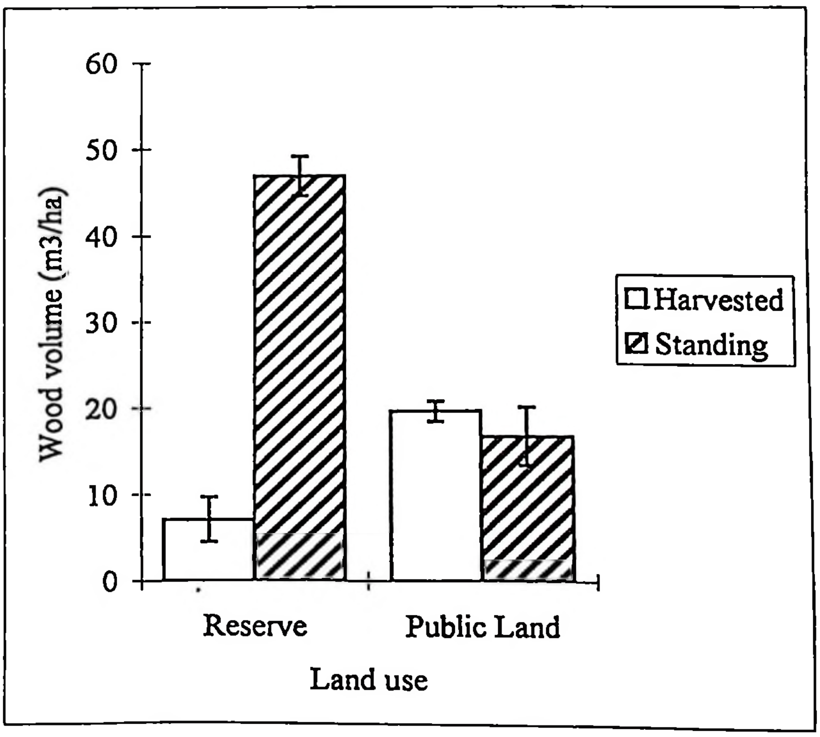

Figure 5.3 Comparison of harvested and standing volume of wood (m^3 ha^{-1}; mean ± SE) in Kitulanghalo Forest Reserve and surrounding public lands, Morogoro, Tanzania.

Table 5.3 Purposes for tree harvesting and their respective contributions (%) to overall harvesting intensity in the Kitulanghalo Forest Reserve and surrounding public lands in miombo woodland, Morogoro, Tanzania.

Purposes	Reserve (n = 34)			Public Land (n = 30)		
	No. of sampled stumps	% of all stumps	Stumps ha^{-1} (mean±SE)	No. of sampled stumps	% of all stumps	Stumps ha^{-1} (mean±SE)
Carving	4	2.2	1±1.2	3	0.5	1±1.0
Charcoal	101	54.6	30±22.9	309	56.4	103±22.9
Fires	10	5.4	3±2.4	16	2.9	5±83.3
Firewood	26	14	8±4.6	11	2	4±3.4
Land preparation	0	0	0	99	18.1	33±17.1
Natural mortality	17	9.2	5±19.0	28	5.1	9±4.0
Poles	16	9	5±2.6	55	10	18±77.1
Ropes*	1	0.5	0	9	1.6	3±3.0
Timber	1	0.5	0	2	0.4	1±0.5
Tracks	0	0	0	9	1.6	3±3.0
Unknown	9	4.9	3±1.1	7	1.3	2±0.9
ALL	182	100	55±9.0	548	100	182±24.2

*Trees felled before bark stripping

Table 5.4 Diameter at breast height (DBH) (mean ± SE) of felled trees in relation to various uses in the Kitulanghalo Forest Reserve and surrounding public lands in miombo woodland, Morogoro, Tanzania.

Purposes of felling	Reserve (n = 34)		Public Land (n = 30)		Statistical parameters	
	DBH (cm)	Range (cm)	DBH (cm)	Range (cm)	t	p
Carving	20.2±0.3	12.0 -25.1	17.2±0.3	12.2 -21.0	0.759	0.241
Charcoal	14.6 ±0.5	3.9 -52.4	14.2±0.6	2.4 -68.6	0.371	0.355
Fires	8.2±0.2	1.8 - 13.7	4.1±0.1	0.9 -7.3	3.865	<0.001
Firewood	12.9±0.4	3.1 -26.1	9.1±0.2	4.2 - 16.9	2.568	0.011
Land preparation	-	-	10.9±0.3	2.8 -27.1	-	-
Natural mortality	6.9±0.4	1.4 - 18.7	8.2±0.3	1.8 -24.4	0.71	0.241
Pole	10.5±0.4	3.5 -33.4	9.0±0.4	2.6 -29.1	0.757	0.226
Ropes	20.0*	-	6.4±0.1	3.6 - 10.5	-	-
Timber	44.2*	-	26.4±0.5	20.7 -32.1	-	-
Tracks	-	-	7.1±0.1	4.2 - 9.5	-	-
Unknown	12.8±0.4	6.2 -23.7	11.1±0.5	2.8 - 29.4	0.37	0.359

* Diameter values without standard errors had only one observation.

The R/S ratios for *C. molle* and *J. globiflora* were 1.83 and 6.85 respectively in public lands and 0.40 for both species in the forest reserve. However, despite high R/S ratios for *C. molle* and *J. globiflora*, their standing volumes were still relatively high, accounting for 8.4% and 4.8% of total volume for *C. molle* and *J. globiflora* respectively in public lands, and 6.2% and 7.8% in the reserve (Table 5.5). *Acacia nigrescens* Oliver had the largest standing volumes on both the public land and the reserve, accounting for 16.7% and 13.8% respectively (Table 5.5), while removal accounted for only 3.7 % and 3.5% respectively (Table 5.5).

Table 5.5 Removed versus standing stock volumes (mean $m^3 ha^{-1} \pm SE$) for all tree species in the Kitulanghalo Forest Reserve and surrounding public lands in miombo woodland, Morogoro, Tanzania.

	Reserve				Public Lands			
Species	Removed	% Removed	Standing	% Standing	Removed	% Removed	Standing	% Standing
Acacia goetzei Harms ssp. *goetzei*	0.08±0.04	1.1	4.28 ±2.18	9.1	0.44 ±0.23	2.2	1.04±0.56	6.2
Acacia nigrescens Oliver	0.25±0.14	3.5	6.50±1.75	13.8	0.73 ±0.27	3.7	2.79±1.18	16.7
Acacia nilotica Delile	0.04±0.03	0.6	1.07±0.38	2.3	0.15±0.13	0.7	0.29±0.16	1.7
Acacia polyacantha Willd.	0.01±0.01	0.1	0.02±0.02	0.1	0.01±0.01	0.1	0.06±0.05	0.4
Acacia robusta Burch.	0	0	3.46±1.48	7.3	0.79±0.29	3.9	0.59±0.26	3.5
Albizia harveyii Fourn.	0.50±0.28	7	0.63±0.28	1.3	1.45±0.49	7.4	0.40±0.13	2.4
Albizia petersiana Oliver	0	0	0.30±0.19	0.6	0	0	0.19±0.09	1.1
Albizia versicolar Welw. ex Oliver	0	0	0.06±0.04	0.1	0	0	0	0
Allophylus rubifolius Engl.	0	0	0.03±0.03	0.1	0	0	0.01±0.01	0.1
Annona senegalensis Pers.	0	0	0.06±0.04	0.1	0.19±0.13	0.9	0.05±0.04	0.3
Boscia salicifolia Oliver	0	0	0.04±0.03	0.1	0.06±0.06	0.3	0.01±0.01	0.1
Brachystegia boehmii Taub.	0.42±0.17	5.9	4.17±1.47	8.8	0.99±0.41	5.1	0.73±0.30	4.3
Brachystegia microphylla Harms	0	0	0.47±0.31	1	0	0	0	0
Brachystegia spiciformis Benth.	0	0	0.88±0.70	1.9	0	0	0	0
Bridelia cathartica Bertol. f.	0.05±0.03	0.7	0.15±0.05	0.3	0.12±0.06	0.6	0.12±0.05	0.7
Cassia abbreviata Oliver	0.05±0.05	0.6	0	0	0	0	0.12±0.09	0.7
Cassia sp.near C. burtii Hook.f	0	0	0	0	0	0	0.01±0.01	0.1
Catunaregum spinosa (Thunb.) Tirveng	0	0	0.03±0.01	0.1	0.02±0.02	0.1	0.02±0.02	0.1
Clerodendrum glabrum E. Meyer	0	0	0.02±0.02	0	0	0	0	0
Combretum adenogonium Steud. ex A.Rich.	0.31±0.22	4.4	0.89±0.37	0.9	1.07±0.44	5.5	0.22±0.07	1.3
Combretum collinum Fresen.	0.02±0.02	0.2	0.01±0.01	0	0.03±0.03	0.1	0	0

Table 5.5 continued

	Reserve				Public Lands			
Species	Removed	% Removed	Standing	% Standing	Removed	% Removed	Standing	% Standing
Combretum molle Engl. & Diels	1.47±0.38	20.7	3.68.±0.78	7.8	2.58±0.63	13.2	1.41±0.34	8.4
Dichrostachys cinerea Miq.	0.11±0.06	1.5	0.32±0.19	0.7	0.04±0.03	0.2	0.24±0.09	1.4
Diospyros kirkii Hiern	0	0	0.09±0.07	0.2	0.02±0.02	0.1	0	0
Diplorhynchus condylocarpon (Muell.-Arg.) Pichon	0.08±0.03	1.1	1.70±0.59	3.6	0.27±0.15	1.4	0.60±0.38	3.6
Dombeya rotundifolia (Hochst.) Planch.	0.24±0.12	3.3	0.41±0.12	0.9	0.02±0.01	0.1	0.16±0.12	1
Erythrophleum africanum (Benth.) Harms	0.13±0.13	1.9	0.13±0.09	0.3	0.19±0.13	1	0.08±0.08	0.5
Erythroxylum sp.	0.05±0.05	0.6	0	0	0	0	0	0
Gardenia ternifolia Schum. & Thonn.	0	0	0	0	0	0	0.03±0.03	0.2
Grewia bicolor Juss.	0	0	0.02±0.02	0	0	0	0.10±0.08	0.6
Grewia similis K. Schum.	0	0	0.11±0.02	0.2	0	0	0	0
Julbernardia globiflora (Benth.) Troupin	1.17±0.49	16.4	2.94±0.87	6.2	5.48±1.77	27.9	0.80±0.21	4.8
Lannea schimperi Engl.	0	0	0.52±0.27	1.1	0.02±0.02	0.1	0.09±0.08	0.5
Lannea schweinfurthii Engl.	0	0	0.33±0.33	0.7	0	0	0.50±0.32	3
Lonchocarpus bussei Harms	0.04±0.04	0.5	0.34±0.21	0.7	0.17±0.07	0.9	0.09±0.04	0.5
Lonchocarpus cappassa Rolfe	0	0	0.05±0.04	0.1	0	0	0	0
Maerua triphylla A.Rich.	0	0	0.01±0.01	0	0	0	0	0
Manilkara mochisia (Bak.) Hubard	0	0	0	0	0.15±0.15	0.8	0	0
Margaritaria discoidea (Baill.) Webster	0	0	0.10±0.08	0.2	0.02±0.02	0.1	0.03±0.02	0.2
Markhamia sanzibarica K. Schum.	0	0	0	0	0.01±0.01	0.1	0.03±0.03	0.2
Milletia sacleuxii Dunn.	0	0	0.03±0.03	0.1	0	0	0	0
Millettia usaramensis Taub.	0	0	0	0	0.03±0.03	0.2	0	0
Ochna leptoclada Oliver	0	0	0	0	0	0	0.01±0.01	0

Table 5.5 continued

	Reserve				Public Lands			
Species	Removed	% Removed	Standing	% Standing	Removed	% Removed	Standing	% Standing
Ormocarpum kirkii S. Moore	0.02±0.02	0.2	0	0	0	0	0.03±0.01	0.1
Pteleopsis myrtifolia Engl. & Diels	0.03±0.03	0.4	0.29±0.18	0.6	0.18±0.14	0.9	0.16±0.10	1
Pterocarpus angolensis DC.	0	0	0.75±0.57	1.6	0.54±0.31	2.7	0.74±0.60	4.4
Pterocarpus rotundifolius Druce	0.22±0.20	3.1	0.98±0.36	2.1	0.26±0.13	1.3	0.17±0.07	1
Pseudolachnostylis maprouneifolia Pax	0.02±0.02	0.3	0.36±0.18	0.8	0.20±0.16	1	0.06±0.04	0.3
Rothmannia fischeri (K. Schum.) Bullock	0	0	0.20±0.20	0.4	0	0	0	0
Sclerocarya birrea ssp. *caffra* Sond.	0	0	2.09±0.82	4.4	0.31±0.20	0.9	0.49±0.40	2.9
Spirostachys africana Sond.	0.15±0.11	2.2	1.40±0.60	3	0.51±0.31	2.6	0.82±0.69	4.9
Steganotaenia araliacea Hochst.	0	0	0.02±0.02	0	0	0	0	0
Sterculia africana (Lour.) Fiori	0.07±0.07	0.9	1.36±1.36	2.9	0	0	0.31±0.31	1.9
Sterculia quinqueloba Sim	0.45±0.45	6.4	0	0	0	0	0	0
Stereospemum kunthianum Cham.	0	0	0.01±0.01	0	0	0	0	0
Tamarindus indica L.	0	0	1.71±1.31	3.6	0	0	0	0
Terminalia sericea Burch. ex DC.	0.20±0.12	2.9	0.71±0.48	1.5	0.44±0.30	2.3	0.12±0.05	0.7
Turraea nilotica Kotschy & Peyr.	0	0	0.02±0.01	0	0.03±0.03	0.1	0.01±0.01	0.1
Vangueria infausta Burch.	0	0	0	0	0	0	0.01±0.01	0
Vitex ferruginea Schum & Thonn.	0	0	0	0	0	0	0.42±0.42	2.5
Xeroderris stuhlmannii (Taub.) Mendonca & Sousa	0.22±0.17	3.1	1.71±0.67	3.6	1.20±0.67	6.1	1.38±0.54	8.3
Ximenia caffra Sond.	0	0	0.04±0.04	0.1	0	0	0.01±0.01	0.1
Zanha africana (Radlk.) Excll	0	0	0	0	0.08±0.08	0.4	0	0
All Species	7.11±1.18	100	46.96±3.38	100	19.62±2.58	100	16.69±2.26	100

Pterocarpus angolensis DC., a species highly favoured for timber, has very low standing stocks especially in the forest reserve. Boaler and Sciwale (1966) estimated that *P. angolensis* constituted about 8% of the tree biomass with DBH >5 cm at sixteen miombo woodland sites in Tanzania, while this study has revealed the contribution by volume of only 4.4% in public land and 1.6% in the forest reserve for trees with DBH >4 cm (Table 5.6). The large harvested volumes of *C. molle* and *J. globiflora*, the low standing volume of *P. angolensis* and the large standing volume of *A. nigrescens* could be attributable to utilisation preference, or natural distribution of these species.

The mean diameter (DBH) of standing trees in the forest reserve was 13.4 ± 0.4 cm, higher than the 8.7 ± 0.4 cm in the public land (MannWhitney $z = 5.845$, $p = 0.0001$). Analysis of diameter distribution indicated that there was a significantly larger number of individuals of diameter 4 –10 cm in public land than in the reserve. The reserve on the other hand had significantly more trees with DBH of >10 cm (both in the 10–20 cm and > 20 cm classes) (Table 5.6). These results indicated that generally wood harvesters prefer trees of >10 cm diameter.

Table 5.6 Size class distributions (mean ± SE) of standing trees in the Kitulanghalo Forest Reserve and surrounding public lands in miombo woodland, Morogoro, Tanzania.

Diameter classes (cm)	Number of stems ha^{-1}		Statistical parameters	
	Reserve (n = 34)	Public Lands (n = 30)	*t*	*p*
4 - 10	172±22.4	286±23.9	3.496	0.0004
10 - 20	122±11.5	66±11.7	3.347	0.0007
>20	51±4.6	12±2.2	7.364	<0.0001

5.4.2 Spatial pattern of wood stocks

There were similar observations of significantly higher values for basal area, biomass and volume in the forest reserve compared with the public lands indicating that levels of stocks were inversely proportional to harvesting intensity (Table 5.7). The stock of firewood (drywood) consistently tended to increase with distance from human settlements (Figure 5.4) with positive regression coefficients. Other stand parameters such as extractable poles, tree density, biomass and volume did not indicate any particular pattern with increasing distance from reserve boundaries or village settlements (Figure 5.4). The regression analyses between stand parameters and distance from boundaries indicated relatively low r^2 values, the highest being 0.15 (linear fit) between amount of firewood and distance from village settlements ($F_{1, 28}$ = 5.004, p = 0.033). All other r^2 values were < 0.1, irrespective of model. The relatively high and significant r^2 for dry wood in relation to distance from settlement boundaries indicated that firewood collection is more pronounced near the settlements.

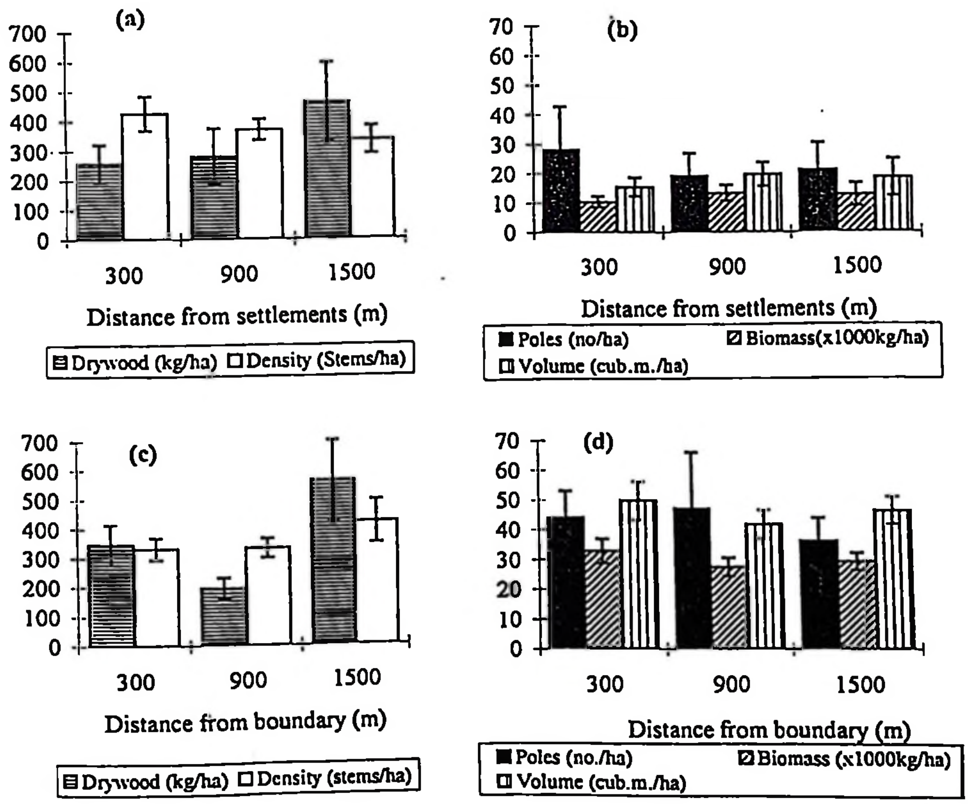

Figure 5.4 Changes in standing wood stocks (mean ± SE) with varying distances from human settlements (**a, b**) in public lands, and from the Kitulanghalo Forest Reserve boundaries (**c, d**) in Morogoro, Tanzania.

Table 5.7 Comparison of various stand parameters (mean ± SE) in the Kitulanghalo Forest Reserve and surrounding public lands in miombo woodland, Morogoro, Tanzania.

Stand parameters	Reserve (n = 34)	Public Lands (n = 30)	Statistical parameters	
			t	*p*
Dry wood (kg/ha)	335.7±56.9	309.3±51.9	0.339	0.3680
Extractable Poles (no./ha.)	43.5±8.9	26.7±5.6	1.561	0.0620
Density (living stems/ha)	347.6±30.6	364.0±25.2	0.406	0.3430
Basal area (m^2/ha)	9.8±0.5	3.1±0.3	6.314	<0.0001
Biomass (1000kg /ha)	36.6±2.5	13.8±1.4	6.268	<0.0001
Volume (m^3/ha).	47.0±3.4	16.7±2.3	6.172	<0.0001

There was a clear trend of increasing wood stocks with distance from the Dar-es-Salaam – Morogoro highway (Figure 5.5). This trend was significant for wood volume ($r^2 = 0.25$, $p = 0.005$, $df = 29$) although not significant for wood density (stems/ha) ($r^2 = 0.03$, $p = 0.365$, $df = 29$). When the two public land sites were compared, the northern site, which is about 10 km from the highway, had biomass and volumes significantly higher than in the southern site, which is bordered by the highway (Table 5.8). Mean diameter of standing trees in the southern block was 8.2 ± 0.6 cm, significantly lower than the 9.4 ± 0.5 cm in the northern block (Mann Whitney $z = 2.265$, $p = 0.02$). These results suggest that the Dar-es-Salaam – Morogoro highway is the major focus of disturbance.

(a) (b)

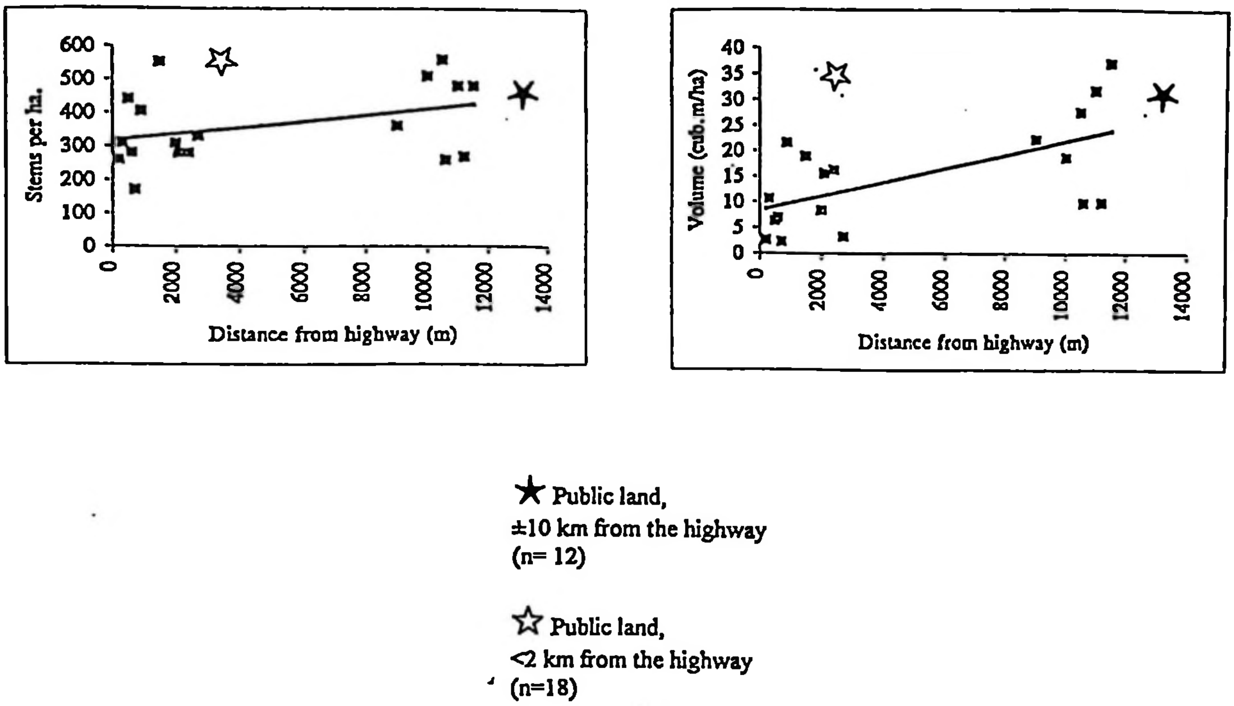

Figure 5.5 Trends in density of stems (a) and wood volume (b) with varying distance from the Dar-es-Salaam–Morogoro highway in public lands surrounding Kitulanghalo Forest Reserve, Morogoro, Tanzania.

The first two principal components of the standardized PCA of the environmental variables showed that distance from the highway is represented by the first axis and distance from the reserve boundary or settlements by the second. Moreover, the long lengths of the vectors for highway and boundary or settlement distances indicate the greater importance of these relative to the other physiographic variables (Figure 5.6). The matrix of physiographic variables indicated a positive correlation for all variables except "distance from the highway" against "slope" and "distance from the nearest track" (Table 5.9). The highest correlation coefficients were 0.70 and 0.62 (Table 5.9) showing that distance from the nearest extraction track increases with increase in slope and altitude respectively, i.e physiographic features affect utilisation pattern through their restriction of human access.

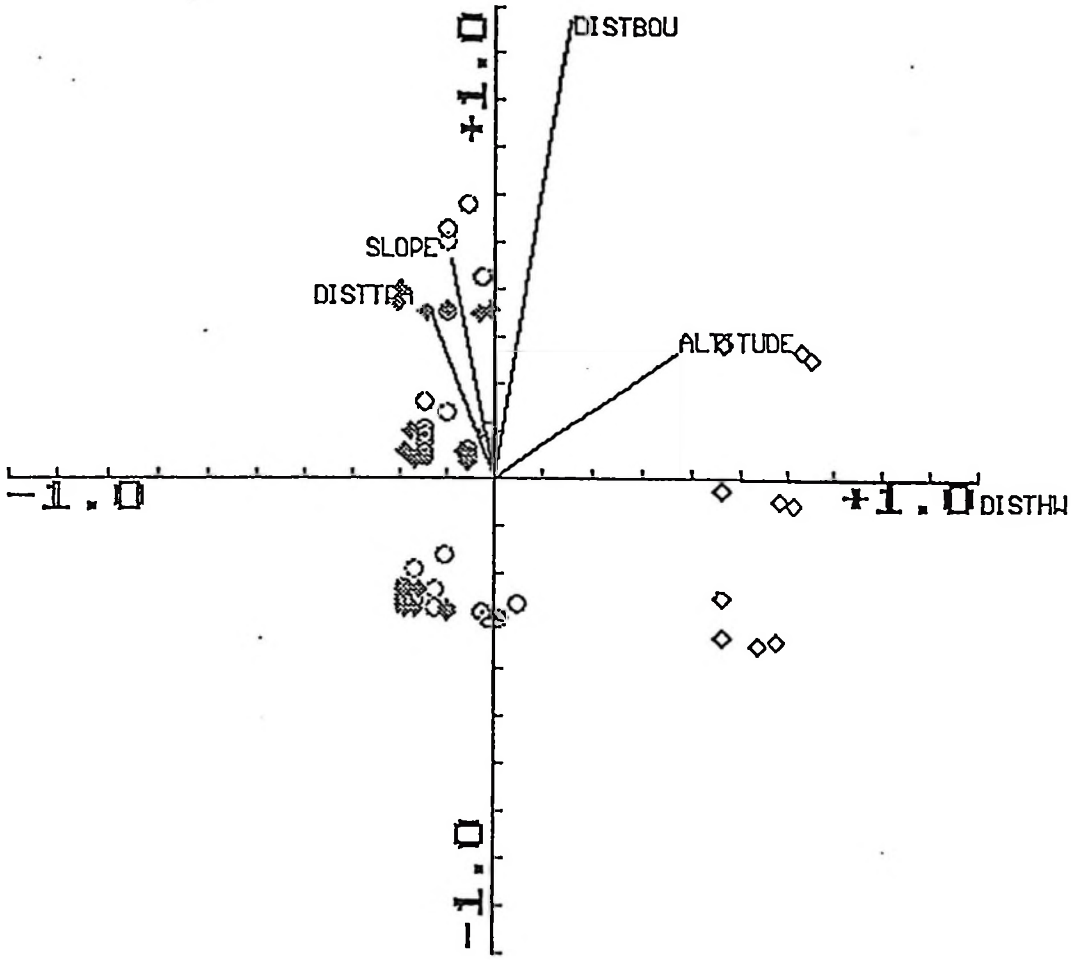

Figure 5.6 A biplot of sites and physiographic variables as defined by the first two axes of a standardized Principal Component Analysis (PCA) in Kitulanghalo Forest Reserve and surrounding public lands, Morogoro, Tanzania. ALTITUDE = Site altitude in m.a.s.l, DISTBOU = Distance from the reserve or village boundaries, DISTHW = Distance from the Dar-es-Salaam–Morogoro highway, DISTTRA = Distance from the nearest extraction track, SLOPE = Site slope in degrees. ◇ = Northern public Lands, ◆= Southern public lands, O = Forest Reserve.

Table 5.8 Comparison of stand parameters (mean ± SE) between the northern and southern public lands, situated ±10 km and < 2 km away from the Dar-es-Salaam – Morogoro highway respectively, Morogoro, Tanzania.

Parameters	Public Land, ±10 km from highway (n= 12)	Public Land, <2 km from highway (n=18)	Statistical parameters	
			t	*p*
Dry wood (kg/ha)	528.7±82.1	163.1±40.4	4.407	<0.001
Extractable Poles (no./ha.)	29.2±7.4	25.0±8.1	0.359	0.361
Density (stems/ha)	394.2±35.7	343.9±34.5	0.977	0.168
Biomass (1000kg/ha)	13.8±1.9	8.8±1.9	1.759	0.044
Volume (m^3/ha)	22.1±3.0	14.0±3.0	1.812	0.047

The eigenvalues and cumulative percentage variance for the Canonical Correspondence Analysis (CCA) indicated that more than 50% of the variance of the measured variables was captured by the first axis of ordination and more than 97% of the variance was expressed by the 4 axes of ordination (Table 5.10, Figure 5.7). This indicated the relatively high effectiveness of the analysis in summarizing the pattern of utilisation. The CCA ordination (Figure 5.7) also showed that charcoal burning activities were associated with increasing distance from the highway, and that most sites associated with charcoal activities were distributed in the northern public lands, while the cutting of trees for land preparation was predominant in the southern public lands. Figure 5.7 revealed that steep slopes are associated with trees which are killed by fire. This could be attributable to the high fire intensity which occurs when a fire advances up a steep slope due to pre-heating effects.

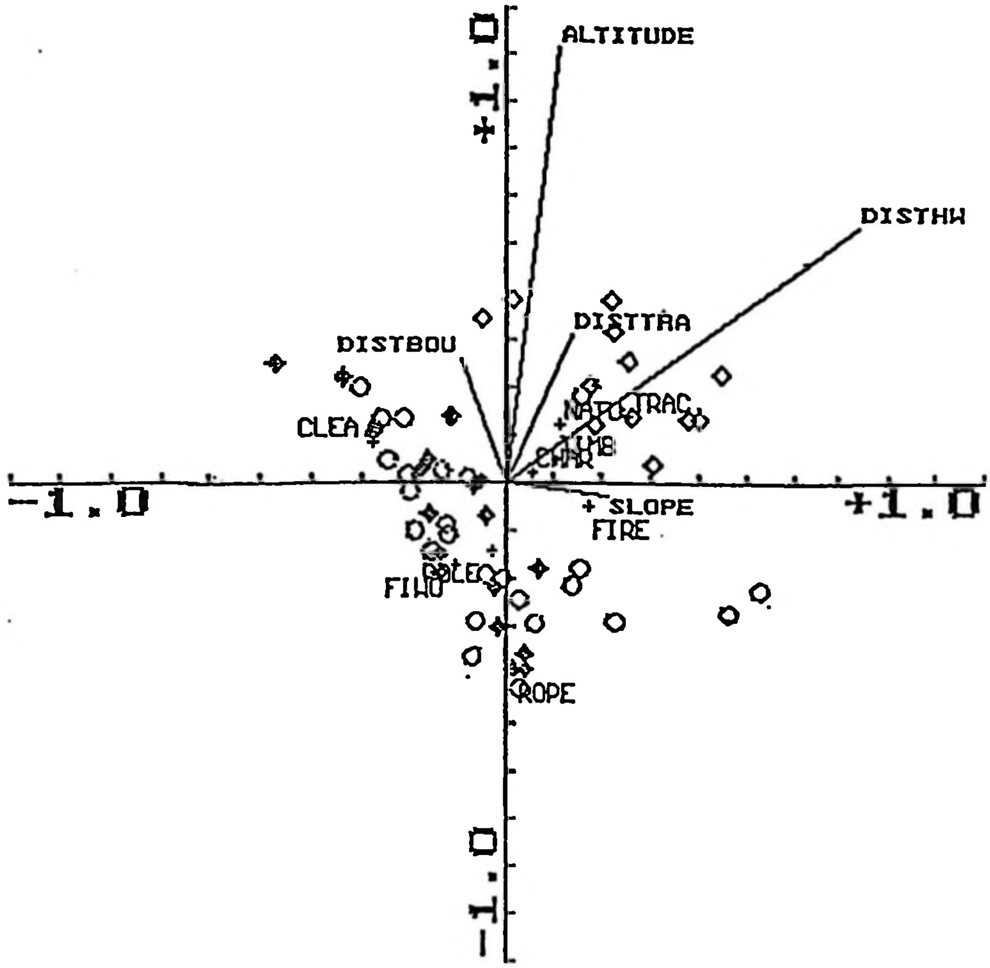

Figure 5.7 A biplot of the first two axes of Canonical Correspondence analysis (CCA) showing ordination of sites, physiographic variables and associated utilization parameters in Kitulanghalo Forest Reserves and surrounding public lands, Morogoro, Tanzania. Physiographic variables: ALTITUDE = Site altitude in m.a.s.l, DISTBOU = Distance from the reserve or village boundaries, DISTHW = Distance from the Dar-es-Salaam–Morogoro highway, DISTTRA = Distance from the nearest extraction track, SLOPE = Site slope in degrees. Utilization variables as stumps harvested for the following purposes: CHAR = Charcoal, CLEA = Clearing for farming, FIRE = Killed by Fires, FIWO = Firewood, NATU = Natural death, POLE = Building poles, ROPE = Ropes, TIMB = Timber, TRAC = extraction tracks. Sites: ◇ = Northern public lands, ◆= Southern public lands, O = Forest Reserve.

The significantly steeper slopes and taller grass in the forest reserve (Table 5.2) result in more intense fires killing relatively larger trees compared with the public lands (Table 5.4). The CCA ordination did not indicate any gradient associated with harvesting for poles or firewood (Figure 5.7) even after making the charcoal column passive during the ordination. The Monte Carlo test showed that the first canonical axis was significant (eigenvalue = 0.31, $F = 3.84$, $p = 0.01$). The overall test also showed significant results (eigenvalue = 0.60, $F = 1.61$, $p = 0.03$). These results show that the linear combination of physiographic features significantly influenced the pattern of tree harvesting, and that the main activity in the northern block of public lands is charcoal burning, while farming is predominant in the southern block of public lands.

Table 5.9 Correlation matrix of physiographic variables which were used in Principal Component Analysis and Canonical Correspondence Analysis in the Kitulanghalo Forest Reserve and surrounding public lands, Morogoro, Tanzania.

	Altitude	Slope	Distance from highway	Distance from boundary
Slope	0.523			
Distance from highway	0.372	-0.092		
Distance from boundary	0.208	0.337	0.155	
Distance from nearest extraction track	0.621	0.699	-0.138	0.175

Table 5.10 Statistical summary of the Canonical Correspondence Analysis in miombo woodlands of the Kitulanghalo Forest Reserve and surrounding public lands, Morogoro, Tanzania.

Axes	1	2	3	4
Eigenvalues	0.31	0.16	0.08	0.00
Utilisation–environment correlations	0.60	0.49	0.44	0.27
Cumulative % variance of utilisation data	7.00	10.7	12.5	13.3
Cumulative % variance of utilisation-environmental relation	51.2	78.1	91.4	97.2

5.5 DISCUSSION

5.5.1 Sustainability

The magnitude of harvesting shows that woodlands in public lands were more affected by human utilisation than those in the forest reserve (Tables 5.1 and 5.6). The estimated annual wood removal of 6.38 ± 2.39 m^3 ha^{-1} in public land (Table 5.1) exceeded the mean annual increment (MAI) in the study area which is reported to be 4.35 m^3 ha^{-1} $year^{-1}$ (Ek, 1994), signifying that the level of harvesting in public lands was not sustainable. In the future, the harvesting pressure is likely to increase in the reserve following further resource depletion in public lands, particularly with an escalation of resource transportation costs due to increased distances that will have to be travelled in public lands in order to bring products to the market centres.

5.5.2 Spatial utilisation patterns

The tendency of decreasing harvesting with increasing distance from the village settlements and reserve boundaries, was not mirrored by similar changes in standing stocks (basal area, stem density and biomass), suggesting that charcoal harvesting patterns, unaffected by distance from settlements (due to vehicles use) masked the overall utilisation pattern as it is the single greatest use of wood. Studies in Zimbabwean miombo (Grundy *et al.*, 1993; Vermeulen, 1996) and South African savannas (Shackleton *et al.*, 1994) indicated that wood harvesting had a higher impact close to the village boundaries and decreases with distance from the settlements. However, there is much less commercial charcoal production in Zimbabwe and South Africa than in Tanzania, Zambia and Malawi (Brigham *et al.*, 1996).

The spatial pattern of harvesting for charcoal overrides the effect of other products as reflected by the number of stems removed and the range of stem diameter classes harvested (Tables 5.3 and 5.4 respectively). A survey of consumption of construction-wood in the area indicated that *J. globiflora* is preferred for walling poles (12%) while *C. molle* is used for roofing poles (12%) (Luoga *et al.*, 2000b). This indicated that other subsistence products may often be collected as by-products from trees chopped primarily for charcoal.

The ordination findings (Figures 5.6 and 5.7) augment results from Table 5.8 and Figure 5.5 which show that the area close to the highway has already been depleted of standing wood stocks with little current potential for charcoal production. This demonstrates that informal trading in miombo products has better prospects along main roads, causing eventual wood depletion before harvesters move further into the forest. Similar findings have been reported elsewhere in miombo woodlands (Campbell *et al.*, 1996).

The significant ordination values demonstrated further that cutting trees does not merely depend on species preference, but also on the distance of the tree from a disturbance focus, altitude and slope; all of which determine the ease of extraction. Increased distance from the nearest extraction track in the steeper terrain (Table 5.9) for example, demonstrates that there is less harvesting due to poor accessibility. This is positive for soil conservation as steep slopes are more prone to erosion if cleared of vegetation.

