UTILISATION AND DYNAMICS OF AN ARID SAVANNA WOODLAND IN THE NORTHERN PROVINCE, SOUTH AFRICA

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ABSTRACT

This thesis reports upon the findings of a study into the socioeconomic and ecological drivers of plant resource utilisation, and dynamics of woody plants used by rural people in the Northern Province, South Africa. The key components were to (1) quantify the range of socioeconomic drivers of plant resource utilisation in rural communities, (2) identify plant species highly preferred by people and their uses, (3) quantify the impacts of plant resource harvesting, (4) seek relationships between spatial distribution patterns of plants and productivity, (5) determine the responses of trees to harvesting regimes, and (6) elucidate the impacts of selected management actions on plant resource supply and hence sustainability. Each of these was pursued through a combination of surveys and empirical experimentation.

High unemployment rate, low educational levels, large family sizes and most importantly low overall family income are characteristic of this rural community. As a result, many people are still reliant on wild growing plants for their household and economic needs. The three main use categories associated with people in this rural village, in order of their importance, are: construction, food and energy. It is construction and energy uses that are associated with very few species. Harvesting of plant materials for these two use categories is destroying the preferred species in communal land. Two plant species, *Colophospermum mopane* and *Androstachys johnsonii*, are the most preferred plant species for construction and energy purposes.

In a protected area the *C. mopane* population is stable, an indication that recruitment balances mortality. The same applies to *A. johnsonii*. However, in communal land the size class frequency distribution of *C. mopane* varies at three distances from the village, suggesting that communal patterns of *C. mopane* utilisation are unfavourable to this species. This is probably so because of intense browsing within the village and high levels of harvesting. However, *A. johnsonii* at two harvest zones in communal land show the same trend as in the protected area: the inverse J-shaped curve which is a characteristic feature of a stable population. Selective harvesting therefore, has little impact on recruitment of young *A. johnsonii* trees.

Conflicting results were evident with respect to the role of competition in tree populations. Spatial distribution methods (i.e. nearest-neighbour analysis and departure from randomness approach) from a number of plots suggested that competition was not important at most plots. Yet, the strong negative relationship between $\log_e$ mean stand basal area and $\log_e$ stand density indicated that competition is a significant factor affecting individual tree and stand woody productivity. Most plots from the communal land, when plotted on the same graph of plots from the protected site, lay far below the thinning line, suggesting that harvesting is promoting rapid growth of trees in communal land.

The five species harvested responded differently from each other. Full and partial harvesting of *C. mopane* trees during December at ≤ 30 cm above ground level resulted in 100% survival rate after one year. The equivalent diameter of coppice shoots was significantly positively related to stump size and light availability. The former suggests that harvesting bigger trees will result in rapid diameter growth of coppice shoots while the latter suggests that shoots are suppressed by shade from neighbouring trees. The equivalent shoot diameter was significantly negatively related to sum of neighbour size divided distance ratios, an indication of competition between neighbouring trees.

All big trees and 70% of the small trees of *A. johnsonii* species died when the same season, height of cutting and harvesting regime applied to *C. mopane* was used. Partial harvesting resulted in 60 and 45% survival rates for big and small trees respectively. Coppice shoot production of the surviving stems was also very low compared to *C. mopane*. A static transition model was developed to simulate requirements for sustainable harvesting of *Colophospermum mopane* woodlands. The model predicts that a combination of high levels of harvesting and browsing will result in the depletion of the resource base within three decades.

DECLARATION

The survey and the experimental work described in this thesis was carried out by the author while he was a student at the Botany Department, University of Cape Town, from January 1997 to September 1999, under the supervision of Dr. J.J. Midgley and Prof. W.J. Bond.

These studies represent original work by the author and have not been submitted in any form to another university. Where use was made of the work of others it has been duly acknowledged in the text.

N.R. Rathogwa
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CHAPTER 1. GENERAL INTRODUCTION

1.1 WOODLANDS AND RURAL LIVELIHOODS

Managing the earth's heritage of biodiversity is an immense twofold challenge: the magnitude of biodiversity is staggering; also staggering are present day human impacts on the biosphere (Gadgil 1997). Confronted with this challenge people have sought to focus biodiversity management action by looking for conservation priorities (Culverwell 1990). Many institutions, including the governments, remain ignorant of the magnitude and distribution of the driving forces behind and the precise course of impacts of human activities on the stock of biodiversity.

Woodlands (both forests and woodlands) are a source of a variety of products for both the rural-poor and urban-rich communities (Gregersen *et al.* 1995; Clarke *et al.* 1996; Shackleton 1997; Shackleton *et al.* 1998). The values associated with these woodlands with regard to rural livelihood sustenance are however not well understood and communicated among the different user groups. As a result, there is potential conflict of interest between local resource user and resource conservation and management groups. Generally, these conflicts have, throughout the world and more specifically in Africa negatively affected the sustainability of resources used by local people as well as resource conservation and hence development initiatives (Culverwell 1990).

In South Africa natural woodlands, if appropriately managed, can contribute significantly to sustainable social and economic development (National Forestry Action Programme 1998) since they occupy a diverse range of environments which have significant although often poorly recognized economic, environmental and social values. The management of these woodlands varies from place to place and, as a result, their conditions also vary from one area to the other. Their contributions to human welfare also differ significantly from one place to the other, and from one group of people to the other. For example, woodlands are a source of income for rural poor communities through the sale of poles to other rural communities for building; fuelwood is sold to both local people as well as those in urban areas; some woodlands are seen as a source of browse for goats and cattle, an aspect so important to sustainable subsistence livestock farming systems of the poor communities; and the success of the wood crafting (wood carving and processing) is also based on these woodlands. As a result, human perceptions of the environment around them also vary.

1.1.1 Dependence of rural people on plant resources

Many people, especially in poor countries worldwide, rely on wild plants for food, construction materials, fuelwood, medicine, craft, browse and many other products and service (Mabogo 1990; Phillips & Gentry 1993a,b; Evans 1994; Gregersen *et al.* 1995; Clarke *et al.* 1996; Cunningham 1996; Wild & Mutebi 1996; Shackleton 1997; Grundy 1999). Generally, this dependence on wild resources by local people is associated with social, cultural and economic aspects of the respective poor communities such as employment status, educational levels, age, gender and family sizes as well as the dynamics of the surrounding woodland systems, or a combination of some of these factors (Evans 1994; Evans *et al.* 1994; Shackleton 1994). At present, it is assumed that the observed declining trend of wild plant resources is partly due to exponential human population growth rates in rural communities (Banks *et al.* 1996) and/or competition between resource use by local communities and other forms of land use.

Studies have shown that the utilisation of woodland resources by local people may result in one or more of the following conditions: a) decreased availability or the depletion of the plant resources (Mabogo 1990; Griffin *et al.* 1993; Ayling *et al.* 1996), b) changes in plant community composition and structure (Shackleton *et al.* 1994), which may also affect the dynamics and functioning of the woodland system and hence productivity, and c) local extinction of rare or over utilised plant and animal species (Wild & Mutebi 1996). Each of these conditions may in turn, directly or indirectly, affect the perceptions of the people who are largely dependent on the woodland for their survival.

In South Africa, rural communities often form a mosaic with National Parks and private and public Nature Reserves. Conservation initiatives within these protected areas are generally based on the need to i) avoid the depletion of the natural resources, ii) maintain productivity of the system, iii) maintain representative samples of the "original" woodland systems and the protection of rare species, iv) provide recreational, educational, research and tourism alternatives and v) for game and timber production purposes (e.g., Heyns *et al.* 1989; Vermeulen 1994). In most cases these products and services are not readily available to the poor communities. Often, the communities are not involved in the decision-making process regarding such conservation and development initiatives, including the management of the natural resources on which they depend. As a result, there is often conflict of interest between natural resource conservation and management authorities and local people. This ignorance of the role of woodland resources with regard to rural livelihood sustenance has also resulted in unsuccessful implementation of conservation and development initiatives in other parts of Africa (Culverwell 1990)

The realisation that uncontrolled utilisation of woodlands is a major problem to ecotourism development as well as to the livelihood systems of the rural communities is rapidly gaining momentum both within the conservation and development authorities and the rural communities themselves. Over the past few years there has been an increasing international appreciation of the important role that woodlands can play in sustaining the livelihood of the rural poor communities (Martin 1995; Cotton 1996) as well as the role that rural people can play in sustainable conservation and development (Gadgil 1987; 1997). Contradicting statements have also been made regarding this change of attitude towards local people. The general trend however suggests that there is a need to determine resource use patterns and management options within the context of rural development. It is assumed that this information can shed light on i) those practices that influence biological diversity patterns in communal woodlands, ii) the resilience of some species to forms of utilisation, iii) management practices which are more likely to be sustainable in the long-term and iv) the dynamics of the natural woodlands where many ecological questions remain unanswered.

It is generally accepted that 'early humans', the so-called primitive people (Jain 1992), which sometimes includes poor rural people, used a wide range of biological resources from a diversity of environments, from which they obtained their products for livelihood needs and economic ends. "As a result, they possessed high levels of cultural diversity depended on and supportive of high levels of biological diversity" (Gadgil 1987). This relationship was, in one way or another, broken down during the colonial era due to massive resource exploitation through the use of advanced technological systems and the destruction of human cultures worldwide. According to Gadgil (1987), biological diversity increases through time as an adaptation to environmental heterogeneity, which itself is continually enhanced by the activities of living organisms, including humans.

Within human cultures, any given human group may also possess a wealth of culturally transmitted behaviour which differs from that of the other groups. This difference in behavioural traits can also shed light on the link between human (practices) and biological diversity. It is often expressed that the diversity of life on earth, including that of human cultures (Martin 1995; Cotton 1996), is under a serious threat. The world is becoming dominated with the technological culture, which, according to (Gadgil 1987), is perceived as the major cause of loss of biological diversity. This cultural dominance and its effects on biological resources have generated some interest: that of understanding how the diversity of human cultures relates to the conservation of biological diversity, and whether attempts to conserve biological and cultural diversity should go hand in hand. However, such an attempt is doomed to fail if resource use in rural communities is still confined to the two main user groups: those living in rural areas and largely dependent on the vegetation around them for subsistence and economic ends (the "ecosystem" people) and the mobile urban people who also use resources in rural areas for their betterment and economic generation (the "biosphere" people) (Gadgil1997).

Poor rural communities in South Africa are closer to these early humans in many respects than urban communities. For example, they are still dependent on wild resources for their household and economic needs, obtaining most of their resources from a variety of woodland systems around them (Shackleton 1998). However, their practices are generally seen as uncontrolled and hence unsustainable. Several interrelated factors, for example, socio-economic and cultural aspects of the local people as well as the dynamics of the woodland system, account for most of the observed resource use conflicts in rural communities.

1.1.2 Resolving resource conflicts in rural communities

Two contradicting views have been suggested on how to resolve resource use and conservation conflicts. One approach suggests the spread of dominant cultures and the diffusion of innovations to other human groups (Gadgil 1987). However, as genetically engineered organisms become an economically viable proposition with the accruing advantages concentrated in the hands of a few human groups, a further drastic reduction in biological and cultural diversity may ensue. Thus, this approach will cause further deterioration of the environment and hence loss of biological diversity.

The second approach involves either the *sharing of benefits* from conservation and development initiatives or the *extraction of resources by rural people* from a portion of the protected areas (Wild & Mutebi 1996). This approach emphasizes the need to provide access to sustainable harvesting in neighbouring areas presently unavailable to rural communities, including conservation and private land (Shackleton 1993; Cunningham 1996; Wild & Mutebi 1996). However, woodlands are often associated with high human population densities (Grundy 1999) and this may affect negatively the status of resources in protected areas.

While measures like the provision of access to protected areas are becoming a reality, relatively little is known of the ecology and effects of harvesting on the sustainability of the varied resources which make up the woodland system. Given this new approach, information on the effects of damage, including felling, lopping and browsing, on yield components of trees becomes a basic requirement for assessment and management of trees for wood production (Milton 1988). This approach is being used in Uganda and has shown that resolving resource use conflicts through collaborative management and an understanding the ecology of the species in rural areas can result in sustainable social, economic and conservation development (Wild & Mutebi 1996; Cunningham 1996). The success of this approach in other regions has not yet been reported, possibly because this initiative has not been implemented.

This new approach is an issue of major concern to both private and public Nature Reserve authorities. For example, there is little information on which resources do people in different areas need and how often. What are socio-economic and ecological drivers of resource use patterns? How do species respond to harvesting? How much of the woodland need can be produced by a particular woodland systems. What are the factors limiting the production of the resources needed by rural communities? These questions have directed ethnobotanical research into a new direction as outlined below.

1.2 TRENDS IN CURRENT PLANT-PEOPLE INTERACTION STUDIES

Ethnobotany has been defined as the study of all aspects of direct relationship of plants with man (Jain 1992) or as "all studies concerning plants and describing local people's interaction with the natural world" (Cotton 1996). As a result current ethnobotanical studies do not only focus on how plants are used, but also on the reciprocal relationships between human societies and the plants on which they depend (Rao & Hajra 1992; Phillips & Gentry 1993a,b; Prance 1995; Prance *et al.* 1995; Cunningham 1996; Wild & Mutebi 1996; Shackleton 1997). This new approach emphasises the importance of local knowledge pertaining to plants, plant uses and plant management.