5.5.3 Impact of utilisation on wood availability

The size and species preference have an impact on tree diameter distribution and structure of the community. *C. molle* and *J. globiflora*, two favoured species for charcoal appear to be negatively affected by increasing levels of disturbance, a trend which seems to favour *A. nigrescens*, a less utilised species (Table 5.5). Formerly *Combretum* spp. appeared to be the most abundant in terms of numbers and biomass in the reserve (Malimbwi *et al.*, 1994) and this study shows that these species combined are the most harvested in the reserve (Table 5.5). Standing volume for *A. nigrescens* in part of the Kitulanghalo Forest Reserve was previously recorded to be 4.86 m^3 ha^{-1} (Malimbwi *et al.*, 1994) as opposed to 6.5 m^3 ha^{-1} in this study. *A. nigrescens* has a dense wood which yields good quality charcoal, but is not favoured by charcoal burners as the hard wood is difficult to chop or crosscut and is thorny, making it difficult to handle. Some charcoal burners also claim its charcoal crumbles easily. Charcoal burners sometimes use fire as a method of felling *A. nigrescens*, a practice which sometimes results in 'accidental' fires (Luoga *et al.*, 2000a). The relatively large standing volumes of *J. globiflora* and *C. molle* despite their high levels of utilisation suggest that community species composition is influenced by local environmental gradients other than disturbance. Similar results were noted by Shackleton et al. (1994) in communally managed South African savannas. It has been reported in selected Tanzanian forest reserves that the removal of poles for commercial and subsistence uses accounted for more than half of the available stems (Hall and Rodgers, 1986). However, the results of this study have indicated a very low percentage of trees harvested for poles (Table 5.3). This is partially attributable to some of the quality pole species (*Diospyros consolatae* Chiov, *Markhamia zanzibarica* K. Schum. and *Milletia usaremensis* Taub.) being found only in the semi-evergreen forest patches (Luoga *et al.*, 2000b) which were not covered by the study. This shows that diversification of harvesting in different plant communities reduces the impact on the resource.

The extremely low levels of *P. angolensis* which was only found in part of the study area was also noted by (Nduwamungu, 1996). The reserve is close to Maseyu village and *P. angolensis* had been widely used in the past to make window frames and doors for houses in the village and for timber (Luoga *et al.*,2000 b). It is thus very plausible that this species was heavily harvested in the reserve before the closure of harvesting in 1985. The depletion of *P. angolensis* has apparently resulted in attention being focussed on the felling of *Sterculia quinqueloba* Sim. in the forest reserve, with this species also appearing to dwindle (Table 5.5). To a lesser extent, *Sclerocarya birrea* ssp. *caffra* Sond. is also harvested in public lands (Table 5.5) for timber and crafts. Traditionally, both this species and *Adansonia digitata* L. were considered "sacred" and thus were not harvested (Luoga *et al.*, 2000b). These temporal changes in utilisation indicate that the current levels of harvesting of different species are also influenced by previous use patterns determining availability.

5.6 CONCLUSION

This study has shown that the levels of harvesting in public lands are not sustainable as the annual removal of 6.38 m^3 ha^{-1} far exceeds the mean annual increment of 4.35 m^3 ha^{-1}. Although there is a significantly larger volume and biomass in the forest reserve than in public lands, there is still substantial utilisation, indicating that the reserve is not being effectively conserved. Prolonged heavy utilisation of wood does not merely change the diameter distribution and standing biomass of the trees, it also affects temporal and spatial heterogeneity within the community. Wood utilisation is affected by: 1) Proximity to the main road which affects the placement of charcoal kilns, 2) Proximity to the settlements which affects utilisation on a subsistence scale and 3) Previous use patterns determining availability. However, further study is needed to show how anthropogenic disturbances and environmental factors (e.g., soil) affect the regeneration, abundance, distribution and population dynamics of important species.

CHAPTER 6

Woody species composition and diversity in miombo woodlands of Kitulanghalo Forest Reserve and surrounding public lands of eastern Tanzania.

Submitted to *Plant Ecology*

6.1 Abstract

This study investigated the impacts of wood harvesting on richness, diversity and composition of woody species and on community-environmental gradients (including human disturbance) in a miombo woodland. Sixty-four modified-Whittaker nested plots were inventoried for all woody species in the Kitulanghalo Forest Reserve and surrounding public lands. *Julbernardia globiflora* (Benth.) Troupin had the highest importance value (sum of relative density and relative dominance) both in the reserve and public lands followed by *Combretum molle* Engl. & Diels and *Dichrostachys cinerea* Miq. in public lands. The Shannon-Wiener diversity index at the 1000 m^2 scale was 2.0 ± 0.1 (SE) in the forest reserve, significantly higher than 1.8 ± 0.1 in the public lands but species richness of 18.7± 0.73 and 18.5 ± 0.80 respectively was similar. A Sørensen's similarity value of 87.7% between the reserve and public lands suggests that heavy wood utilization has minimal effect on floristic composition. Although for multivariate analysis (CCA), the physiographic variables showed the highest cumulative percentage variance of 87% for the species environment relationship, the highest eigenvalue of 1.42 was recorded from the ordination of species with all environmental variables. Thus the linear combination of all variables significantly influenced species gradients relative to only edaphic or physiographic variables. Most species were not significantly associated with a particular soil type, catenal position or land use category, but associated with human disturbance. Although the study categorises species into those which are favoured and not favoured by human-disturbances, this miombo woodland generally shows a relatively high degree of stability in species composition in response to wood harvesting.

Key words: Canonical correspondence analysis, human disturbances, savanna ecology, species-environment relationship.

Abbreviations & acronyms: ANOVA–Analysis of variance, CA–Correspondence analysis, CANOCO–Canonical community ordination, CCA–Canonical correspondence analysis, CEC–Cation exchange capacity, DBH–Diameter at breast height, *H'*–Shannon-Wiener diversity index, HSD–Honestly significantly difference test, *IVI*–Importance value index, PCA–Principal Components Analysis, *Qs*–Sørensen's quotient of similarity, *S*–species richness, W/V– Weight/Volume XRF–X-ray fluorescence.

6.2 INTRODUCTION

'Miombo' are open, annually burnt, Zambezian deciduous woodlands dominated by the arborescent genera *Brachystegia* and *Julbernardia* (both Fabaceae, sub-family Caesalpinioideae) and tall grasses of the genera *Panicum*, *Hyparrhenia* and *Andropogon* (White, 1983). Miombo woodlands are dominant in eastern and central Africa (Lind and Morrison ,1974; White, 1983). The human impacts on tropical forests and woodlands can roughly be divided into five categories: selective removal of certain species, partial or complete removal of vegetation, burning and introduction of other plant and animal species (Boerboom and Wiersum, 1983; Werger, 1983). In miombo woodlands the impacts of disturbances have been well documented with studies on fire (Trapnell, 1959; Kikula, 1986a; Stromgaard, 1986; Chidumayo, 1988), large wild herbivores (Guy, 1976; Guy, 1989; Frost, 1996) and livestock (Lawton, 1980; Grundy, 1995). However, little research has been done on the impact of wood harvesting on tree diversity (Chidumayo, 1987b; Campbell and du Toit, 1994). Much human utilization of miombo woodlands is selective of species and stem sizes while clearing for cultivation and charcoal production is largely non-selective (Chidumayo, 1987a; Monela *et al.*, 1993; Luoga *et al.*, submitted a). A combination of type, frequency and scale characterises a disturbance regime (White and Pickett, 1985), which may influence species composition (Horn *et al.*, 1989).

Successful management, restoration, conservation and sustainable development of resources require the role of disturbance in the target system to be evaluated (Pickett *et al.*, 1992). The 'intermediate disturbance hypothesis' asserts that diversity is expected to be maximised at intermediate frequencies or intensities of disturbance (Connell, 1978). The majority of species do not survive very intensive disturbances and few species persist in the highly competitive communities that arise when disturbance is very mild (Connell, 1978; Huston, 1979). The intensity of disturbance also varies within a landscape as a function of land-use, accessibility, topography and the type of vegetation present (Luoga *et al.*, submitted a). The increase in dominance of small woody trees in harvested miombo woodlands (Chidumayo, 1987b, c; Luoga *et al.*, submitted a) suggests that the woodlands may degrade to shrublands following anthropogenic pressures. The aim of this study was to investigate the ecological impact of wood harvesting on arborescent S and H' and to relate woody community composition to physiographic and edaphic factors.

6.3 METHODS

6.3.1 Study area

The study area lies between 6°34'S–6°45'S and 37°53'E–38°04'E and comprises the Kitulanghalo Forest Reserve (2 452 ha), which because of restricted entry, is less disturbed than the surrounding public lands (13 500 ha). The site is about 50 km east of Morogoro and 150 km west of Dar-es-Salaam on the Dar-es-Salaam–Morogoro highway, which is the major route of transport for people and woodland products to these urban centres (Figure 6.1). The southern block of the communal lands is close to the highway and is estimated to cover about 7 800 ha of woodlands and shrublands, which are largely in early secondary successional stages. Charcoal producers have recently shifted their attention to the northern public lands which cover some 5 700 ha of land about 10 km north of the highway (Luoga *et al.*, submitted a).

The climate is sub-humid with a mean annual rainfall of about 900 mm which is seasonally distributed providing a wet season from October to May and a dry season from June to September. The year-to-year variation in rainfall is also high (Kielland-Lund, 1990a). The mean annual daily temperature is 24.3°C while the annual minimum and maximum daily temperatures are 18.6°C and 28.8°C respectively.

The miombo is generally a nutrient poor savanna woodland (Campbell *et al.*, 1996). The soils of the study area are well drained, red, acid (pH of about 6.0), sandy clay loams with brown friable top soil covered by decomposing litter (Fleetwood, 1981). The geology is Precambrian Usagaran metasedimentary rocks consisting of garnet biotite gneiss. In low-lying areas, mixed alluvial and colluvial deposits derived from these rocks are present (Msanya *et al.*, 1995). The topography ranges from rolling or steep relief to fairly gentle slopes. The mean slope is 11° and the mean altitude is about 340 m above sea level.

Most of the reserve and the surrounding public lands are covered with open miombo woodlands with some scattered trees of *Julbernardia globiflora* (authors listed in table 6.2), *Acacia nigrescens* and *Pterocarpus rotundifolius* reaching heights of 15 m to 20 m, while most of the trees form an under-storey, 5 to10 m high consisting mostly of *Diplorhynchus condylocarpon*, *Combretum* spp., *Acacia* spp. and *Dichrostachys cinerea*.

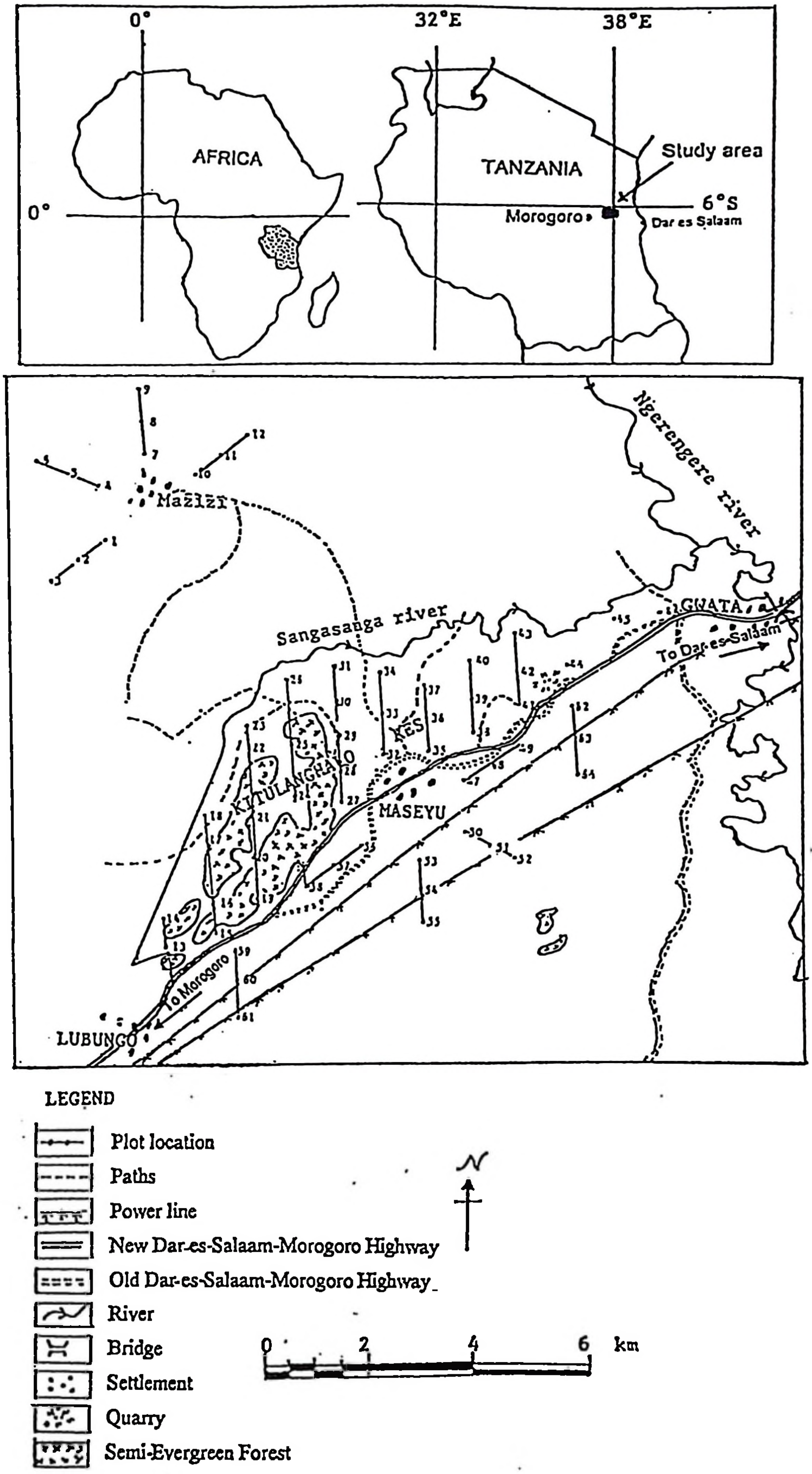

Figure 6.1 The location of Kitulanghalo Forest Reserve and position of plots in the reserve and surrounding public lands, Morogoro, Tanzania.

The area has no large wild mammalian herbivores or livestock owing to the presence of tsetse flies (*Glossina* spp.) which transmit sleeping sickness (nagana) to domestic animals. As a consequence, the herbaceous layer comprises a dense tall grass layer with an average height of 0.7 m. These high fuel loads result in frequent grass fires and a substantial portion of the woodland is burnt annually.

The study area is categorised as a commercial fuelwood (charcoal) production zone (MNRT, 1989; Luoga *et al.*, 2000a & b) and the predominant mode of farming is shifting cultivation, where the land is cultivated for six years and left fallow for four years (Luoga *et al*,. 2000a). Human disturbance is more pronounced in public lands, along the Dar-es-Salaam–Morogoro highway and near village settlements and tends to decrease with distance from these disturbance foci (Luoga *et al.*, submitted a). Most villages were formed by the government in 1974 during the resettlement schemes when people were concentrated in settlements mostly along the tarmacked highway which was constructed in 1970/1971.

6.3.2 Field data collection

Data collection was undertaken between August and October 1997 using the modified-Whittaker nested plot method (Stohlgren *et al.*, 1995). Ten 1 m^2 (0.5 x 2 m) and two 10 m^2 (2 x 5 m) subplots were arranged systematically inside the perimeter of a 1000 m^2 (20 x 50 m) plot and one 100 m^2 (5 x 20 m) subplot was centred in the plot. Sixty-four plots were surveyed, 34 in the reserve and 30 in public lands. Of the 30 plots in the public lands, 12 were placed in the northern block, about 10 km away from the Dar-es-Salaam–Morogoro highway (north of Mazizi hamlet) and the other 18 in the southern block, less than 2 km on average from the highway (south of Maseyu village) (Figure 6.1). In the reserve, plots were laid along parallel transects at intervals of 300 m, 900 m and 1500 m from the boundaries termed the near, intermediate and far plots respectively. In public lands, line transects radiated outward from village settlements at the same intervals and two transects established at the same distances from the highway (Figure 6.1). The purpose of this layout was to study how *S* differs with distance from the reserve boundaries, settlements or the highway.

6.3.3 Vegetation sampling

All arborescent plant species in the ten, outer perimeter, 1 m^2 sub-plots, were identified to species and enumerated. The same procedure was applied for the two 10 m^2 outer perimeter non-overlapping sub-plots and within the 100 m^2 central sub-plot. Any additional species were listed from the remaining area of the 1000 m^2 plot. All woody plants with DBH of < 4 cm (mostly saplings) were measured only within the 100 m^2 sub-plot because they were very numerous. Trees of DBH of ≥ 4 cm were measured for DBH throughout the 1000 m^2 plot and the cross sectional area (m^2) at breast height (representing basal area) of each sampled tree was then calculated.

6.3.4 Environmental variables

Soil samples were collected from all plots at two depths (0–10 cm and 20–30 cm), representing the A and B horizons respectively. Surface litter was first removed before soil sampling. Physiographic and other biotic information recorded from each plot included distance from the highway, distance to the nearest extraction track (reflecting harvesting intensity) (Luoga *et al.*, submitted a), number of harvested trees (stumps), altitude, slope, grass height, grass cover (% of ground surface) and litter cover. Grass height and cover and litter cover are physiographic variables because they are surrogates for fuel load and hence potential fire intensity.

Each soil sample was air dried and passed through a 2 mm sieve prior to analysis. Soil texture was measured using the Bouyoucos hydrometer method. Soil pH was measured potentiometrically in 1 M KCl at a ratio of 1: 2.5 soil: KCl solution (W/V). Organic carbon was determined by the wet oxidation method. The CEC and exchangeable bases (Na^+, K^+, Ca^{2+} and Mg^{2+}) were extracted by saturating the soil with neutral 1 M ammonium acetate and the bases measured by atomic absorption spectrophotometry (Thomas,1982). The Kjeldahl method was used to determine total nitrogen (Bremner and Mulvaney, 1982). Available phosphorus was extracted by the Bray and Kurtz-1 method (Bray and Kurtz, 1945), while total phosphorus was determined by wet digestion and molybdenum blue spectroscopy. The total elemental composition of Al, Ba, Ca, Cr, Cu, Co, Fe, K, Mg, Mn, Mo, Na, Ni, P, Rb, Si, Ti and Zn was analysed by XRF of finely ground 5 g samples (Jones, 1982).

6.3.5 Data Analysis

6.3.5.1 Species richness and diversity

S was enumerated at the 1 m^2, 10 m^2, 100 m^2 and 1000 m^2 scales. For each species the following values were calculated: density (number of stems per ha), basal area per ha, relative density (as a percentage of total stems per ha) and relative dominance (as a percentage of total basal area per ha). *IVI* was calculated as the sum of relative density and relative dominance (Mueller-Dombois and Ellenberg, 1974). The *Qs* was calculated on the basis of the number of species under each land use and those which are common to both (Mueller-Dombois and Ellenberg, 1974).

Species-area curves (Shmida, 1984) for the forest reserve and public lands were constructed: $S = b + d\log A$, where *S* is species number, *A* is sub-plot area, *b* is a constant and *d* is slope. These graphs were used to estimate larger scale patterns in *S*. Tree and shrub diversity were calculated at the 1000 m^2 scale using the equation:

$H' = -\sum_{i=1}^{s} p_i \ln p_i$, where *s* is number of species, p_i is the proportional abundance of the the i^{th} out of *s* species for a finite sample of discrete individuals and *ln* is logarithm to the base *e* (Kent and Coker, 1996). *H'* is the most widely used diversity index because it combines *S* and equitability and is not affected by sample size (Kent and Coker, 1996).

6.3.5.2 Statistical analyses

Student *t*-tests were used to compare *S* and *H'* between the reserve and public lands and between the more disturbed southern public lands and the less disturbed northern public lands and to compare slopes of the species-area curves (Zar, 1984). Two-way ANOVA and Tukey's HSD tests were used to compare differences in *S* and *H'* between the near, intermediate and far plots and between the reserve and two blocks of public lands. One-way ANOVA and Tukey's HSD tests were used to compare physiographic and edaphic variables between the reserve and two blocks of public lands. Regression analyses (best fit of either linear, natural log, exponential or power) were performed to establish the influence of distance from the settlements, reserve boundaries and the highway (independent variables) on *S* and *H'* (dependent variables).

6.3.5.2 Species-environment relationship

Multivariate analysis was used to identify which environmental variables are important determinants of the composition and structure of woody vegetation. Vegetation gradients were assessed by multivariate analysis using the CANOCO package (ter Braak, 1988) which allows environmental variables to be analysed concurrently with vegetation data. Basal area was used as the measure of abundance. The environmental and vegetation gradients were firstly assessed by standardised PCA and CA respectively to identify redundancy among species and environmental variables. The PCA and CA ordination scores and biplots were used to reduce the number of environmental variables from 74 to 28 and species from 90 to 36. The PCA results and biplot, for example, displayed a high correlation between most of the A and B soil horizon pairs, indicated by the relatively similar lengths of their vectors and the small angles subtended by the pairs (Figure 6.2). In such cases one variable (with a lower value) was removed per set.

The species and environmental variables were subsequently analysed using CCA which is the most appropriate technique for relating woody community composition to environmental factors (ter Braak, 1986). With CCA, the ordination axes are constrained to be linear combinations of the included environmental variables. Three runs of CCA were made, each for the physiographic, edaphic and all factors combined. The significance of the overall CCA ordination for each run was tested with a Monte-Carlo re-randomisation procedure, which is a direct test of whether the included environmental variables have a significant effect on compositional variation. All tests were run using 99 permutations and the null hypothesis was that each explanatory (environmental) variable explained an equal amount of the variation in species composition.

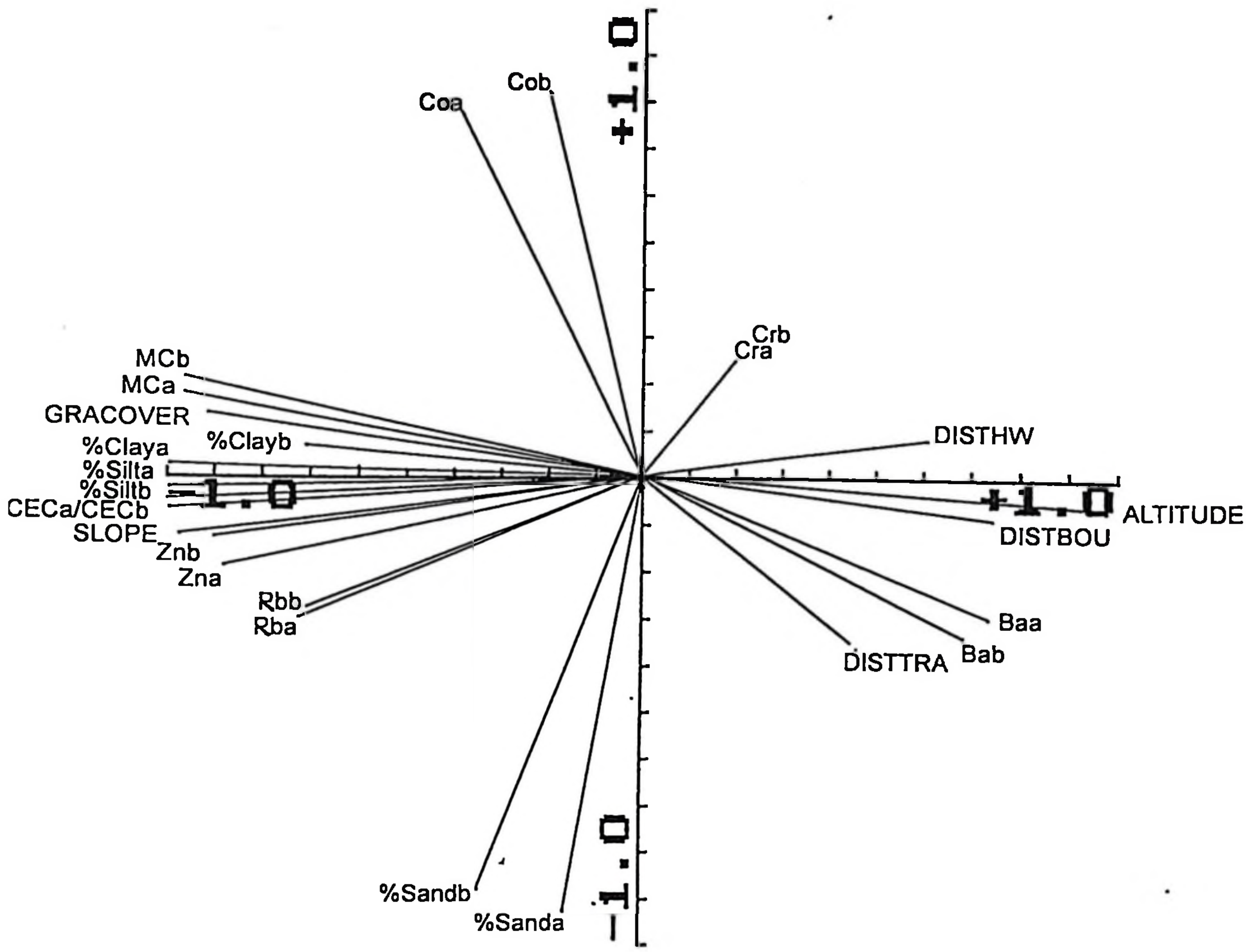

Figure 6.2 Ordination of environmental variables as defined by the first two axes of a standardized PCA in Kitulanghalo Forest Reserve and surrounding public lands, Morogoro, Tanzania. ALTITUDE = Site altitude, DISTBOU = Distance from the reserve or village boundaries, DISTHW = Distance from the Dar-es-Salaam–Morogoro highway, DISTTRA = Distance from the nearest extraction track, SLOPE = Site slope in degrees. GRACOVER = Ground cover, MCa = Moisture content A-horizon, MCb = Moisture content B-horizon, %Claya = Percentage of clay A-horizon, %Clayb = Percentage of clay B-horizon, %Silta = Percentage of silt A-horizon, %Siltb = Percentage of silt B-horizon, CECa = Cation Exchange Capacity A-horizon, CECb = Cation Exchange Capacity B-horizon, Zna = Zinc A-horizon, Znb = Zinc B-horizon, Rba = Rubidium A-horizon, Rbb = Rubidium B-horizon, %Sanda = Percentage of sand A-horizon, %Sandb = Percentage of sand B-horizon, Baa = Barium A-horizon, Bab = Barium B-horizon Cra = Chromium A-horizon, Crb = Chromium B-horizon, Coa = Cobalt A-horizon, Cob = Cobalt B-horizon.

6.4 RESULTS

6.4.1 Environmental factors

Comparisons of environmental variables between the reserve and public lands indicated that six of the eight physiographic / biotic variables were significantly different ($p < 0.05$) among land uses as compared with only 13 of the 66 edaphic variables (Table 6.1, Appendix 3). The only physiographic / biotic variables which were not significantly different were slope and grass cover. The soil properties that differed significantly among the land uses were pH (A-horizon), available P (B-horizon), CEC (A-horizon), exchangeable Ca^{2+} and K^{+} (B-horizon), Mo (A and B horizon), Rb (B-horizon), Co (A-horizon), Ca (A and B horizon) and Na (A and B horizon). The soils of the area are predominantly sandy-loams grading to sandy-clays with depth. The soils in the northern public lands have significantly lower CEC relative to the southern block, which is mirrored by the lower levels of total organic carbon (Table 6.1). The similarity in edaphic factors is attributable to the uniform substrate as a result of similar latitude, geology and climate.

6.4.2 Woody community composition

The ranking of species by *IVI* indicated that *J. globiflora* was the most important species in the reserve and the public lands. The next most important species were *Combretum molle* in both land uses followed by *Dichrostachys cinerea* in the public lands (Table 6.2). The familial *IVI* indicated that the sub-family Mimosoideae with 9 species in the reserve and 8 species in the public lands had the highest *IVI* of 40.6 and 39.0 respectively (Table 6.2). The second most important family in the reserve was Combretaceae (36.8) while in the public lands it was sub-family Caesalpinioideae (36.7). The families Ebenaceae and Loganiaceae, were each represented by only one species, *Euclea divinorum* and *Strychnos spinosa* respectively and had the lowest *IVI* ranging from 0 to 0.04 in both the reserve and public lands. The richest genera in number and importance values in both the reserve and public lands were *Combretum* and *Acacia* with each being represented by 5 species. *Combretum* had an *IVI* greater than 30.0 in each of the land uses, while *Acacia* seemed to be distributed mostly in the reserve, with an *IVI* of 26.1 as compared with 15.4 in the public lands.

Table 6.1 Environmental variables (physiographic, biotic and edaphic, mean ± SE) at Kitulanghalo Forest Reserve and surrounding public lands, Morogoro, Tanzania. Different superscript letters within rows indicate significant differences ($p < 0.05$, Tukey HSD). Soils: A = 0–10 cm, B = 20–30 cm depths.

Environmental variables		Soil Horizon	Reserve	Public Lands		ANOVA	
				Southern block	Northern block	*F*	*p*
Physiographic and biotic	Altitude (m.a.s.l)	–	334±11 ^{ab}	294±15 ^{a}	381±18 ^{b}	7.327	0.001
	Slope (°)	–	13.9±1.3	9.7±1.8	10.2±2.2	2.186	0.121
	Dist. from highway (m)	–	1309±134 ^{a}	1061±212 ^{a}	9900±259 ^{b}	454.308	<0.0001
	Dist. from nearest extraction track (m)	–	382±55^{b}	130±75 ^{a}	152±92 ^{a}	4.641	0.013
	Grass height (m)	–	0.84±0.04 ^{a}	0.70±0.06 ^{ab}	0.61±0.07 ^{b}	4.503	0.015
	Grass cover (%)	–	57.4 ±2.4	65.1 ±3.1	62.6 ±4.0	2	0.144
	Litter cover (%)	–	41.0±2.0 ^{a}	52.8±2.7 ^{a}	24.7±3.3 ^{b}	21.085	<0.0001
	Stumps (harvested trees/ha)	–	55.0±17.9 ^{b}	187.0 ±24.6^{a}	177.0 ±30.2^{a}	12.033	<0.0001
Edaphic	Clay (%)	A	14.9±1.03	16.5±1.41	16.1±1.73	0.442	0.644
		B	22.8±1.98	22.1±2.73	27.9±3.34	1.047	0.357
	Silt (%)	A	8.00±0.64	6.71±0.89	9.93±1.08	2.643	0.079
		B	6.99±1.03	4.21±1.42	5.72±1.73	1.272	0.287
	Sand (%)	A	77.1±1.15	76.9±1.58	74.0±1.93	0.989	0.378
		B	71.3±2.00	73.7±2.75	66.2±3.37	1.518	0.227
	Moisture content (%)	A	5.93±1.10	5.70±1.51	5.82±1.85	0.008	0.992
		B	5.13±0.89	5.06±1.22	3.21±1.49	0.654	0.524

Table 6.1 continued

Environmental variables		Soil Horizon	Reserve	Public Lands		ANOVA	
				Southern block	Northern block	*F*	*p*
Edaphic	pH (KCl)	A	5.78±0.07 [ab]	5.55±0.09 [a]	5.92±0.11 [b]	3.695	0.031
		B	5.13±0.14	4.81±0.19	4.97±0.24	0.912	0.407
	Total P (%)	A	0.07±0.02	0.09±0.02	0.05±0.03	0.590	0.557
		B	0.04±0.03	0.13±0.04	0.03±0.04	2.516	0.089
	Available P ($\mu g\ g^{-1}$)	A	4.96±0.70	4.28±0.56	5.97±1.17	0.616	0.543
		B	2.11±0.28 [a]	1.58±0.39 [a]	3.46±0.48 [b]	4.840	0.011
	Total N (%)	A	0.15±0.01	0.16±0.01	0.13±0.02	1.133	0.329
		B	0.16±0.04	0.11±0.06	0.12±0.07	0.217	0.806
	Organic Carbon (%)	A	2.19±0.12	2.69±0.29	1.84±0.35	1.842	0.167
		B	1.54±0.15	1.49±0.20	1.20±0.25	0.733	0.485
	Exchangeable acidity (m.e / 100g)	A	1.41±0.15	1.15±0.21	1.29±0.26	0.492	0.614
		B	1.53±0.28	2.31±0.38	1.56±0.47	1.457	0.241
	CEC (m.e / 100g)	A	14.3±0.68 [a]	15.0±0.93 [a]	10.8±1.14 [b]	4.477	0.015
		B	13.1±0.81	11.3±1.11	10.1±1.36	2.118	0.129
	Ex. Ca^{2+} (m.e / 100g)	A	1.48±0.22	1.09±0.30	1.03±0.37	0.858	0.429
		B	0.77±0.10 [a]	0.69±0.14 [a]	0.27±0.17 [b]	3.322	0.043
	Ex. Mg^{2+} (m.e / 100g)	A	1.83±0.10	1.81±0.13	1.84±0.16	0.009	0.991
		B	1.44±0.96	3.78±1.32	0.83±1.62	1.332	0.272
	Ex. K^{+} (m.e / 100g)	A	1.07±0.07	0.95±0.09	1.02±0.11	0.560	0.574
		B	0.72±0.06 [a]	0.34±0.08 [b]	0.63±0.09 [a]	8.333	0.001
	Ex. Na^{3+} (m.e / 100g)	A	1.84±0.77	0.35±1.06	0.32±1.30	0.882	0.419
		B	0.33±0.58	0.35±0.80	2.62±0.98	2.204	0.119

Table 6.2 Importance values as sums of relative density and relative dominance (basal area) (mean ± SE) of all species and families (calculated on species basis) recorded in Kitulanghalo Forest Reserve and surrounding public lands, Morogoro, Tanzania. Arranged in alphabetical order by family.

Species	Species Importance Values (*IVI*)		Family /	Familial Importance Values (*IVI*)	
	Reserve (n = 34)	Public Lands (n = 30)	sub-family	Reserve	Public Lands
Lannea schimperi Engl.	0.85 ± 0.43	1.10 ± 0.51	Anacardiaceae	5.18	5.12
Lannea schweinfurthii Engl.	0.55 ± 0.39	1.35 ± 0.71	"		
Sclerocarya birrea ssp. *caffra* Sond.	3.78 ± 1.46	2.67 ± 1.28	"		
Annona senegalensis Pers.	0.32 ± 0.18	0.27 ± 0.24	Annonaceae	0.32	0.27
Diplorhynchus condylocarpon (Muell.-Arg.) Pichon	5.03 ± 1.83	2.59 ± 1.22	Apocynaceae	5.03	2.59
Ehretia amoena Klotzsch	0.56 ± 0.28	2.02 ± 0.91	Bignoniaceae	0.70	3.53
Ehretia sp.	0.08 ± 0.07	0.80 ± 0.49	"		
Markhamia obtusifolia Sprague	0	0.22 ± 0.22	"		
Markhamia sanzibarica K. Schum.	0.05 ± 0.05	0.49 ± 0.49	"		
Stereospermum kunthianum Cham.	0.01 ± 0.01	0	"		
Commiphora africana (A. Rich.) Engl.	2.80 ± 0.80	1.60 ± 0.63	Burseraceae	2.80	1.60
Brachystegia boehmii Taub.	8.61 ± 2.59	7.02 ± 2.90	Caesalpinioideae	33.43	36.68
Brachystegia bussei Harms	0	1.18 ± 0.91	"		
Brachystegia microphylla Harms	1.29 ± 0.75	0.16 ± 0.13	"		
Brachystegia spiciformis Benth.	1.23 ± 0.83	0	"		
Cassia abbreviata Oliver	0.32 ± 0.16	1.09 ± 0.50	"		
Cassia sp. nr *C. burtii* Bak. f.	0.01 ± 0.01	0.05 ± 0.03	"		
Erythrophleum africanum (Benth.) Harms	0.67 ± 0.59	0.54 ± 0.38	"		
Julbernardia globiflora (Benth.) Troupin	19.10 ± 3.96	26.63 ± 5.45	"		

Table 6.2 Continued

Species	Species Importance Values (*IVI*)		Family /	Familial Importance Values (*IVI*)	
	Reserve (n = 34)	Public Lands (n = 30)	sub-family	Reserve	Public Lands
Tamarindus indica L.	2.20 ± 1.58	0.01 ± 0.01	"		
Boscia salicifolia Oliver	0.99 ± 0.33	0.62 ± 0.24	Capparaceae	5.56	5.82
Maerua triphylla A. Rich.	4.57 ± 2.10	5.20 ± 1.72	"		
Maytenus senegalensis (Lam.) Exell	0.25 ± 0.24	0	Celastraceae	0.25	0
Combretum adenogonium Steud. ex A. Rich.	3.19 ± 1.28	1.43 ± 0.44	Combretaceae	36.81	36.15
Combretum collinum Fresen.	0.02 ± 0.02	0.02 ± 0.02	"		
Combretum molle Engl. & Diels	17.61 ± 2.11	19.38 ± 3.51	"		
Combretum obovatum F. Hoffm.	3.20 ± 1.95	4.86 ± 1.79	"		
Combretum zeyheri Sond.	6.97 ± 1.85	7.29 ± 3.83	"		
Pteleopsis myrtifolia Engl. & Diels	2.22 ± 0.98	1.10 ± 0.64	"		
Terminalia mollis Engl. & Diels	0.39 ± 0.29	0.43 ± 0.43	"		
Terminalia sericea Burch. ex DC.	3.21 ± 2.02	1.64 ± 0.92	"		
Vernonia sp.	0	0.04 ± 0.04	Compositae	4.71	0.44
Diospyros kirkii Hiern	0.47 ± 0.27	0.40 ± 0.26	"		
Diospyros sp.	4.24 ± 1.06	8.60 ± 3.15	"		
Euclea divinorum Hiern	0	0.04 ± 0.03	Ebenaceae	0.00	0.04
Bridelia cathartica Bertol. f.	3.24 ± 1.04	2.87 ± 0.97	Euphorbiaceae	19.36	14.14
Drypetes gerrardii Hutch.	0.03 ± 0.03	0	"		
Flueggea virosa (Roxb. ex Willd.) Voigt	6.05 ± 2.25	5.66 ± 2.22	"		
Margaritaria discoidea (Baill.) Webster	1.07 ± 0.52	0.31 ± 0.17	"		
Pseudolachnostylis maprouneifolia Pax	0.69 ± 0.28	0.87 ± 0.45	"		
Spirostachys africana Sond.	8.28 ± 3.49	4.43 ± 2.56	"		
Strychnos spinosa Lam.	0.04 ± 0.04	0.04 ± 0.04	Loganiaceae	0.04	0.04

Table 6.2 Continued

Species	Species Importance Values (*IVI*)		Family /	Familial Importance Values (*IVI*)	
	Reserve (n = 34)	Public Lands (n = 30)	sub-family	Reserve	Public Lands
Turraea nilotica Kotschy & Peyr.	0	0.03 ± 0.03	Meliaceae	0.70	2.01
Turraea sp.	0.70 ± 0.36	1.98 ± 1.14	"		
Acacia goetzei Harms ssp. *goetzei*	3.87 ± 1.41	4.89 ± 1.40	Mimosoideae	40.56	38.97
Acacia nigrescens Oliver	13.21 ± 2.78	6.24 ± 1.92	"		
Acacia nilotica Delile	4.17 ± 1.17	1.84 ± 0.96	"		
Acacia polyacantha ssp. *campylacantha* Willd.	0.12 ± 0.01	0.17 ± 0.11	"		
Acacia robusta Burch.	6.69 ± 2.59	2.28 ± 0.62	"		
Albizia anthelmintica Brongn.	0.23 ± 0.18	0	"		
Albizia harveyi Fourn.	1.22 ± 0.44	3.43 ± 1.34	"		
Albizia petersiana Oliver	0.81 ± 0.35	0.86 ± 0.36	"		
Albizia versicolor Welw. ex Oliver	0.11 ± 0.08	0.23 ± 0.23	"		
Dichrostachys cinerea Miq.	10.13 ± 2.55	19.03 ± 4.71	"		
Ochna holstii Engl.	0.06 ± 0.06	1.24 ± 0.88	Ochnaceae	0.19	1.70
Ochna leptoclada Oliver	0	0.15 ± 0.12	Ochnaceae		
Ochna macrocalyx Oliver	0.13 ± 0.08	0.31 ± 0.31	"		
Ximenia caffra Sond.	0.40 ± 0.24	0.17 ± 0.11	Olacaceae	0.40	0.17
Dalbergia melanoxylon Guill. & Perr.	3.22 ± 0.99	5.28 ± 1.68	Papilionoideae	25.71	28.00
Dalbergia nitidula Welw. ex Baker	1.09 ± 0.44	4.89 ± 2.89	"		
Dalbergia obovata E. Meyer	0.10 ± 0.07	0.04 ± 0.04	"		
Dalbergia sp.	0	1.24 ± 0.95	"		
Erythrina abysinica Lam	0	0.05 ± 0.04	"		
Indigofera spp.	9.08 ± 2.91	2.74 ± 2.32	"		
Lonchocarpus bussei Harms	3.08 ± 1.03	2.94 ± 1.30	"		

Table 6.2 Continued

Species	Species Importance Values (*IVI*)		Family/	Familial Importance Values (*IVI*)	
	Reserve (n = 34)	Public Lands (n = 30)	sub-family	Reserve	Public Lands
Lonchocarpus capassa Rolfe	0.37 ± 0.22	0.09 ± 0.09	"		
Millettia usaramensis Taub.	0	0.01 ± 0.01	"		
Millettia sacleuxii Dunn	0.18 ± 0.18	0.00 ±0.00	"		
Ormocarpum kirkii S. Moore	0.02 ± 0.01	0.84 ± 0.42	"		
Pterocarpus angolensis DC.	1.37 ± 0.10	2.13 ± 1.17	"		
Pterocarpus rotundifolius Druce	4.87 ± 1.53	3.64 ± 1.38	"		
Xeroderris stuhlmannii (Taub.) Mendonca & Sousa	2.33 ± 0.87	4.11 ± 1.61	"		
Catunaregum spinosa (Thunb.) Tirveng.	2.09 ± 0.85	0.10 ± 0.49	Rubiaceae	3.88	4.19
Gardenia ternifolia Schum. & Thonn.	0.01 ± 0.01	0.19 ± 0.18	"		
Leptactinia sp. nr. *L. benguellensis* Good	0.46 ± 0.39	2.48 ±2.48	"		
Rothmannia fischeri (K. Schum.) Bullock	0.41 ± 0.41	0	"		
Rytiginia sp.	0.91 ± 0.56	0.04 ± 0.04	"		
Vangueria infausta Burch.	0	1.38 ± 0.83	"		
Zanthoxylum chalybeum Engl.	0.24 ± 0.13	0.20 ± 0.13	Rutaceae	0.24	0.20
Allophylus rubifolius Engl.	3.73 ± 1.28	1.36 ± 0.64	Sapindaceae	3.88	1.86
Deinbolia borbonica Scheff.	0	0.12 ± 0.08	"		
Zanha africana (Radlk.) Exell	0.15 ± 0.09	0.38 ± 0.22	"		
Harissonia abyssinica Oliver	0.77 ± 0.33	0.58 ± 0.29	Simaroubaceae	0.77	0.58
Dombeya rotundifolia (Hochst.) Planch.	6.85 ± 1.67	1.88 ± 0.83	Sterculiaceae	7.77	2.98
Sterculia africana (Lour.) Fiori	0.92 ± 0.92	1.10 ± 1.10	Sterculiacea		
Grewia bicolor Juss.	0.55 ± 0.31	2.06 ± 1.79	Tiliaceae	1.35	3.12
Grewia forbesii S. Moore	0.25 ± 0.25	0.67 ± 0.67	"		

Table 6.2 Continued

Species	Species Importance Values (*IVI*)		Family /	Familial Importance Values (*IVI*)	
	Reserve (n = 34)	Public Lands (n = 30)	sub-family	Reserve	Public Lands
Grewia similis K. Schum	0.55 ± 0.37	0.39 ± 0.39	"		
Steganotaenia araliacea Hochst.	0.10 ± 0.08	0	Umbelliferae	1.10	0.00
Clerodendrum glabrum E. Meyer	0.40 ± 0.25	0	Verbenaceae	0.40	0.85
Vitex ferruginea Boj. ex Schau.	0	0.85 ± 0.85	"		

The genus *Brachystegia*, which is a major component of miombo woodlands elsewhere (Lind and Morrison 1974; White 1983; Rodgers 1996), was represented by four species with importance values of 11.7 and 8.4 in the reserve and public lands respectively. The proportional dominance of *Combretum* spp. in both the reserve and public lands demonstrated that the vegetation of this area was a transition between miombo and coastal woodlands to the east which are dominated by species of *Combretum*, *Terminalia* and *Lannea* (White, 1983; Rodgers, 1996).

The total number of species enumerated in the reserve and public lands was 79 and 83 respectively, of which 71 species were common to both, giving a *Qs* of 87.7%. Although the chances of recording more species was higher in the public land (about 6 x greater area than the reserve) this is balanced to a certain extent by greater sampling in the forest reserve. *Julbernardia globiflora* and species of *Combretum* dominated throughout the reserve and public lands, while eight species were recorded exclusively in the reserve: *Albizia anthelmintica*, *Brachystegia spiciformis*, *Clerodendrum glabrum*, *Drypetes gerrardii*, *Maytenus senegalensis*, *Rothmannia fischeri*, *Stereospermum kunthianum* and *Steganotaenia araliacea*. Other species which were more abundant in the reserve are *Allophylus rubifolius*, *Dombeya rotundifolia*, *Flueggea virosa* and *Spirostachys africana* (Appendix 4).

Species with higher densities in public lands relative to the reserve and hence appear to be unaffected or positively influenced by human-disturbances are *Julbernardia globiflora, Combretum molle, Dalbergia nitidula* and *Dichrostachys cinerea* (Appendix 4). However, in all four cases the basal area is lower relative to the reserve. *Combretum obovatum, Combretum zeyheri* and *Maerua triphylla* are tolerant as they had similar abundance (both density and basal area) in public lands and the reserve (Table 6.2, Appendix 4). Another 12 species which were only recorded in public lands and thus could be 'invasive', tolerant of disturbance or may have been planted by people were *Brachystegia bussei*, *Dalbergia* sp., *Deinbolia borbonica*, *Erythrina abyssinica*, *Euclea divinorum*, *Markhamia obtusifolia*, *Millettia usaramensis*, *Ochna leptoclada*, *Turraea nilotica*, *Vangueria infausta*, *Vernonia* sp. and *Vitex ferruginea* (Table 6.2, Appendix 4). The total number of species enumerated in the northern public lands (area = 5 700 ha) was 59 compared with 73 species in the southern public lands (area = 7 800 ha) with 50 species common to both blocks giving a *Qs* of 75.8%. The *Qs* between the reserve and southern public lands was 86.8% compared with 73.9% between the reserve and northern public lands. *Euclea divinorum* and *Vernonia* sp. were recorded exclusively in the northern block. *Ochna holstii* was also recorded mostly from the northern block although it also occurred in the reserve (Appendix 4). *Dalbergia* sp., *Deinbolia borbonica*, *Markhamia obtusifolia* and *Turraea nilotica* were recorded solely in the southern public lands. However, almost all species which were recorded only in public lands seem to have very patchy distributions considering their low basal areas, densities and relatively high standard error values (Appendix 4).

6.4.3 Species richness and diversity

H' at the scale of 1000 m^2 was 2.0 ± 0.1 (SE) in the forest reserve, significantly higher than 1.8 ± 0.1 in the public lands while *S* was not significantly different (Table 6.3). Significant differences in both *H'* and *S* were recorded between the two blocks of public lands, where the more disturbed southern public land which is closer to the Dar-es-Salaam–Morogoro highway had *S* of 19.6 ± 1.1 and *H'* of 2.0 ± 0.1, both significantly higher than in the northern public land which is about 10 km from the highway (Table 6.3).

The negative regression coefficients of *S* and *H'* indicated that they decrease with increasing distance from the reserve boundaries and the human settlements. However, the r^2 values were relatively low (0.16, *ln* fit) between *H'* and distance from village settlements. *S* and *H'* also tended to decrease with increasing distance from the Dar-es-Salaam–Morogoro highway in public lands with r^2 = 0.23 (*ln*) and 0.22 (*exp*) respectively. *S* tended to increase with an increase in harvesting (number of stumps) (r^2 = 0.14) while there was no relationship for *H'* with harvesting (r^2 = 0.02). The relatively higher r^2 values for distance from the highway (0.23 (*ln*) and 0.22 (*exp*)) compared with distance from the reserve and settlement boundaries (0.16, *ln*) illustrates that the presence of the highway is an important determinant of community *H'* and *S*.

Table 6.3 Species richness (*S*) and diversity (Shannon-Wiener (*H'*)) from 1000 m^2 plots in the Kitulanghalo Forest Reserve and surrounding public lands in Morogoro, Tanzania.

Species variable	Forest reserve (n = 34)	Public Lands (n = 30)		*t*	*p*
S	18.7 ± 0.73	18.5 ± 0.80		0.133	0.447
H'	2.0 ± 0.07	1.8 ± 0.07		1.892	0.032
		Southern block (n = 18)	Northern block (n = 12)		
S		19.6 ± 1.12	16.9 ± 0.94	1.167	0.050
H'		1.96 ± 0.08	1.60 ± 0.11	2.750	0.005

One-way ANOVA showed no significant differences of *S* with distance from boundaries in each of the three blocks although the highest mean value of 20.2 ± 2.1 species per 1000 m^2 was calculated for near sites of the southern public lands (Table 6.4). A significant difference in *H'* was recorded in the reserve where sites far from the boundary exhibited lower *H'* than near sites (Table 6.4). A two-way ANOVA showed no significant differences in *S* with distance or land use, but a significantly higher *H'* in the reserve than either of the two blocks of public lands ($F_{2,61}= 4.612$, $p = 0.018$, Tukey HSD).

The reserve species area curve ($y = -0.25 + 6.32logx$, $r^2 = 0.81$) had a similar slope to the southern public lands curve ($y = -0.84 + 6.64logx$, $r^2 = 0.83$) and the northern public lands curve ($y = 0.75 + 5.47logx$, $r^2 = 0.84$) ($F_{2,250} <0.0001$, p>0.25) (Figure 6.3). The similar slopes and coefficients of determination (r^2) indicate further the close similarities in *S* between the reserve and public lands. The landscape scale species-area curves showed that the slope of each curve declined as sample area increased and all approached an asymptote (Figure 6.4).

Table 6.4 Species richness (S) and diversity (Shannon-Wiener (H')) from 1000 m^2 plots with increased distance from the Kitulanghalo Forest Reserve boundary or from human settlements in public lands, Morogoro, Tanzania.

Land-use	Species richness (S)			ANOVA			Diversity (H')			ANOVA		
	Near (300 m)	Intermediate (900 m)	Far (1500 m)	*d.f.*	*F*	*p*	Near (300 m)	Intermediate (900 m)	Far (1500 m)	*d.f.*	*F*	*p*
Forest reserve (n = 34).	17.64 ± 1.03	19.73 ± 1.28	19.67 ± 1.73	2,31	0.999	0.380	2.11 ± 0.09^{a}	2.00 ± 0.11^{ab}	1.68 ± 0.14^{b}	2,31	3.339	0.050
Public lands, southern block (n = 18).	20.17 ± 2.05	19.67 ± 1.20	19.00 ± 2.00	2,15	0.080	0.922	1.91 ± 0.149	2.09 ± 0.14	1.87 ± 0.14	2,15	0.731	0.498
Public lands, northern block (n = 12).	17.50 ± 1.67	15.25 ± 1.67	18.00 ± 1.67	2,9	0.774	0.489	1.64 ± 0.20	1.48 ± 0.18	1.69 ± 0.20	2,9	0.310	0.741

Different superscript letters within rows indicate significant differences ($p < 0.05$, Tukey HSD).

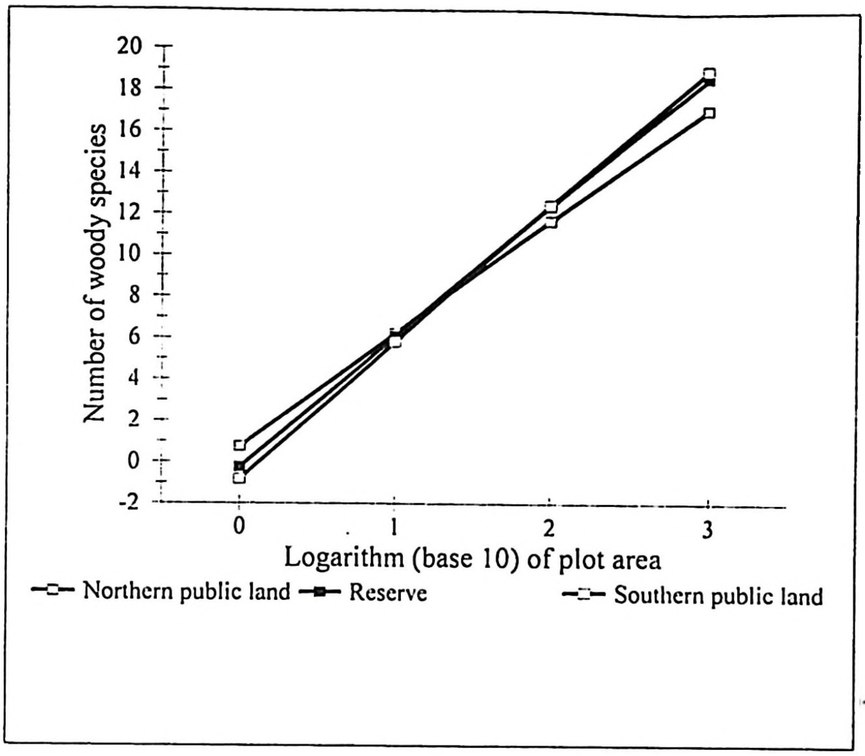

Figure 6.3 Relationship between species richness of woody plants and subplot area (species-area curves) in the Kitulanghalo Forest Reserve and surrounding public lands in Morogoro, Tanzania.

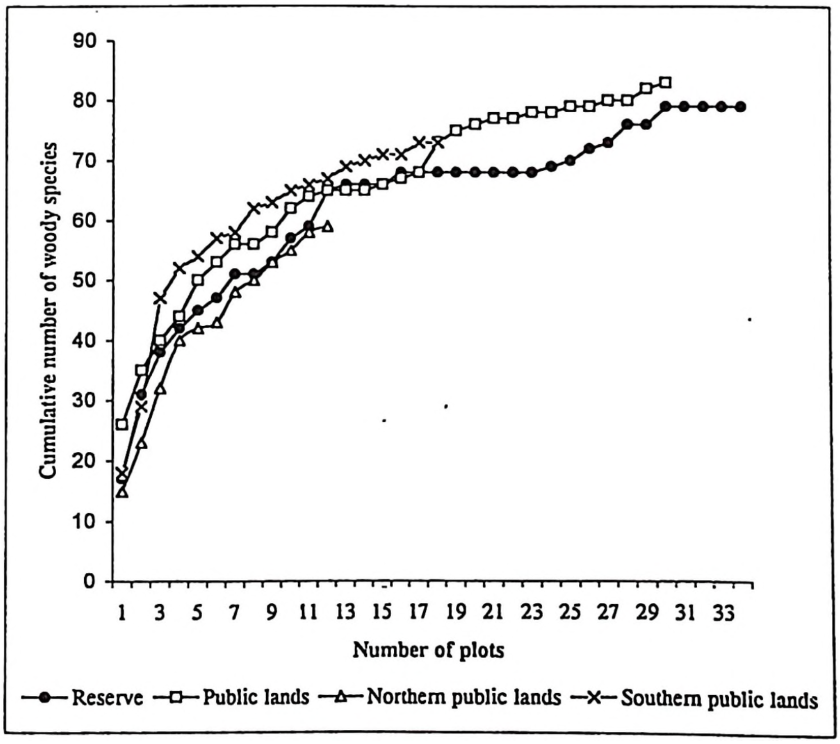

Figure 6.4 Cumulative species richness of woody plants from 1000 m^2 plots in the Kitulanghalo Forest Reserve and surrounding public lands in Morogoro, Tanzania.

6.3.4 Species-Environment relationship (CCA)

The cumulative percentage variance accounted for by the four axes of the species environmental relationship was 87% for physiographic variables compared with 61% for edaphic and 57% for all variables combined (Table 6.5). The Monte-Carlo permutation tests showed significance in an overall test for the ordination using physiographic variables (Table 6.5). The highest eigenvalue of 1.42 was recorded from the ordination of species with all environmental variables. Thus the linear combination of all variables significantly influenced species gradients relative to edaphic or physiographic variables alone.

Table 6.5 Results of ordination by CCA for species data with physiographic, edaphic and all environmental variables in miombo woodlands of Kitulanghalo Forest Reserve and surrounding public lands of Morogoro, Tanzania.

Test		Axis order				Overall test (trace)		
		1	2	3	4	Eigen value	*F*	*p*
Spp vs physiographic variables	Eigenvalue	0.19	0.17	0.1	0.1			
	Spp-env. correlation	0.8	0.69	0.61	0.61	0.58	1.62	0.01
	Cumulative % variance of spp-env relationship	32.3	61.4	75	86.9			
Spp vs edaphic variables	Eigenvalue	0.24	0.21	0.15	0.14			
	Spp-env. correlation	0.8	0.81	0.79	0.78	1.22	1.27	0.07
	Cumulative % variance of spp-env relationship	19.9	36.9	48.9	60.9			
Spp vs all environmental variables	Eigenvalue	0.26	0.23	0.17	0.15			
	Spp-env. correlation	0.89	0.77	0.82	0.84	1.42	1.22	0.06
	Cumulative % variance of spp-env relationship	18.4	34.8	46.6	56.8			

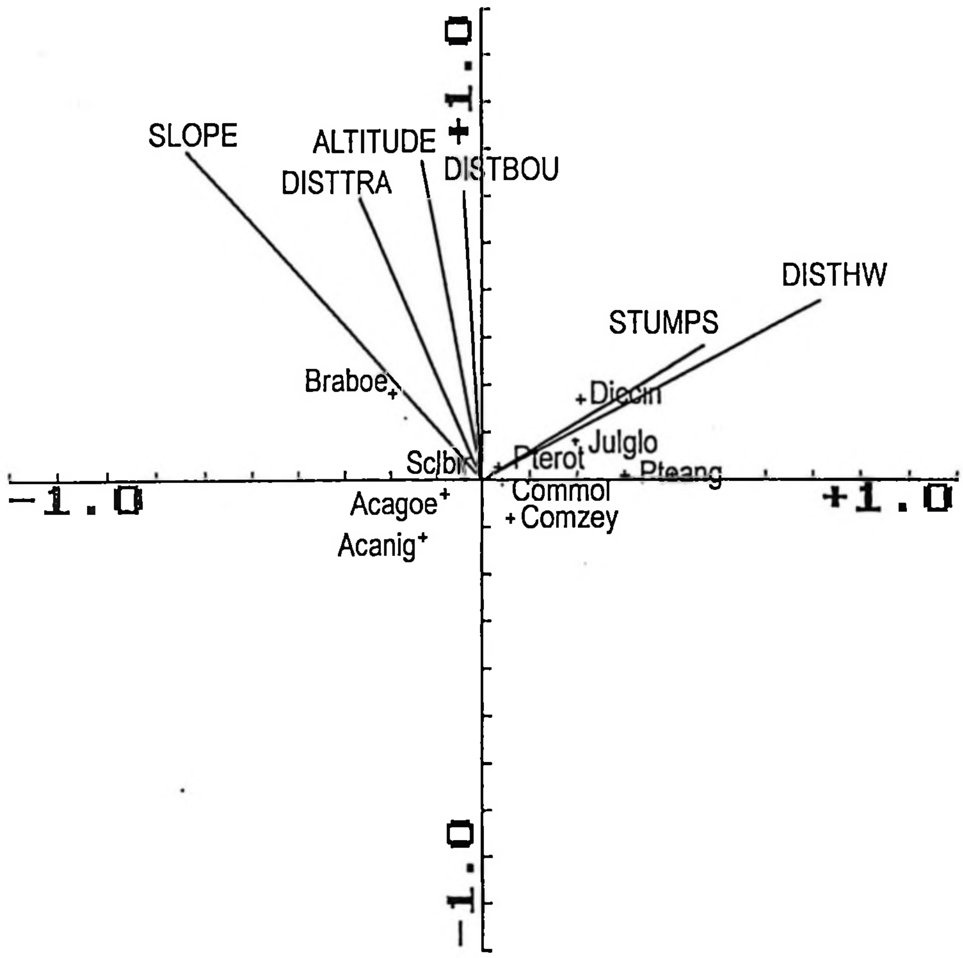

Figure 6.5 A biplot of the first two axes of CCA showing ordination of physiographic variables and species in Kitulanghalo Forest Reserves and surrounding public lands, Morogoro, Tanzania. Physiographic variables: ALTITUDE = Site altitude, DISTBOU = Distance from the reserve or village boundaries, DISTHW = Distance from the Dar-es-Salaam–Morogoro highway, DISTTRA = Distance from the nearest extraction track, SLOPE = Site slope in degrees. Species positions marked by '+': Braboe = *Brachystegia boehmii,* Sclbir= *Sclerocarya birrea* ssp. *caffra*, Acagoe = *Acacia goetzei* ssp. *goetzei,* Acanig = *Acacia nigrescens*, Comzey= *Combretum zeyheri*, Commol= *Combretum molle*, Pteang = *Pterocarpus angolensis*, Pterot =*Pterocarpus rotundifolius,* Julglo = *Julbernardia globiflora,* Diccin = *Dichrostachys cinerea.* Other species not shown in the figure because they tend to overlap towards the middle.

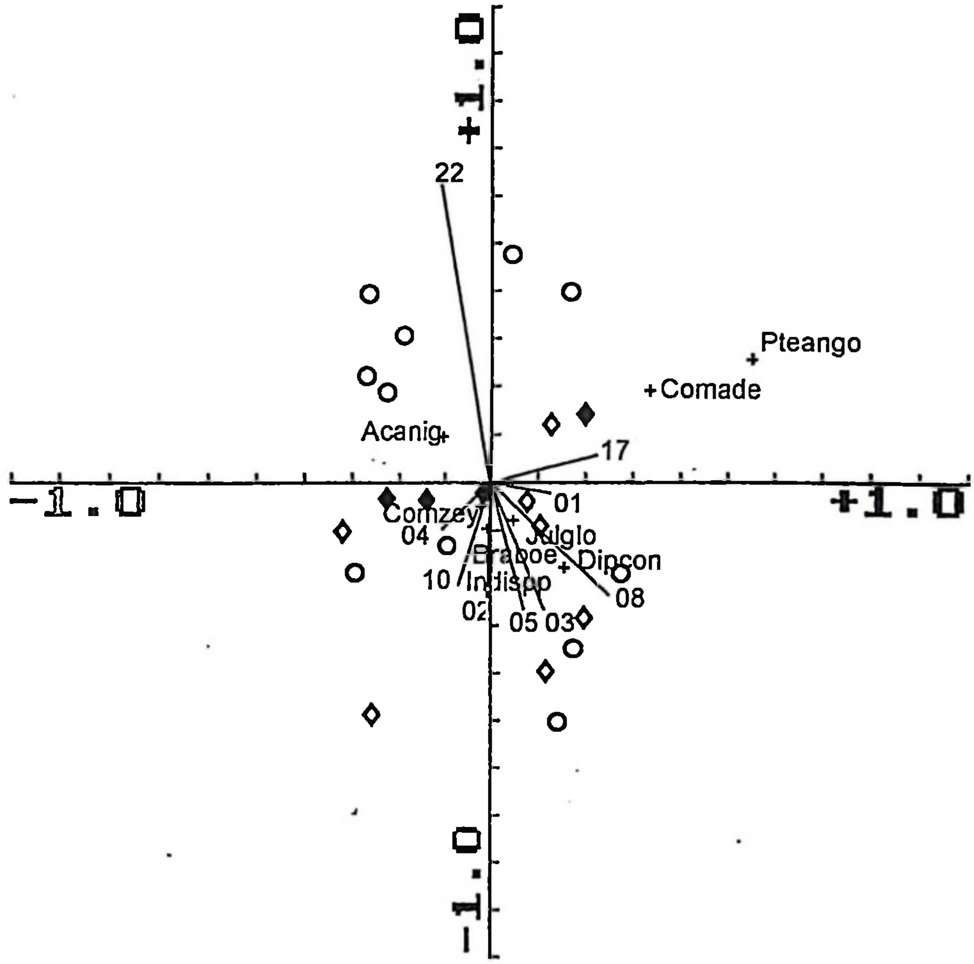

Figure 6.6 A biplot of the first two axes of CCA showing ordination of sites, environmental variables and associated species in Kitulanghalo Forest Reserve and surrounding public lands, Morogoro, Tanzania. Environmental variables: 01 = Site altitude, 02 = Distance from the Dar-es-Salaam–Morogoro highway, 03 = Distance from the reserve or village boundaries, 04 = Grass height, 05 = No of stumps, 08 = Available P (ppm) A-horizon, 10 = Total N (%) A-horizon, 17 = Cation exchange Capacity (m.e. / 100g) A-horizon, 22 = Cation exchange Capacity (m.e. / 100g) B-horizon; Species positions marked by '+': Acanig = *Acacia nigrescens*, Comade= *Combretum adenogonium*, Pteang = *Pterocarpus angolensis*, Comzey= *Combretum zeyheri*, Braboe = *Brachystegia boehmii*, Indispp = *Indigofera* spp., Dipcon = *Diplorhynchus condylocarpon*; Other species not shown in the figure because they tend to overlap towards the middle. Sites: ◊ = Northern public lands, ◆= Southern public lands, O = Forest Reserve.

By extending the physiographic arrows in both directions and dropping perpendicular lines from each species (ter Braak, 1987) we inferred that *Combretum molle* and *Combretum zeyheri* had the highest weighted averages with respect to flat slopes, lower altitude and shorter distance from the nearest extraction tracks, all associated with more harvesting (Luoga *et al.*, submitted a) (Figure 6.5). In contrast, *Acacia goetzii* and *Acacia nigrescens* had the highest weighted averages in less disturbed areas. The species in the upper right-hand side of the CCA species-physiographic biplot (Figure 6.5) appear to be associated with intense harvesting as indicated by their association with 'number of stumps' These species, which are dominant in the harvested areas, include *Julbernardia globiflora*, *Pterocarpus angolensis*, *Pterocarpus rotundifolius* and *Dichrostachys cinerea*. The approximate ranking of the centres of occurrence of the species with respect to the sites indicates that *A. nigrescens* is mostly associated with the reserve, while most species including *Combretum* spp., *Brachystegia boehmii* and *Julbernardia globiflora* are associated with both the reserve and public lands (Figure 6.6).

6.5 DISCUSSION

6.5.1 Community woody composition

There was a high <u>*Qs*</u> (87.7%) and similar *S* between the reserve and public lands (Table 6.3, Figures 6.3 and 6.4). In contrast, the forest reserve had a wood standing volume of 47 m^3 ha^{-1} as compared to only 16.7 m^3 ha^{-1} in public lands because of greater harvesting (Luoga *et al.*, submitted a). Increased woody *S* associated with reduced biomass has also been reported in miombo woodlands of Zambia (Chidumayo, 1987b, c), on Kalahari sands in Zimbabwe (Vermeulen, 1996) and peasant farming areas in Zimbabwe (McGregor, 1994). Thus, heavy wood utilization in miombo woodlands affects floristic composition of woodlands less than their structure.

The significantly lower *H'* in the public lands relative to the reserve (Table 6.3) is related to lower equitability due to very strong single species dominance (*J. globiflora*) in the public lands (Table 6.2, Appendix 4). The removal of the relatively strong single species dominance during harvesting in Zimbabwean miombo woodlands resulted in increased *H'* values (Campbell and du Toit, 1994). Although all the additional species recorded in the public lands are indigenous, they may have been introduced. For example, the indigenous fruit trees *Vangueria infausta* and *Vitex ferruginea*, which were recorded exclusively in public lands were probably planted. *Vangueria infausta* has also been reported to have a higher frequency of occurrence in South African communal lands relative to reserves (Shackleton, 2000a). Species can be introduced by people into a habitat accidentally or deliberately (through planting), thereby increasing *S* (Boerboom and Wiersum, 1983).

The significantly higher *S* and *H'* in the more disturbed but recovering southern public lands (near the highway) than in the northern public lands (Table 6.3) may be the result of a larger area of 7 800 ha as compared to 5 700 ha in the northern block which could increase the chances of enumerating more species. The difference could also be a result of increased patchiness in the environment after harvesting as the southern public lands are largely in early secondary successional stages, thereby providing opportunities for the establishment of different functional groups of species without the disappearance of the original species (Denslow, 1980; Shackleton *et al.*, 1994; Shackleton 2000a). The closer similarity in species composition between southern public lands and the reserve (Qs = 86.8%) than between the northern public lands and the reserve (Qs = 73.9%) may be accounted for by the close proximity, as they are only separated by the Dar-es-Salaam–Morogoro highway. Prior to the proclamation of the reserve in 1955, they formed a continuous woodland. The general similarities of *S* between the reserve and public lands shows that although drastic changes in land-use, such as transformation of woodlands to bushlands, results in reduced *H'* (Stromgaard, 1986), more subtle human-induced changes sometimes increase local *S* (Sala *et al.*, 1986).

Regeneration of most miombo trees starts in the first year after harvesting with coppicing from root suckers and regrowth from stems (Frost, 1996). The taller stumps left after cutting with axes or machetes (about 40 cm) are likely to have more axillary buds than shorter stumps, thus increasing chances of regeneration. This hypothesis requires further study. Farmers predominantly use hand hoes (Luoga *et al*,. 2000a), which normally scratch the soil to a depth of <10 cm thereby causing minimal damage to the stumps and root systems which are the sources of resprouts. When mechanised tools are used for intensive agriculture in miombo woodlands, they cause far greater disturbance of tree roots which has a profound impact on biodiversity (Rodgers, 1996).

Permanent cultivation also results in reduced *S* in miombo woodlands because it involves a change in land use (Campbell and du Toit, 1994). For plant communities with a large proportion of species that resprout after logging, as is the case in miombo woodlands (Frost, 1996), the initial cycles of shifting cultivation result in very little change in diversity although repeated cycles of slash and burn in tropical deciduous forests in Mexico reduced woody species diversity by about 25% (Miller and Kauffman, 1998). Most sites in the studied public lands are in their third cycle of shifting cultivation (each cycle takes about 10 years) as extensive shifting cultivation only started in 1974 when people were grouped in villages along the highway as part of the resettlement scheme. These results suggest that although disturbances are required for regeneration and hence are important in the maintenance of biodiversity, the frequent clearing for shifting cultivation will probably alter *S* in the long-term.

The two species with highest *IVI*, *J. globiflora* and *C. molle* (Table 6.2, Appendix 4), are also the species with the highest removal volumes (Luoga *et al.*, submitted a), suggesting that they have higher recovery levels, thus maintaining their dominance. These species are able to coppice and hence are less vulnerable to anthropogenic disturbance than those with poor coppicing ability (Daniels *et al.*, 1995). Luoga *et al.* (submitted a) found that *A. nigrescens* had the highest wood volume in both the reserve and public lands, which is also reflected in the relatively high basal area ha^{-1} values (Appendix 4). The lower importance values of *A. nigrescens* than *J. globiflora* and *C. molle* (Table 6.2) indicate that the high volume of *A. nigrescens* was contributed by a few very large trees, as the species is less preferred for charcoal production compared to *J. globiflora* and *C. molle*. The families Loganiaceae and Ebenaceae are threatened with local extinction because each comprises a single species giving very low *IVI* with high use values. *Strychnos spinosa* (Loganiaceae) for example had the highest use value owing to multiple uses (Luoga *et al.*, 2000b). Although less is known about the local fitness of this population in terms of its dynamics the few recorded individuals (Appendix 4) suggests that more conservation efforts should be directed at such locally endangered species.

6.5.2 Vegetation gradients

There is no evidence to support the intermediate disturbance hypothesis with reference to the distance from reserve boundaries and settlements (Table 6.4). One of the possible reasons is that miombo woodlands, like other African savannas are fundamentally dis-equilibrium systems whose dynamics are externally driven especially by frequent unpredictable fluctuations in rainfall (Ellis and Swift, 1988) and by fires (Kikula, 1986a; Frost, 1996). The intermediate disturbance hypothesis is more applicable in stable systems where the species have come into equilibrium with disturbance (Turner *et al.*, 1993). Another possible explanation is that the study looked at only woody species and not herbaceous species which normally colonise disturbed areas. The results also indicate the possibility of the intermediate disturbance pattern being constrained by other underlying disturbance foci especially the Dar-es-Salaam–Morogoro highway and the localised clear-cutting for charcoal. Charcoal harvesting patterns are little affected by distances from settlements due to the use of vehicles to collect charcoal from the woodlands, unlike the pattern for subsistence products (Luoga *et al.*, submitted a).

There is no obvious reason for a significantly lower *S* in the northern public lands compared to the reserve or the southern public land (Table 6.3, Figures 6.3 and 6.4). Thus changes arising from human activities are difficult to predict, a view which is shared by Campbell and du Toit (1994). One plausible explanation could be that the disturbance in the southern public lands could be relatively 'intermediate' as the vegetation is in an early successional phase as compared to the newly harvested northern public lands ('high disturbance') and relatively undisturbed reserve ('low disturbance').

6.5.3 Species-environment relationships

The higher cumulative % variance of the species-environmental relationship for physiographic variables relative to edaphic variables (Table 6.5) could be attributed to fewer physiographic compared with edaphic variables. However the significant Monte Carlo test indicates that physiographic variables influence plant species associations in the study area because of their significant differences among land-uses (Table 6.1) and close correlations with harvesting (disturbance) patterns (Luoga *et al.*, submitted a). Despite a comprehensive analysis of the soils, few differences were found between land uses and there was minimal variation. Similarly, elsewhere in miombo woodlands, topographic and edaphic factors were found to be relatively unimportant in determining vegetation patterns amongst the *Brachystegia* and *Julbernardia* woodland subtypes (Lawton, 1978; McGregor, 1994; Campbell *et al.*, 1995). In contrast in South African savannas on granite the vegetation is strongly associated with catenal variation of soils resulting in distinct zonation of vegetation into top-land and bottom-land communities (Witkowski and O'Connor, 1996; Higgins *et al.*, 1999). Thus on a local scale, factors which are associated with disturbances are the most important to determine species composition in miombo woodlands especially when the edaphic factors are similar (Table 6.1).

D. cinerea dominates heavily harvested sites (Figure 6.5, Appendix 4) as it does in disturbed South African savanna woodlands (Shackleton *et al.*, 1994). The relatively higher dominance of *Acacia* spp. in the reserve than in public lands (Table 6.2, Figures 6.5 and 6.6) suggests that these species may be sensitive to harvesting or that in the study area *Acacia* spp. are climax species when disturbance is minimal. For example, *Acacia nilotica* was classified as a sensitive species in South African savannas (Shackleton *et al.*, 1994). The dominance of *J. globiflora* in both the reserve and public lands suggests that the study area is essentially miombo woodland (White, 1983) although the other important genus *Brachystegia* is not well represented (Table 6.2, Appendix 4). The species composition clearly suggests that the study area is a transition between the miombo biome and the Zanzibar-Inhambane ecosystem which runs along the East African Indian-Ocean coast (White, 1983). Eight common Zanzibar-Inhambane species, *Acacia robusta*, *Albizia petersiana*, *Combretum collinum*, *Lonchocarpus bussei*, *Sterculia appendiculata*, *Tamarindus indica*, *Terminalia sambesiaca* and *Terminalia sericea*, were recorded in the area. Near the coast (150 km away), reduced seasonality of rainfall, higher humidity and higher temperatures reduce the abundance of *Brachystegia* spp. and increase the numbers of *Combretum*, *Lannea*, *Terminalia* and *Tamarindus* species (Rodgers, 1996). Thus while physiographic factors (which are associated with disturbance gradients) affect diversity at a local scale, climatic factors are important determinants of species composition in miombo woodlands at a broader spatial scale.

6.6 CONCLUSION

Although the forest reserve is currently protected from indiscriminate anthropogenic disturbances such as clear felling, its woody floristic composition is not significantly different from the highly disturbed public lands. Thus high levels of extraction have an impact on *H'*, but less effect on species composition. However, although harvesting intensity in public lands does not appear to affect *S* negatively in the short-term, it is apparent that if levels of harvesting continue to outstrip the production capacity of the woodlands (Luoga *et al.*, submitted a) and shifting cultivation continues unabated, *S* or *H'* or both may decrease along with the growing stock. This implies that woodlands in public lands may recover and maintain *S* and *H'* provided the two major causes of damage, charcoal production and shifting cultivation, are kept within limits. The dominance of *C. molle* and *J. globiflora*, despite having the highest levels of harvesting, suggests for a study of their population dynamics.

CHAPTER 7

The effect of harvesting on population dynamics of four miombo tree species including coppicing effectiveness and silvicultural prescriptions

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7.1 Abstract

This study was conducted in miombo woodlands of eastern Tanzania. The study compared and contrasted the natural regeneration, recruitment, mortality and growth rates of the four preferred species, *Combretum molle* Engl.& Diels (preferred for fuelwood), *Julbernardia globiflora* (Benth.)Troupin (fuelwood), *Pterocarpus angolensis* DC. (carpentry) and *Spirostachys africana* Sond. (building poles) in a reserve and disturbed public lands. Data for the study were collected between August and October 1997 using sixty-four 20 x 50 m plots laid systematically in the reserve and public lands and two permanent sample plots (PSPs), one in each land use. The PSPs were established in 1992 and re-inventoried in 1993, 1994 and 1995. Eighty-three percent of the 30 harvested woody species in the forest reserve resprouted after harvesting compared with 90% of the 39 species in the public lands. The effectiveness of resprouting from stumps depended on species, plant size/age at the time of cutting, stump height and the percentage of the stand removed. Although most species resprout vigorously after cutting, there is limited recruitment of trees from sapling to pole size because of a fire induced bottleneck. The highest mean diameter increment of 7.4 ±0.5 mm tree $^{-1}$ year $^{-1}$ (1992/1995) was recorded for *J. globiflora* in public lands. The species differed in their relative growth rates in the following sequence: *J. globiflora* (public lands) > *P. angolensis* (public lands) > *J. globiflora* (reserve) > *S. africana* (reserve). The decrease in number of plants through harvesting or self-thinning natural mortality is accompanied by an increase in average size, thereby enhancing wood productivity in public lands. The high coppicing and growth rates of coppice shoots in public lands lead to the recommendation of managing the woodland under coppice rotation as a silvicultural system. In the reserve, selective thinning is recommended, where the allowable cut (harvesting rate) should be no greater than the current increment of individual species.

Key words: Coppice rotation, coppice shoots, growth rate, mortality, regeneration, self-thinning.