The traditional botanical knowledge (TBK) approaches (Cotton 1996) and the Rapid Vulnerability Assessment (RVA) method (Cunningham 1994, 1996; Wild & Mutebi 1996) are generally used to study this relationship between plants and people. TBK refers to 'the total botanical knowledge held by any non-industrialised community, including all the utilitarian, ecological and cognitive aspects of both plant use and vegetation management'

(Martin 1995; Cotton 1996). RVA is "a systematic method developed by Cunningham to rapidly assess the vulnerability of plant species to use by local people" (Wild & Mutebi 1996). The fundamental unit of these two approaches is the species. Thus, the new approach has as its main purpose the potential to link people and plants, an element so essential for successful conservation and development in rural communities.

1.3 EFFECTS OF RESOURCE USE ON PLANT POPULATION DYNAMICS

Problems in poor rural communities, especially communities largely dependent on natural plant resources for their subsistence and economic ends, include the observed declining patterns of plant resources around the villages. If access to protected areas and subsequent harvesting are to be successful and sustainable, it is necessary to have an understanding of the natural and management factors that influence the population dynamics of the target species. These may include coppicing vigour and subsequent growth of coppice (sprouts) after harvesting, ecological factors affecting biomass production patterns, recruitment strategies employed by the different species and management interventions required for the sustainability of the target species. This information alone is not enough. There is a need to understand local people's plant species preferences and uses and hence harvesting methods, the population demography of some preferred plant species under contrasting management systems, and the responses of trees to harvesting intensity, height and season. Given this information, a strategy for resource utilisation in both the protected and communal lands can be formulated.

Nevertheless, the redistribution of existing wood resources has received little attention in open forums (Shackleton 1994). Also, sustainable harvesting, use of natural products and multiple-purpose land-use have a conservationist basis: the sustainable use of natural resources is advocated by the Strategy for Sustainable Living (IUCN 1991 in Shackleton 1994), while social forestry arguably has its roots in a preservationist philosophy of protecting existing woodlands by providing alternatives rather than looking at the judicious use of existing resources (Shackleton 1994). Generally, these strategies lead to resource use conflicts, and have impacted negatively on conservation and development initiatives (Cotton 1996).

1.4 AIMS AND OBJECTIVES OF THE STUDY

The aim of the study was to gain an understanding of factors influencing plant resource use and availability patterns and hence sustainability in a rural communal land.

The primary objectives of this study were:

1. To gain an understanding of the influence of socio-economic conditions of a rural community on plant species knowledge and uses.
2. To identify plants and plant uses that are regarded as highly important to this community.
3. To identify uses and practices that are most likely influencing the sustainability of the woodland resources and hence resource status.
4. To gain an understanding of the population demography of some selected tree species under contrasting management systems.
5. To determine the effects of competition on woody production.
6. To determine plant response patterns to harvesting regimes.
7. To gain an understanding of the management systems that are influencing woodland population stability and hence sustainability.

The following key questions were asked:

How does socio-economic status within a rural village influence plant resource knowledge and hence use and sustainability?

What is the socio-economic condition of this rural community?

Which plant resources are needed by rural communities and for which purposes?

Are plant resource knowledge and use related to socio-economic conditions?
What is the impact of resource utilisation on the status of the resource?

How does management of the needed resources affect the plant populations?
What is the population size structure of the most needed species under contrasting management regimes?
Which factors are influencing the observed size class distribution patterns?
What are the implications of the observed size class distribution patterns?
What conditions do seedlings require for recruitment?

What limits productivity of the arid savanna woodland system?
Is inter- and intraspecific competition limiting woody production of the needed plant resources?

How does harvesting affect woody production of the people's needed resources?
Which factors influence survival, coppicing and regrowth of the needed plant resources after harvesting?

How much of the woodlands needs can be harvested on a sustainable basis?
Which management systems are affecting sustainability?

1.5 STUDY AREA

The study was conducted in the Northern Province which is about 60 km northeast of Thohoyandou (Figure 1.1) in both a communal land (Mukomawabani village, Ha-Makuya) and a nature reserve (Makuya Park / Nature Reserve). The study area lies between 30^0 50'E and 31^0 05'E, and 22^0 25'S and 22^0 35'S. These two contrasting sites are separated from each other by Tshikondeni mine.

The geology of much of the study area is described as the Karroo Sequence. The major geological features of this area are described as white feldspathic grit, sandstone, conglomerate and in some places quartzitic (Geological Survey 1981). No specific temperature and annual rainfall statistics are available for the area, although the area is well known for its high summer temperatures and moderate to warm winter temperatures. Temperatures vary between extremes of 1.5 and 42.5 ^{0}C, with an average of 22 ^{0}C. Mean daily maximum and minimum temperatures at Macuville (ca. 80 km west of the study area) during December are 32.8^{0}C and 20.4^{0}C respectively, while during July they are 24.8^{0}C and 6.7^{0}C respectively (Smit 1994).

Annual summer rainfall from Pafuri, which is about 20 km from the study area, is from 250 to more than 500 mm, with a mean of 438 mm per year (Gertenbach 1983).

The vegetation is classified as Mopane Bushveld (Low & Rebelo 1996) and is characterized by a fairly dense growth of Mopane (*Colophospermum mopane)* and mixtures of *Combretum apiculatum*, associated with *Acacia nigrescens, Adansonia digitata, Commiphora* spp., *Boscia albitrunca, Terminalia prunioides, Kirkia acuminata* and, on rocky outcrops, *Androstachys johnsonii.* The sandy-loam soils, low rainfall, high temperatures and lack of frost influence the distribution of this vegetation type.

Cattle, goat and game farming, ecotourism and mining are the most important economic land uses within the study area (Low & Rebelo 1996).

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* *All plant names used in this study are from Arnold & de Wet (1993).*

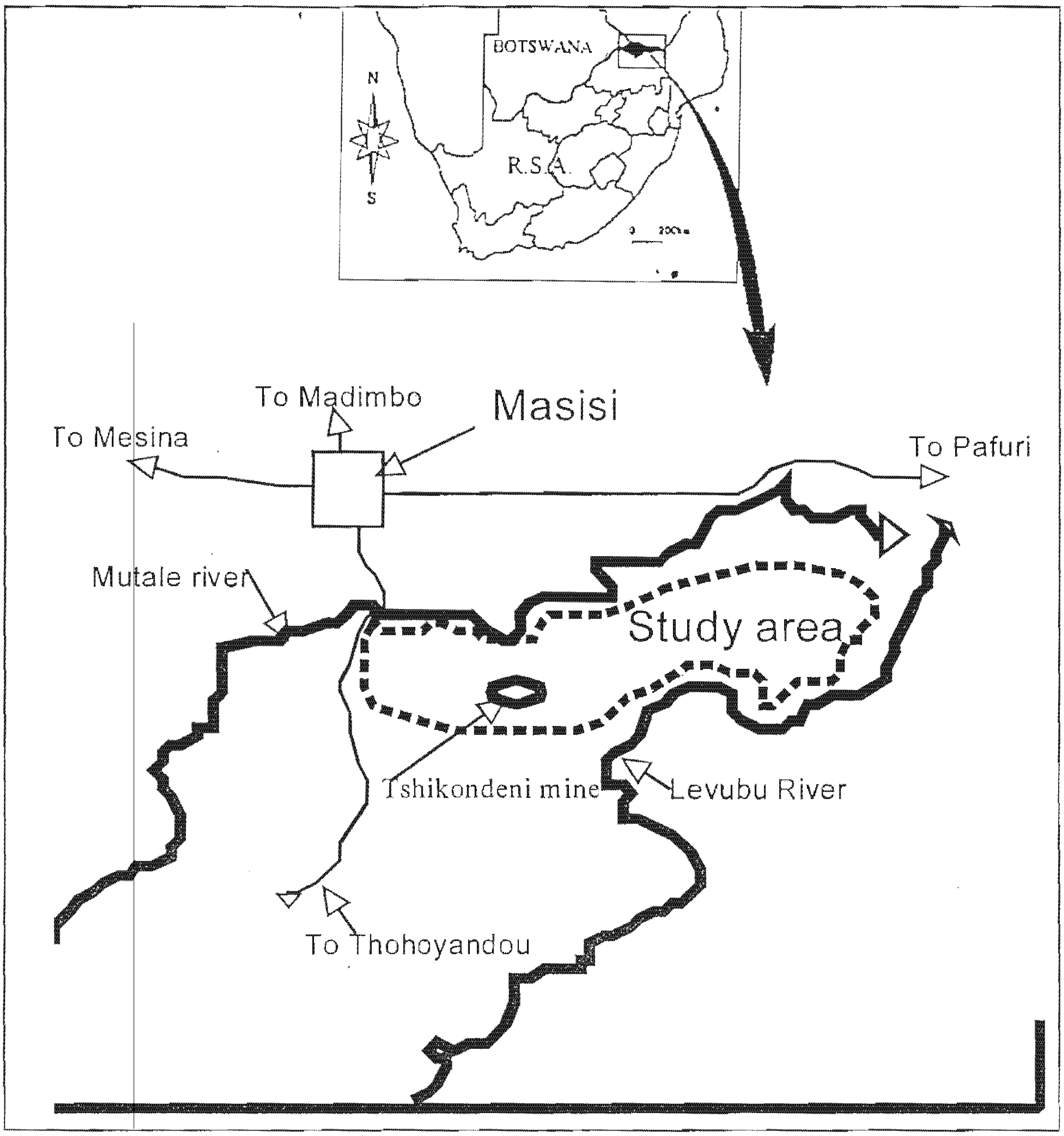


Figure 1.1 Location of the study site (Mukomawabani and Makuya Park).

CHAPTER 2. PEOPLE AND PLANTS: PLANT RESOURCE NEEDS

2.1 INTRODUCTION

Southern Africa is a land of tremendous resource and cultural diversity. The diverse cultures exhibit modes of social organisation with different and sometimes conflicting strategies of resource management reflected in a variety of land-use activities (Katerere 1997). Some people often reject cultural practices as irrelevant and part of an older order while other cultural groups often reject authoritarian, top-down management that separates the bureaucrat from the environmental user and imposes technocentric solutions upon cultural landscapes and environments (Griggs 1997).

Since culture is an evolving and dynamic relationship between a society and the environment, it is believed that culture can provide a key to both explaining environmental conflicts and resolving them (Griggs 1997), including woodland resource use and management conflicts throughout Africa.

Woodlands (both forests and woodlands) are a source of a variety of products for both the rural-poor and urban-rich communities (Kokwaro 1983; Gregersen *et al.* 1995; Clarke *et al.* 1996; Shackleton 1997). Yet their values with regard to rural livelihood sustenance are not well understood and communicated among the different user groups. As a result, there is often conflict of interest between resource user and resource conservation and management groups. These conflicts have, throughout the world, negatively affected the sustainability of resources used by local people as well as resource conservation and hence development initiatives.

In seeking solutions to these conflicts it has been suggested that natural resources be socially defined (Katerere 1997) since social behaviour of humans interacts with ecological systems. Consequently, a new paradigm of sustainable development based on participation, governance and a need to balance social, economic and environmental objectives has evolved: the joint forest management (Katerere 1997; Prah 1997) and community-based forest management (Wily 1997). Participation by local communities, the right to and access to natural resources and benefits, capacity building, accesses to technology and investment in rural enterprise are all central themes of the new paradigm.

This chapter investigates plant resources needed by rural communities and how socioeconomic factors influence plant resource knowledge and utilisation. Major uses of plants that are influencing the availability and hence sustainability of plant resources in communal land are also investigated and quantified. Since the socio-economic status of people in rural communities are also changing, knowledge of the variations in plant resources knowledge and hence utilisation with socio-economic status is important in seeking solutions to sustainability and successful conservation and development initiatives. This chapter attempts to quantify these trends.

2.1.1 Literature survey

Resource use patterns are usually investigated through observations and interview surveys. In this way plants and their uses are identified and recorded. These methods have their inherent problems: they require longer time to gain an understanding of the cultural aspects of resource uses and are expensive to gather relevant information successfully (Conroy 1996; Schultes & Von Reis 1995). This approach makes ethnobotany what it was from the beginning: the field of plant identification, observation of local plant uses and management, and then documentation.

The adoption of TBK and RVA approaches resulted in drastic changes with regard to ethnobotanical data collection approaches: a change from long-term observational and documentation studies (e.g Mabogo 1990; Schultes & Von Reis 1995) to a combination of short-term observation and rapid participatory research (Phillips & Gentry 1993a,b; Evans *et al.* 1994; Prance *et al.* 1995; Cunningham 1996; Wild & Mutebi 1996; Martin *et al.* 1998). These techniques are used to establish the use-value or the vulnerability of certain plant species, plant family or forest system (Phillips & Gentry 1993a,b; Prance *et al.* 1995; Martin 1995; Cotton 1996) to utilisation.