7.2 INTRODUCTION

Little is actively done to improve the productivity of Zambezian savanna (miombo) woodlands as a result of lack of knowledge about how the ecosystem responds to management and disturbances (Chidumayo, 1988; Gauslaa, 1989). Disturbances may have profound effects on the dynamics of plant populations by influencing recruitment, mortality, dominance and distributions (Harper, 1977). Disturbances in African woodlands include foraging, browsing and trampling by wildlife and anthropogenic clearance of land for cultivation, subsequent abandonment, harvesting of trees for different purposes and initiation of fires (Strang, 1974; Lawton, 1978; Frost, 1996). Miombo woodlands are the most extensive vegetation type in the Zambezian region stretching from Tanzania to Zimbabwe and cover 40% of Tanzania (White, 1983). The canopy of miombo woodlands is dominated by *Brachystegia* and *Julbernardia* (Fabaceae, subfamily Caesalpinioideae) and the herbaceous layer by grasses of the tribe Andropogoneae (White, 1983). The effect of human disturbances differs from one plant species to another depending on their resilience. For example, *Julbernardia globiflora* (authors listed in Table 7.1) and *Combretum molle* were found to be dominant in the study area (Luoga *et al.*, submitted b), despite being the species most preferred and harvested for fuelwood (Luoga *et al.*, 2000a, submitted a). *Pterocarpus angolensis* is preferred for carpentry and *Spirostachys africana* for building poles. *P. angolensis* is the most commmercialised indigenous tree species throughout eastern and southern Africa as a source of valuable indigenous timber for carpentry and carving, but is dwindling because of over-exploitation (Vermeulen, 1990; Mushove, 1996; Clarke *et al.*, 1996; Nduwamungu, 1996).

Most miombo trees resprout from roots and stumps once the above ground parts have been removed or killed (Boaler and Sciwale, 1966; Strang, 1974; Grundy, 1995; Frost, 1996). These shoots grow faster than newly established seedlings, because they already have a well established root system with stored reserves (Chidumayo, 1993a; Grundy, 1995). In miombo woodlands, seedling establishment is not common amongst the woody species due to unreliability of fruit production (Chidumayo, 1997), pre-dispersal seed predation (Chidumayo and Frost, 1996; Chidumayo, 1997), limited seed dispersal distance (Malaisse, 1978; Chidumayo, 1992), very low field survival because of drought stress (Grundy, 1995; Chidumayo and Frost, 1996) and seedling predation (Grundy, 1995). The rarity of seedlings and their low survival rate in miombo woodlands suggests that regeneration can best be promoted by managing coppice shoots (resprouts), but very few relevant studies have been undertaken (Grundy, 1995).

The published growth rates for elements of miombo woodlands are variable and dependent on a number of interrelated factors such as climate, soil, species, age, standing volume and land use history (Grundy, 1995; Chidumayo and Frost, 1996; Shackleton, submitted). Since *C. molle, J. globiflora, P. angolensis* and *S. africana* are the most preferred and merchantable species in the study area, they are logical choices for in-depth studies of population dynamics.

Forest management is more difficult when there are external impacts induced by the human-resource interface (Hall, 1983). This study aims to motivate the formulation of more efficient management practices in miombo woodlands, as well as promoting sound silvicultural prescriptions in woodlands severely disturbed by exploitation. The objectives of the study were: (i) to determine the levels of resprouting of all harvested and /or damaged tree species in the forest reserve in contrast to the disturbed public lands; (ii) to relate resprouting to tree size and stump height; (iii) to compare and contrast the recruitment, mortality and growth rates of selected species in the reserve and public lands; and (iv) to determine long term sustainable harvesting levels for the selected species.

7.3 MATERIALS AND METHODS

7.3.1 Study area

The study site is about 50 km east of Morogoro and 150 km west of Dar-es-Salaam, comprising the Kitulanghalo Forest Reserve (2 452 ha) and surrounding public (communal) lands (>13 000 ha). The area is bisected by the Dar-es-Salaam–Morogoro highway, which marks most of the southern boundary of the reserve and is the main transportation route for forest products to urban and commercial centres such as Dar-es-Salaam and Morogoro (Figure 7.1). A total population of 4640 people live in 1012 households in three villages (Lubungo, Maseyu and Gwata). The surrounding woodlands are important for subsistence purposes and as a source of income, because the majority of the local people depend on these woodlands for construction materials, fuel wood and medicines (Luoga *et al.*, 2000a & b).

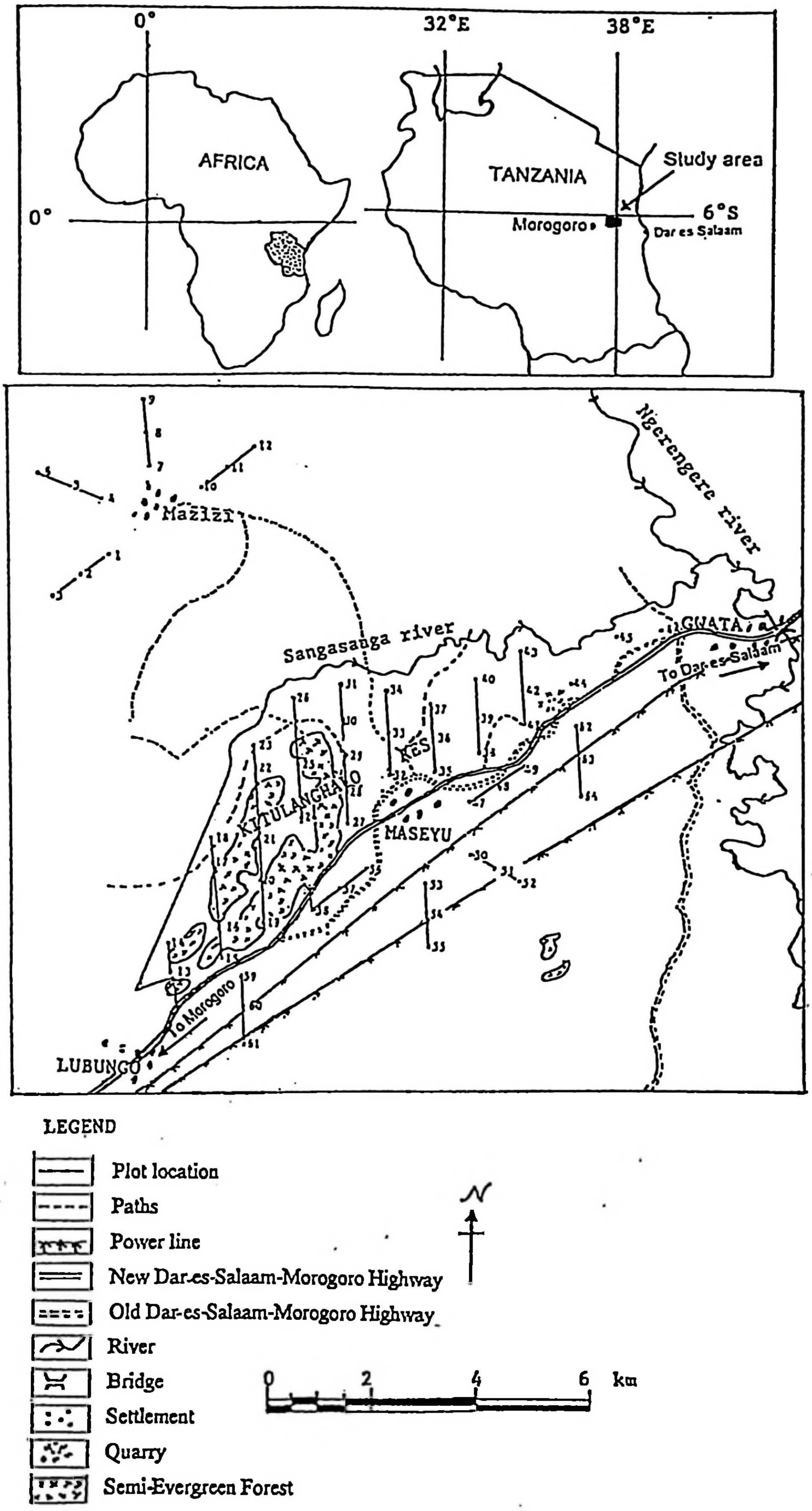


Figure 7.1 The location of the study area and plots in the Kitulanghalo Forest Reserve and surrounding public lands, Morogoro, Tanzania.

The area experiences a tropical and subhumid climate (Kielland-Lund, 1990 a), with a seasonally distributed mean annual rainfall of about 900 mm, providing a wet season from November to May and a dry season from June to October. The annual mean temperature is 24.3°C while the annual minimum and maximum temperatures are 18.6°C and 28.8°C, respectively.

Most parts of the reserve and the surrounding public lands are covered by open miombo woodlands with most of the trees in an understorey, 5–10 m high and consisting mostly of *Diplorhynchus condylocarpon*, *Combretum* spp. and *Dichrostachys cinerea*. Amongst these are scattered *J. globiflora*, *Brachystegia* spp. and *Pterocarpus rotundifolius*, which are canopy trees reaching heights of 15–20 m. The herbaceous layer comprises dense grass dominated by *Themeda triandra* with an average height of 0.7 m. Grass fires are common in the area, burning substantial proportions of the woodlands annually.

The presence of tsetse flies, which transmit the sleeping sickness pathogen, limits domestic animals and no large wild mammalian herbivores are found in the area. The local farming system is characterized by shifting cultivation of food crops for subsistence consumption and the market (Luoga *et al.*, 2000a).

7.3.2 Data collection

Data for the study were collected between August and October 1997 using sixty-four 20 x 50 m plots which were arranged systematically along transects (Figure 7.1), 34 in the reserve and 30 in public lands. Of the 30 plots in public lands, 12 were placed in the northern block about 10 km from the Dar-es-Salaam–Morogoro highway (North of Mazizi village) and the other 18 in the southern block about 2 km from the highway (South of Maseyu village).

In each plot, tree stumps of all species were identified (criteria for identification listed in Luoga *et al.*, submitted a) and their diameters above the basal swelling and heights measured. The number of coppice shoots from each stump was counted, and the height at which they coppiced measured. An inventory of the four preferred species, *C. molle*, *J. globiflora*, *P. angolensis* and *S. africana*, was undertaken. The extent of field regeneration was estimated by counting all individuals of < 4 cm diameter (seedlings/resprouts and saplings) which are vulnerable to annual fires in miombo woodlands (Kielland-Lund, 1990b). All trees were measured for diameter at breast height (DBH).

Two permanent sample plots (PSPs) which had been established in 1992 (Ek, 1994) were the sources of data on recruitment, mortality and growth of the four selected species. One PSP of 0.5 ha was located in the Kitulanghalo Forest Reserve, and the other (0.2 ha.) in public lands south of the Dar-es-Salaam–Morogoro highway. In these PSPs, all trees of ≥3 cm DBH were initially measured for their diameter (cm) and height (m) in September1992, and re-inventoried at the same time of year in 1993, 1994 and 1995. The public lands PSP was located in a regrowth miombo woodland which was abandoned in 1976 after shifting cultivation (Kielland-Lund, 1990a). Noticeable harvesting for charcoal in the public lands PSP started in 1994 (Ek, 1994). Unfortunately, by September 1997, almost all the woodland within the PSP (including the trees in the PSP) had been converted to farmland.

7.3.3 Data analysis

From the 64 plots, the inventory data of the standing preferred species were tallied in five diameter classes. In this study, individuals of 0 – <1 cm diameter are categorised as seedlings or resprouts. Seedlings originate from seeds and have not yet been damaged and thus have never resprouted. Resprouts originate from active buds on stumps or roots after damage. Saplings are defined as individuals with diameters of 1 – <4 cm. Individuals of 4 – <10 cm are defined as poles, 10 – <20 cm as small reproductive trees and those of ≥20 cm as large reproductive trees. These classes were designed with reference to the structural composition of the woodlands (Luoga *et al.*, submitted a) and for particular use categories (Luoga *et al.*, 2000a & b). 'Poles' are mostly harvested for building purposes while 'small reproductive trees' are harvested for fuelwood (charcoal) and 'large reproductive trees' for charcoal, timber or carving, depending on species. Comparisons between the harvested and standing volumes of each preferred species were made by calculating removed / standing volume ratios using inventory results extracted from Luoga *et al.* (submitted a).

For regeneration status, comparisons of the number of seedlings /resprouts of each species between the reserve and public lands was performed using student's *t*-test. The percentage of harvested stumps that sprouted for each species were calculated and comparisons made. Coppicing effectiveness was calculated as means of coppice shoots per stump for each harvested species in the reserve and public lands. A coppicing effectiveness >1 indicates the ability of a particular species to produce multiple stems. Coppicing effectiveness of all size classes for each species were also expressed as percentages with the species with highest coppicing effectiveness value taken to be 100% and the other species expressed proportionally. The average of the two percentages (coppicing effectiveness and % resprouting stumps) was then used to categorise each species thus, 80–100% = very high resprouter, 60–79% = high resprouter, 40–59% = average resprouter, 20–39% = low resprouter and <20% = very low resprouter.

The basal diameters of the stumps (BD) were converted to the DBH of standing trees before harvesting using a linear relationship developed by Luoga *et al.* (submitted a) for all species: DBH = -1.003 + 0.87 BD (r^2 = 0.98). The harvested trees were then tallied in the same diameter classes and comparisons of sprouting in different diameter classes done using analysis of variance (ANOVA) followed by Tukey multiple range tests. Simple (best fit of linear, natural log, exponential or power) and multiple regression analyses were performed to determine the response of number of coppice shoots as a function of stump diameter and height.

From the PSPs, mortality was determined for each species as the number of dead trees ha^{-1} in the periods 1992/1993, 1993/1994 and 1994/1995, while recruitment was calculated as the number of seedlings or resprouts of each species attaining a DBH of 3 cm. From the DBH measurements (cm), tree growth for each species was calculated as diameter increments in mm yr^{-1}, and the DBH class distributions for each of the species at the first (1992) and last (1995) census at the two sites were compared by establishing survivorship histograms. DBH and height measurements were used to calculate biomass in metric tons (1000 kg) and volume (m^3) for each species with the equations developed by Malimbwi *et al.* (1994). Current mean annual increments of biomass and volume (tons or m^3 ha^{-1} $year^{-1}$) for each species were calculated as the difference between two consecutive years and comparisons between the reserve and public lands were made for those species which appeared in both land uses.

7.4 RESULTS

7.4.1 Coppicing

Although some of the species were represented by only a few stumps, 83% of the 30 harvested species in the forest reserve were resprouting, compared to 90% of the 39 species in the public lands. There was an overall higher coppicing effectiveness of 5.1±1.9 (SE) shoots stump^{-1} in public lands than in the forest reserve (3.2±1.7 shoots stump^{-1}) on a mean species basis (Table 7.1, Figure 7.2). Comparison of 16 species which were sampled in both the reserve and public lands showed that the coppicing effectiveness was significantly higher in public lands than in the reserve (paired t_{15} = 2.433, p = 0.014), but the percentage of stumps resprouting was not significantly different (paired t_{15} = 1.440, p = 0.085). No single species was categorised as a 'very high sprouter' in the reserve, as opposed to 4 species, *Bridelia cathartica*, *Catunaregum spinosa*, *D. rotundifolia* and *P. angolensis* in public lands (Table 7.1). Most species had maximum resprouting potential in public lands. Among the preferred species, *C. molle*, *J. globiflora* and *P. angolensis* appeared to be vigorous resprouters especially in public lands as opposed to *S. africana* which seemed to be a weak resprouter with a coppicing effectiveness of only 0.4±0.4 shoots stump^{-1} in public lands (Table 7.1).

There was no significant difference in coppicing effectiveness for *J. globiflora* and *C. molle* between land uses. However, there was a significant difference in coppicing effectiveness between diameter classes for *J. globiflora* and a significant interaction between landuse and diameter classes for *C. molle* (Table 7.2). Most species in public lands had their highest coppicing effectiveness within the 10 – <20 cm diameter class (Figure 7.2). The ≥20 cm diameter class displayed lower coppicing values for *J. globiflora* than the other classes ($F_{3, 143}$= 8.623, p < 0.001, Tukey HSD). Thus compared to other preferred species, *J. globiflora* appeared to loose coppicing vigour with an increase in girth, the latter being positively related to tree age.

Table 7.1 Coppicing effectiveness (mean ± SE) by diameter class and percentage of stumps resprouting for all harvested species (arranged in alphabetical order by species) in miombo woodlands of Kitulanghalo Forest Reserve, and surrounding public lands (P. lands), Morogoro, Tanzania (figures in parentheses indicate the number of stumps). Sprouting categories:80–100% (A) = very high resprouter,60–79% (B)= high resprouter, 40–59% (C)= average resprouter, 20–39% (D) = low resprouter and <20% (E)= very low resprouter.

Species	Family	Landuse	Coppicing effectiveness: Diameter classes (cm) <4	4 – <10	10 – <20	≥20	Total	% of highest coppicing effectiveness	% of stumps resprouting	Sprouting category
Acacia goetzei		Reserve	-	0 ±0 (2)	1.3±1.3 (3)	-	0.8±0.8 (5)	8	20	E
Harms ssp. *goetzei*	Mimosoideae	P. lands	2 (1)	2.8±0.8 (6)	3.1±0.7 (7)	5 (1)	3.1±0.5 (15)	29	87	C
Acacia nigrescens		Reserve	9 (1)	1 (1)	0 (1)	0±0 (2)	2.0±1.8 (5)	19	40	D
Oliver	Mimosoideae	P. lands	0 (1)	3.5±0.5 (2)	2.1±1.3 (6)	0±0 (4)	1.5±0.7 (13)	14	38	D
Acacia nilotica		Reserve	1 (1)	0 (1)	9 (1)	-	3.3±2.8 (3)	31	67	C
Delile	Mimosoideae	P. lands	2 (1)	0±0 (4)	0±0 (2)	-	0.3±0.3 (7)	3	14	E
Acacia robusta		Reserve	-	-	-	-	-	-	-	-
Burch.	Mimosoideae	P. lands	-	0 (1)	9.4±2.5 (7)	3.0±3.0 (3)	6.8±2.0 (11)	64	64	B
Acacia polyacantha ssp.		Reserve	-	1 (1)	-	-	1 (1)	-	-	-
campylacantha Willd.	Mimosoideae	P. lands	-	0±0 (3)	-	-	0±0 (3)	0	0	E
Albizzia harveyi		Reserve	-	0±0 (2)	0±0 (2)	1.7±0.9 (3)	0.7±0.5 (7)	7	29	E
Fourn.	Mimosoideae	P. lands	13.5±1.5 (2)	3.5±1.2 (14)	8.8±1.7 (18)	9.1±3.3 (7)	7.3±1.1 (41)	69	76	B
Annona senegalensis		Reserve	-	-	-	-	-	-	-	-
Pers.	Annonaceae	P. lands	-	6.0±1.0 (2)	6.5±1.5 (2)	0 (1)	5.0±1.4 (5)	47	80	B
Boscia salicifolia		Reserve	-	-	-	-	-	-	-	-
Oliver	Capparaceae	P. lands	-	-	1.0±1.1 (2)	-	1.0±1.1(2)	-	-	-
Brachystegia boehmii		Reserve	3 (1)	3.2±1.4 (6)	2.2±1.4 (5)	3 (1)	2.8±0.8 (13)	26	62	C
Taub.	Caesalpinioideae	P. lands	3 (1)	5.8±1.2 (17)	6.3±1.3 (16)	4.2±2.8 (5)	5.7±0.8 (39)	54	87	B

Table 7.1 continued

Species	Family	Landuse	Coppicing effectiveness					% of highest	% of stumps	Sprouting
			Diameter classes (cm)					coppicing	resprouting	category
			<4	4 – <10	10 – <20	>20	Total	effectiveness		
Bridelia cathartica		Reserve	-	3 (1)	0 (1)	-	1.5±1.5 (2)	-	-	-
Bertol. f.	Euphorbiaceae	P. lands	-	-	8.3±3.0 (3)	-	8.3±3.0 (3)	78	100	A
Catunaregum spinosa		Reserve	-	-	-	-	-	-	-	
(Thunb.) Tirveng.	Rubiaceae	P. lands	-	5.3±1.6 (3)	12 (1)	-	6.9±1.5 (4)	65	100	A
Cassia abbreviata		Reserve	-	-	3 (1)	-	3 (1)	-	-	-
Oliver	Caesalpinioideae	P. lands	-	-	-	-	-	-	-	-
Cassia abbreviata		Reserve	-	-	3 (1)	-	3 (1)	-	-	-
Oliver	Caesalpinioideae	P. lands	-	-	-	-	-	-	-	-
Combretum adenogonium Steud. ex		Reserve	-	1.3±0.6 (4)	1.5±0.5 (2)	12.5±5.5 (2)	4.1±3.0 (8)	39	75	C
A.Rich.	Combretaceae	P. lands	4 (1)	5.5±1.2 (13)	8.2±2.0 (11)	3.0±1.1 (4)	6.1±1.0 (29)	58	79	B
Combretum collinum		Reserve	-	-	3 (1)	0 (1)	1.5±1.5 (2)	-	-	-
Fresen.	Combretaceae	P. lands	-	-	9 (1)	-	9 (1)	-	-	-
Combretum molle		Reserve	5.0±1.0 (2)	4.2±1.3 (15)	2.8±0.5 (19)	7.0±3.1 (6)	4.0±0.7 (42)	38	76	C
Engl. & Diels	Combretaceae	P. lands	3.8±0.9 (18)	5.3±0.7 (39)	8.1±1.1 (43)	4.3±1.1 (9)	6.1±0.6 (109)	58	87	B
Combretum zeyheri		Reserve	-	6.0±1.0 (2)	1.3±1.3 (3)	6.0±1.0 (3)	3.5±1.1 (8)	33	63	C
Sond.	Combretaceae	P. lands	3.2±1.2 (5)	4.6±1.4 (12)	6.9±1.9 (15)	16.5±0.5 (2)	6.1±1.1 (34)	58	85	B
Dalbergia melanoxylon		Reserve	0 (1)	0.7±0.7 (3)	0±0 (4)	0±0 (3)	0.2±0.2 (11)	2	9	E
Guill. & Perr.	Papilionoideae	P. lands	13.5±1.5 (2)	0±0 (2)	0±0 (2)	0 (1)	4.5±2.9 (7)	42	28	D
Dalbergia nitidula		Reserve	-	6 (1)	0 (1)	-	3.0±3.0 (2)	-	-	-
Welw. ex Baker	Papilionoideae	P. lands	3.0±3.0 (2)	7.0±3.0 (2)	-	-	6.0±3.0 (4)	57	75	B

Table 7.1 continued

Species	Family	Landuse	Coppicing effectiveness: Diameter classes (cm) <4	4 – <10	10 – <20	≥20	Total	% of highest coppicing effectiveness	% of stumps resprouting	Sprouting category
Dichrostachys		Reserve	7 (1)	0.5±0.5 (2)	8 (1)	-	4.0±2.0 (4)	38	75	C
cinerea Miq.	Mimosoideae	P. lands	4.0±4.0 (2)	2.3±0.8 (6)	-	-	2.6±1.0 (8)	25	63	C
Diospyros kirkii		Reserve	-	-	-	-	-	-	-	-
Hiern	Ebenaceae	P. lands	4 (1)	2 (1)	-	-	3.0±1.0 (2)	28	100	B
Diplorhynchus condylocarpon		Reserve	-	6.3±2.1 (6)	7 (1)	-	6.4±1.8 (7)	60	86	B
(Muell.-Arg.) Pichon	Apocynaceae	P. lands	-	3 (1)	4.4±3.0 (5)	2 (1)	3.8±2.1 (7)	36	57	C
Dombeya rotundifolia		Reserve	-	5.5±2.2 (4)	0±0 (2)	-	3.7±1.8 (6)	35	67	C
(Hochst.) Planch.	Sterculiaceae	P. lands	6.0±1.0 (2)	20 (1)	-	-	10.6±4.7 (3)	100	100	A
Erythrophleum africanum (Benth.)		Reserve	-	0 (1)	2.7±2.7 (2)	3.1±3.1 (2)	2.3±2.9 (5)	22	40	D
Harms	Caesalpinioideae	P. lands	-	3.1±0.8 (9)	5.0±2.0 (2)	-	3.5±0.7 (11)	33	82	C
Erythroxylum		Reserve	-	0±0 (3)	0 (1)	-	0±0 (4)	0	0	E
sp.	Erythroxylaceae	P. lands	-	-	-	-	-	-	-	-
Julbernardia globiflora		Reserve	-	6.0±2.5 (6)	9.8±3.2 (6)	1.6±1.6 (7)	5.6±1.6 (19)	53	63	C
(Benth.) Troupin	Caesalpinioideae	P. lands	5.7±1.7 (10)	6.1±0.7 (43)	6.1±1.1 (23)	1.8±0.8 (16)	5.3±0.5 (92)	50	76	B
Lannea schimperi		Reserve	-	-	-	-	-	-	-	-
Engl.	Anacardiaceae	P. lands	-	3 (1)	-	-	3 (1)	-	-	-
Lonchocarpus bussei		Reserve	-	0 (1)	-	-	0 (1)	-	-	-
Harms	Papilionoideae	P. lands	0 (1)	0 (1)	8.7±2.9 (3)	-	5.2±2.7 (5)	49	60	C
Manilkara mochisia		Reserve	-	-	-	-	-	-	-	-
(Bak.) Hubard	Sapotaceae	P. lands	-	-	0 (1)	0 (1)	0±0 (2)	-	-	-

Table 7.1 continued

Species	Family	Landuse	Coppicing effectiveness					% of highest coppicing effectiveness	% of stumps resprouting	Sprouting category
			Diameter classes (cm)							
			<4	4 – <10	10 – <20	≥20	Total			
Margaritaria discoidea (Baill.) Webster	Euphorbiaceae	Reserve	-	-	-	-	-	-	-	-
		P. lands	-	2 (1)	-	-	2 (1)	-	-	-
Markhamia sanzibarica K. Schum.	Bignoniaceae	Reserve	-	-	-	-	-	-	-	-
		P. lands	-	-	0 (1)	0 (1)	0±0 (2)	-	-	-
Millettia usaramensis Taub.	Papilionoideae	Reserve	-	-	-	-	-	-	-	-
		P. lands	0±0 (2)	0±0 (3)	-	-	0±0 (5)	0	0	E
Ormocarpum kirkii S. Moore	Papilionoideae	Reserve	-	0 (1)	-	-	0 (1)	-	-	-
		P. lands	-	-	-	-	-	-	-	-
Pteleopsis myrtifolia Engl. & Diels	Combretaceae	Reserve	-	-	0 (1)	-	0 (1)	-	-	-
		P. lands	-	0±0 (3)	4.6±1.8 (5)	7 (1)	3.3±1.3 (9)	31	56	C
Pterocarpus angolensis DC.	Papilionoideae	Reserve	-	-	-	-	-	-	-	-
		P. lands	-	4 (1)	8.7±1.8 (9)	2.5±2.5 (2)	7.3±1.5 (12)	69	92	A
Pterocarpus rotundifolius Druce	Papilionoideae	Reserve	-	5.0±4.0 (2)	-	2 (1)	4.0±2.5 (3)	38	100	B
		P. lands	-	5.0±2.2 (5)	5.4±2.7 (5)	-	5.2±1.6 (10)	49	60	C
Pseudolachnostylis maprouneifolia Pax	Euphorbiaceae	Reserve	6 (1)	-	-	-	6 (1)	-	-	-
		P. lands	8 (1)	2.7±2.2 (3)	6.2±1.9 (5)	15 (1)	6.2±2.7 (10)	58	80	B
Sclerocarya birrea ssp. *caffra* Sond.	Anacardiaceae	Reserve	-	-	-	-	-	-	-	-
		P. lands	-	-	3.7±1.7 (3)	2.5±0.5 (2)	3.2±1.0 (5)	30	100	B
Spirostachys africana Sond.	Euphorbiaceae	Reserve	-	-	-	1.0±1.0 (2)	1.0±1.0 (2)	-	-	-
		P. lands	0±0 (6)	0±0 (7)	1.0±1.0 (7)	0±0 (2)	0.4±0.4 (22)	4	5	E

Table 7.1 continued

Species	Family	Landuse	Coppicing effectiveness					% of highest coppicing effectiveness	% of stumps resprouting	Sprouting category
			Diameter classes (cm)							
			<4	4 – <10	10 – <20	≥20	Total			
Sterculia africana (Lour.) Fiori	Sterculiaceae	Reserve	-	3.1±2.2 (2)	-	-	3.1±2.2 (2)	-	-	-
		P. lands	-	-	-	-	-	-	-	-
Sterculia quinqueloba Sim	Sterculiaceae	Reserve	-	-	-	6.5±2.5 (2)	6.5±2.5 (2)	-	-	-
		P. lands	-	-	-	-	-	-	-	-
Terminalia sericea Burch. ex DC.	Combretaceae	Reserve	-	0 (1)	4.3 ±3.4 (3)	0 (1)	2.6±2.1 (5)	25	40	D
		P. lands	0 (1)	8 (1)	8.7±3.5 (3)	4 (1)	6.3±2.1 (6)	59	83	B
Turraea sp.	Meliaceae	Reserve	-	-	-	-	-	-	-	-
		P. lands	0 (1)	6.1±3.4 (2)	-	-	2.1 ±0.4 (3)	20	67	C
Xeroderris stuhlmannii (Taub.) Mendonca & Sousa	Papilionoideae	Reserve	-	1 (1)	-	4 (1)	2.5±1.5 (2)	-	-	-
		P. lands	-	9 (1)	-	1.3±0.9 (3)	3.3±2.0 (4)	31	75	C
Zahna africana (Radlk.) Exell	Sapindaceae	Reserve	-	-	-	-	-	-	-	-
		P. lands	-	-	-	11 (1)	11 (1)	-	-	-
All species combined		Reserve	4.0±2.2 (9)	3.3±1.2 (70)	3.0±2.1 (63)	3.6±1.9 (40)	3.2±1.7 (182)			
		P. lands	4.0±1.4 (61)	4.5±1.3 (210)	6.6±1.7 (208)	3.8±2.2 (69)	5.1±1.9 (548)			

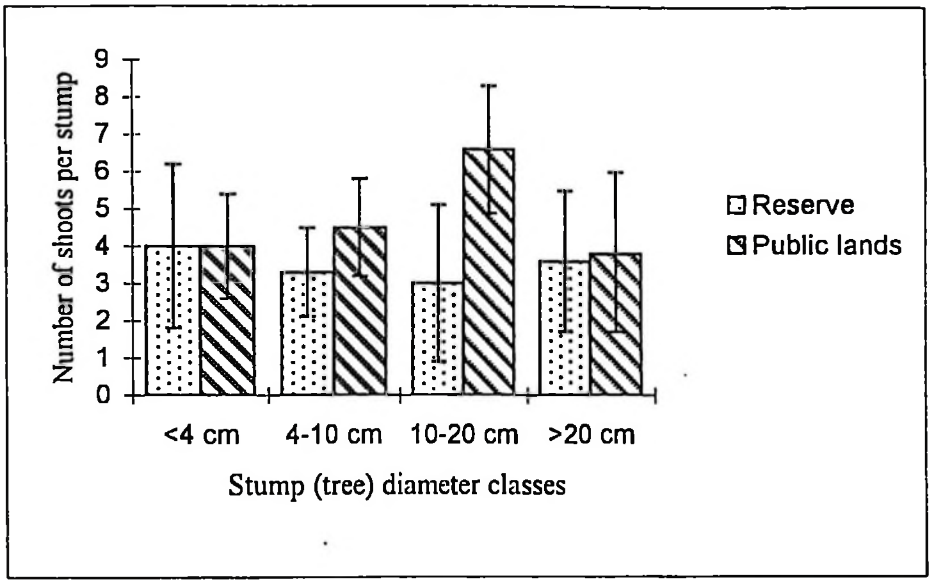


Figure 7.2 Coppicing effectiveness (mean±SE) for all harvested species within diameter classes in the Kitulanghalo Forest Reserve and surrounding public lands, Morogoro, Tanzania.

Table 7.2 Comparison of coppicing effectiveness of the two most harvested species, *Combretum molle* and *Julbernardia globiflora* (2-way ANOVA), within four size classes and between two land-uses, in Kitulanghalo Forest Reserve and surrounding public lands of Morogoro, Tanzania. (*P. angolensis* and *S. africana* were not analysed because of lack of representation in both land uses. Data in Table 7.1).

Sources of Error	*Combretum molle*			*Julbernardia globiflora*		
	d.f.	*F*	*p*	*d.f.*	*F*	*p*
Land use	1, 143	0.23	0.632	1, 96	0.82	0.368
Diameter class	3, 143	0.229	0.876	2, 96	8.623	<0.0001
Land use x Diameter class	3, 143	2.886	0.038	2, 96	1.08	0.344

The average stump height for all preferred species was 40.6±2.1 cm, ranging from 15.0±12.0 cm for *S. africana*, to 56.0±4.9 cm for *C. molle*, both in the reserve. Seventy five per cent of *P. angolensis* resprouts originated from the base of harvested stumps compared with *J. globiflora* and *C. molle* with about 50% of the resprouts originating from the base. This was further confirmed by a low sprouting height (average height from the ground to the coppice shoots) of 1.7±1.1 cm (Table 7.3). *J. globiflora* and *C. molle* showed increased sprouting height with stump height (r^2 = 0.40–0.63) (Table 7.3).

There was a weak positive relationship for the number of coppice shoots as a function of stump height (r^2 = 0.20, linear model for *S. africana* in public lands). The inclusion of stump diameter in the linear model (multiple regression) improved the r^2. to 0.28 for *J. globiflora* in the reserve. Thus, stump height has less effect on the production of coppice shoots than stump diameter, although stump height influences sprouting height of individual stumps.

7.4.2 The standing and harvested stocks

The standing stock data from the 64 field plots showed a tendency of more seedlings/ resprouts and saplings in public lands, and more trees of ≥10 cm diameter in the reserve (Table 7.4). The opposite was shown for *P. angolensis* which tended to have more trees ≥10 cm in public lands than in the reserve and *S. africana* which tended to have a higher number of seedlings and saplings in the forest reserve than in public lands (Table 7.4). However in both cases the differences were not significant. There were also fewer individuals in the pole class (4 – <10 cm) than in the next class of 10 – <20 cm (Table 7.4).

The comparison between harvested and standing individuals of the four most popular tree species showed the highest removal/standing volume ratio of 6.85 for *J. globiflora* in the public lands (Table 7.5). *S. africana* in the reserve had the lowest removal/standing volume ratio of 0.11. No removal of *P. angolensis* was detected in the reserve plots.

Table 7.3 Relationship of sprouting height as a function of stump height of harvested trees of *Combretum molle*, *Julbernardia globiflora*, *Pterocarpus angolensis* and *Spirostachys africana* in the Kitulanghalo Forest Reserve and surrounding public lands of Morogoro, Tanzania.

Species	Forest Reserve				Public Lands			
	Stump height (STH) (cm)	Sprouting height (SPH) (cm)	n	Best fit model	Stump height (STH) (cm)	Sprouting height (SPH) (cm)	n	Best fit model
Combretum molle	56.0±4.9	20.6±4.8	42	SPH = -7.83 + 0.10 STH $r^2 = 0.46$	44.5±2.9	16.7±2.8	109	SPH = -9.15 + 0.58 STH $r^2 = 0.40$
Julbernardia globiflora	39.3±2.9	12.1±2.9	19	SPH = -11.15 + 0.63 STH $r^2 = 0.48$	37.1±3.5	17.6±8.2	92	SPH = -26.32 + 0.26 STH $r^2 = 0.63$
Pterocarpus angolensis	-	-	0#	-	33.0±4.3	1.7±1.1	12	SPH = Log 5.11 - 0.10 STH $r^2 = 0.19$
Spirostachys africana	15.0±12.0	13.0*	2	-	27.7±3.0	13.0*	22	0

= No stumps were recorded from the forest reserve
* = Only two stumps resprouted, one in each land use

Table 4 Comparison of size class distributions (as stems ha^{-1} ± SE) of the four most preferred tree species between the Kitulanghalo Forest Reserve (n=34) and surrounding public lands (n=30) in miombo woodland, Morogoro, Tanzania.

Species	Diameter classes (DBH in cm)	Number of stems ha^{-1} Reserve (n = 34)	Public lands (n = 30)	*t*	*p*
Combretum molle	0 – <1	2498±241	4164±1295	1.127	0.132
	1 – <4	241±48	400±80	1.751	0.042
	4 – <10	24±5	45±9	2.099	0.02
	10 – <20	19±4	14±5	0.755	0.227
	≥20	6±2	2±1	2.042	0.023
	Total	2788±837	4625±1374	1.142	0.129
Julbernardia globiflora	0 – <1	3732±730	4676±1190	0.694	0.245
	1 – <4	165±45	589±122	3.464	<0.001
	4 – <10	14±5	40±12	2	0.023
	10 – <20	7±2	2±1	1.679	0.039
	≥20	4±1	0±0	2.816	0.003
	Total	3922±752	5307±1267	0.803	0.173
Pterocarpus angolensis	0 – <1	2±1	26±16	1.681	0.049
	1 – <4	1±1	11±5	2.044	0.023
	4 – <10	1±1	7±3	1.778	0.04
	10 – <20	1±1	2±2	0.831	0.204
	≥20	0±0	1±1	1.066	0.145
	Total	5±3	47±26	1.854	0.037
Spirostachys africana	0 – <1	890±454	130±51	1.565	0.061
	1 – <4	27±14	11±6	0.934	0.177
	4 – <10	1±1	3±1	1.3	0.099
	10 – <20	2±2	5±4	0.771	0.222
	≥20	2±2	1±1	0.842	0.202
	Total	922±469	159±60	0.652	0.258

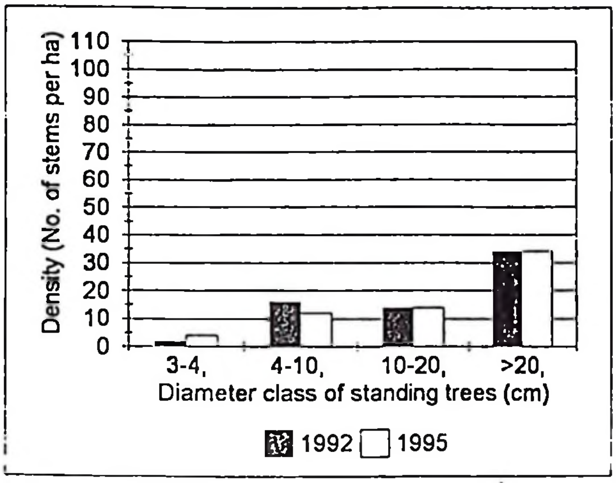
Table 7.5 Comparison of the removed and standing volume (from Luoga *et al.*, submitted a) of the four most preferred tree species between the Kitulanghalo Forest Reserve and surrounding public lands, Morogoro, Tanzania.