2.2 OBJECTIVES

The primary objectives of this study were:

1. To gain an understanding of the socio-economic conditions of a rural community and how these influence plant species knowledge and uses.
2. To identify plants and plant uses that are regarded highly important to this community.
3. To identify uses and practices that are most likely influencing the dynamics of the woodland resources and hence resource status.
4. To gain an understanding of resource availability and sustainability patterns using resource status perceptions of rural people.

The following key questions were asked:

1. How are plant resource knowledge and use patterns influenced by socio-economic conditions of local people?
2. Which woodland species and uses are highly preferred by the community?
3 Which uses are more likely influencing the dynamics of the woodland?
4. What is the impact of resource utilisation on the status of the resource?

2.3 METHODS AND MATERIALS

Analytical tools have also developed (Adu-Tutu *et al.* 1979; Phillips & Gentry 1993a,b; Martin 1995; Prance *et al.* 1995; Cotton 1996) to facilitate the quantification and cross-verification of ethnobotanical data. Data on local significance of plant species and management may be analysed quantitatively on the basis of various numerical indices developed recently for general or specific data (Phillips & Gentry 1993a,b; Martin 1995;

Prance *et al.* 1995; Cotton 1996). For example, the 'index of saliency' gives an idea on those plants which are in common usage; 'preference ranking' is a mean numerical value or value given to a plant species according to its perceived cultural and/or economic significance and the 'use-value' statistic estimates the overall usefulness of a given plant (Martin 1995; Cotton 1996).

During the survey, the *law of diminishing returns* (Martin 1995; Cotton 1996) may be used to assess if the number of plant species supplied by respondents is "enough" or complete for the purpose of the study. The law of diminishing returns states that we get a decreasing amount of new information from each interview we make: we learn much from the first person to whom we talk, the second interview gives us some new information but some of what the first informant give will probably be repeated, and so on. Eventually, we find that each new person we talk with tell us things that we have already heard from the others and thus our data is assumed to be complete.

Most of these new methods have not been tested here in South Africa. It is hoped that if adopted, with minor modifications to suit local conditions, these methods will strengthen studies of people/plant relationships.

In this study two basic approaches were used to collect data: the structured interview approach for collecting data on socio-economic, cultural and ecological aspects within the village area and the field-based approach to collect data for the interpretation of plant resource status, availability and response to forms of utilisation.

2.3.1 Household survey

A preliminary household survey was conducted to gain insight on household composition and some local practices. A meeting was arranged personally with the headmen who, after the informal discussions about the project, gave permission to conduct the research in his village. The names of the household owners were obtained from the headman who, on request, agreed to work with the researcher to identify randomly the households to be interviewed and to supply the researcher with the gender information for the household owners. Seventy-six households were identified within this community.

Each household was assigned a number from one to seventy-six. A sample of 38 households (50.0% sample) was randomly selected. About 32 households are controlled by women compared with 44 that are controlled by men, while there is only one businessman in the area. The 38 households sample was divided into nineteen each for women and men controlled households respectively.

After the identification of the households, the headman was requested to call a general meeting of all the people so that the objectives of the research could be explained to the community and that the researcher be introduced to the community. The meeting was unsuccessful due to funeral commitments of the headmen. The headman personally informed all the household owners about the objectives of the research and urged his people to welcome the researcher. This was personally confirmed when I arrived at each household by the warm and friendly welcome shown by household heads. I explained the objectives of the research again and, in all the households, people mentioned that the same message was conveyed to them by the headman.

2.3.1.1 Socio-economic trends within the community

A questionnaire with predetermined questions on the social, cultural, economical and ecological aspects was used to obtain information from household "heads". Before the questionnaire was adopted for data collection, it was evaluated by our Social Scientist colleague, namely Jeremy Evans of CSIR, Environmentek. The respondents were asked to supply information on their age, school standard passed, employment status, type of employment, income per month, other people's income per month if sharing the household, number of people per household and other economic and subsistence activities. This information was used to gain an understanding of the influence of household socio-economic conditions on woodland resource use perceptions.

2.3.1.2 Cultural-ecological significance of plants

A modified free-listing approach referred here to as the *sequence of mentioning plant species* (*somps*) was used to collect data on cultural significance of certain plant species. *Somps* was divided into random mentioning of plant species (*r-mops*) and preference mentioning of plant species (*p-mops*), based on free-listing method (Martin 1995; Prance *at al.* 1995; Cotton 1996). In the *r-mops* and *p-mops* approaches no method for reminding people about plants or plant uses was used during the process of data collection, people listed plant species first, randomly and secondly, in order of preference. The sequence of mentioning plant species was generated by assigning scores, from the highest for the highly preferred plant species to the least, to the plants mentioned. The basic assumption of *somps* is that people in the same community will tend to mention the same plant species but the sequence of mentioning increases with the cultural importance of the individual plants (Martin 1995).

Random mentioning of plant species (*r-mops*)

This method was used to collect data on the sequence at which plant species are randomly ordered by the respondents. No order was requested nor a limit set for the maximum number of species a particular informant could give. In each interview, each species mentioned first was given a score of 10, if mentioned second a score of nine and so on until if number nine and a score of two. All other plant species whose mentioning was recorded after the respondent has mentioned nine other plant species were assigned a score of one. This procedure was repeated until all respondents were interviewed. From this interview, the cultural significance or importance value (IV)of the species was calculated as the product of the sum of scores and number of respondents who mentioned that species and then divided by the total number of people interviewed.

During the *r-mops* survey, the *law of diminishing returns* (Martin 1995; Cotton 1996) was used to assess if the number of plant species supplied by respondents was "enough" or complete for the purpose of this study.

Preference mentioning of plant species (*p-mops*)

Using the *p-mops* approach, respondents were asked to list only the five most preferred plant species in order of their importance, starting with the most important of the five plant species, to the least important one. The most important or highly preferred species was again given a score of 10, the following one of 9, then of eight until six for the least preferred species. This procedure was repeated until all the informants have been interviewed. From this survey of preferred species, the cultural significance or importance value (IV) of the species was calculated as the product of the sum of scores and number of respondents who mentioned that species and then divided by the total number of people interviewed.

Economic, cultural and ecological significance of plant uses

For each species given in the *p-mops* survey, informants were again asked to give (or free-list as it is called (Prance *et al.*1995; Cotton 1996)) all the uses associated with each of their preferred species, including parts used and purpose, harvest methods, harvest seasons, place of collection and availability and reasons thereof. Based on the uses associated with these highly preferred species, informants were asked to give information on the units of plants used (for example, the smallest unit of fuelwood is a headload, while the largest unit is a full-truck load), local price of the unit if any, duration of units and market availability.