Species	Reserve			Public lands		
	Removed volume $m^3\ ha^{-1}$ (R)	Standing volume $m^3\ ha^{-1}$ (S)	R/S Ratio	Removed volume $m^3\ ha^{-1}$ (R)	Standing volume $m^3\ ha^{-1}$ (S)	R/S Ratio
Combretum molle	1.47	3.68	0.4	2.58	1.14	1.83
Julbernardia globiflora	1.17	2.94	0.4	5.48	0.8	6.85
Pterocarpus angolensis	0	0.75	0	0.54	0.74	0.73
Spirostachys africana	0.15	1.4	0.11	0.51	0.82	0.62

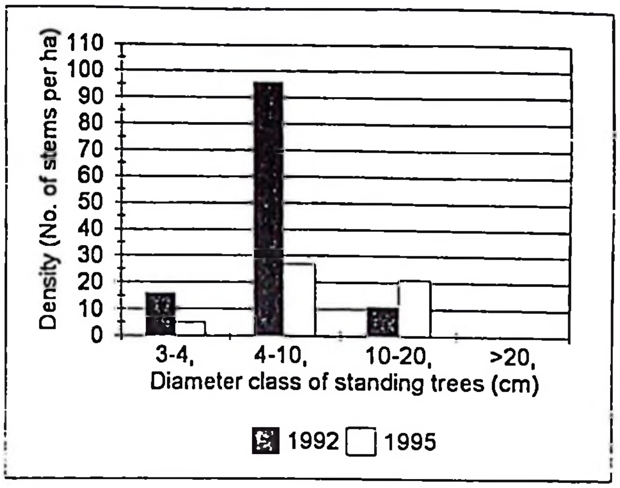
7.4.3 Growth rates

J. globiflora was the only species occuring in the PSPs in the reserve and public lands. *P. angolensis* was only recorded in public lands and *S. africana* only in the reserve. *C. molle* was not recorded in either PSP. The mean DBH of *J. globiflora* in the reserve at the first enumeration in 1992 was 24.6±2.8 cm (range 3.2–55.8 cm), significantly higher than the 6.8±0.4 cm (range 3.2–11.4 cm) for the same species in public lands (t_{34} = 6.348, p <0.0001). *P. angolensis* and *J. globiflora* have displayed continuous population decline in public lands whereas *S. africana* and *J. globiflora* in the reserve have constant populations (Figure 7.3).

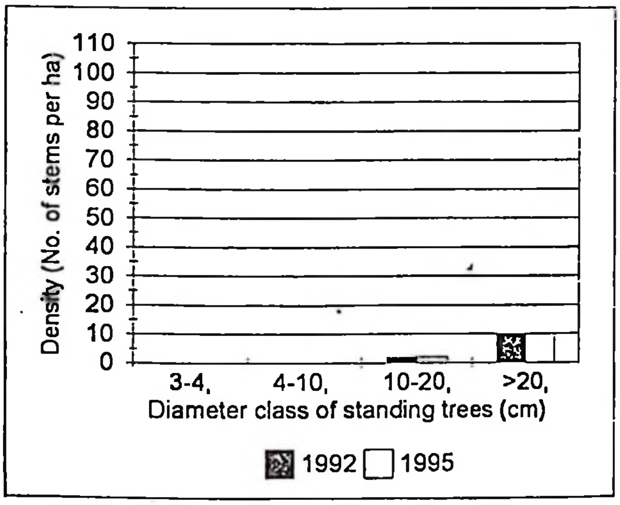
The highest mean annual increment in DBH (7.4 ±0.5 mm $tree^{-1}$ $year^{-1}$ (1992/1995)) was recorded for *J. globiflora* in public lands while the lowest increment (2.8±2.1 mm $tree^{-1}$ $year^{-1}$) was for *S. africana* in the reserve (Table 7.6). Both absolute and relative diameter growth rates of *J. globiflora* (Table 7.6) were significantly higher in public lands than in the reserve (absolute growth t_{16} = 4.260, p=0.0003: relative growth t_{16} = 5.448, p=0.0003).



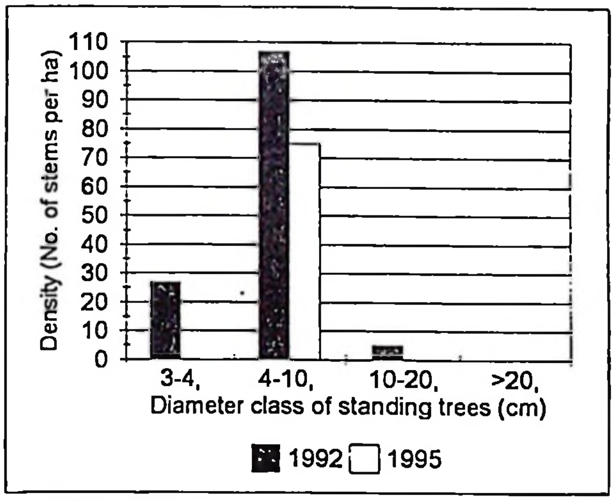
Julbernardia globiflora (reserve)



Julbernardia globiflora (public land)



Spirostachys africana (reserve)



Pterocarpus angolensis (public land)

Figure 7.3 Comparison of diameter class distributions of the most preferred tree species in 1992 and 1995 from permanent sample plots (PSPs) in the Kitulanghalo Forest Reserve and surrounding public lands, Morogoro, Tanzania.

The species differed in their relative growth rates in the following sequence: *J. globiflora* (public lands) > *P. angolensis* (public lands) > *J. globiflora* (reserve) > *S. africana* (reserve). The highest growth rates of between 8% and 14% tree^{-1} year^{-1} were recorded from the pole diameter class of 4–10 cm for *J. globiflora* in public lands compared to ≤8% in the reserve (Figure 7.4). The slopes of linear regression equations for the relative growth rate of *J. globiflora* as a function of tree diameter in the two land uses

Table 7.6 Absolute growth rates for diameter (mm tree^{-1} year^{-1} ±SE), biomass (tonnes tree^{-1} year^{-1} ±SE) and volume (m^3 tree^{-1} year^{-1} ±SE) of *Julbernardia globiflora*, *Pterocarpus angolensis* and *Spirostachys africana* in miombo woodlands of the Kitulanghalo Forest Reserve and surrounding public lands in Morogoro, Tanzania. Figures in bold are the relative growth rate increment as a percentage.

Landuse	Species	1992/1993			1993/1994			1994/1995			MEAN (1992/1995)		
		Dia.	Bio.	Vol.	Dia.	Bio.	Vol.	Dia.	Bio.	Vol.	Dia.	Bio.	Vol.
Reserve	*J. globiflora* (n=33)	5.7 ± 1.7	0.032 ± 0.011	0.042 ± 0.019	3.0 ± 1.6	0.026 ± 0.010	0.045 ± 0.013	1.4 ± 0.7	0.036 ± 0.029	0.058 ± 0.029	3.0 ± 0.6 **2.1 ±0.4**	0.030 ± 0.008 **9.4 ±1.3**	0.045 ± 0.011 **9.1±1.3**
	S. africana (n =6)	3.0 ± 3.2	0.038 ± 0.024	0.049 ± 0.038	2.3 ± 1.1	0.018 ± 0.006	0.027 ± 0.008	5.7 ± 3.8	0.026 ± 0.013	0.041 ± 0.021	2.8 ± 2.1 **1.0 ±0.7**	0.0270 ± 0.011 **7.2 ±1.6**	0.039 ± 0.016 **6.4 ±1.4**
Public lands	*J. globiflora* (n=23)	7.6 ± 1.3	0.004 ± 0.001	0.006 ± 0.001	8.4 ± 1.5	0.007 ± 0.001	0.012 ± 0.002	4.6 ± 0.4	0.002 ± 0.000	0.004 ± 0.001	7.4 ± 0.5 **9.8 ±1.1**	0.004 ± 0.000 **31.3 ±3.6**	0.07 ± 0.000 **26.0 ±3.1**
	P.angolensis (n=26)	3.3 ± 1.3	0.001 ± 0.000	0.002 ± 0.001	2.1 ± 0.7	0.001 ± 0.000	0.001 ± 0.000	2.9 ± 0.5	0.001 ± 0.000	0.002 ± 0.000	2.9 ± 0.5 **5.1 ±0.9**	0.001 ± 0.000 **15.1 ±2.9**	0.002 ± 0.000 **14.4 ±2.8**

were significantly different ($t_{37} = 7.459, p < 0.0005$). Thus, trees in public lands grow faster than those in the forest reserve. *P. angolensis* in public lands was the most variable species in terms of growth rate ranging from 2% to10% within the pole class of 4 – <10 cm (Figure 7.4). *S. africana* in the reserve had a slow growth rate with little effect of tree size on growth rates. *S. africana* had a higher diameter increase in 1994/1995 when the rainfall was higher (866 mm) than in 1992/1993 (743 mm), and 1993/1994 (745 mm) (Table 7.6). *P. angolensis* showed a relatively constant diameter increment between years, while *J. globiflora* had the lowest increase in both the reserve and public lands when rainfall was highest (Table 7.6).

Trees growing in public lands have also shown a higher percentage of individuals with an increase in diameter growth each year compared to the reserve. For example, 88.7% of the individuals of *J. globiflora* increased in diameter in public lands in contrast to 70.1% in the reserve (Table 7.7). The lowest percentage (61.1%) of individuals with increased diameter was *S. africana* in the reserve (Table 7.7).

7.4.4 Recruitment and mortality

P. angolensis had the highest density of 139 trees ha^{-1} in public land PSP in 1992 but this declined markedly by 54% after three years and no new recruits were recorded. *J. globiflora* showed a similar decline of 43% in public lands for the corresponding period (Table 7.8). These sharp declines are attributed to high rates of harvesting (23 and 11 trees ha^{-1} $year^{-1}$ respectively) (Table 7.8). In the forest reserve, *J. globiflora* and *S. africana* exhibited constant densities. *J. globiflora* had approximately equal recruitment and mortality rates, whereas *S. africana* was not removed, had not died nor was recruited to the minimum diameter class over the enumeration period (Table 7.8).

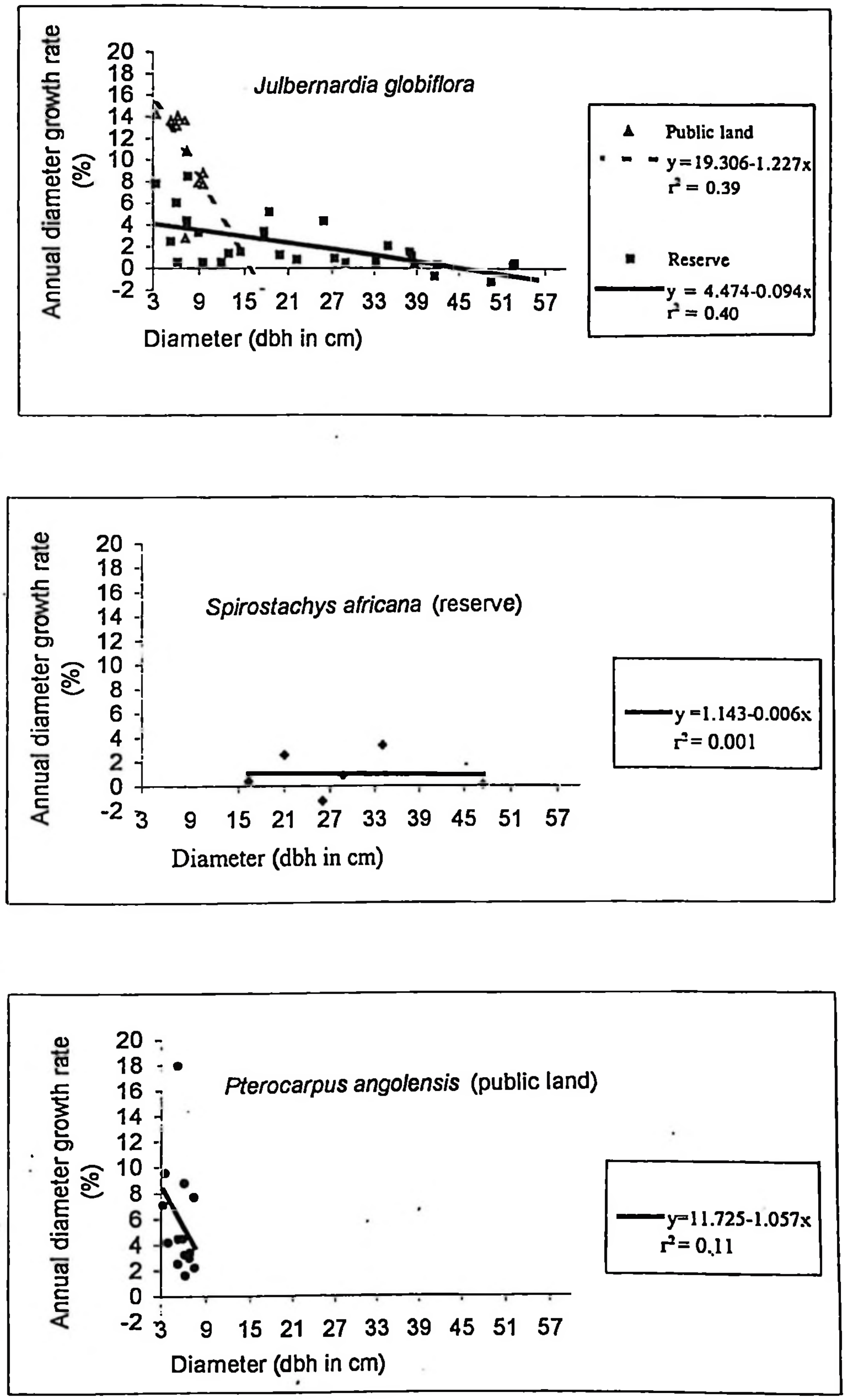


Figure 7.4 Relationships between diameter at breast height (dbh) of standing trees and growth rates (as %; 1992/95) of the most preferred tree species from permanent sample plots (PSPs) in the Kitulanghalo Forest Reserve and surrounding public lands, Morogoro, Tanzania.

Table 7.7 Change in stem diameter(percentage of individuals) of *Julbernardia globiflora*, *Pterocarpus angolensis* and *Spirostachys africana* trees in miombo woodlands of the Kitulanghalo Forest Reserve, and surrounding public lands in Morogoro, Tanzania.

Species	Growing season	Reserve: Change in diameter (DBH) growth (%) Inc-rease	No change	De-crease	n	Public lands: Change in diameter (DBH) growth (%) Inc-rease	No change	Dec-rease	n
J. globiflora	1992/93	78.1	6.3	15.6	33	84.2	10.5	5.3	15
	1993/94	71	16.1	12.9	31	81.8	9.1	9.1	11
	1994/95	61.3	9.7	29	31	100	0	0	9
	Mean	70.1	10.7	19.2	32	88.7	6.5	4.8	12
P. angolensis	1992/93	-	-	-	0	69.6	13	17.4	23
	1993/94	-	-	-	0	66.7	13.3	20	15
	1994/95	-	-	-	0	100	0	0	14
	Mean	-	-	-	0	78.8	8.8	12.5	17
S. africana	1992/93	50	16.7	33.3	6	-	-	-	0
	1993/94	88.6	16.7	16.7	6	-	-	-	0
	1994/95	66.6	16.7	16.7	6	-	-	-	0
	Mean	61.1	16.7	22.2	6	-	-	-	0

The annual death rates for *J. globiflora* were 3.7 trees ha^{-1} yr^{-1} in public lands compared to 0.7 trees ha^{-1} yr^{-1} in the forest reserve. The annual harvesting rates for the species were 23 trees ha^{-1} yr^{-1} in public lands compared to only 0.7 trees ha^{-1} yr^{-1} in the forest reserve summing to a total mortality of 26.7 trees ha^{-1} yr^{-1} and 1.4 trees ha^{-1} yr^{-1} in public lands and the reserve respectively (Table 7.8). *P. angolensis* had the same rates of natural death and harvesting of 10.7 trees ha^{-1} yr^{-1} in public lands and the reserve while *S. africana* in the reserve recorded neither natural nor harvesting mortality (Table 7.8). The highest recruitment rate to the minimum size class over the inventory period was only 3.7 trees ha^{-1} $year^{-1}$ recorded for *J. globiflora* in public lands. The virtual absence of recruitment for *P. angolensis* and *S. africana*, and very low number of recruits for *J. globiflora* in the reserve suggests high mortality of seedlings and fire suppression of saplings.

Table 7.8 Life tables and differences in mortality and recruitment for *Julbernardia globiflora*, *Pterocarpus angolensis* and *Spirostachys africana* in miombo woodlands of the Kitulanghalo Forest Reserve and surrounding public lands in Morogoro, Tanzania.

Landuse	Species	Live trees ha^{-1} in 1992 (a)	Live trees ha^{-1} in 1995 (b)	Net change (b-a)	Rate of increase (b/a)	Recruitment	Mortality (Trees ha^{-1} yr^{-1})			Recruitment Mortality ratio c/ (d+c)
						Trees ha^{-1} yr^{-1} (c)	Natural (d)	Harvesting (c)	Total (d+c)	
Reserve	*J. globiflora*	66	66	0	1	1.33	0.67	0.67	1.34	0.99
	S. africana	12	12	0	1	0	0	0	0	-
Public lands	*J. globiflora*	123	53	-70	0.43	3.67	3.67	23	26.7	0.15
	P. angolensis	139	75	-64	0.54	0	10.7	10.7	21.3	0

7.5 DISCUSSION

7.5.1 Regeneration

Despite being heavily utilised, the regenerative potential of *J. globiflora* and *C. molle* appears considerable because of effective resprouting from stumps (Table 7.1) and high sapling densities (Table 7.4). The absence of large herbivores may partially account for the high density of recruits, especially of *J. globiflora*, which was reported to be adversely affected by grazing and browsing ungulates in Zimbwabwe (Grundy, 1995). Although *P. angolensis* displayed a high coppicing effectiveness (Table 7.1), there is a remarkable paucity of standing trees (especially in the forest reserve). *P. angolensis* is reported to have been over-exploited from the reserve prior to closure of harvesting in 1985 (Nduwamungu, 1996). The use of power saws and two-man cross-cut saws to cut the trees nearly flush to the ground might have resulted in a lack of resprouting at that time and hence depleted numbers at present. *P. angolensis* is categorised as a protected species and should not be harvested without a permit, although many wood harvesters do not observe this requirement. *S. africana* lacks regeneration and was only recorded in the mature size class of ≥20 cm (Figure 7.3). The high levels of utilisation of *P. angolensis* and *S. africana* (Luoga *et al.*, 2000a & b), low stocking levels (Luoga *et al.*, submitted a, Table 7.4), and lack of recruitment (Figure 7.3, Table 7.8), together with very low coppicing and growth rates for *S. africana* could lead to local extinction if they are not effectively managed.

Most tree species in this miombo woodland are able to coppice (Table 7.1). Miombo species have both vertically and horizontally extensive root systems which facilitate rapid recuperation after cutting (Malimbwi *et al.*, 1994; Mistry, 2000). The maximum lateral root length recorded for *J. globiflora* is 27 m (Strang, 1965) and most miombo dominants have tap roots of about 5 m in depth (Mistry, 2000). The horizontally extensive root systems may additionally produce root suckers once the above-ground parts have been removed (Strang, 1974). The contribution of root suckers to total regeneration needs further study.

The effectiveness of resprouting from stumps varies with species, plant size/age at time of cutting, stump height and the percentage of the stand removed (Table 7.1, Shackleton, 2000; Luoga *et al.*, submitted a). The significantly higher coppicing effectiveness in public lands than in the reserve is attributed to more extensive harvesting which stimulates resprouting. Other factors that affect coppicing effectiveness in miombo woodlands are higher levels of exposure to sunlight because of the removal of the canopy which stimulates coppicing (Chidumayo, 1993b), site characteristics (where *J. globiflora* was shown to coppice better in shallow than in deep soils), angle of cutting and sharpness of cutting tools (sharp tools encourage vigorous regrowth from the stumps) (Grundy, 1995).

Grundy (1990) noted that cutting *J. globiflora* at ground level resulted in significantly fewer sprouts per stump compared with cutting it at a height of 120 cm. For *Colophospermum mopane* (sub-family Caesalpinioideae), sprouting height increased significantly with stump height but the latter had variable effects on the number of coppice shoots produced, although the general tendency was for tall stumps to produce more coppice shoots than short stumps (Mushove and Makoni, 1993). This tendency, which has also been reported from South African savanna trees, is attributed to increased surface area, thus more buds on the stump (Shackleton, 1997).

The season of the year during which the cutting is effected is also an important determinant of the number of coppice shoots produced. The best time to resprout is just before the onset of the rains when abundant moisture facilitates recovery from harvesting (Pawlick, 1989). Cutting too low on the stem of the tree may encourage fungal infection because of moisture from the ground or decay of the stump, while cutting too high may result in loss of sprouting vigour and poor shoot growth (Pawlick, 1989). Thus, stump height has a definite positive effect on sprouting height, but variable influences on the number of coppice shoots produced.

7.5.2 Diameter distribution after harvesting

Many miombo trees produce large seed crops only when they have developed large crowns (Chidumayo, 1993 b). The diameter distribution of standing trees shows very few individuals of ≥10 cm DBH (Table 7.4), thus the regeneration of the selected species is seed-limited as most of the mature seed-producing trees have been harvested. The high proportion of stems in the smallest size classes of 0 – <1 cm and 1 – <4 cm (Table 7.4) shows that there is ongoing recruitment into the population, especially for *J. globiflora* and *C. molle*. However the few individuals in the 4 – <10 cm size class (Table 7.4) shows a restricted recruitment from the sapling to the pole phase. This is largely the result of anthropogenic dry season fires causing considerable stem mortality of small resprouting stems (Kielland-Lund, 1990 b).

Surveys of unplastered dwellings in the study area showed that *S. africana* contributes 28% of all walling poles with a mean diameter of 7.1 cm (Luoga *et al.*, 2000a & b,) which is within the impacted diameter class of 4 – <10 cm. The size selectivity while harvesting *S. africana* for building poles will also contribute to altering the diameter class profile by impacting chiefly on the pole size class (Table 7.4). Almost all harvested *P. angolensis* trees in PSPs (Table 7.8) were removed for charcoal burning in the pole class of 4 – <10 cm. In South Africa, the minimum size for commercial felling of indigenous timber trees (including *P. angolensis*) is 35–40 cm DBH (Geldenhuys, 1996). Therefore, the non-selectivity for species and size classes when harvesting for charcoal (Luoga *et al.*, submitted a) will have a considerable impact on *P. angolensis*, the most merchantable timber species.

The diameter distribution in both the reserve and public lands as depicted in Figure 7.3 and Table 7.4 suggests that these woodlands are far from the 'inverse J-shaped curves' typical of stable or growing uneven-aged populations (Meyer, 1952). Thus management interventions are important to ensure sustainable yields from the woodlands.

7.5.3 Growth and mortality

The mean annual diameter increase of 2.9±0.5 mm^{-1} $year^{-1}$ for *P. angolensis* in public lands is within the range of 1.5 mm^{-1} $year^{-1}$ to 10.7 mm^{-1} $year^{-1}$ reported from different countries in eastern and southern Africa (van Daalen *et al.*, 1992). Growth rates however, must be treated with caution as growth is highly dependent on size class profile of the sample population (Figure 7.4; Shackleton, submitted), which is not always reported (van Daalen *et al.*, 1992). Usually bigger trees have higher absolute growth rates than smaller trees because of larger photosynthetic crowns, but the reverse is true for relative growth (Manokaran and Swaine, 1994). The relatively higher percentage of *P. angolensis* individuals which showed no diameter change or shrank compared to *J. globiflora* in public lands (Table 7.7), could result from the stunted growth in the suffrutex stage whilst the root system develops until it has sufficient vigour to furnish a permanent stem (Vermeulen, 1990).

The growth rates of *J. globiflora* and *P. angolensis* in public lands (Table 7.8; Figure 7.4) suggest fast growth of coppice shoots in the initial years of regrowth as they had well established root systems. Similar conclusions were drawn by Chidumayo (1992) and Grundy (1995). However, they remarked that growth slows down after about 15–20 years. Nutrient availability seems to have a minimal impact on differences between the reserve and public lands, because of similar levels of litter cover, total nitrogen and total organic carbon (Luoga *et al.*,submitted b). Nitrogen and carbon mineralization in miombo woodlands is controlled by litter quantity and quality (Mtambanengwe, 1999).

The annual mortality rate of 5.4% for *J. globiflora* and *P. angolensis* in public lands is comparable with the annual mean of 4.4% recorded across several species and stem sizes in South African woodlands (Shackleton, 1997) but it is markedly less than the annual mortality from harvesting of 13.2% for the two species in public lands. Thus in public lands, the main cause of mortality of trees greater than 4 cm is harvesting. Natural mortality in plant populations is a density-dependent process which may involve competition between individuals. It also appears that individuals survive harvesting if sufficient time for replenishing of below-ground reserves occurs. Repeated harvesting of the same individual increases the probability of mortality as reflected by the higher mortality in public lands relative to the reserve, despite the lower levels of competition (shown by higher growth rates than in the reserve).

Shackleton (1997) and Rathogwa (2000) found a significant negative relationship between basal area and stand density in southern African woodlands, suggesting that competition is a significant determinant of stand productivity. Thus, for harvested stands such as the public lands, the decrease in number of plants through harvesting or self-thinning natural mortality is accompanied by an increase in average size, therefore enhanced wood productivity. In the case of the reserve, dominant trees tend to limit the growth of codominants and hence stand productivity is limited by competition (Weiner, 1985). This shows that protection of the reserve since 1955 and a subsequent ban on harvesting imposed in 1985 did not enhance productivity. Management techniques such as thinning which mimic some of the natural disturbances will favour the regeneration and productivity of the old-growth woodlands in the reserve (Rathogwa, 2000).

Both the reserve and public lands have a herbaceous layer of grass of 70 cm in height forming a continuous fuel load during the dry season (Luoga *et al.*, submitted a). Early season fires result in a patchwork of burnt and unburnt areas as the moisture content of grass is relatively high compared to cured grass during late dry season burning. The higher strata miombo dominants of *Brachystegia* and *Julbernardia* are sensitive to late dry season fires (Trapnell, 1959) while *P. angolensis* is considered successful in terms of survival from fires (Calvert, 1993). *S. africana* seems to be a fire-sensitive species as it was mostly growing along the interface zones of miombo woodlands and semi-evergreen forests, which experience less fire due to lower herbaceous biomass than the open miombo. Thus, fire is another disturbance factor which has a major impact on woodlands.

Protective burning (e.g., early season burning when dry fuel load is low) proved successful in averting late season hot destructive fires in Zambian miombo woodlands (Chidumayo, 1993 a). Other benefits of early season annual burning in Zambian miombo (Trapnell, 1959; Chidumayo, 1993a) are: preservation of original woodland with a slight increase in stocking of canopy and under-storey trees, slight increase in regeneration of canopy species, and little change in grass flora. There is no policy regarding fire management in Tanzanian miombo woodlands.

7.5.4 Yield regulations and management implications

In southern Africa, the raising of indigenous tree species from seed is limited by lack of seed availability, problems of storage and pre-treatment requirements, drought, die-back and inadequate knowledge of site factors (Piearce, 1993; Grundy, 1995; Shackleton, submitted). The best option for regeneration will therefore be sustainable *in-situ* conservation of existing woodlands.

The high coppicing effectiveness and growth rates of coppice shoots supports the management of miombo woodlands under coppice rotation as a silvicultural system (Grundy, 1995; ODA/FRP, undated). ODA/FRP (undated) proposes a 3–5 year coppice rotation for firewood, 6–10 years for small poles, 15 years for large poles, and 40 years for timber. From this study if we assume that in the public land PSP (where the age of the stand is known) the annual average diameter increase of *J. globiflora* applies to all species, the best time to harvest trees for fuelwood production would be

24–44 years when trees attain the diameter class of 10 – <20 cm DBH and when they have maximum coppicing effectiveness after harvesting (Figure 7.2). Harvesting for poles could be done between the ages of 14–24 years when trees attain size classes of 4 – <10 cm DBH.

The removal of all mature trees (Table 7.4) and repeated harvesting of coppice shoots (Table 7.8) may ultimately prevent seed production by eliminating all the reproductive individuals thereby limiting regeneration from seedlings. Ultimately, seedling regeneration is essential to maintain the long term persistence of a species. To ensure seed production, a proportion of seed-bearing individuals should be retained, commonly referred to as coppice with standards where a few trees (about 100 trees ha^{-1} for all species) are left to grow to a large size (as standards) whilst others are cut on shorter coppice rotations (Grundy, 1995; ODA/FRP, undated). To maintain high survival coppice shoots, singling could be done where coppice shoots are reduced to one or two of the healthiest stems (ODA/FRP, undated). It is recommended that singling should be done not later than one year after resprouting so as to restore apical dominance (Shackleton, 1997).

The mean annual increment of *J. globiflora* in public lands was 2.94 m^3 ha^{-1} $year^{-1}$ (0.07 m^3 $tree^{-1}$ $year^{-1}$ x 42 trees ha^{-1} = 2.94 m^3 ha^{-1} $year^{-1}$) while the harvesting rate was 5.48 m^3 ha^{-1} $year^{-1}$ (Table 7.5); indicating that current harvesting levels are not sustainable and will lead to continuous population decline (Table 7.4). One way of ensuring the sustainable supply of products is through adopting a geographical rotation system where the majority of trees are harvested in one limited part of the woodland each year (cutting unit) or by determining a harvesting quota where a few trees are removed over the whole area each year (Hofstad, 1992). From this study the first option is recommended to be adopted in public lands because harvesting for fuelwood production is not selective of species, while the latter can be used in the reserve in order to improve the productivity of the remaining trees.

The average proposed cutting cycle for fuelwood (charcoal) is 34 years. With the total area covered by woodlands / shrublands (<5 km from settlements and <10 km from the highway) estimated at 13 300 ha (Luoga *et al.*, in press), each cutting unit would then be 391 ha $year^{-1}$ (13 300 ha / 34 years). Assuming that a stock similar to the present 16.7 m^2 ha^{-1} (Luoga *et al.*, submitted a) is harvested every 34 years on the same 391 ha site, the resulting wood output would be 6530 m^3 $year^{-1}$ (16.7 m^3 ha^{-1} x 391 ha $year^{-1}$). With the population of 4640 people the sustainable per capita wood consumption for fuelwood would be 1.4 m^3 $capita^{-1}$, $year^{-1}$, while the current wood consumption for charcoal stands at 6.0 m^3 $capita^{-1}$ $year^{-1}$ (Luoga *et al.*, in press). This shows that with the current stocking, charcoal production which is not a subsistence activity, is not sustainable in the woodland. Reducing the geographical rotation to 24 years, when coppice shoots would attain the size of 10 cm DBH, the cutting unit will increase to 554 ha $year^{-1}$ with per capita consumption of 2.0 m^3 $capita^{-1}$ $year^{-1}$. The volume of wood used for subsistence purposes of fuel and housing in the study area is 1.6 m^3 $capita^{-1}$ $year^{-1}$ (Luoga *et al.* 2000a). Thus only subsistence and essential to life daily uses are sustainable in the area. The proposed prescription for subsistence harvesting in public lands which is based on 24 years coppice with standards rotation is shown in Table 7.9, where thinning twice, at 10 and 19 years will increase the productivity of the remaining stems. The increased productivity is expected to offset for the increased demand due to human population growth (at least initially), thus maintaining the sizes of the cutting units for the first cycles, after which the cutting units have to be increased or wood pattern use has to be adjusted in order to reduce the per capita demand as population growth increases further.

To maintain sustainable use of the woodlands, the allowable harvesting rate (allowable cut) should be based on the growth rate of the trees in the stand (Hofstad, 1992; Geldenhuys, 1993). For the forest reserve, selective thinning is recommended and the allowable cut can be set to no greater than mean annual increment although increased cut can lead to increased increment (Table 7.10).

Table 7.9. The recommended silvicultural prescription for 24 years coppice rotation within one cutting unit (554 ha) in miombo woodlands of public lands around the Kitulanghalo Forest Reserve, Morogoro, Tanzania.

Year	Operation	Remarks
0	Harvesting	- * Retention of all protected species (e.g., *Pterocarpus angolensis*) and 100 trees ha^{-1} of all species for future seed production. - Trees to be cut 40 cm from the ground (this study) at an angle of 45° (Grundy, 1995)
1	Gap filling	Broadcasting of seeds or planting seedlings in suitable micro-sites
1	Shoot pruning (singling)	Removal of weak coppice shoots and retention of one or two of the healthiest shoots per stump
10	Thinning	Removal of 25% of the stock with mean DBH of 2–3 cm for firewood and poles (withies) for building
19	Thinning	Removal of 25% of the stock with mean DBH of 6–7 cm for firewood and poles (wall erecting, beam and roofing)
1–24	Resource protection	- Prescribed early season burning and maintenance of firebreaks - Policing for illegal harvesting.
24	Harvesting	Cutting of all trees except the protected species and the standards.

* All retained seed bearing trees and *Pterocarpus angolensis* can be harvested after three rotations (72 years). To ensure continuity in seed production, 100 trees ha^{-1} of all species should be converted to standards at the end of second rotation.

Table 7.10 The recommended allowable cut (based on mean annual increment) as a silvicultural prescription of miombo woodlands in the Kitulanghalo Forest Reserve, Morogoro, Tanzania.

Species	Individual tree increment (m^3 tree^{-1} year^{-1}) (a)	Stocking (trees ha^{-1}) (b)	Gross increment (m^3 ha^{-1} year^{-1}) (a*b)	Mortality (m^3 ha^{-1} year^{-1}) (c)	Mean annual increment (m^3 ha^{-1} year^{-1}) ((a*b)-c)
J. globiflora	0.045	25	1.13	0.03	1.1
S. africana	0.016	5	0.08	0	0.08

With the reserve area of 2 452 ha, the harvesting quota for *J. globiflora* will be 2697m^3 year^{-1} (1.10 m^3 ha^{-1} year^{-1} x 2 452 ha) and that of *S. africana* will be 196 m^3 year^{-1} (0.08 m^3 ha^{-1} year^{-1} x 2 452 ha) equivalent to 13 077 building poles (196 m^3 year $^{-1}$ / 0.015 m^3 pole^{-1}). As *J. globiflora* is a dominant species in the reserve, the reduced stocking will open the canopy and increase the productivity of the co-dominants.

7.6 CONCLUSIONS

This study adds to the limited but growing number of studies on impacts of harvesting on regeneration and growth of miombo trees. Although most species resprout vigorously after cutting, there is limited recruitment of trees from sapling to pole size because of a fire-induced bottleneck. This serves to emphasize the extreme importance of managing fires in the woodlands. All the preferred species were previously over-utilised. Thus monitoring of these species is required in order to manage them for sustainable use and conservation. *J. globiflora* can be sustainably maintained through silvicultural systems of coppice or coppice with standards in public lands or through quota harvesting in the reserve. In the case of *P. angolensis*, harvesting young plants for fuelwood or poles is very wasteful and longer cutting cycles will be required, aimed at producing larger dimension logs with maximum yield of heartwood. The lack of regeneration of *S. africana* and extremely low stocking requires immediate silvicultural intervention and resource-switching to lessen the levels of utilisation. This study has set a base for developing growth models with a wider representation in terms of species, ages/diameter classes, sites, climate and disturbance regimes.

CHAPTER 8

The potential of local communities to sustainably manage miombo woodland resources: a case study from rural Tanzania.

Submitted to *Ambio*

8.1 Abstract

In Tanzania, well-defined land tenure and resource protection apply in forest reserves which account for 30% of forested land, while the remaining 70% (mostly miombo woodlands) are public lands without any protection. The aim of this study is to determine local people's ownership rights, knowledge and institutional capacity for sustainable management of resources in forest reserves and public lands. Data were collected using participatory rural appraisal (PRA), structured and semi-structured interviews, as well as aerial photographs and landsat images. In public lands, woodlands declined by 50% between 1964 and 1996, bushlands & croplands increased by 599%, and settlements & homegardens increased by 277%. These landuse changes are attributed to growth in population, harvesting for charcoal production and shifting cultivation. Common property regimes and local institutional capacities are weak and need to be strengthened before local people can be given the full responsibility of managing the public lands and assisting in policing the forest reserve. The issues of land tenure and village empowerment are not only institutional but political in nature. Government institutions should provide and motivate for an enabling environment, including acknowledgment of traditional knowledge, well defined property rights and operational village by-laws. In order to ensure equity and sustainable development of natural resources, the paradigm shift in management is important whereby communal goods are to be managed for the benefit of the local society.

Key words: common property regime, institutional capacity building, land tenure, land use/cover changes.

8.2 INTRODUCTION

For many decades, Tanzania's natural resources have been controlled by the state with management policies being characterised by centralised decision-making processes. Well-defined land tenure and resource protection apply in forest reserves which account for 30% of forested land, while the remaining 70% (mostly miombo woodlands) are public lands without any protection (Monela and Ole-Meiludie, 1997). "A forest reserve is defined as a forest area for either production of timber and other forest produce (productive) and/or for the protection of water catchments and biodiversity (protective), controlled under the Forest Ordinance and declared by the Minister" (MNRT, 1998). Although the centralised management system provides legal protection for forest reserves, it does not effect protection as illegal harvesting continues in the reserves (Nduwamungu, 1996, Luoga *et al.* submitted a). The state ownership of land and/or natural resources weakens traditional systems of resource management that have functioned for hundreds of years, and consequently leads to profound changes in resource use, usually in the direction of overexploitation (Berkes, 1989). The biggest challenge for resource conservation is the trade-off between meeting present needs through agricultural production and forest-based products and the longer term conservation of resources.

Ethnobotanical and utilisation studies of communities living in miombo woodlands, which cover about 45% of Tanzania, have shown that resources are defined by use and culture (Mukamuri, 1989; Bruce *et al.*, 1993; Katerere, *et al.*, 1999; Luoga *et al.*, 2000b), and that the bulk of the forest-based needs of both urban and rural people in the miombo region are met from the woodlands (Clarke *et al.*, 1996). Rural people in savanna woodlands require ownership of or guaranteed access to land as a basic asset to ensure food security as well as reduce unemployment and poverty (Shackleton, 1996). In Tanzania, most woodlands in communal lands are neither managed nor have any legal protection, although administratively they fall under the jurisdiction of local governments. This exposes them to over-exploitation and degradation (Rodgers and Saleh, 1996; Matose and Wily, 1996). Some public lands are administered by fairly well-defined groups of villages, hence referred to as 'communal' lands, but the motive of profit maximisation from resource extraction and poor law enforcement allows individuals to overuse common resources (Luoga *et al.*, in press). Other natural forests in preserved land are exclusively state-owned and exclude resource-use rights for local people. However there are growing doubts about the effectiveness of forest reserves for sustainable resource management because of increased illegal exploitation following recent population increases and concomitant increased resource needs (Castro, 1991; Luoga *et al.*, submitted a).

Common property regimes in African rural settings are not strong (Katerere *et al.*, 1999). It is postulated however that resource degradation is not the result of the inherent failings of the common property regime, as in the 'tragedy of the commons' scenario popularised by Hardin (1968), but rather the erosion of local community rights and hence responsibility and capacity to manage resources (Gilmour *et al.*, 1989; Arnold and Stewart, 1991). These views regarding poor resource management under common property regimes call for a study to explore the potential of rural people as alternative custodians of resources.

The new Tanzania forest policy document (MNRT, 1998) recognises explicitly the role of the government, private individuals and local communities as stakeholders in resource conservation, but very few studies have been conducted on the perceptions of local people (Rodgers and Saleh, 1996) and mechanisms to involve local communities in resource management partnerships (Sjoholm and Wily, 1995). The concept of co-management is defined as the right of communities to share management power and responsibility with the state (McCay and Acheson, 1987), which is rooted in the concept of common property resources (CPR). The basic concept of CPR management is that local communities can manage common property resources successfully if they have the legal right, knowledge and institutional capacity to do so (Gilmour *et al.*, 1989; Arnold and Stewart, 1991).

The effectiveness of conservation management depends on the development of an integrated approach to management which incorporates both production and conservation. The aim of this study is to ascertain the local people's ownership rights, knowledge and institutional capacity, being prerequisites for the sustainable management of resources in miombo woodlands of Tanzania. The specific objectives of the study are: (a) to review the management strategies and control mechanisms which have been applied by the government to the woodlands since the start of colonial time in the late 19th century; (b) to analyse land use/cover changes between

1964 and1982 (under centralised planning) and from 1982 to1996 (under a more market-oriented economy); (c) to examine traditional management practices by local people that have been applied to maintain biodiversity in the woodlands; (d) to investigate how local communities are currently involved in managing the woodlands; (e) to examine the institutional capacity of local communities for managing woodlands; (f) to analyse land tenure and its implication for management of natural resources and (g) to recommend a mechanism through which local communities can best be involved in managing the woodlands in the future.

8.3 METHODS

8.3.1 Study area

The study was conducted at the Kitulanghalo Forest Reserve and the villages in the surrounding public (communal) lands. The area is located about 50 km east of the Morogoro Municipality along the highway to Dar-es-Salaam, which is about 150 km further east (Figure 8.1). The reserve was officially declared and gazetted in June 1955 as a 'productive reserve' indicating a primary objective of wood production with utilization controlled through the issuing of licences. In 1985 the reserve, which also serves as a water catchment, was closed for any utilisation although illegal harvesting continued (Nduwamungu, 1996).

Three villages, Lubungo, Maseyu and Gwata are in close proximity to the reserve, with their 16 hamlets scattered in the public lands around the reserve. The total population in the three villages is 4640 people in 1012 households. Although Lubungo and Gwata are traditional settlements, most people were moved from scattered settlements north of the reserve and concentrated near the highway during the resettlement schemes (villagisation policy) of 1974/75.

The annual rainfall is 900 mm, which is seasonally distributed, providing a wet season from November to May and a dry season from June to October. The annual mean temperature is 24.3 °C while the annual minimum and maximum temperatures are 18.6 °C and 28.8 °C respectively. This climate supports a regular rain-fed cropping regime, the main crops being maize, sorghum and peas. The farms in the area are reported to have low yields because of inherently infertile soil, lack of adequate soil moisture (Shayo-Ngowi *et al.*, 1995) and poor tools, as well as lack of markets (Luoga *et al.*, 2000b). In areas where woodlands are cleared for charcoal production, subsistence farming (shifting cultivation) is practiced in the more fertile (arable) patches. These patches are cultivated for about six years and then left fallow for about four years (Luoga *et al.*, 2000a). No cattle graze in the area because of the prevalence of tsetse flies transmitting *nagana* (sleeping sickness).

The major type of vegetation is open miombo woodland dominated by the tall tree species *Julbernadia globiflora*, *Brachystegia boehmii* and *Pterocarpus rotundifolius*. The most common smaller trees and shrubs are various *Combretum* species, *Diplorynchus condylocarpon* and *Dichrostachys cinerea*. The ground is covered by a tall grass layer nearly one metre high, which, forms a continuous matrix of fuel during the dry season, resulting in a high risk of large-scale woodland fires which are consequently common in the area.

8.3.2 Data collection and analysis

Data were collected over two months, December 1997 and January 1998, using participatory rural appraisal (PRA) and structured and semi-structured interviews. Visual PRA methods included participatory resource mapping. transect walks. time lines and chronologies, seasonal calendars, matrix scoring and the use of venn (pie) diagrams (Anon, 1990; Campbell *et al.*,1995). For example, venn diagrams were used to assess the relative perceived importance of each local institution. All institutions were written on pre-prepared manila sheets (pies) and villagers were told to place each institution in a big 'community' circle drawn on the ground, with proximity to the centre of the circle indicating high relative significance of the institution to the community.

Structured questionnaire interviews (Appendix 2) were administered to the heads of 80 households in eight hamlets of two villages. Maseyu and Gwata, representing a sampling intensity of 8% (Luoga *et al.*, 2000a). The selection of households was made systematically in order to obtain a representative sample in terms of wealth, gender and age classes. Unstructured interviews were used to obtain information from key informants who were two village leaders, and four government employees at local and provincial levels. Data from the interviews were analysed using cross-tabulation, descriptive and inferential statistics and content analysis. Use was also made of documented secondary information.

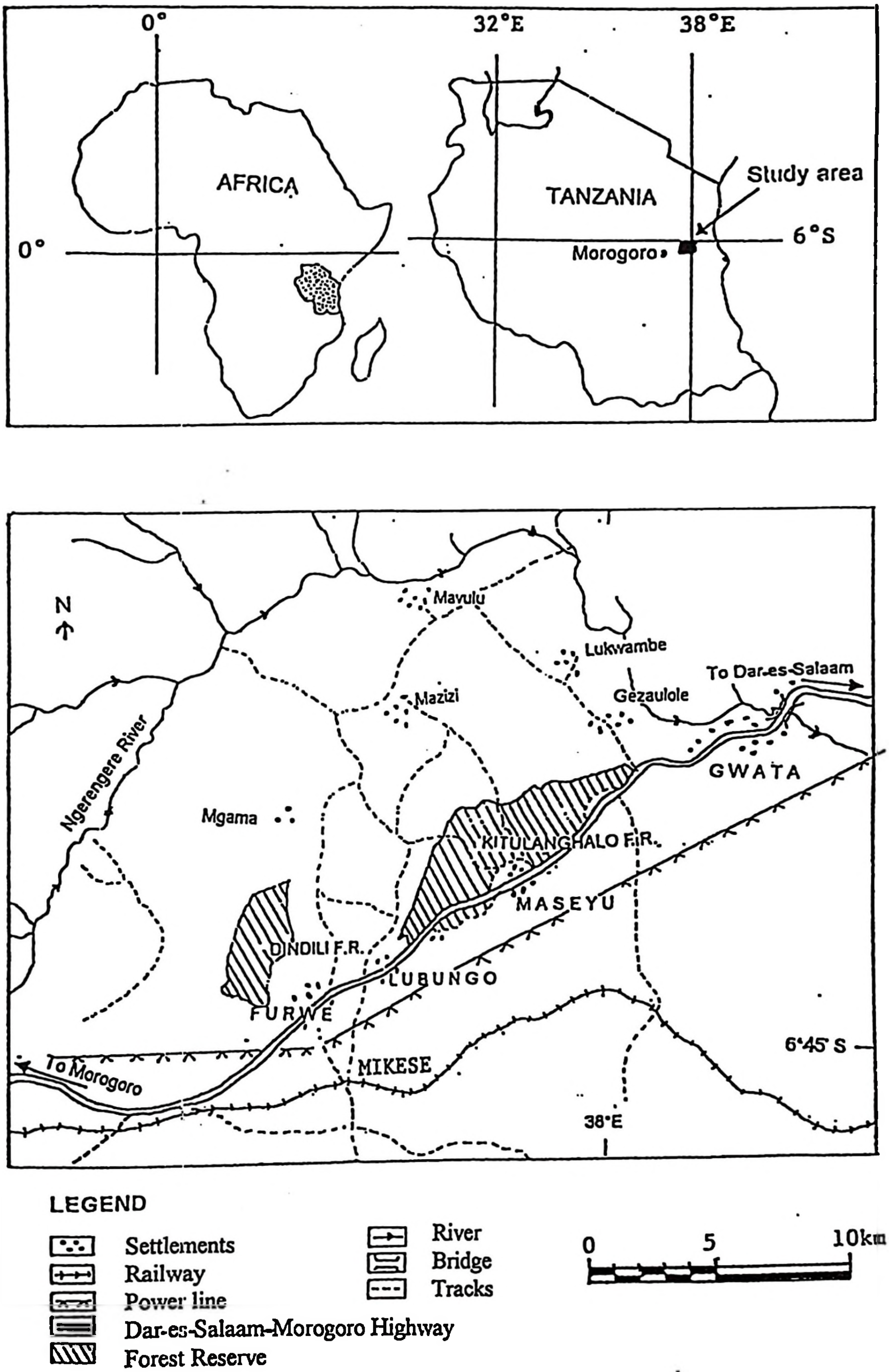


Figure 8.1 The location of Kitulanghalo Forest Reserve and surrounding public lands, Morogoro, Tanzania.

The land use/ cover analysis was based on 1964 and 1982 aerial photographs with scales of 1 : 36 000 and 1 : 72 000 respectively and the 1996 landsat image. The landsat TM image was of 1 : 50 000 scale and comprised three bands, 3 (blue), 4 (red) and 5 (green). From the aerial photographs and satellite images, the land cover maps were drawn to the scale of 1 : 100 000 showing distinctive broad-scale landscape units such as semi-evergreen forests, woodlands and sisal plantations. Unseparated units included (a) bushland and scattered cropland and (b) settlement and home gardens. Cartographic grid overlays were used to provide quantitative estimates of aerial land cover changes.

8.4 RESULTS

8.4.1 Past and current resource management by the government

During the pre-colonial era (prior to 1885), regulations governing the management of natural resources were based on customary laws which operated mostly through sanctions imposed in the event of contravention of regulations. The colonial administration between 1885 and 1961 was characterised by the creation of a centralised management system including the establishment of the Forestry Department in 1889. For more than 50 years the main activity of the department had been extraction of commercial timber for export, which was followed by the demarcation of forest reserves. The first forestry policy was adopted in 1953 and the first forestry ordinance was enacted in 1957 (MNRT, 1989).

After independence in 1961, the government continued operating with the colonial forestry policy although a few amendments were made. The chiefdom (traditional leadership) was abolished, resulting in further breakdown of those customary institutions which were traditionally responsible for local resource management. The adoption of the Arusha Declaration in 1967, which was the blueprint for a socialist state, consolidated centralised management by declaring public ownership of the land (TANU, 1967). The declaration of public lands, which cover 70% of the total forested area, effectively created 'open access' areas without any protection.

In 1982, the decentralisation programme was launched with the re-introduction of district councils (local governments) and public lands being put under the jurisdiction of local governments. Village governments then became statutory arms of local government. In the mid 1980's, Tanzania entered into an agreement with the International Monetary Fund (IMF) and World Bank to institute a structural adjustment programme (SAP) which essentially shifted the country from a centralised to a market-oriented economy. The changes under the decentralisation and SAP necessitated a review of the old forestry policy. Thus a new policy was drafted in 1986 and officially adopted in March 1998 (MNRT, 1998).

The Kitulanghalo Forest Reserve was gazetted in 1955, and has been under the control of central government (Forestry & Beekeeping Division). It was a 'productive' reserve and harvesting was controlled by issuing of licences, until 1985 when a total ban on harvesting in the reserve was established. The communal/public lands have been under the control of district foresters who were employed by the Morogoro district council. This parallel management system shows fragmentation in forestry activities as the forestry division had very little or no authority over district foresters who encouraged the exploitation of natural resources by issuing harvesting licences as one of the sources of revenue for the district council. Eighty percent of the revenue collected accrued to the district council and only the remaining 20% retained at the village where the revenue was collected.

8.4.2 Land use/cover changes between 1964 and 1996

In 1964, woodlands covered 82.3% in both the reserve and public lands. In the public lands, woodland has declined by 50% between 1964 and 1996 (Table 8.1), representing an overall mean annual decline of 1.6%. By 1996, woodland remained the dominant cover type, but had declined to 77.4% of the reserve and 41.2% of the public lands (Table 8.1, Figure 8.2).

In public lands, the long established relationship between people and their local environment has shaped the landscape of the study area, creating a mosaic of woodland, bushland, cropland, settlements, homegardens, plantations and forests (Figure 8.2). Most land degradation took place after 1974 when the people who were staying in scattered homesteads to the north of the reserve (Figure 8.2) were moved involuntarily to the south of the reserve along the Dar-es-Salaam–Morogoro highway (Figure 8.2). This was the implementation of the village resettlement scheme under the policy of socialism (TANU, 1967). The accelerated deforestation during and after resettlement can be accounted for by increased demand for woodland resources for building materials as well as for more farm land.

Farming was the major expanding land use in public lands, as the scattered croplands and bushlands increased from 5.6% of the land in 1964, to 39.0% in 1996 (Table 8.1). Between 1982 and 1996 some people moved back to the old settlements (Figure 8.2). This was apparently due to the failure of the resettlement schemes, and their search for more land for shifting cultivation and for better stocked woodlands for charcoal production after those near the highway had been depleted (Luoga *et al.*, submitted a). The demand for charcoal, especially in Dar-es-Salaam, has risen considerably since the 1980's (Shechambo, 1986) triggering increased demand from woodlands near the city and along the highway (Monela *et al.*, 1993; Luoga *et al.*, submitted a).

In 1964, a large tract of land south-east of the study area was covered by sisal plantations (Figure 8.2) which created employment for both locals and people from other parts of the country. These plantations were abandoned because of the fall of the world market prices for natural fibres in the 1970's and they subsequently reverted to bushlands (Table 8.1, Figure 8.2).

Since 1955 the highway was the main southern boundary of the reserve. The impact of the highway had remained negligible at least until 1964, but the re-alignment and construction of the tarmac TANZAM (Tanzania–Zambia) highway in 1971 (referred as the Dar-es-Salaam–Morogoro highway) was the main reason for confusion over boundaries and subsequent encroachment into the south west part of the reserve (Figure 8.2). The encroached area represents about 5.7% of the reserve most of which was woodland has subsequently been converted into scattered croplands and bushland.

8.4.3 Tenure rights for natural resources

According to the 1983 agricultural policy, all villages were to be surveyed, mapped and provided with 999-year title deeds. A village could then sublease the land under its statutory entitlement to individuals for renewable 33 year periods.

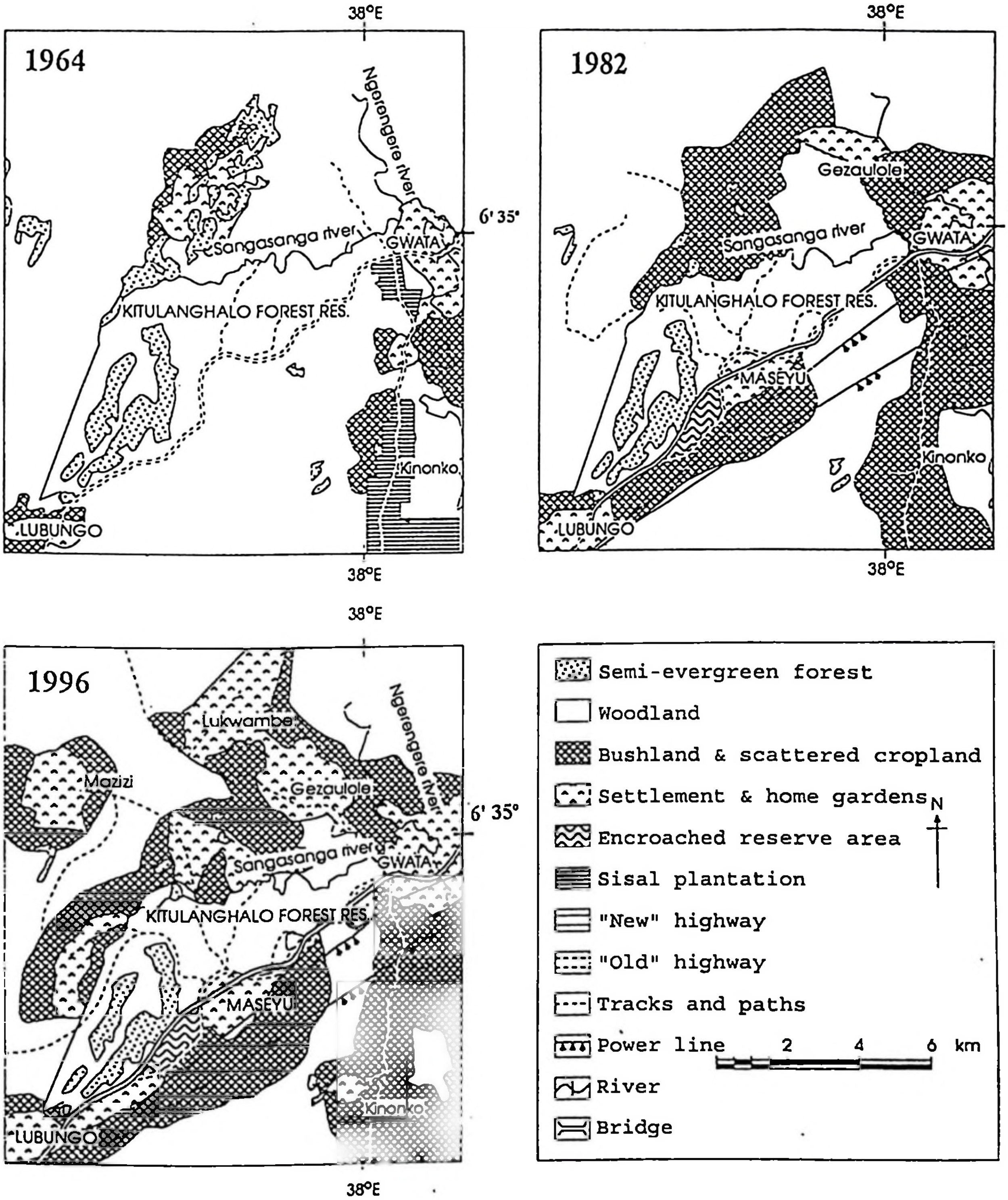


Figure 8.2 Land use/ cover in 1964, 1982 and 1996 in Kitulanghalo Forest Reserve and surrounding public lands, Morogoro, Tanzania.

Table 8.1. Land use/cover changes (1964–1996) in the Kitulanghalo Forest Reserve (2 452 ha) and surrounding public land (16 464 ha) in Morogoro, Tanzania

Protection Status	Year	Woodland			Bushland and scattered croplands			Settlement and homegardens			Sisal Plantations			Semi-evergreen forests		
		Area (ha)	% cover	% change	Area (ha)	% cover	% change	Area (ha)	% cover	% change	Area (ha)	% cover	% change	Area (ha)	% cover	% change
Forest Reserve	1964	2018	82.3		0	0		0	0		0	0		434	17.7	
				-5.9			∞			0			0			-4.8
	1982	1899	77.4		140	5.7		0	0		0	0		413	16.8	
				0			0			0			0			0
	1996	1899	77.4		140	5.7		0	0		0	0		413	16.8	
	Overall change 1964 – 1996			-5.9			∞			0			0			-4.8
Public land	1964	13558	82.3		917	5.6		841	5.1		741	4.5		407	2.5	
				-20.7			444			48.0			-100			-76.2
	1982	10753	65.3		4985	30.3		1245	7.6		0	0		76	0.6	
				-36.9			28.6			155			0			-21.6
	1996	6780	41.2		6413	39.0		3174	19.3		0	0		97	0.5	
	Overall change 1964 – 1996			-50.0			599			277			-100			-48.9

One village (Gwata) was surveyed in 1994 but the survey report has not yet been submitted, while the second village (Maseyu) has never been surveyed and mapped. Interestingly, during PRA it was found that villagers had clear perceptions of their village boundaries despite a lack of cadastral maps of the area. In 1996 settlements and homegardens covered an area of 3 174 ha (Figure 8.2) and were owned by individual households, with an average of 3.1 ha household^{-1} (3 174 ha / 1 012 households). This land is more or less freehold and could be acquired through inheritance, while land located outside the settlements and home gardens within the public land (>13 000 ha) fell under a common property management regime where every member of the community was free to utilise it for farming or collection of wood resources. In 1996 the villages had no written by-laws governing the use of land and other resources, indicating weak tenure rights to land and other resources, thus exacerbating misuse of resources.

The questionnaire survey revealed that 90% of villagers preferred cultivation in communal lands, a significantly higher proportion than the other preferences such as tree cover (7.5%) or grazing (2.5%) ($\chi_2^2 = 173.8$, $p < 0.0001$). Thus, local people were much more concerned about food security than about wood-based products or conservation. The significantly low percentage preference for grazing, is attributed to the presence of tsetse flies in the area. Elsewhere in the tsetse fly-free areas in the country and in large parts of Africa, cattle is regarded as a symbol of wealth and its intrinsic value is high.

8.4.4 Local managerial knowledge and practices

A large proportion of respondents agreed that wild fires were hazardous as they destroy houses (42.0%) and the environment (21.5%). Other negative impacts mentioned included killing small trees and animals and destroying farm crops. Respondents gave a wide range of causes of wild fires in the area, including flushing out game for hunting (48.8%) and careless disposing of cigarette butts by motorists and pedestrians (17.5%) (Figure 8.3). Of the villagers, 78.5% had attended fire seminars where they were educated on fire control especially when preparing land for farming where fire is used as a tool for land-clearing (slash and burn). The low percentage of fires attributed to land preparation (Figure 8.3) indicated the success of the seminars.

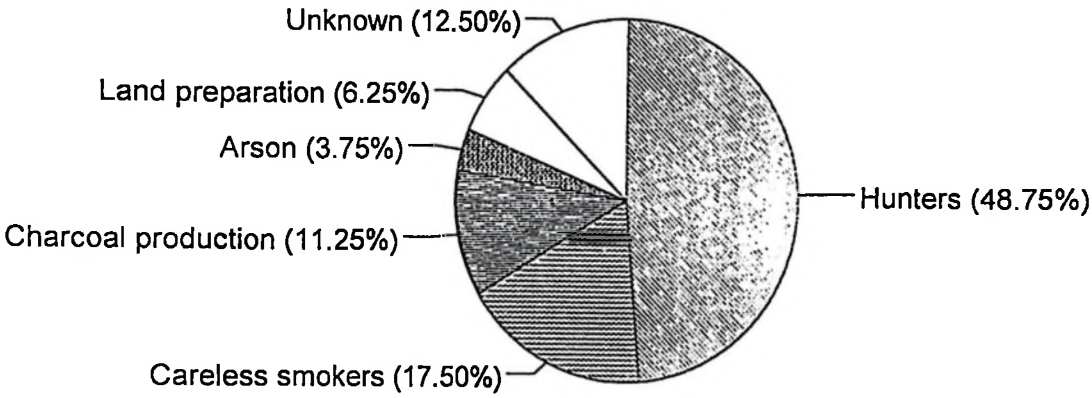


Figure 8.3 Responses concerning the causes of wild fires in Kitulanghalo Forest Reserve and public lands in Morogoro, Tanzania. n = 80 respondents, $\chi^2_5 = 64.9$, p <0.0001.

More than 90% of the respondents mentioned individual trees which were regarded as sacred. These were *Adansonia digitata*, *Sterculia africana* and *Sclerocarya birrea* subsp. *caffra.* Only 41% commented on the prohibition of cutting sacred trees while more than half of the respondents acknowledged that there were no rules regarding the conservation of sacred trees. Of the villagers interviewed, 66.2% mentioned that they were unaware of any ritual places in the forest. The remaining community members who were aware of the existence of ritual places reported that the main regulations concerning sacred sites prohibited cutting trees or setting fires. However, there were no punitive measures for transgressors, which clearly indicated an attenuation of customary laws regarding resource conservation.

Of the residents interviewed, 71.3% mentioned that they participated in the protection of the woodlands (both in communal land and reserve) mainly through reporting offences or by fighting wild fires, but there was no systematic patrolling by community members. Of the villagers, 86.3% have planted exotic trees, of which 68% were fruit trees (mostly mango, orange and pawpaw) and only 32% are trees for wood (mostly *Senna siamea*). Although the mean number of exotic trees per household was 16 ± 2.8 (SE), the area of planted trees was difficult to estimate because trees were scattered around homesteads and farms. The major reason given for the lack of extensive tree planting (41.3%) was the lack of seedlings (Figure 8.4). The villagers have no tree seedling nurseries and normally depend on hand-outs from the district council nurseries.

Of the households interviewed, 56% have retained and nurtured indigenous trees on their farms or around their homesteads. The average number of indigenous trees kept by these households was 5.7 ± 0.6 trees per household. Trees were retained and nurtured to provide shelter when working on farms or resting/shade around homesteads. Some of the trees were preserved because they are sacred, medicinal, bear edible fruits, or simply were too big to cut. Generally trees were retained so that they did not cast much shade on agricultural crops; one of the prerequisites for the selection of trees in agroforestry schemes.

When asked about their views on how to improve the management practices for natural forests in the area, 86.1% of the respondents made suggestions, the main ones being that the government should place more emphasis on law enforcement (18.7%) and that local people should be involved in utilising and safeguarding the resources (Table 8.2).

8.4.5 Current institutional capacity

Both the central and local governments have insufficient technical and law enforcement staff. The reserve (2 452 ha) was manned by two forest attendants. Communal lands, which were far more extensive than the reserve (>13 000 ha), had only three attendants, each of whom collected revenue from licenced woodcutters and controlled illegal exploitation from one village. Forest attendants patrolled on foot (not even bicycles are provided). This extremely low capacity of the central and local governments indicates a clear need for involving local people in safeguarding the resources.

The two villages surveyed have more or less similar local institutions, which could be grouped as governmental, religious, political and social. In both villages, the village government was the most important institution (Figure 8.5). Each village had a democratically elected chairman and a village executive officer who was employed by the local government. Each village was divided into five hamlets, with each hamlet having an elected leader. The hamlets, in turn, were sub-divided into groups of about ten households each, each group with an elected leader. Therefore, village government is the most legitimate local institution because it represents all members of the community.

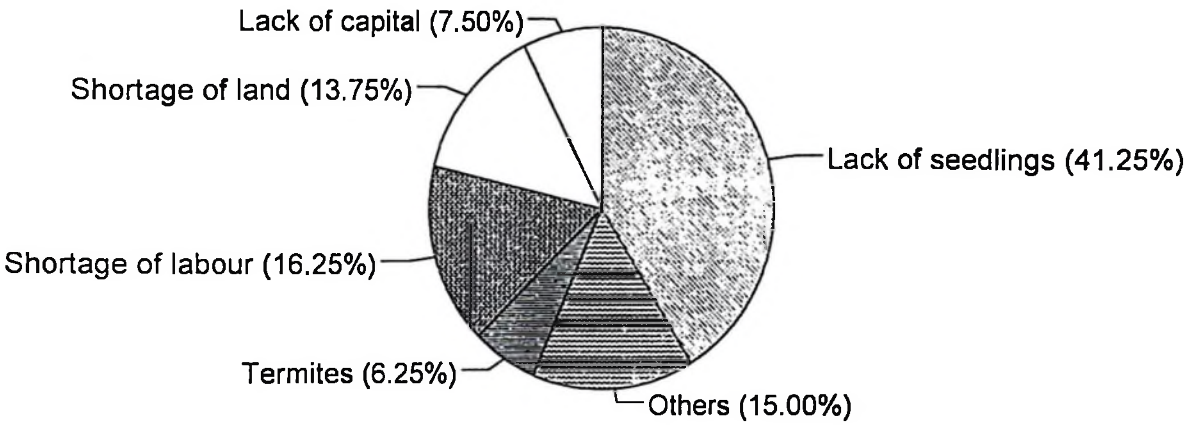
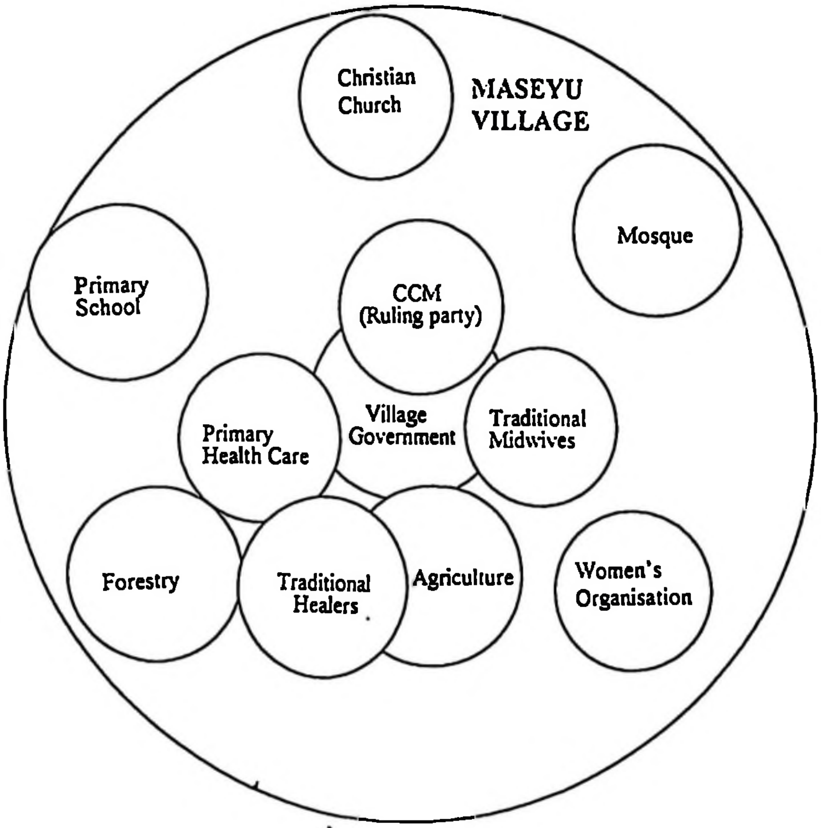


Figure 8.4 Responses concerning the limitations to tree planting in communal lands surrounding the Kitulanghalo Forest Reserve in Morogoro, Tanzania. n = 80 respondents. $\chi^2_5 = 43.7$, p= 0.002.

Table 8.2 Local people's suggestions on practices to improve forest management in the Kitulanghalo Forest Reserve and communal woodlands surrounding the reserve in Morogoro, Tanzania (n =80 respondents).

Suggestions	Responses (% of respondents)
1. The government should place more emphasis on law enforcement	18.7
2. Local people should be involved in utilising and safeguarding the resources	16.2
3. There should be strict control over harvesting trees, especially for charcoal and timber	13.7
4. Plant more trees to reduce the demand from the forest	13.7
5. Hold more seminars to sensitise people on woodland management	10.0
6. Control wild fires	10.0
7. Expand employment opportunities to reduce pressure on the forest	3.8
8. No comment	13.9



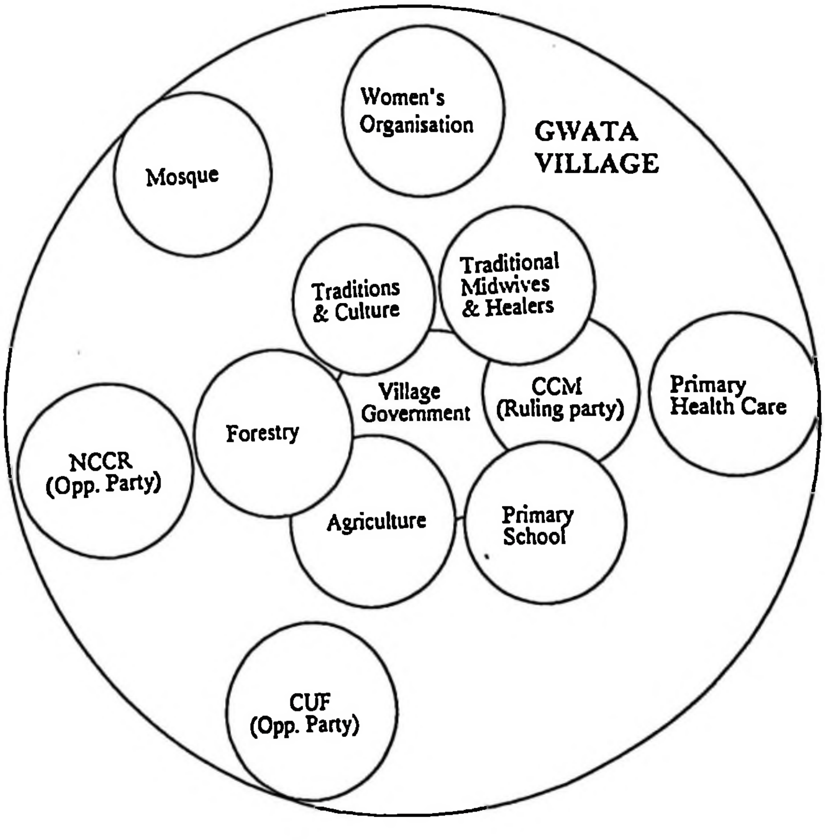


Figure 8.5 Venn (Pie) diagrams indicating the relative importance of local institutions to the community in Maseyu and Gwata villages, Morogoro, Tanzania.

The prevailing kinship is patri-linear with men taking the dominant status in families. This kinship is also augmented by religious beliefs as most of the residents are Moslem. Only 13% of the households were headed by females (unmarried or widowed). The PRA daily activity profiles with respect to gender indicated that men had more leisure time compared to women. Men were expected to deal mostly with farming activities and sometimes they produced charcoal for the market. Women collected firewood, fetched water and attended to all household chores despite participating fully in farming activities. Thus unless there are deliberate efforts to involve women in decision-making, they will continue to have subordinate positions although they form an important user-group of natural resources.

8.5 DISCUSSION

8.5.1 Land use/cover changes

Factors that have lead to marked changes in land use and hence vegetation cover in the area including and surrounding Kitulanghalo Forest Reserve include: (1) the concentration of people during resettlement schemes; (2) the Dar-es-Salaam –Morogoro highway; (3) shifting cultivation; (4) commercial harvesting of wood for charcoal and (5) population growth.

(1) The concentration of people into nucleated settlements during the resettlement schemes resulted in land degradation (Figure 8.2) and in other places in the country a complete disruption of traditional land management systems (Kikula, 1986b). The villagization (resettlement) programme failed to consider the environmental implications and set in motion a chain of events that culminated in land degradation (Kikula, 1986b; Kaoneka and Solberg, 1994; Yanda and Mung'ong'o, 1997). Thus, poor planning by government institutions can lead to environmental destruction.

(2) The highway users including motorists have been implicated in starting wild fires through careless disposal of cigarette butts (Table 8.2). The highway has been connected with disturbances which affect the structure of the vegetation as there was a clear trend of decreasing wood stocks with distance from the highway (Luoga *et al.*, submitted a). The highway has also contributed to the boundary encroachment in the reserve (Figure 8.2). Thus, though development projects like highways are

essential in developing the economy of a country, they can have a negative impact on the environment.

(3) The increase in land under cultivation is also fueled by shifting cultivation. The short 10-year cycles of farming and fallow (Luoga *et al.* 2000a) have changed the 'forest' fallow (long time cycles to allow succession to original woodland) into bush fallow (short time cycles), resulting in woodland degradation. However. shiftingcultivation has been shown to increase woody species richness in the area compared with permanent cultivation. The patchwork in the landscape after abandonment of the land provides opportunities for different functional groups of species without the disappearance of the original species (Luoga *et al.*. submitted b). Permanent cultivation results in reduced species richness in miombo woodlands because it involves a complete change of land use (Campbell and du Toit, 1994; Rodgers, 1994).

(4) The commercial harvesting of trees for charcoal is another cause of the decline of woodlands by 36.9% between 1982–1996. This higher decline than between 1964–1982 coincides with the increased demand for charcoal in Dar-es-Salaam (Shechambo, 1986) and the introduction of the market economy in the country. Trade is market driven, thus the control of wood and charcoal markets in urban centres will reduce the demand from the woodlands. Energy sources which can be used as substitutes for charcoal as domestic fuel in urban centres are electricity, coal, natural gas, solar energy, and petroleum products (Ministry of Water Energy and Minerals –MWEM, 1992), although with the increased price of oil in 1999/2000, the latter is unlikely to be economically viable Among these. electricity has great potential, although only 5% of the entire population in the country have access to electricity (MWEM, 1992). A complementary approach would therefore be to promote the use of substitute energy sources in order to reduce pressure on the woodlands.

(5) Population growth causes degradation directly through increased resource consumption and indirectly through fueling poverty and the breakdown in social institutions. Although there is no specific population data, the increase in the settlement and homegarden cover by 277 % from 1964 to 1996 (Table 8.1) indicates a considerable population increase. Thus, population pressure is one of the root

causes of deforestation and land degradation, yet in planning efforts for natural resources, population aspects tend to be neglected (Ahlbäck 1995).

8.5.2 Local management systems

Retaining indigenous tree species in farm plots seems to be an important aspect of indigenous forest management in the area. Elsewhere in the country there are reports of farmers planting or nurturing indigenous species on their farms and being reluctant to plant exotic trees in fear of depletion of soil nutrients and water (Mgeni, 1992; O'Kting'ati and Mvena,1992; Kajembe, 1994). Other practices, which aid conservation in the study area, are taboos against cutting certain tree species, respect of burial sites as sacred groves and collection of dead wood for fuelwood (Luoga *et al.*, 2000b). Thus although most of the customary rules were dismissed, some traditional practices were still applied to maintain biodiversity in the area.

Fire is an important tool in natural regeneration of miombo woodlands as it is a useful pre-treatment agent for seeds of certain species (Msanga, 1998) and is a traditional tool for land preparation and hunting (Figure 8.3). Although fire seminars have reduced accidental fires (Figure 8.3), it is difficult to eliminate wild fires due to the range of causes. The best alternatives would be to make firebreaks on each side of the highway and reduce the fuel load through deliberate early season burning (May–July) which affects mainly the herb and shrub layers whereas late season burning (August–September) can completely destroy fire sensitive species (Trapnell, 1959; Chidumayo, 1993a). This suggestion calls for more fire seminars to the villagers who are expected to participate most in safeguarding the woodlands against uncontrollable fires.

The preference for farming on public lands indicated the importance of food security to the rural people. Edible fruits from indigenous trees are consumed exclusively for subsistence (Luoga *et al.*, 2000a). Where food production and generation of income take priority, other conservation goals provided by trees (e.g., biodiversity conservation) are subverted. The extensive planting of exotic fruit trees on the farms could reflect not only their dietary importance to the people but also the economic potential of the fruits which may be sold for cash in local markets or along the highway, as farmers adopt agroforestry practices when clear economic incentives to do so arise at regional and household levels (Scherr, 1995).

The lack of incentives to maintain communal/public land under tree cover could also be attributed to there being no perceived scarcity of wood-based products. For example, a study by Luoga *et al.* (2000b) indicated that problems relating to wood-based products were ranked lowest among socio-economic concerns raised by the people. This calls for more extension services in order to educate people on the importance of maintaining the tree cover in the area, a suggestion made by some of the community members themselves (Table 8.2).

8.5.3 Land tenure and its implication for resource management

Although wood harvesting and land clearing for the purpose of cultivation was permitted for the members of the community (Luoga *et al.*, 2000a), human rights are compromised because land tenure is not clearly defined. Although co-management by conflicting right-holders may offer a solution to conflicts involving overlapping tenure niches (Bruce *et al.*, 1993), there are considerable social, institutional and land tenure drawbacks which need to be addressed before contemplating any forms of partnership in resource conservation. Conservation activities such as maintaining land under tree cover are normally not supported by local communities, particularly when they result in reduced access to resources, employment and income (Wild and Mutebi, 1997).