The use-value (UV_{is}) statistic was used to estimate the overall use-value of species (UV_s).

$$UV_{is} = \sum U_{is} / n_{is}$$

where UV_{is} stands for the use-value (UV) attributed to a particular species (s) by one informant (i). This value is a function of the uses of a species, calculated by summing all the uses mentioned in each interview by the informant (U_{is}) and then dividing by the total number of interviews in which an informant gave information on the species (n_{is}). For example, if you have interviewed an informant i two times and the number of uses attributed to species *s* are six and seven respectively, the use-value of this species is given by formula above:

$$UV_{is} = (6+7)/2 = 6.5.$$

Similarly, if only one interview was conducted, as it was in the case of this study, the use-value would be:

$$UV_{is} = 6/1 = 6$$

This result can be added to use-values derived from other informants ($\sum UV_{is}$) and then divided by the total number of people interviewed about that particular species n_s to yield the overall use-value (UV_s):

$$UV_s = \sum UV_{is} / n_s$$

Assuming that all the respondents had equal chance of mentioning that species and hence stating all its uses, the UV_s is again divided by the total number of respondents to obtain a relative overall use-value (RUV_s). However, this does not change the relative usefulness of a species and as such, was not calculated.

The derived importance values (IVs) from *r-mops* and *p-mops* surveys were correlated with each other to establish the type of relationship that exists between the two sets of data. If there is a significant positive and linear relationship, it suggests that the community is still highly dependent on natural plant resources for their household and/or economic needs. Lack of a significant relationship or a significant but negative relationship suggests that the community is less dependent on natural resources for its household and economic needs. This is so if the community has depleted much of the needed resources and hence rely on anything that is available for use irrespective of whether it is good or bad. Another explanation for this pattern is that people are changing with changing economic status and that the dependence of this community on natural plant resources is about to come to minimum due to increased household economy. Again, the mean importance values of the species were correlated with number of uses of species, while the total number of plants mentioned during the *r-mops* survey were correlated with the respondent's age, income, school standard passed, employment status and type and sex. The gender variation with regard to the total number of plants mentioned were also assessed.

Although preliminary measures of quantities of materials utilised were made, no effort has been made to analyse these data in this thesis. This is because time prohibited a detailed analysis of spatial context. Also institutional ownership of land and illegal utilisation of plant resources made quantification difficult.

2.3.2 A field-based ecological survey

A field survey was conducted to make independent observations regarding plant resource status and for the interpretation of people's perceptions of resource availability. Two most preferred species were studied: *Androstachys johnsonii* and *Colophospermum mopane*. Before this survey, communities were asked to rank the availability of parts of resources used as follows: available - if abundant and within reach; scarce - if not readily available within the community but available next to the village; and rare if hard to find around the community. People were also asked to indicate how far these resources are located relative to their homesteads using either some geographic features such as roads, hills and hilltops, area names or some distance measures. Based on this information, three areas or zones of resource utilisation were generated: those stands within 0.5 km from the village edge, stands between 0.5 km and 2 km from the edge and stands 2 km or more from a village edge.

Five 0.04 ha circular plots were randomly laid in each of the harvest zones in *C. mopane* stands. Five 0.04 ha plots were also randomly laid in the 0.5 - 2 km and 2 km or more harvest zones in *A. johnsonii* stands. Within each plot, all plant species ≥ 2 cm in basal diameter were identified and recorded. Basal diameters of all individuals at 30 cm above ground or above basal swelling were measured using a diameter tape. Also, the percentage grass and rock cover were estimated and recorded and the position of each plot was recorded using GPS. Individual tree and stem densities were analysed graphically to assess size-class distribution patterns within the three zones of utilisation. Populations and communities of these two species were also sampled in the protected site (see Chapter 3 for details).

2.4 DATA ANALYSIS AND RESULTS

2.4.1 Socio-economic conditions of household heads

Twelve of the 38 respondents (i.e. about 32%) in this community have formal full-time employment. Of these people, 83% (10 people) and 17% (2 people) are men and women, respectively. Also, 11 respondents have no employment at all and the majority of them are women (8 out of 11). Four out of five each are pensioners and informal full-time employed women, respectively (Table 2.1). The overall household socio-economic aspects are shown in Appendix 1.

Eighteen of the household heads have no education or have gone to school up to Grade B and thirteen of them are women.

The number of people who have educational level of Std 1 to 5 are five for both men and women, respectively. Seven of the nineteen men interviewed have passed school standard level 5 to 10 compared to only one woman (Table 2.1).

More than 50% (21 of the 38) of the household heads interviewed are employed or have sources of monthly income. The majority of them are men (14 out of 21). Of the seventeen unemployed household heads, 12 of them are women (Table 2.1). The majority of household men earn between R1000.00 and R1999.00 while most women earn between R100.00 and R499.00 per month. The overall mean monthly income for the 38 respondents is 1092.95.

Table 2.1 Household employment, educational and income levels within Mukomawabani rural community based on interviews with 38 heads of families.

Employment type	None	Pensioner	Contract-Formal	Informal-Full-time	Formal-Full time	Business person	Headmen
Women	8	4	1	4	2	0	0
Men	3	1	3	0	10	1	1
Total	11	5	4	4	12	1	1

Education	None to Grade B	Std 1-5	Std 6-10	Above 10	Mean Std passed
Women	13	5	1	0	1.3 (=1)
Men	5	5	7	2	5.7 (=6)
Total	18	10	8	2	3.5 (=4)

Employment status	Employed	Unemployed
Women	7	12
Men	14	5
Total	21	17

Income ranges per month (R)	0 - 99	100 - 499	500 - 999	1000 - 1999	2000 and more	Mean income
Women	7	10	1	1	-	253.74
Men	2	0	3	9	5	1932.16
Total	9	10	4	10	5	1092.95

When the data was pooled together, there was no relationship between number of plant species listed and a) age (r^2 = *0.077, p = 0.0908*), b) standard passed (r^2 = *0.036, p = 0.251*), and c) total income (r^2 = *0.000, p = 0.974*). The breakdown of data into gender also revealed the same pattern for males and females except that there is a significant negative relationship between number of plant species mentioned by females and employment status (r^2 = *0.25, p = 0.031*).

There is no significant difference between the number of plants listed by males and females as well as the ages of the two groups (Table 2.2).

Table 2.2 Summary of the relationships between male and female respondents. See Appendix 1 for codes used.

Variables	**Means**		**p-value**
	Males	**Females**	
Trees listed	24.84	21.68	0.395
Age	41.00	47.63	0.173
Standard passed	5.73	1.26	0.001
Total income per month	2393.21	582.68	0.005

However, males and females differ significantly in terms of school standards passed, employment status, types of employment and their total monthly income (Table 2.2).

When asked to list their general needs, 36 of the 38 respondents mentioned clean water (Table 2.3). This was followed by electricity (28) and better roads (15) respectively. Also, houses and jobs were mentioned by nine and eight respondents respectively.

Table 2.3 Overall community needs given by the respondents.

Overall community needs	No. of respondents	% of total respondents
Clean water	36	94.74
Electricity	28	73.68
Better road	15	39.47
Houses	9	23.68
Jobs	8	21.05
Small business area	5	13.16
School	4	10.53
Drought-relief foods	3	7.89
Transport	3	7.89
Community Hall / Entertainment centers	2	5.26
Creche	2	5.26
Clinic	2.	5.26
Pension for the aged	1	2.63
Grass for stock	1	2.63
Toilets	1	2.63
Wild animals	1	2.63
Farming Aid	1	2.63
Soccer grounds	1	2.63
Training center	1	2.63
Phones	1	2.63

2.4.2 Plant species and uses preferred mostly by the community

One hundred and forty six tree species were listed by the community (Appendix 2) of which only 36 were repeatedly listed in the *p-mops* survey (Table 2.4). The completeness of a plant list was assessed graphically using the law of diminishing returns (Figure 2.1) and results show that the number of plant species mentioned increases with the number of people interviewed. Results show that there is no significant relationship between number of plants known or mentioned by a respondent and his/her age ($r^2 = 0.077; p < 0.09$). Trees listed or known were negatively, but not significantly, related to the school standard passed and type of employment (see Section 2.4.1).

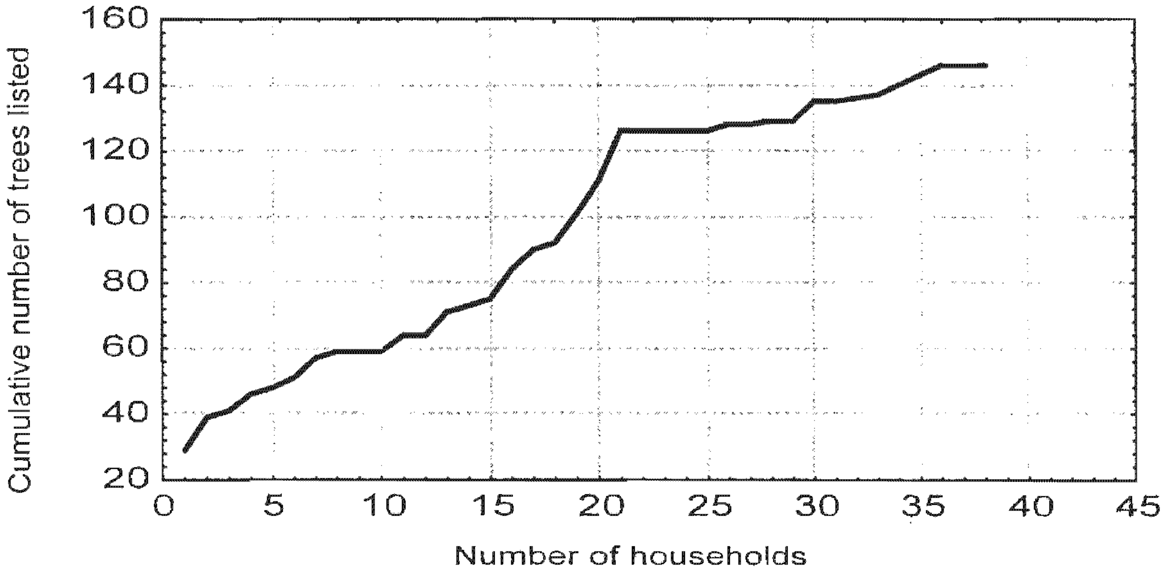


Figure 2.1 The relationship between number of plant species listed and number of households.

There is a significant positive relationship between *r-mops* (IV_1) and *p-mops* (IV_2) importance values ($r^2 = 0.83; p < 0.001$).

The *r-mops* survey and mean importance values indicate that the important plant species for this community are, in order of their preference, *Colophospermum mopane, Adansonia digitata, Androstachys johnsonii, Sclerocarya birrea subsp. caffra, Kirkia acuminata, Terminalia prunioides, Combretum appiculatum, Commiphora mollis, Acacia nigrescens, Berchemia discolor, Boscia albitrunca, Spirostachys africana* and *Manilkara mochisia* (Table 2.4).

Table 2.4 The importance values (IV_1, IV_2 and Mean IV), uses and rank scores for the different species mentioned in the *r-mops* and *p-mops* surveys

Species names	r-mops survey			p-mops survey			Mean IV	Rank	Uses
	Sum of	Number of		Sum of scores	Number of				
Colophospermum mopane	308	38	308.00	292	32	245.89	276.95	1	13
Adansonia digitata	227	37	221.03	206	25	135.53	178.28	2	8
Androstachys johnsonii	125	36	118.42	180	22	104.21	111.32	3	8
Sclerocarya caffra	113	27	80.29	126	16	53.05	66.67	4	9
Kirkia acuminata	138	31	112.58	23	3	1.82	57.20	5	2
Terminalia prunioides	105	26	71.84	54	7	9.95	40.89	6	5
Combretum apiculatum	111	26	75.95	38	5	5.00	40.47	7	3
Commiphora mollis	96	29	73.26	6	1	0.16	36.71	8	1
Acacia nigrescens	95	25	62.50	47	6	7.42	34.96	9	2
Berchemia discolor	59	21	32.61	104	13	35.58	34.09	10	6
Boscia albitrunca	84	17	37.58	45	6	7.11	22.34	11	5
Spirostachys africanum	48	20	25.26	48	6	7.58	16.42	12	14
Manilkara mochisia	40	18	18.95	64	8	13.47	16.21	13	3
Lannea stuhlmannii	54	20	28.42	14	2	0.74	14.58	14	1
Xanthocercis zambeziaca	44	19	22.00	15	2	0.79	11.39	15	3
Ficus sp.	37	19	18.50	27	4	2.84	10.67	16	4
Syzygium cordatum	30	20	15.79	13	2	0.68	8.24	17	2
Acacia xanthophloea	48	12	15.16	6	1	0.16	7.66	18	1
Acacia tortilis	35	16	14.74	7	1	0.18	7.46	19	1
Trichilia emetica	28	16	11.79	22	3	1.74	6.76	20	4
Schotia brachypetala	30	13	10.26	24	3	1.89	6.08	21	2
Diospyros mespiliformis	25	13	8.55	23	3	1.82	5.18	22	2
Breonadia microcephala	19	12	6.00	7	1	0.18	3.09	23	2
Mutaladzi	18	10	4.74	7	1	0.18	2.46	24	1
Cassine transvaalensis	13	4	1.37	25	3	1.97	1.67	25	1
Grewia flavescens	11	10	2.89	6	1	0.16	1.53	26	1
Diplorhynchus condylocarpon	11	7	2.03	15	2	0.79	1.41	27	1
Markhamia acuminata	20	5	2.63	7	1	0.18	1.41	28	2
Mutololwe	8	7	1.47	14	2	0.74	1.11	29	1
Vangueria infausta	5	5	0.66	14	2	0.74	0.70	30	2
Albizia sp.	5	5	0.66	6	1	0.16	0.41	31	1
Combretum imberbe	3	3	0.24	9	1	0.24	0.24	32	2
Cyperus sexangularis	5	2	0.26	7	1	0.18	0.22	33	1
Obetia tenax	2	2	0.11	7	1	0.18	0.14	34	1
Burkea africana	1	1	0.03	6	1	0.16	0.09	35	1
Phoenix reclinata	0	0	0	6	1	0.16	0.08	36	1

The same plants have been found to be the most importance species using the *p-mops* survey. However, the order is slightly different from the fifth plant but the same first four plant species are still in the same order.