The continuing decline in aerial woodland cover in the communal lands which also leads to loss of plant diversity (Luoga *et al.*, submitted b) suggests that common property regimes and local institutional capacities are weak in enforcing control mechanisms to check the overuse of resources. These sentiments are expressed in the country's new forestry policy which questions the technical capacity of local governments on forestry activities (MNRT, 1998). Customary controls over the woodlands have the greatest potential for being effective (Dème, 1998; Hilhorst and Coulibaly, 1998), but it is difficult to implement these control systems in Tanzania due to the breakdown of the socio-political system as a result of revoking traditional leadership and the imposition of centralised control of land by the state (Lane and Scoones, 1993). Similarly in Namibia, erosion of the power and status of traditional leaders contributed significantly to the development of 'open access' situations in much of the country's communal lands which resulted in considerable land degradation (Jones, 1999).

8.5.4 Resource conservation: present and future participation of local people

As the main users of resources from the communal woodlands, local people have to be given full responsibility for managing the public lands. The ownership of resources will eventually create a sense of responsibility, which will lead to effective policing especially against 'outsiders' who seem to have no long-term interest in the local resources (Luoga *et al.*, 2000a). In order to improve policing in public lands, tax derived from wood harvesters and retained at the village level could be ploughed back into the community as salaries and bonuses for forest guards. However, the vesting of powers in local people should only be done after instituting stronger rights to resources, and the operation of the rule of law in supporting these rights (Shackleton and Shackleton, 2000).

One way to build local capacity for managing natural resources is to offer local residents the chance to gain formal conservation skills directly through workshops (paraprofessional training) (Tuxill and Nabhan, 1998). In social forestry, paraprofessional training may give local residents greater skills in seed collection and treatment, establishment of nurseries and field planting of valuable trees which have been depleted because of overexploitation. However, social forestry programmes such as the establishment of woodlots are more likely to fail than succeed due to insecurity of land tenure. A complementary approach may be to improve farming and help people to engage in alternative cash generating activities (Luoga *et al.*, 2000a). The improvement of the current traditional agroforestry system could be a viable option. However, very limited research has been done on suitable agroforestry systems in miombo woodlands compared with the fertile highland areas (O'Kting'ati, 1984b).

The protection of the Kitulanghalo Forest Reserve is relatively well effected compared to communal lands (Luoga *et al.*, submitted a; Figure 8.2). It is thus recommended that the reserve should continue to be managed by the central government despite a view that participation of local communities is a means of sustaining protected areas (de Bour and Baquete 1998). The low pressure in the reserve is because of the extent of woodlands and bushlands in public land (>13,000 ha). However, local people should assist in policing against wood-poaching and assist with fire management in the reserve. The full involvement of local people in utilization and management of forest reserves becomes crucial only when people have limited alternative sources of resources (Wild and Mutebi 1997). It is suggested further that local people should participate in protection of the reserve by 'material incentives', where people can provide labour in return for free collection of firewood, medicines and wood . The latter can be obtained from harvested materials especially the valuable wood of *Spirostachys africana* which should be thinned in the reserve as a silvicultural operation to increase productivity (Luoga *et al.*, submitted c).

Despite the relatively small size of the surveyed villages, their well-structured legitimate village governments show that 'traditional institutions' are being reconstructed to meet current needs. Similar features have facilitated the enforcement of regulations in other places in Tanzania, Zimbabwe and Mali where village teams patrol their territories to ensure that natural resources are being exploited in accordance with their by-laws (Sjoholm and Wily, 1995; Matose and Wily, 1996; Dème, 1998). Thus, although socialism has failed to attain its objectives in Tanzania, villages have became the basic units in the social structure of the country and the most appropriate unit of action for rural development (Ahlbäck, 1995)..

The implementation of meaningful development initiatives based on sustainable harvesting of savanna resources, requires the practice of multi-purpose land use management to be fostered at all levels from grassroots to policy makers (Shackleton 1996). The lack of well-defined land tenure in the study area is likely to limit local people's capabilities as custodians of the resources (Ham and Theron, 1998). Experience gained from the Zimbabwean Communal Areas Management Programme for Indigenous Resources (CAMPFIRE) projects suggests that the full leap to local proprietorship of resources is possible provided that government agencies maintain a facilitatory and regulatory role (Child, 1996).

8.6 CONCLUSION

The village governments have introduced a hierarchy which mimics traditional local institutions that were responsible for management of natural resources prior to the colonial period, although their capacities have to be strengthened. The issues of land tenure and village empowerment to promote resource conservation are not only institutional, but political in nature and are largely beyond the control of local communities. Social forestry projects, for example, which will reduce the exploitation of natural forests will only be successful when land and tree tenure systems are clearly defined and desirable seeds/seedlings are available. This calls for government institutions, especially the central government and district councils, to provide and motivate for an enabling environment, such as:

- provision of appropriate usufructary rights as incentives for protecting resources in the reserve and public land
- motivation for defined property and tenure rights over land and other resources in public land
- equipping local people with the formal skills and knowledge needed to manage natural resources (paraprofessional training)
- acknowledgement of positive indigenous management systems and applying them in sustainable resource management
- assistance in improving agricultural systems and provision for alternative cash generating activities
- promotion of the use of substitute energy sources to reduce pressure on the woodlands.

As the main stakeholders, the local people in turn are expected to play the following roles:

- management of natural resources in public lands
- participation in protection against illegal exploitation in the forest reserve
- formulation and enforcement of by-laws
- collection of revenue to be used for resource policing
- involvement in social forestry e.g., establishment of woodlots to reduce pressure on the woodlands.

CHAPTER 9

Synthesis and general discussion

9.1 INTRODUCTION

People are an essential part of the fabric of landscapes, as there is probably no ecosystem which remains unaffected in at least some way by human disturbances (Brunckhorst *et al.*, 1997). Human modification of land-cover has created fragmented landscapes retaining patches of natural vegetation cover within areas converted to other land uses (Chapter 8). The long term viability of such remnants has recently been recognised as a cause of concern (Beer and Fox, 1997).

The inherent connectivity of nature, including human component suggests that the compartmentalised institutional approaches are limited in resource conservation (Odum, 1982). Similarly in chapter 8 it is shown that local people should be encouraged in their active participation in natural resource conservation. Local people and researchers have their own well developed sets of skills and knowledge bases (Chapter 2). Therefore, both would benefit from access to the others' knowledge because they are fundamentally complementary. The objectives of this chapter are: (i) to provide methodological recommendations for similar studies in other savanna ecosystems (ii) to discuss the broader pertinency of this study elsewhere and especially in African savannas and (iii) to indicate areas for future research, required to provide even better management practices.

9.2 METHODOLOGICAL RECOMMENDATION

There is a need to standardise the methodologies of collecting ethnobotanical, socio-economic and ecological data within savanna ecosystems to facilitate comparison of results. For example, the use of modified Whittaker nested plots (Stohlgren *et al.* 1995) has allowed direct comparability between this study (Chapter 6) and that of Shackleton (2000a) in a South African savanna. Whittaker plots also provide the facility of constructing species-area curves (Chapter 6) making it possible to compare areas where plots of different sizes have been used. Quantitative methodology in ethnobotany is another area where standardisation is important. The ordinal ranking system of Prance *et al.*(1987) distinguishes between major and minor uses and is an improvement over the simple percentage useful calculations; consequently it was used in this study (Chapter 2) and should be used in others. Another useful method is the informant-indexing technique which is centred on local people's opinions on the utility of various species (Phillips and Gentry, 1993).

In savanna ecosystems and particularly in miombo woodlands, there is a paucity of ecological data (Desanker *et al.*, 1997). Permanent sample plots (PSPs) have to be established over a wide range of land uses and sites (replication) to determine variability in regeneration, growth and mortality. The measurements to be collected from PSPs and the methods for taking them should be standardised to facilitate data exchange and establishment of a common database within the miombo and for savannas in general. For example, the establishment of a database on a website for the region of standardised data, will stimulate new questions, encourage collaboration among researchers and reduce duplication of effort. This recommendation has also been put forward by the International Geosphere-Biosphere Programme (IGBP) / Land-Use and Cover Changes (LUCC) miombo network (Desanker *et al.*, 1997). Indeed, the network, in collaboration with the Global Environmental Change Programme of the University of Virginia has produced a LUCC CD-ROM with some useful data sets which include information on the source of the data. However, the majority of the data available at present are biophysical, with very little detailed socio-economic data. This reflects the critical need for collation and synthesis of socio-economic data across the region.

9.3 GENERAL SYNTHESIS

9.3.1 Land degradation within savannas

Land degradation is defined as an irreversible change in land use. Changes are considered irreversible if recovery takes ≥10 years (Nelson, 1988). Three forms of land degradation can be identified (Nelson, 1988): (1) loss of economic potential to produce goods and services of direct human-use value; (2) loss of ecological function necessary to maintain ecosystem processes; and (3) loss of biodiversity at the ecosystem, community or genetic level. This study has identified that human disturbance at the current levels results in the loss of economic potential of miombo woodlands (Chapters 3 and 4) and loss of biodiversity (Chapter 6). Although the loss of ecological function could not be dealt with in detail, the significant reduction in biomass and changes in vegetation structure in the public lands (Chapter 5) could be used as surrogates for the potential loss of ecological function (Chapter 1). Thus, despite the high resilience of miombo woodlands to disturbance (Chapter 7), land degradation is taking place.

Land degradation due to charcoal production near highways and cities has been reported elsewhere in miombo woodlands (Chidumayo, 1991; Monela *et al.*, 1993; Brigham *et al.*, 1996). Similar studies at different localities away from cities and at a much broader scale are necessary and thus determine whether what is occurring in and around Kitulanghalo is a local phenomenon or a general biome-wide trend. If the latter, there are very serious consequences for the persistence of miombo woodlands in Tanzania and Africa.

The social and economic reasons for irreversible declines in the production potential of the world's savannas are complex but are generally associated with increased grazing pressure, deforestation for charcoal production and firewood, unsustainable agricultural practices and inappropriate fire regimes (Young and Solbrig, 1993; Mistry, 2000). All these factors (which also apply in the study area, with the exception of high grazing pressure) are anthropogenic in nature, yet in the past, the human dimension has been excluded from most ecological studies and planning (Young and Solbrig, 1993; Ahlbäck, 1995).

In the African savannas, superficial studies have blamed the "local people's ignorance, apathy and bad farming methods for land degradation" (Kinlund, 1996). This study has shown that the underlying causes, which are poverty, population pressure and government policies triggered the process of land degradation. Government policies in Tanzania date back to colonialism when more than 70% of the forested land was taken out of local-community control and left as open access without any protection (Chapter 8). The pre-colonial allocation of land by traditional heads was also common in the savannas of southern Africa (Mentis and Seijas, 1993; Murphree and Cumming, 1993), west Africa (Mistry, 2000) and the *cerrado* and *ilanos* of central and southern America (Redmond and Spencer, 1994). Lack of security of land tenure after colonialism has also been reported in Indian savannas (Gadgil, 1993), Zimbabwe (Murphree and Cumming, 1993; Dahlberg, 1994), South Africa (Mentis and Seijas, 1993; Dahlberg, 1994), Botswana (Kinlund, 1996), Mozambique (Dahlberg, 1994), Angola (Dahlberg, 1994) and Central and South America (Redmond and Spencer, 1994; Mistry, 2000). In each case the root cause of land degradation was colonial mis-management.

Rural communities in Brazil also depend on medicines, firewood and building materials from savannas for subsistence (Ahlo and Martins, 1995). Similarly, the production of charcoal for the steel industry in Brazil exerts most of the pressure on the *cerrados* (Mistry, 2000). The use of fire as a management tool (Chapter 8) is common throughout miombo woodlands which probably constitutes the single largest area burned in the world (Scholes, 1996). Fires are also the oldest, cheapest and most widely used tool in the central and south American savannas (Anderson and Posey, 1989; Coutinho, 1990). Woodland fires are an important source of trace gas emissions (e.g., methane, carbon monoxide and nitrous oxide) which contribute to the green house warming effects (Scholes, 1996). Prescribed burning, is now being recognised as an effective tool for averting uncontrolled late season wildfires in the central and south American savanna (Mistry, 2000) as has also been recommended in this study (Chapter 7).

Changes in land use / cover from woodlands to bushlands or settlements (Chapter 8) have an impact on environmental processes, such as increased albedo, increased air temperatures, reduced carbon storage and transpiration and affect hydrology and local microclimate (Malaisse, 1978; Shukla *et al.*, 1990). The IGBP / LUCC miombo network is aimed at understanding these impacts at a regional level (Desanker *et al.*, 1997). Remotely sensed satellite data can play a major role in the regional project. The miombo region is within the coverage of the South African receiving station at Hartesbeesthoek, although the high cost of high resolution satellite data will be an obstacle to its ready acquisition.

9.3.2 Interdisciplinary resource management

The results of this study have shown that almost all socio-economic and biophysical interactions presented in the conceptual model (Figure 1.1, Chapter 1) are pertinent in the study area. However, for natural resource conservation, the biophysical, socio-economic and socio-political factors in are linked in a more complex system of cause and effect than conceptualised earlier. Current planning and natural resource management paradigms commonly fail to employ methodologies that will contribute information essential to coherent decision making (Brunckhorst *et al.*, 1997). This study has shown that natural resource conservation problems cannot be treated separately by fragmented institutions and policies.

The similarity of socio-economic drivers which led to land degradation in the miombo woodlands and the world savannas at large suggests that the sustainable management recommendations given in this study (Chapter 8) may be applicable to other savannas world-wide. The over-arching inter-disciplinary model (Figure 9.1) may thus be developed further in different environments through quantitative simulation (what if questions). Simulation models of plant community dynamics have been developed in the miombo region (e.g., Desanker and Prentice 1994). However, the use of modeling to achieve integration among ecological and economic disciplines is a recent development in African savannas. Ecological Economics (2000), volume 33, issue no 3 includes seven papers on land use options in dry tropical woodland ecosystems in Zimbabwe. Each of these papers was developed from a model, and components of these models were used to prepare an integrated model of woodland and landuse in western Zimbabwe which includes aspects of ecology, woodland use by people and the state, agriculture, population growth, other land-uses and carbon sequestration (Campbell *et al.*, 2000). For example, the ecological model showed that removing trees in miombo woodlands and reducing the levels of grazing by livestock causes an increase in grass fuel load and a corresponding increase in the frequency of fires (Gambiza *et al.*, 2000). Another important finding was that carbon sequestration outweighs many of the local use values in net present value (NPV), but lack of compensation for maintaining some woodlands as carbon stores understandably creates strong incentives for households to convert woodlands to agricultural land (Kundhlande *et al.*, 2000). Therefore models are important inter-disciplinary tools because one can generate different scenarios to test different options and management strategies.

In the past, the study of indigenous knowledge systems and traditional land practices was conducted solely by anthropologists, but it has now come to be seen as a valuable source of information for other scientists as well (Gadgil *et al.*, 1993; Chapters 2 and 8). Dahlberg (1994) quoting different studies on land degradation in southern Africa, acknowledged the usefulness of involving local people in conservation studies. Irons (1997) proposed the innovative approach of Whole Catchment Management (WCM) in Australian savannas, which is a holistic and integrated approach to natural systems management and conservation.

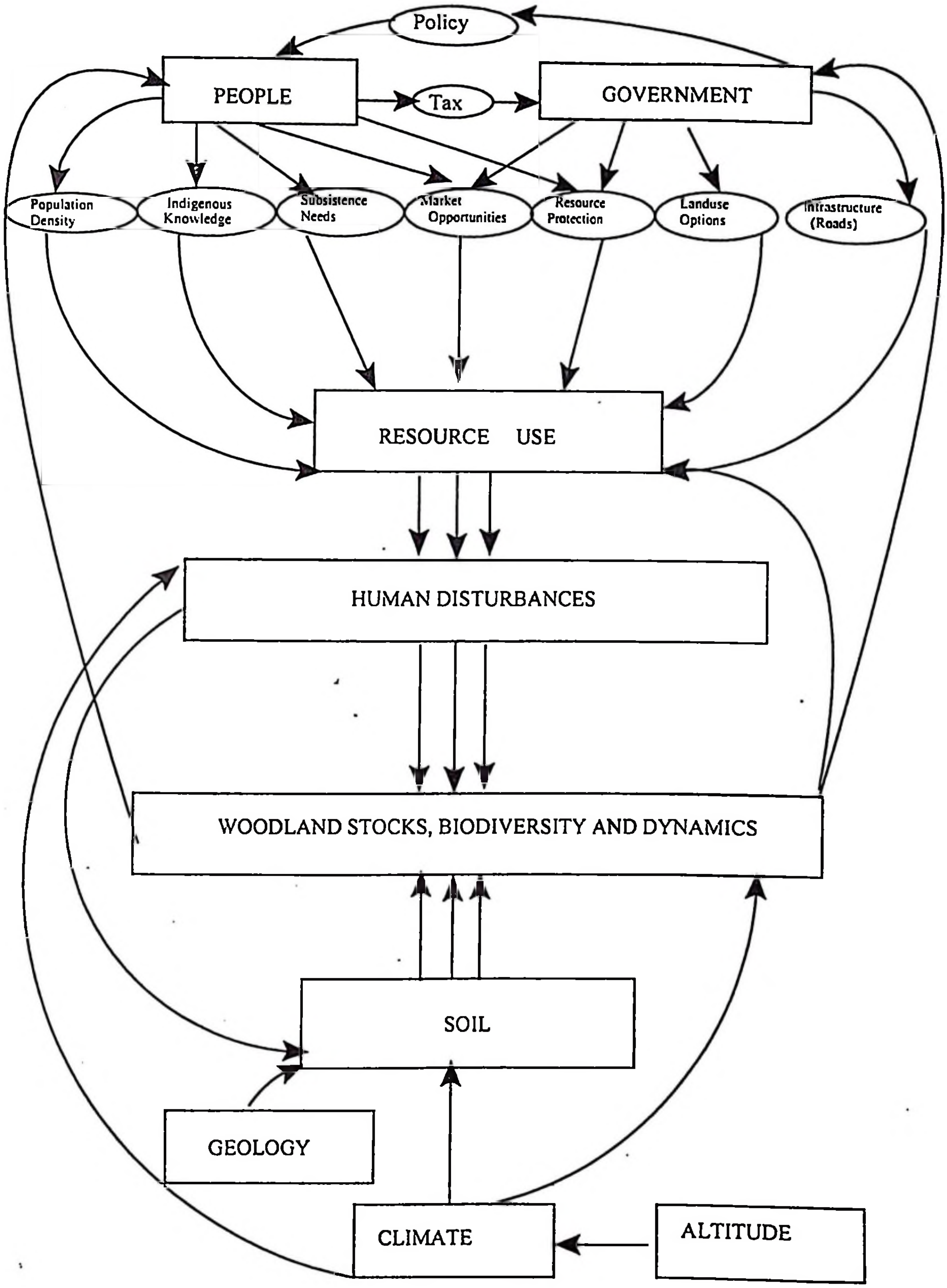


Figure 9.1 Schematic presentation of the interaction of socio-economic, political and biophysical parameters which have an impact on woodland stocks, dynamics and biodiversity in miombo woodlands of eastern Tanzania. (Triple arrows indicate strong feedback).

The WCM approach aims to ensure that all stakeholders participate in setting priorities, cooperate in achieving them and evaluate the activities (Irons, 1997). This approach seems to be plausible in the study area and elsewhere, where the objective is to balance the social, economic and biophysical requirements of both urban and rural ecosystems over the long term. However, the effectiveness of this approach depends on capacity building for all stakeholders. This needs commitment from governments to (1) develop policies which will enhance the capacities of local people who are the main stakeholders, (2) have the political will to ensure that the responsibility for the management of resources is shared and (3) commit resources for the monitoring of natural biological resources which requires regular measurement and subsequent interpretation (Irons, 1997; Sinnamom, 1997). Therefore, new interdisciplinary paradigms that account for the interactions between local communities, the natural resource base, markets and the socio-political environment need to be developed.

9.3.3 Sustainable resource development

The concept of sustainable development, which presumes that development can only occur if land use and policies are environmentally sustainable, has received widespread attention over the last decades (WCED, 1987). The issues surrounding sustainability should take all economic, ecological and social considerations into account. For example, from the cost benefit analysis (CBA) results in Chapter 3 the narrow vision of only focusing on profit maximisation would maintain that charcoal production is justifiable as long as the net benefits are being optimised, while sustainable development should be geared toward making trade-offs between meeting present and future tangible and intangible needs.

The 'People and Plants' initiative which is a partnership between the World Wide Fund for Nature (WWF), UNESCO and the Royal Botanical Gardens, Kew, aims to contribute to the sustainable and equitable use of plant resources in developing countries (Martin, 1995; Tuxill and Nabhan, 1998). Although field projects (most of which involve capacity building) are undertaken under 'People and Plants' particularly in Kenya, Tanzania, Uganda and Zimbabwe (Tuxill and Nabhan, 1998), very few studies have been conducted in this region on how to meet the local needs of people without compromising the long term objectives of resource conservation (sustainable development). This study will help to fill this gap by providing basic information on: economics of rural households, the use of land and natural products, the value of these products, indigenous technical knowledge, beliefs and local practices, all of which are important aspects in local-level management of natural resources. Hence sustainable resource development should address the interrelated issues of agriculture, resource use and policies as discussed below.

9.3.3.1 Sustainable agriculture

The main agricultural practice in the study area and generally elsewhere in African savanna woodlands is slash-and-burn and shifting cultivation (Chapter 3; Chidumayo, 1987 a). Fallowing remains a component of shifting cultivation systems in many parts of Asia, Africa and Latin America today (Mistry, 2000). However, from this study, the present10-year fallow cycles (Chapter 4) are too short to allow the vegetation to revert to the original woodland state (Chapter 8). The transformation of the country to a more market-oriented economy led to a decline in subsistence agriculture as people could not afford to buy farm inputs while state support has mainly been geared towards commercial farming. Similar situations of marginalisation of peasants with subsequent degradation of communal lands have been reported in Zimbabwe (Murphree and Cumming, 1993), Botswana (Kinlund, 1996) and Brazil (Klink *et al.*, 1993). However, in Botswana, people have shown a readiness to change and a willingness to adopt new ideas, practices and measures to forward land conservation, but only if these fit within the agricultural and socio-economic situation of the household (Kinlund, 1996). Thus, environmental considerations cannot be separated from the socio-economic realities of the people concerned.

9.3.3.2 Sustainable resource utilisation

The commercial potential of miombo trees for poles, carpentry products and charcoal has resulted in overexploitation with subsequent wood depletion, especially of *S. africana* (poles) and *P. angolensis* (carpentry) (Chapters 2, 3, 4 and 5). The sustainable production of wood-based products from communal lands (Chapter 3) requires an effective management system to reduce the rate at which the woodland is harvested. For example, the economic valuation of the main woody products (Chapter 3) prioritised tree use in order of maximum benefits as carpentry/carving timber > poles > charcoal > firewood. An integrated resource use management plan is important in order to avoid the use of valuable trees for lower value uses such as charcoal. This may entail a complete halt (or drastic cut-back) of charcoal production and shifting cultivation. These recommendations will prove extremely difficult to implement given the overall high unemployment rates, low educational levels and low family incomes. Thus there are no quick fixes to the problems concerning resource over-utililisation experienced in rural communities.

The significantly higher stocks of wood in the reserve than in the public lands (Chapter 5) could lead to conservation goals being accomplished through the coercive means of excluding people to regulate resource use (Chapter 8). It can, however, be argued that the higher stocks in the reserve have been accomplished because of the relatively extensive woodlands in the public lands which provide alternative sources. But the public woodlands are becoming progressively depleted due to local and urban human population increase and increased domestic fuel demand in urban areas, with the forest reserve likely to be more heavily utilised in the future as a result. In Africa, where local people have been excluded from resource use in state-owned areas and have limited alternative sources, they harbour bitter feelings towards protected areas, a situation which frequently leads to poaching and other forms of abuse (Wild and Mutebi, 1997). Gadgil (1993) suggested that forest reserves in Indian savannas should be brought into a system of production restricted to non-wood forest produce of commercial value. This recommendation agrees with that made in this study (Chapter 7) that local people should be involved in the protection of the reserve using a 'material incentive' system.

CBA revealed that wood is an undervalued resource because it is regarded as a free commodity (Chapter 3). Campbell *et al.* (1997) reported the changing patterns of use and reduced extraction of resources in relation to reduced abundance within an impoverished local community in Zimbabwe. However, very few studies have been conducted on the actual valuation of resources used for livelihoods by the inhabitants of African savannas (Shackleton and Shackleton, 2000) and the quantification of the contribution of biodiversity to ecosystem function (Scholes, 1996; Kundhlande *et al.*

2000). This provides a challenge for resource economists to provide actual values of the natural capital because the consequence of undervaluation is continued overutilisation of resources.

9.3.3.3 Sustainable policies

Lack of planning led to the institutional failure of the resettlement programmes and culminated in land degradation as has been reported in Zimbabwe (Murphree and Cumming, 1993). Elsewhere in the savanna ecosystem, it is reported that most development plans are formulated without considering their implications for the livelihoods of local people (Young and Solbrig, 1993). Top-down decisions always overlook the long term negative impacts on the people and the resource base, thus participation of local people should form an additional bottom-up channel of communication for effective interaction between the main stake holders.

Property rights in public lands are not completely specified, with the government retaining the property entitlement of the reserve. However, the vegetation remnants created as a result of human activity (such as those in public lands) are not true islands, as they interact with other elements in the surrounding landscape, thereby preserving plant species (Beer and Fox, 1997). The high woody species Sørensen's similarity of 88% between the reserve and public lands (Chapter 6) shows that a high species richness also remains outside the reserve system. Therefore, government institutions must provide and motivate for an enabling environment for appropriate usufructary rights as incentives for protecting resources in the reserve and public land and motivation for defined property and tenure rights over land and other resources in public lands (Chapter 8).

9.3.4 Common property resource management

Since the mid-1980's many Indian states have decentralised political decision-making to village and district levels, and have thus motivated people and created more favourable conditions for better management of forest resources (Gadgil, 1993). In the communal lands of Indian savannas, most woodlands are managed by relatively small and homogenous communities such as village hamlets (Gadgil,1993) where these user groups are empowered to establish sustainable resource use regimes. The traditional or local institutional structures that facilitated collective action against land degradation in communal lands do not function in most parts of the African savannas (Chapter 8; Kinlund, 1996; Katerere *et al.* (1999). In an integrated ecological-economic model, Grundy *et al.* (2000) found that joint management of the resource base between the state and forest dwellers yielded the greater net benefits than expulsion of the dwellers from state forests. This study recommends village community-based management for involving people positively in the sustainable use and restoration of local forest resources (Chapter 8). However, the implementation of joint or community-based management needs commitment from the government to share power with local communities and to strengthen the capacity of local institutions.

9.3.5 Diversification of income generating activities

This study recommends the diversification of income generating activities in order to reduce pressure on communal woodlands (Chapters 4 and 8). In Kenya, the diversification of sources of income and improvement of agriculture resulted in a reduction of land degradation (Tiffen *et al.*,1994). The intensification of wildlife-based tourism provides far greater return on land than other landuses in wooded savannas and has a minimal environmental impact on land (Murphree and Cumming, 1993). Livestock production in the woodlands is compatible with woodland management, both from economic and ecological perspectives (Campbell *et al.* 2000; Gambiza *et al.*, 2000). However in the study area there is lack of livestock and wild big game and livestock cannot be introduced due to tsetse flies. An alternative is the carving industry with high value products being sold along the highway. However, beekeeping (in conjunction with other compatible activities) seems to have the greatest long term potential in the area due to the extent of the woodlands, the low capital requirement, the ecological soundness and the potential steady local and overseas market for honey and wax (Chihongo, 1995). Other activities which have been recommended (Chapter 4) are collection of *Tamarindus indica* and *Adansonia digitata* fruits which are sometimes exported to the Middle East for making beverages. The option of local people making commercial beverages to add value to the fruits can not be feasible in the short term because of unreliable supply of safe running water (Chapter 2). Currently there are none of these diversifications in the area.

9.4 FUTURE RESEARCH

9.4.1 Biodiversity and population dynamics

- This study focused on the population dynamics of four species (*Combretum molle, Julbernardia globiflora, Pterocarpus angolensis* and *Spirostachys africana*) in the reserve and disturbed public lands. These species were selected on the basis of high utilisation, but there is a need to consider other species, especially those which are rare and have relatively high use values (e.g., *Strychnos spinosa*) (Chapter 2).
- The issue of endemism has not been covered. There are different levels of endemism in miombo woodlands. The dominant genera, *Brachystegia, Julbernardia* and *Isoberlinia,* for example are endemic to miombo woodlands as they are not found outside the miombo biome. Other possible levels of endemism could be country, or restricted area such as a single mountain or forest. Species that are endemic to smaller areas are more threatened, especially when their utilisation is not regulated.
- The study has focused on woody species and hence did not consider plant diversity in its totality, thus there is a need to consider herbaceous species. In addition, it is often amongst herbs and suffrutescents that the more localised endemics are found.
- The study has focused on natural regeneration from stump coppice shoots (Chapter 7). However miombo trees also regenerate from seeds and root suckers (Strang, 1974). Seventeen percent of the species in the reserve and 10% from public lands did not resprout from stumps after harvesting. Thus further study is needed on other factors which limit resprouting and on seedling regeneration.
- Fire has been shown to be the major constraint for recruitment of saplings to the pole stage of growth, yet very little research has been conducted on fire in miombo (Trapnell, 1959; Kikula, 1986a, Chidumayo, 1988). Thus a long term study on the impact of fires of various frequencies and in different seasons on the population dynamics of savanna woodlands would be valuable.

9.4.2 Policy issues and sustainable farming

- Habitat destruction may be the result of negative changes in landuse. Expanding farmlands are evident symptoms of land degradation. hence there is clearly a need to investigate what appropriate farming system could replace shifting cultivation. Agroforestry may be a viable option.
- Fuel demand in cities causes over-harvesting of wood resources in adjoining rural areas. Thus, a CBA study to determine alternative economically viable household fuels in the cities is required.

9.5 CONCLUSION

Until recently, scientists and policy makers knew little about traditional management systems and accorded them little credibility (McNeely *et al.*, 1995). The study has shown that in the African savannas, where human beings form an integral part of the ecosystem, biodiversity cannot be conserved in the long term without the support of local people. To achieve the sustainable use and development of resources, there is a need for new resource management systems which: 1) combine techniques from both industrialised and developing countries, 2) adopt useful indigenous resource management systems and 3) improve local-level institutions. It is against this background that a more holistic approach is needed to view the management of savanna woodlands from the social, political, economic and ecological perspectives. An action centred network of community, government and professional capacities can greatly contribute to an integrated inter-disciplinary approach to conservation and sustainable development. Thus the conservation of natural resources is not the responsibility of a few specialists but every individual must take part in this challenge.

CHAPTER 10

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Appendix 1. Total use values of trees and shrubs in woodlands of kitulanghalo forest reserve and surrounding public lands (Uses: Ca = Carving, Cha = Charcoal, Fi = Firewood, Fo = Food, Li = Live fence, Me = Medicine, Mi = Miscellaneous, Po = Poles, Ri = Rituals, Ro = Rope fibre, Ti = Timber, Wi = Withies)
[1-6] Species pairs with same super-script numbers bear the same local name.

Species and Author	Local Name (s)	Family	Use Value	Main uses
1 *Adansonia digitata L.*	Mbuyu	Bombacaceae	2.5	Fo, Ri
2 *Acacia goetzei* Harms ssp. *goetzei*	Kisasa	Mimosoideae	1	-
3 *Acacia goetzei* ssp. *microphylla* Roxb. ex Steud.	Msese	Mimosoideae	1	-
4 *Acacia nigrescens* Oliver	Mkambala	Mimosoideae	2.5	Cha
5 *Acacia nilotica* Delile	Mkandekande/Kifunganyumbu	Mimosoideae	1.5	Me
6 *Acacia pentagona* Hook.f.	Lusewa	Mimosoideae	0.5	-
7 *Acacia robusta* Burch.	Mkongowe	Mimosoideae	3.5	Cha, Fi, Me
8 *Acacia polyacantha* ssp. *campylacantha* Willd.	Muwindi	Mimosoideae	0.5	-
9 *Acacia seyal* Delile	Mkese	Mimosoideae	0.5	-
10 *Adenium obesum* (Forssk.) Roem.& Schult.	Chipela	Apocynaceae	0	-
11 *Afzelia quanzensis* Welw.	Mkongo	Caesalpinioideae	2.5	Ti
12 *Albizia anthelmintica* Brongn.	Mfuleta	Mimosoideae	0.5	-
13 *Albizia harveyi* Fourn.	Msisimisi	Mimosoideae	2	-
14 *Albizia petersiana* Oliver	Mkenge/Mkengepori/Msagati	Mimosoideae	3	Cha, Me
15 *Albizia versicolor* Welw. ex Oliver	Mkingu/Mnyanza	Mimosoideae	1.5	-
16 *Annona senegalensis* Pers.	Mtopetope/Mtomokwe	Annonaceae	1	Fo.
17 *Allophylus rubifolius* Engl.	Msempelele	Sapindaceae	1	Fo
18 *Bauhinia petersiana* C. Bolle	Msegese	Caesalpinioideae	0	-
19 *Boscia salicifolia* Oliver	Mguluka	Capparaceae	0	-
20 *Brackenridgea zanguebarica* Oliver	?	Ochnaceae	0	-
21 *Brachystegia boehmii* Taub.	Myombo	Caesalpinioideae	4	Cha, Fi, Ro
22 *Brachystegia bussei* Harms [1]	Mbonha	Caesalpinioideae	3	Cha, Fi
23 *Brachystegia microphylla* Harms	Mseni	Caesalpinioideae	3	Cha, Fi
24 *Brachystegia spiciformis* Benth. [1]	Mbonha	Caesalpinioideae	3	Cha, Fi
25 *Bridelia cathartica* Bertol. f.	Msinzila/Chikundilekwima	Euphorbiaceae	1	-
26 *Cassia abbreviata* Oliver [2]	Mkundekunde	Caesalpinioideae	1	-
27 *Cassia afrofistula* Brenan [2]	Mkundekunde	Caesalpinioideae	1	-
28 *Cassia* sp. nr *C. burtii* Bak. f.	Mhumba	Caesalpinioideae	0	-
29 *Cassine aethiopica* Eckl. & Zeyh.	Mlimbolimbo/Chilimbolimbo	Celastraceae	0	-
30 *Catunaregum spinosa* (Thunb.) Tirveng.	Mtutuma	Rubiaceae	0	-
31 *Clausena anisata* Hook.f.	Mkomavikali	Rutaceae	1	Me
32 *Clerodendrum glabrum* E. Meyer	Mtulavula	Verbenaceae	1	Me
33 *Combretum adenogonium* Steud. ex A.Rich.	Mlama-ng'ombe	Combretaceae	2.5	Cha, Fi
34 *Combretum collinum* Fresen.	Mlama-doli	Combretaceae	2.5	Cha, Fi
35 *Combretum padoides* Engl. & Diels	Mkungalungo	Combretaceae	2.5	Cha, Fi
36 *Combretum molle* Engl. & Diels	Mlama-mweusi	Combretaceae	3	Cha, Fi
37 *Combretum obovatum* F. Hoffm.	Mgona -nyehe	Combretaceae	2.5	Cha, Fi
38 *Combretum zeyheri* Sond.	Mlama-mwekundu	Combretaceae	3	Cha, Fi
39 *Commiphora africana* (A. Rich.) Engl. [3]	Mtwinhi	Burseraceae	1	Li
40 *Commiphora eminii* ssp. *zimmermannii* Engl.	Mkongolo	Burseraceae	0.5	-
41 *Commiphora pteleifolia* Engl. [3]	Mtwinhi	Burseraceae	1	Li
42 *Crossopteryx febrifuga* (Afzel. ex G. Don) Benth.	Kisasagala/Msikosiko	Rubiaceae	0	-
43 *Cussonia zimmermannii* Harms	Mntindi	Araliaceae	0	-

Appendix 1 continued

Species and Author	Local Name (s)	Family	Use Value	Main uses
44 *Croton* sp.	Mkambaku	Euphorbiaceae	0	-
45 *Dalbergia melanoxylon* Guill. & Perr.	Mpingo/Mhingo	Papilionoideae	3	Me, Ca
46 *Dalbergia nitidula* Welw. ex Baker	Mzezegele	Papilionoideae	0	-
47 *Dalbergia obovata* E. Meyer	Mgoweko	Papilionoideae	0	-
48 *Deinbolia borbonica* Scheff.	Mmoyomoyo	Sapindaceae	2	Me, Wi
49 *Dichrostachys cinerea* Miq.	Kikulagembe	Mimosoideae	3	Fi, Me
50 *Diospyros consolatae* Chiov.	Msungura	Ebenaceae	3	Po, Wi, Mi
51 *Diospyros kirkii* Hiern	Mkulwi	Ebenaceae	2	-
52 *Diospyros* sp.	Mdaha	Ebenaceae	1.5	Mi
53 *Diospyros zombensis* (B.L. Burt) F. White	Msofu	Ebenaceae	1	Fo
54 *Diospyros* sp.	Mlenga	Ebenaceae	0	-
55 *Diplorhynchus condylocarpon* (Muell.-Arg.) Pichon	Mtogo	Apocynaceae	2	Me
56 *Dobera loranthifolia* Warb. ex. Harms	Msiga	Salvadoraceae	1	Mi
57 *Dombeya rotundifolia* (Hochst.) Planch.	Msosowana/Mlwati	Sterculiaceae	3.5	Po, Me
58 *Dombeya cincinnata* K. Schum. ex Engl.	Mkareleng'ala	Sterculiaceae	0	-
59 *Drypetes gerrardii* Hutch.	Chisakilasengo	Euphorbiaceae	1	Po
60 *Ehretia amoena* Klotzsch	Mkilika	Boraginaceae	1	-
61 *Erythrina abyssinica* Lam.	Mnungu-magoma	Papilionoideae	2	Me, Ri
62 *Erythrophleum africanum* (Benth.) Harms	Mkarati	Caesalpinioideae	1.5	-
63 *Erythroxylum* sp.	Msaluti	Erythroxylaceae	2	Po, Wi
64 *Euphorbia candelabrum* Trem. ex Kotschy	Bamba-langali	Euphorbiaceae	1	Mi
65 *Euphorbia nyikae* Pax ex Engl.	Bamba-chihililo	Euphorbiaceae	0	-
66 *Ficus glumosa* Delile [4]	Mkuyu	Moraceae	0	-
67 *Ficus sycomorus* L. [4]	Mkuyu	Moraceae	0	-
68 *Flueggea virosa* (Roxb. ex Willd.) Voigt	Mkwambe	Euphorbiaceae	1.5	Me
69 *Gardenia ternifolia* Schum. & Thonn.	Kilemelantembo	Rubiacea	0	-
70 *Grewia bicolor* Juss.	Mkole	Tiliaceae	4	Fo, Ri
71 *Grewia ectasicarpa* S. Moore	Mkongodeka/Mdandebande	Tiliaceae	0	-
72 *Grewia similis* K. Schum	Mkole/Mnangu	Tiliaceae	2	Fo
73 *Harissonia abyssinica* Oliver	Mkusu/Mkunju	Simaroubaceae	1	Me
74 *Heinsia crinita* ssp. *parviflora* (Afzel.) G. Taylor	Kibiki	Rubiacea	0	-
75 *Holarrhena pubescens* Wall.	Imelele/Chocho	Apocynaceae	0	-
76 *Hoslundia opposita* Vahl	?	Labiatae	0	-
77 *Hyphaena coriacea* Gaertn.	Mkoche	Palmae	1	Mi
78 *Indigofera* spp.	Mbaazi pori	Papilionoideae	0	-
79 *Julbernardia globiflora* (Benth.) Troupin	Mhnondolo	Caesalpinioideae	4	Cha, Fi, Ro
80 *Kigelia africana* (Lam.) Benth.	Mwegea	Bignoniaceae	1	Mi
81 *Lannea schimperi* Engl.	Mnindi-pori	Anacardiaceae	1	Mi
82 *Lannea schweinfurthii* Engl.	Mumbu	Anacardiaceae	1.5	Me
83 *Lannea welwitschii* Engl.	Mumbu Luzigwe	Anacardiaceae	0	-
84 *Lecaniodiscus flaxinifolia* Baker	Mbwewe	Sapindaceae	2	Fi
85 *Leptactinia* sp. nr. *L. benguellensis* Good	Mfyonzefonze	Rubiaceae	0	-
86 *Lonchocarpus bussei* Harms [5]	Mfumbili	Papilionoideae	2.5	Cha. Fi
87 *Lonchocarpus capassa* Rolfe [5]	Mfumbili	Papilionoideae	2.5	Cha, Fi
88 *Maerua triphylla* A . Rich.	Mdudu	Capparaceae	1	Fo
89 *Margaritaria discoidea* (Baill.) Webster	Kisakulankwale	Euphorbiaceae	0.5	-
90 *Markhamia obtusifolia* Sprague [6]	Mtalawanda	Bignoniaceae	2.5	Po, Wi

Appendix 1. Total use values of trees and shrubs in woodlands of kitulanghalo forest reserve and surrounding public lands (Uses: Ca = Carving, Cha = Charcoal, Fi = Firewood, Fo = Food, Li = Live fence, Me = Medicine, Mi = Miscellaneous, Po = Poles, Ri = Rituals, Ro = Rope fibre, Ti = Timber, Wi = Withies)

[1-6] Species pairs with same super-script numbers bear the same local name.

Species and Author	Local Name (s)	Family	Use Value	Main uses
1 *Adansonia digitata L.*	Mbuyu	Bombacaceae	2.5	Fo, Ri
2 *Acacia goetzei* Harms ssp. *goetzei*	Kisasa	Mimosoideae	1	-
3 *Acacia goetzei* ssp. *microphylla* Roxb. ex Steud.	Msese	Mimosoideae	1	-
4 *Acacia nigrescens* Oliver	Mkambala	Mimosoideae	2.5	Cha
5 *Acacia nilotica* Delile	Mkandekande/Kifunganyumbu	Mimosoideae	1.5	Me
6 *Acacia pentagona* Hook.f.	Lusewa	Mimosoideae	0.5	-
7 *Acacia robusta* Burch.	Mkongowe	Mimosoideae	3.5	Cha, Fi, Me
8 *Acacia polyacantha* ssp. *campylacantha* Willd.	Muwindi	Mimosoideae	0.5	-
9 *Acacia seyal* Delile	Mkese	Mimosoideae	0.5	-
10 *Adenium obesum* (Forssk.) Roem.& Schult.	Chipela	Apocynaceae	0	-
11 *Afzelia quanzensis* Welw.	Mkongo	Caesalpinioideae	2.5	Ti
12 *Albizia anthelmintica* Brongn.	Mfuleta	Mimosoideae	0.5	-
13 *Albizia harveyi* Fourn.	Msisimisi	Mimosoideae	2	-
14 *Albizia petersiana* Oliver	Mkenge/Mkengepori/Msagati	Mimosoideae	3	Cha, Me
15 *Albizia versicolor* Welw. ex Oliver	Mkingu/Mnyanza	Mimosoideae	1.5	-
16 *Annona senegalensis* Pers.	Mtopetope/Mtomokwe	Annonaceae	1	Fo.
17 *Allophylus rubifolius* Engl.	Msempelele	Sapindaceae	1	Fo
18 *Bauhinia petersiana* C. Bolle	Msegese	Caesalpinioideae	0	-
19 *Boscia salicifolia* Oliver	Mguluka	Capparaceae	0	-
20 *Brackenridgea zanguebarica* Oliver	?	Ochnaceae	0	-
21 *Brachystegia boehmii* Taub.	Myombo	Caesalpinioideae	4	Cha, Fi, Ro
22 *Brachystegia bussei* Harms [1]	Mbonha	Caesalpinioideae	3	Cha, Fi
23 *Brachystegia microphylla* Harms	Mseni	Caesalpinioideae	3	Cha, Fi
24 *Brachystegia spiciformis* Benth. [1]	Mbonha	Caesalpinioideae	3	Cha, Fi
25 *Bridelia cathartica* Bertol. f.	Msinzila/Chikundilekwima	Euphorbiaceae	1	-
26 *Cassia abbreviata* Oliver [2]	Mkundekunde	Caesalpinioideae	1	-
27 *Cassia afrofistula* Brenan [2]	Mkundekunde	Caesalpinioideae	1	-
28 *Cassia* sp. nr *C. burtii* Bak. f.	Mhumba	Caesalpinioideae	0	-
29 *Cassine aethiopica* Eckl. & Zeyh.	Mlimbolimbo/Chilimbolimbo	Celastraceae	0	-
30 *Catunaregum spinosa* (Thunb.) Tirveng.	Mtutuma	Rubiaceae	0	-
31 *Clausena anisata* Hook.f.	Mkomavikali	Rutaceae	1	Me
32 *Clerodendrum glabrum* E. Meyer	Mtulavula	Verbenaceae	1	Me
33 *Combretum adenogonium* Steud. ex A.Rich.	Mlama-ng'ombe	Combretaceae	2.5	Cha, Fi
34 *Combretum collinum* Fresen.	Mlama-doli	Combretaceae	2.5	Cha, Fi
35 *Combretum padoides* Engl. & Diels	Mkungalungo	Combretaceae	2.5	Cha, Fi
36 *Combretum molle* Engl. & Diels	Mlama-mweusi	Combretaceae	3	Cha, Fi
37 *Combretum obovatum* F. Hoffm.	Mgona -nyehe	Combretaceae	2.5	Cha, Fi
38 *Combretum zeyheri* Sond.	Mlama-mwekundu	Combretaceae	3	Cha, Fi
39 *Commiphora africana* (A. Rich.) Engl. [3]	Mtwinhi	Burseraceae	1	Li
40 *Commiphora eminii* ssp. *zimmermannii* Engl.	Mkongolo	Burseraceae	0.5	-
41 *Commiphora pteleifolia* Engl. [3]	Mtwinhi	Burseraceae	1	Li
42 *Crossopteryx febrifuga* (Afzel. ex G. Don) Benth.	Kisasagala/Msikosiko	Rubiaceae	0	-
43 *Cussonia zimmermannii* Harms	Mntindi	Araliaceae	0	-

Appendix 1 continued

Species and Author	Local Name (s)	Family	Use Value	Main uses
44 *Croton* sp.	Mkambaku	Euphorbiaceae	0	-
45 *Dalbergia melanoxylon* Guill. & Perr.	Mpingo/Mhingo	Papilionoideae	3	Me, Ca
46 *Dalbergia nitidula* Welw. ex Baker	Mzezegele	Papilionoideae	0	-
47 *Dalbergia obovata* E. Meyer	Mgoweko	Papilionoideae	0	-
48 *Deinbolia borbonica* Scheff.	Mmoyomoyo	Sapindaceae	2	Me, Wi
49 *Dichrostachys cinerea* Miq.	Kikulagembe	Mimosoideae	3	Fi, Me
50 *Diospyros consolatae* Chiov.	Msungura	Ebenaceae	3	Po, Wi, Mi
51 *Diospyros kirkii* Hiern	Mkulwi	Ebenaceae	2	-
52 *Diospyros* sp.	Mdaha	Ebenaceae	1.5	Mi
53 *Diospyros zombensis* (B.L. Burt) F. White	Msofu	Ebenaceae	1	Fo
54 *Diospyros* sp.	Mlenga	Ebenaceae	0	-
55 *Diplorhynchus condylocarpon* (Muell.-Arg.) Pichon	Mtogo	Apocynaceae	2	Me
56 *Dobera loranthifolia* Warb. ex. Harms	Msiga	Salvadoraceae	1	Mi
57 *Dombeya rotundifolia* (Hochst.) Planch.	Msosowana/Mlwati	Sterculiaceae	3.5	Po, Me
58 *Dombeya cincinnata* K. Schum. ex Engl.	Mkareleng'ala	Sterculiaceae	0	-
59 *Drypetes gerrardii* Hutch.	Chisakilasengo	Euphorbiaceae	1	Po
60 *Ehretia amoena* Klotzsch	Mkilika	Boraginaceae	1	-
61 *Erythrina abyssinica* Lam.	Mnungu-magoma	Papilionoideae	2	Me, Ri
62 *Erythrophleum africanum* (Benth.) Harms	Mkarati	Caesalpinioideae	1.5	-
63 *Erythroxylum* sp.	Msaluti	Erythroxylaceae	2	Po, Wi
64 *Euphorbia candelabrum* Trem. ex Kotschy	Bamba-langali	Euphorbiaceae	1	Mi
65 *Euphorbia nyikae* Pax ex Engl.	Bamba-chihililo	Euphorbiaceae	0	-
66 *Ficus glumosa* Delile [4]	Mkuyu	Moraceae	0	-
67 *Ficus sycomorus* L. [4]	Mkuyu	Moraceae	0	-
68 *Flueggea virosa* (Roxb. ex Willd.) Voigt	Mkwambe	Euphorbiaceae	1.5	Me
69 *Gardenia ternifolia* Schum. & Thonn.	Kilemelantembo	Rubiacea	0	-
70 *Grewia bicolor* Juss.	Mkole	Tiliaceae	4	Fo, Ri
71 *Grewia ectasicarpa* S. Moore	Mkongodeka/Mdandebande	Tiliaceae	0	-
72 *Grewia similis* K. Schum	Mkole/Mnangu	Tiliaceae	2	Fo
73 *Harissonia abyssinica* Oliver	Mkusu/Mkunju	Simaroubaceae	1	Me
74 *Heinsia crinita* ssp. *parviflora* (Afzel.) G. Taylor	Kibiki	Rubiacea	0	-
75 *Holarrhena pubescens* Wall.	Imelele/Chocho	Apocynaceae	0	-
76 *Hoslundia opposita* Vahl	?	Labiatae	0	-
77 *Hyphaena coriacea* Gaertn.	Mkoche	Palmae	1	Mi
78 *Indigofera* spp.	Mbaazi pori	Papilionoideae	0	-
79 *Julbernardia globiflora* (Benth.) Troupin	Mhnondolo	Caesalpinioideae	4	Cha, Fi, Ro
80 *Kigelia africana* (Lam.) Benth.	Mwegea	Bignoniaceae	1	Mi
81 *Lannea schimperi* Engl.	Mnindi-pori	Anacardiaceae	1	Mi
82 *Lannea schweinfurthii* Engl.	Mumbu	Anacardiaceae	1.5	Me
83 *Lannea welwitschii* Engl.	Mumbu Luzigwe	Anacardiaceae	0	-
84 *Lecaniodiscus flaxinifolia* Baker	Mbwewe	Sapindaceae	2	Fi
85 *Leptactinia* sp. nr. *L. benguellensis* Good	Mfyonzefonze	Rubiaceae	0	-
86 *Lonchocarpus bussei* Harms [5]	Mfumbili	Papilionoideae	2.5	Cha, Fi
87 *Lonchocarpus capassa* Rolfe [5]	Mfumbili	Papilionoideae	2.5	Cha, Fi
88 *Maerua triphylla* A . Rich.	Mdudu	Capparaceae	1	Fo
89 *Margaritaria discoidea* (Baill.) Webster	Kisakulankwale	Euphorbiaceae	0.5	-
90 *Markhamia obtusifolia* Sprague [6]	Mtalawanda	Bignoniaceae	2.5	Po, Wi

Appendix 1 continued

Species and Author	Local Name (s)	Family	Use Value	Main uses
91 *Markhamia sanzibarica* K. Schum.	Mtalawanda	Bignoniaceae	2.5	Po, Wi
92 *Maytenus senegalensis* (Lam.) Exell	Mwambangoma	Celastraceae	1	Ri
93 *Millettia usaramensis* Taub.	Mhanvi	Papilionoideae	2.5	Po, Wi
94 *Millettia sacleuxii* Dunn	Mfumbili-mlima	Papilionoideae	2.5	Cha, Fi
95 *Ochna holstii* Engl.	Mhatakwa	Ochnaceae	1.5	Mi
96 *Ochna leptoclada* Oliver	Mhatakwa/Mkumbi	Ochnaceae	2	Me, Ri
97 *Ochna macrocalyx* Oliver	Mnenekanda	Ochnaceae	0.5	-
98 *Ormocarpum kirkii* S. Moore	Kihimbulumbu	Papilionoideae	0.5	-
99 *Ozoroa insignis* Delile	Mkomachuma	Anacardiaceae	0	-
100 *Pavetta crassipes* K. Schum.	Chisangosango	Rubiacea	0	-
101 *Pteleopsis myrtifolia* Engl. & Diels	Mgovu/Mgoji	Combretaceae	2.5	Cha, Fi
102 *Pterocarpus angolensis* DC.	Mninga/Mhagata	Papilionoideae	3	Ti
103 *Pterocarpus rotundifolius* Druce	Mhambalasha	Papilionoideae	1.5	-
104 *Pseudolachnostylis maprouneifolia* Pax	Msolo	Euphorbiaceae	3	Cha, Fi, Ri
105 *Rhoicissus rivoilii* Planch.	Mtongotongo/Kifungang'ombe	Vitaceae	0	-
106 *Rothmannia fischeri* (K. Schum.) Bullock	Mpuuzi/Mduyuyu/Msewe	Rubiaceae	1	Cha
107 *Rytiginia* sp.	Mlavilavi	Rubiaceae	2	Wi, Mi
108 *Sclerocarya birrea* ssp. *caffra* Sond.	Mng'ongo	Anacardiaceae	2.5	Ri
109 *Scrodophleous fischeri* (Taub.) J. Leonard	Mhande	Caesalpinioideae	2.5	Po, Mi
110 *Spirostachys africana* Sond.	Mharaka/Msaraka	Euphorbiaceae	3.5	Po, Me
111 *Sterculia africana* (Lour.) Fiori	Moza	Sterculiaceae	0	-
112 *Sterculia appendiculata* K. Schum. ex Engl.	Mgude/Mfune	Sterculiaceae	0	-
113 *Sterculia quinqueloba* Sim	Mhembeti	Sterculiaceae	1	Ti
114 *Stereospermum kunthianum* Cham.	Mkomanguku/Myuwe	Bignoniaceae	0	-
115 *Steganotaenia araliacea* Hochst.	Mhogola	Umbelliferae	1	Me
116 *Strychnos spinosa* Lam.	Mtonga	Loganiaceae	2.5	Cha, Fi
117 *Suregada xanzibariensis* Baill.	Mdimumbago	Euphorbiaceae	0	-
118 *Tamarindus indica* L.	Mkwaju/Mkwezu	Caesalpinioideae	3	Fi, Fo
119 *Terminalia sambesiaca* Engl. & Diels	Mkulungo	Combretaceae	0.5	-
120 *Terminalia sericea* Burch. ex DC.	Mtanga/Mfumba	Combretaceae	3	Cha, Fi, Po
121 *Turraea nilotica* Kotschy & Peyr.	Mnyamafu/Mulyampofu	Meliaceae	0	-
122 *Turraea* sp.	Mgwejameno/Mulyampofu	Meliaceae	1	Ri
123 *Uvaria* sp.	Mzindanguruwe	Annonaceae	0	-
124 *Vangueria infausta* Burch.	Msada	Rubiaceae	2	Fo, Mi
125 *Vernonia* sp.	Mtugutu	Compositae	0	-
126 *Vitex buchanani* Guerke	?	Verbenaceae	0	-
127 *Vitex ferruginea* Boj. ex Schau.	Mfuru	Verbenaceae	1	Fo
128 *Xeroderris stuhlmannii* (Taub.)Mendonca & Sousa	Mnyenye	Papilionoideae	2.5	-
129 *Xerophyta spekei* Baker	Mseyu	Velloziaceae	1	Mi
130 *Ximenia caffra* Sond.	Mhingi/Mtwindi	Olacaceae	0	-
131 *Zanha africana* (Radlk.)Exell	mdaula	Sapindaceae	1.5	Me
132 *Zanthoxylum chalybeum* Engl.	Mhunungu	Rutaceae	1	Fo
133 *Ziziphus mucronata* Willd.	Mnyangwe/Mgagawe	Rhamnaceae	0	-

Appendix 2

Structured household questionnaire for collection of socio-economic and resource utilisation data from villages surrounding the Kitulanghalo Forest Reserve in eastern Tanzania.

VILLAGE: ....

DATE : ....

ENUMERATOR: ....

HOUSEHOLD IDENTIFICATION'S NUMBER: ....

A. GENERAL INFORMATION :

1. Name of the household head ....

1.1 Gender

1. Male ☐
2. Female ☐

1.2 Age ....Years

1.3 Education

1. No formal education ☐
2. Adult education ☐ years .....
3. Primary education ☐ years .....
4. Secondary education ☐ years .....

1.4 What is the age composition of your household members?

Male (Age)	Female (Age)
1. 2 3 4 5	1 2 3 4 5

B. FARMING SYSTEM :

2 What crops do you grow on your farm and specify whether grown for food, cash or both.

Crops	Food	Cash	Both
1 2 . . n			

2.1 Do you apply any fertiliser to your crops?

1. Yes ☐
2. No ☐

2.1.1 If yes, what type of fertiliser?

1. Inorganic ☐
2. Organic ☐

2.1.2 How much do you apply per hectare? ....

2.1.3 How often? ....

Appendix 2 continued

2.2 What main system do you use to grow your crops and how big is the farm?

1. Permanent plots; monocropping ☐ Hectares ....
2. Permanent plots; mixed cropping ☐ ....
3. Shifting cultivation, monocropping ☐ ....
4. Shifting cultivation, mixed cropping ☐ ....
5. Agroforestry ☐. ....

2.3 In what manner do you prepare the field before ploughing

1. By clearing all the vegetation ☐
2. By retaining a few trees ☐

2.4 If you practice shifting cultivation, how many years do you continuously cultivate the field before abandoning it? ....

2.4.1 For how long do you leave the land fallow?........................

C. ETHNOBOTANY / UTILIZATION

3 Where do you get your forest based products? Are there any fees charged by the government for the collection?

Product	Where collected		Fees Charged
	Public land	Forest reserve	
1 2 . . n			

Fuelwood

4. What type of fuel do you use in your household?

1. Firewood ☐
2. Charcoal ☐
3. Kerosine ☐

4.1 If firewood and /or charcoal, which tree species do you prefer to collect or burn respectively? Give reason for preference.

Type of fuel	Tree species	Size	Reason for preference
Firewood	1 2 . . n		
Charcoal	1 2 . . n		

Appendix 2 continued

4.2 Which tree species are never cut down for fuel, and why?

Tree species	Reason for not cutting
1 2 . . n	

4.3 How many head-loads of firewood, tins of charcoal or litres of kerosine do your family consume in one week?

1. Firewood .... (Headloads)
2. Charcoal .... (Tins)
3. Kerosine .... (Litres)

4.4 Have you ever bought firewood, charcoal or kerosine for home consumption?

1. Yes ☐
2. No ☐

4.4.1 If Yes, what are the 1997 fuel prices at the village

Fuel type	Unit price (Tanzanian Shs)
Firewood Charcoal Kerosine	

4.5 How many hours does a member of the family spend in firewood collected

....

4.6 What is the approximate distance to the firewood collection sites ....

4.7 What type of wood do you collect?

1. Dry ☐
2. Live ☐

4.7.1 If live wood, which part of the tree is cut?

1. Branches ☐
2. Whole tree ☐

4.8 Is your household involved in charcoal production?

1. Yes ☐
2. No ☐

Medicines /Remedies

5 Which tree/shrub species and which parts of the trees do you use for medicines/remedies?

Tree	Disease	Part of the plant collected				
		stem	bark	roots	leaves	fruits
1 2 . . n						

Appendix 2 continued

5.1 Which category of medicine (between "modern" and "indigenous") is more effective for common diseases?
1. Modern ☐
2. Indigenous ☐
3. Both ☐

5.2 Comment on the availability of modern and indigenous medicines in the vicinity
....
....

5.3 How do you acquire the indigenous medicines?
1. Own collection ☐
2. From traditional practitioner ☐

5.3.1 If you do your own collection, where do you collect them from?
1. Public land ☐
2. Forest reserve ☐
3. Both ☐

5.3.2 If buying from the practitioner, how much money on average does your family spend monthly on medicines/remedies?
....

5.3.3 How does this amount (5.3.2) compare with monthly costs of modern medicines?

Construction and Domestic Materials.

6. Where do you get materials for construction of your houses?
1. Public land ☐
2. Forest reserve ☐
3. Both ☐

6.1 Which tree species do you use mostly in house construction?

Type of material	Species	Price/unit
Beams Walling poles Roofing poles Frames Withies Ropes Thatch		

6.2 How often do you re-build your houses..................(Years)

Appendix 2 continued

7. Which tree species do you use to make domestic items and other artifacts?

Item	Tree species
Chairs / tables Beds Mortar Pestle Baskets, mats & brooms Glue Paints Bows Arrows Tooth and other types of brush Drums Gun handles Beer fermentation catalysts Hair combs Others (Specify)	

Food

8. Which tree species and which parts of the trees do you use as food?

Tree species	Part of the Tree		
	Roots	Fruits	Leaves
1 2 . . n			

9. Do you have bee hives in the forest?
   1. Yes ☐
   2. No ☐

9.1 If yes, how many? ....

9.2 Which tree species provide materials (wood and bark) for making hives?

Tree species		Materials		Size of tree
		Wood	Bark	
1 2 . . n				

Appendix 2 continued

17. List the reasons why forests are important to the environment?
1...
2...
3...
4...

18. Is there any place in the forest which is used for ritual purposes?
1. Yes ☐
2. No ☐

18.1 If yes, what are the rules and regulations pertaining to this forest?
1...
2...
3..
4..

18.2 What happens to a person if he/she breaks the rules?
....

19. Are there any individual trees which are used for ritual purposes?
1. Yes ☐
2. No ☐

19.1 If yes, which are these tree species?
....

19.2 What are the rules and regulations pertaining to these tree species?
1...
2,..
3...
4.......:..

19.3 What happens to a person if he/she breaks the rules?
....

20. Do you have your own planted trees?
1. Yes ☐
2. No ☐

20.1 If yes, what did you plant them for?
....

20.2 What tree species have you planted and how have you arranged them?

Tree species	Spatial arrangement			
	Woodlot	Scattered	Line	Mixed with crops
1 2 . . n				

Appendix 2 continued

21. What type of natural tree species have you retained (nurtured) in your field and what is the reason for tree retention

Tree species	Number	Reason
1 2 . . n		

22. What most limits tree planting in this area?
    1. Land shortage ☐
    2. Labour unavailability ☐
    3. Insecurity of land/tree tenure ☐
    4. Unavailability of planting stock ☐
    5. Fires ☐
    6. Lack of capital ☐
    7. Lack of reliable markets ☐
    8. Others ☐
       Specify:

....

....

23. Give your general comments on what could be done to improve the management of natural forests in this area.

....

THANK YOU VERY MUCH

Appendix 3 Elemental composition of the soils (mean ± SE) of the Kitulanghalo Forest Reserve and surrounding public lands, Morogoro, Tanzania. Soils: A = 0–10 cm, B = 20–30 cm depths.

Element ($\mu g\ g^{-1}$)	Soil horizon	Reserve	Public lands		ANOVA	
			Southern block	Northern block	F	p
Mo	A	2.65±0.26 ^{a}	3.06±0.35 ^{ab}	4.25±0.43 ^{b}	5.075	0.009
	B	2.91±0.30 ^{a}	3.28±0.41 ^{ab}	4.58±0.50 ^{b}	4.090	0.022
Rb	A	41.4±3.43	29.7±4.71	43.6±5.77	2.482	0.092
	B	46.7±3.49 ^{a}	29.7±4.80 ^{b}	53.4±5.88 ^{a}	5.944	0.004
Zn	A	35.7±2.75	36.8±3.88	34.5±4.64	0.077	0.926
	B	41.9±2.71	34.8±3.72	34.0±4.56	1.768	0.179
Cu	A	5.91±2.48	9.50±3.41	15.42±4.18	1.954	0.151
	B	9.94±3.40	11.94±4.67	21.17±5.72	1.440	0.245
Ni	A	39.7±7.61	28.2±10.5	57.1±12.8	1.533	0.224
	B	64.5±16.6	34.1±22.9	76.9±28.0	0.844	0.435
Co	A	8.27±0.67 ^{a}	7.31±0.92 ^{a}	13.3±1.13 ^{b}	9.386	0.001
	B	8.74±1.30	7.64±1.78	9.67±2.18	0.270	0.764
Ba	A	615±49.0	557±67.3	464±52.4	1.272	0.288
	B	565±49.8	580±82.2	552±101	0.025	0.976
Cr	A	137±30.3	87.7±18.7	178±51.1	0.977	0.382
	B	238±93.9	102±20.6	216±44.5	0.600	0.552
Ti	A	2641±172 ^{a}	3850±549 ^{ab}	5850±1584 ^{b}	6.137	0.004
	B	3288±228	3674±546	5051±1157	2.565	0.085
Ca	A	16036±534 ^{a}	14600±1403 ^{a}	8595±1350 ^{b}	11.29	<0.0001
	B	14876±1325 ^{a}	11730±1684 ^{a}	5333±769 ^{b}	7.965	0.001
Fe	A	30087±1082	37888±5236	36717±5188	1.342	0.269
	B	39704±3268	41184±6453	40881±6679	0.028	0.972
Mn	A	458±47.2	590±92.4	452±113	0.748	0.478
	B	458±71.1	478±131	271±86.5	0.827	0.442
K	A	13023±1099	9557±1486	13221±2187	1.398	0.255
	B	11114±1881	8298±1461	14639±3156	2.606	0.082
Si	A	334856±5922	306137±20267	360619±17474	3.021	0.066
	B	302207±8311	302922±25109	333698±21370	0.869	0.425
P	A	640±38.4	712±93.9	724±115	0.302	0.740
	B	535±40.3	466±55.4	456±67.8	0.768	0.468
Al	A	87300±1168	87395±3518	78973±3650	2.131	0.127
	B	100999±3768	91607±5630	96121±6896	0.932	0.399
Mg	A	6752±678	5176±932	5472±1141	1.102	0.339
	B	8885±1612	4462±1093	5075±1208	2.399	0.099
Na	A	16263±733 ^{a}	15345±1753 ^{a}	7833±1572 ^{b}	10.99	<0.0001
	B	12438±1009 ^{a}	13313±1741 ^{a}	6455±1165 ^{b}	5.274	0.008

Different superscript letters within rows indicate significant differences ($p < 0.05$, Tukey HSD).

Appendix 4 Basal area ha^{-1} and density (stems ha^{-1}) of trees and shrubs (arranged in alphabetical order by species) in miombo woodlands of Kitulanghalo Forest Reserve and surrounding public lands, Morogoro, Tanzania.

Species	Family / Subfamily	Reserve (n = 34)		Public lands (n = 30)	
		Basal area (m^2 / ha)	Density (Stems / ha)	Basal area (m^2 / ha)	Density (Stems / ha)
Acacia goetzei Harms ssp. *goetzei*	Mimosoideae	0.240±0.106	78.2±29.4	0.229±0.113	210±58.9
Acacia nigrescens Oliver	Mimosoideae	1.198±0.225	662±170	0.366±0.239	123±70.8
Acacia nilotica Delile	Mimosoideae	0.194±0.050	810±253	0.050±0.053	158±102
Acacia robusta Burch.	Mimosoideae	0.504±0.147	253±74.8	0.116±0.156	67.3±35.7
Acacia polyacantha ssp. *campylacantha* Willd.	Mimosoideae	0.007±0.006	12.7±8.80	0.011±0.006	1.00±0.56
Albizzia anthelmintica Brongn.	Mimosoideae	0.004±0.002	79.4±53.7	0	0
Albizzia harveyi Fourn.	Mimosoideae	0.116±0.039	60.3±27.6	0.105±0.042	216±73.0
Albizzia petersiana Oliver	Mimosoideae	0.048±0.023	100±23.0	0.043±0.025	42.0±24.0
Albizzia versicolor Welw. ex Oliver	Mimosoideae	0.010±0.008	0.59±0.72	0.013±0.008	1.00±0.75
Annona senegalensis Pers.	Annonaceae	0.016±0.011	22.7±13.3	0.013±0.011	3.33±3.00
Allophylus rubifolius Engl.	Sapindaceae	0.031±0.011	1079±377	0.020±0.012	395±224
Boscia salicifolia Oliver	Capparaceae	0.019±0.080	212±56.6	0.012±0.008	97.0±41.3
Brachystegia boehmii Taub.	Caesalpinioideae	0.615±0.156	400±239	0.216±0.166	553±254
Brachystegia bussei Harms	Caesalpinioideae	0	0	0.006±0.004	70.0±67.9
Brachystegia microphylla Harms	Caesalpinioideae	0.067±0.030	123±61.7	0.005±0.032	47.0±35.7
Brachystegia spiciformis Benth.	Caesalpinioideae	0.098±0.054	78.3±34.1	0	0
Bridelia cathartica Bertol. f.	Euphorbiaceae	0.085±0.021	604±186	0.062±0.023	422±198
Cassia abbreviata Oliver	Caesalpinioideae	0.007±0.015	70.6±34.3	0.045±0.015	35.3±26.5
Cassia sp. nr *C. burtii* Bak. f.	Caesalpinioideae	0.000±0.001	2.94±2.94	0.003±0.001	7.33±5.30
Catunaregum spinosa (Thunb.) Tirveng.	Rubiaceae	0.015±0.006	328±93.2	0.012±0.007	169±89.2
Clerodendrum glabrum E. Meyer	Verbenaceae	0.006±0.004	70.9±37.0	0	0
Combretum adenogonium Steud. ex A.Rich.	Combretaceae	0.200±0.057	163±60.3	0.053±0.061	70.7±34.2
Combretum collinum Fresen.	Combretaceae	0.003±0.002	18.8±13.3	0.001±0.002	0.33±0.33
Combretum molle Engl. & Diels	Combretaceae	0.769±0.112	2701±339	0.478±0.119	4615±1419
Combretum obovatum F. Hoffm.	Combretaceae	0.053±0.059	809±645	0.133±0.063	1200±687
Combretum zeyheri Sond.	Combretaceae	0.213±0.054	1317±425	0.138±0.058	774±353
Commiphora africana (A. Rich.) Engl.	Burseraceae	0.083±0.020	563±157	0.033±0.022	329±147
Dalbergia melanoxylon Guill. & Perr.	Papilionoideae	0.118±0.060	509±143	0.144±0.064	574±173
Dalbergia nitidula Welw. ex Baker	Papilionoideae	0.030±0.030	352±145	0.070±0.032	1168±655
Dalbergia obovata E. Meyer	Papilionoideae	0.001±0.000	26.5±15.0	0.000±0.000	10.0±9.95
Dalbergia spp.	Papilionoideae	0	0	0.012±0.006	230±172
Deinbolia borbonica Scheff.	Sapindaceae	0	0	0.000±0.002	23.3±20.8
Dichrostachys cinerea Miq.	Mimosoideae	0.188±0.079	3046±924	0.356±0.084	8614±4145
Diospyros kirkii Hiern	Ebenaceae	0.019±0.010	124±64.6	0.006±0.010	54.0±38.7

Appendix 4. continued

Species	Family / Subfamily	Reserve (n = 34) Basal area (m² / ha)	Reserve (n = 34) Density (Stems / ha)	Public lands (n = 30) Basal area (m² / ha)	Public lands (n = 30) Density (Stems / ha)
Diospyros sp.	Ebenaceae	0.038±0.015	871±225	0.062±0.016	1800±741
Diospyros sp.	Ebenaceae	0.000±0.000	11.8±11.6	0	0
Diplorhynchus condylocarpon (Muell.-Arg.) Pichon	Apocynaceae	0.310±0.093	196±72.2	0.122±0.099	126±76.8
Dombeya rotundifolia (Hochst.) Planch.	Sterculiaceae	0.176±0.040	1109±226	0.059±0.043	198±95.1
Drypetes gerrardii Hutch.	Euphorbiaceae	0.000±0.000	8.82±6.44	-	-
Ehretia amoena Klotzsch	Boraginaceae	0.016±0.016	109±76.1	0.045±0.017	237±100
Ehretia spp.	Boraginaceae	0.021±0.015	13.5±8.30	0.009±0.016	150±56.4
Erythrina abyssinica Lam.	Papilionoideae	0	0	0.002±0.001	3.67±2.28
Erythrophleum africanum (Benth.) Harms	Caesalpinioideae	0.008±0.011	10.9±8.29	0.017±0.012	4.33±3.71
Euclea divinorum Hiern.	Ebenaceae	0	0	0.000±0.000	16.7±8.09
Flueggea virosa (Roxb. ex Willd.) Voigt	Euphorbiaceae	0.119±0.087	1339±505	0.089±0.084	35.0±18.2
Gardenia ternifolia Schum. & Thonn.	Rubiacea	0.000±0.005	0.29±0.37	0.008±0.005	0.67±0.39
Grewia bicolor Juss.	Tiliaceae	0.015±0.026	124±58.2	0.053±0.028	267±172
Grewia fobersii S. Moore	Tiliaceae	0.008±0.006	32.4±32.4	0.005±0.007	240±166
Grewia similis K. Schum	Tiliaceae	0.026±0.018	43.2±27.0	0.009±0.019	73.3±54.4
Harissonia abyssinica Oliver	Simaroubaceae	0.009±0.004	224±93.1	0.060±0.050	137±69.1
Indigofera spp.	Papilionoideae	0.134±0.038	2195±706	0.023±0.041	787±742
Julbernardia globiflora (Benth.) Troupin	Caesalpinioideae	0.564±0.143	3953±1201	0.620±0.152	5327±1702
Lannea schimperi Engl.	Anacardiaceae	0.065±0.026	21.8±15.7	0.239±0.027	97.7±41.9
Lannea schweinfurthii Engl.	Anacardiaceae	0.043±0.041	41.5±26.5	0.076±0.043	28.3±20.2
Leptactinia sp. nr. *L. benguellensis* Good	Rubiaceae	0.004±0.012	182±182	0.017±0.012	650±467
Lonchocarpus bussei Harms	Papilionoideae	0.102±0.033	442±139	0.064±0.035	275±148
Lonchocarpus capassa Rolfe	Papilionoideae	0.001±0.003	18.8±6.85	0.004±0.003	0.67±0.39
Maerua triphylla A. Rich.	Capparaceae	0.040±0.019	1686±783	0.050±0.020	1443±533
Margaritaria discoidea (Baill.) Webster	Euphorbiaceae	0.029±0.015	197±91.5	0.010±0.016	71.4±50.1
Markhamia obtusifolia Sprague	Bignoniaceae	0	0	0.002±0.001	27.6±26.7
Markhamia sanzibarica K. Schum.	Bignoniaceae	0.000±0.007	8.82±8.82	0.011±0.008	45.0±31.5
Maytenus senegalensis (Lam.) Exell	Celastraceae	0.001±0.001	58.8±40.8	0	0
Millettia usaramensis Taub.	Papilionoideae	0	0	0.001±0.000	0.33±0.23
Millettia sacleuxii Dunn	Papilionoideae	0.006±0.004	1.47±1.07	0.000±0.005	0.00±1.14
Ochna holstii Engl.	Ochnaceae	0.000±0.007	17.7±17.7	0.013±0.008	183±87.3
Ochna leptoclada Oliver	Ochnaceae	0	0	0.003±0.001	55.9±29.4
Ochna macrocalyx Oliver	Ochnaceae	0.002±0.001	32.4±20.9	0.001±0.001	36.7±29.7
Ormocarpum kirkii S. Moore	Papilionoideae	0.000±0.004	8.82±6.39	0.015±0.005	78.7±37.0
Pteleopsis myrtifolia Engl. & Diels	Combretaceae	0.053±0.022	229±103	0.033±0.024	206±109
Pterocarpus angolensis DC.	Papilionoideae	0.100±0.079	5.06±17.1	0.135±0.084	45.0±26.2

Appendix 4 continued

Species	Family / Subfamily	Reserve (n = 34)		Public lands (n = 30)	
		Basal area (m^2 / ha)	Density (Stems / ha)	Basal area (m^2 / ha)	Density (Stems / ha)
Pterocarpus rotundifolius Druce	Papilionoideae	0.216±0.054	527±191	0.197±0.058	467±210
Pseudolachnostylis maprouneifolia Pax	Euphorbiaceae	0.059±0.021	34.1±29.4	0.021±0.022	101±41.5
Rothmania fischeri (K. Schum.) Bullock	Rubiaceae	0.032±0.024	0.29±0.21	0	0
Rytiginia sp.	Rubiaceae	0.004±0.002	224±102	0.000±0.002	10.0±10.0
Sclerocarya birrea ssp. *caffra* Sond.	Anacardiaceae	0.274±0.084	6.47±3.01	0.122±0.092	28.7±17.9
Spirostachys africana Sond.	Euphorbiaceae	0.229±0.111	930±640	0.216±0.118	157±150
Sterculia africana (Lour.) Fiori	Sterculiaceae	0.001±0.027	3.53±2.19	0.042±0.029	0.33±0.33
Stereospermum kunthianum Cham.	Bignoniaceae	0.001±0.001	0.29±0.21	0	0
Steganotaenia araliacea Hochst.	Umbelliferae	0.173±0.122	9.41±6.44	0	0
Strychnos spinosa Lam.	Loganiaceae	0.000±0.000	0.33±0.33	0.000±0.000	10.0±10.0
Tamarindus indica L.	Caesalpinioideae	0.196±0.106	42.1±30.5	0.001±0.113	0.33±0.23
Terminalia mollis Engl. & Diels	Combretaceae	0.007±0.005	79.4±57.9	0.003±0.000	56.7±56.7
Terminalia sericea Burch. ex DC.	Combretaceae	0.080±0.028	562±281	0.042±0.029	142±98.6
Turraea nilotica Kotschy & Peyr.	Meliaceae	0	0	0.001±0.000	0.33±0.33
Turraea sp.	Meliaceae	0.013±0.005	71.2±43.1	0.024±0.006	352±138
Vangueria infausta Burch.	Rubiaceae	0	0	0.024±0.012	218±92.3
Vernonia sp.	Compositae	0	0	0.002±0.002	3.33±3.33
Vitex ferruginea Boj. ex Schau.	Verbenaceae	0	0	0.044±0.030	0.33±0.23
Xeroderris stuhlmannii (Taub.) Mendonca & Sousa	Papilionoideae	0.221±0.072	15.6±7.18	0.158±0.076	45.7±31.8
Ximenia caffra Sond.	Olacaceae	0.011±0.007	29.7±17.7	0.008±0.007	17.3±18.8
Zanha africana (Radlk.) Exell	Sapindaceae	0.001±0.004	41.2±23.6	0.007±0.004	57.3±32.6
Zanthoxylum chalybeum Engl.	Rutaceae	0.005±0.135	91.2±52.7	0.003±0.002	63.3±36.1