Overall use-value (UV_s) results show that *C. mopane, S. africana, A. johnsonii* and *S. birrea* subsp. *caffra* are also the most important species in this community. However, a range of other species which are found to be less important using IV values approach appears to be important using this UV_s approach (Table 2.5).

Table 2.5 Overall use-value of species mentioned in the *p-mops* survey. UVs is the mean of individual use-values (UV^{is}) for each species given by each respondent.

Local name	**Scientific name**	**Respondents**	**UVs**
Mupane	*Colophospermum mopane*	32	4.13
Muonze	*Spirostachys africanum*	7	3.29
Musimbiri	*Androstachys johnsonii*	22	2.91
Mufula	*Sclerocarya birrea subsp. caffra*	16	2.25
Mushato	*Xanthocercis zambeziaca*	2	2.00
Mutate	*Cyperus sexangularis*	1	2.00
Mulakholomo	*Markhamia acuminata*	1	2.00
Mutololwe	?	2	2.00
Muthobi	*Boscia albitrunca*	6	2.00
Muzwiri	*Combretum imberbe*	1	2.00
Mutshema	*Phoenix reclinata*	1	2.00
Mutulume	*Breonadia microcephala*	1	2.00
Munanga	*Acacia nigrescens*	6	1.83
Muhuyu	*Ficus sp.*	4	1.75
Munie	*Berchemia discolor*	13	1.69
Muvhuyu	*Adansonia digitata*	25	1.68
Mutshikili	*Trichilia emetica*	3	1.67
Mutu	*Syzygium cordatum*	2	1.50
Muzwilu	*Vangueria infausta*	2	1.50
Mushashandau	*Terminalia prunioides*	7	1.43
Mutsingidzi	*Combretum apiculatum*	5	1.40
Musuma	*Diospyros mespiliformis*	3	1.33
Mununzwu	*Schotia brachypetala*	3	1.33
Muvumela	*Kirkia acuminata*	3	1.33
Munambo	*Manilkara mochisia*	8	1.25
Muukhuthu	*Commiphora mollis*	1	1.00
Muvhazwi	*Obetia tenax*	1	1.00
Muunga	*Acacia tortilis*	1	1.00
Munzhelenga	*Acacia xanthophloea*	1	1.00
Mukuvhazwivhi	*Cassine transvaalensis*	2	1.00
Muthowa	*Diplorhynchus condylocarpon*	2	1.00
Mupfumbadzi	*Albizia forbesii*	1	1.00
Mufhulu	*Burkea africana*	1	1.00
Murabva	*Grewia flavescens*	1	1.00
Mutaladzi	*Mimusops sp2*	1	1.00
Mulivhadza	*Lannea stuhlmannii*	2	1.00

Nine major plant use categories were identified in this village (Table 2.6).

Table 2.6 Minor and major plant uses associated with Mukomawabani rural community. Minor uses scores are frequencies of occurrence of each use from the *p-mops* survey while major use score is the sum of minor uses scores.

Major Uses	Minor uses	Minor uses scores	Major uses scores
Food	Fruits	76	
	Worms	17	
	Kernels	7	
	Vegetables	4	
	Porridge	3	
	Condiments	2	
	Honey	2	
	Govhole	1	112
Construction	Roofing	43	
	Fencing	35	
	Building: house walls	20	
	Kraals	12	
	Ropes	5	
	Toilets	2	117
Browse and chicken food	Browse	27	
	Mabofe	2	29
Beverages	Beer	14	
	Tea	1	15
Shade	Shade	29	29
Energy	Firewood	71	
	Beer-fire	6	77
Craft	Drums	4	
	Doorframes	3	
	Mats	2	
	Dye	2	
	Spoons	2	
	Tables	2	
	Chairs	2	
	Phetho (wooden stirrers)	1	
	Brooms	1	
	Doors	1	
	Wardrobes	1	
	Beds	1	22
Medicinal	Medicinal	19	19
Income generation	Cash	2	2
Others	Windbreak	1	
	Attraction	1	
	Shelter	1	
	Earthing	1	
	Water protection	2	
	Water cooling	1	
	Aesthetic	1	8

The six most important ones, in order of their importance, are construction, food, energy, browse and chicken food, shade and lastly craft respectively. Considering individual minor uses, fruits, firewood, roofing and fencing are the most important plant uses associated with this community. Other minor uses and services also important to this community include shade, browse, building, medicine, worms and beer.

Different species are associated with different minor uses in this community. For example, the most preferred fruit trees are, in order of their importance, *A. digitata, B. discolor* and *S. birrea* subsp. *caffra* respectively. The most preferred firewood species are *C. mopane, A. nigrescens, T. prunioides* and *C. apiculatum* while trees used mostly for roofing are *C. mopane* and *A. johnsonii*, but *A. johnsonii* and *C. mopane* respectively for fencing. The most preferred shade trees are *A. digitata, B. discolor* and *K. acuminata* respectively. Two most important trees for both browse and building are *C. mopane* and *A. johnsonii* respectively while *C. mopane* and *S. birrea* subsp. *caffra* are preferred over others for worms and beer respectively. Many plants have been mentioned as sources of medicine but again *C. mopane* seem to be the most preferred species.

2.4.3 Resource availability patterns

Generally, *C. mopane* stands have very few young trees within 0.5 km from the village edge (Figure 2.2).

The number of young stems or individual trees increases as one moves away from the village edge for both *C. mopane* and *A. johnsonii* species. This affected the mean basal diameters of both species as shown in the figure (Figure 2.3). Statistical analysis (ANOVA) revealed that *C. mopane* stands close to the village (200 - 500 m) are stocked with trees whose equivalent diameters are significantly larger than those located far away from the village edge ($p < 0.0001$).

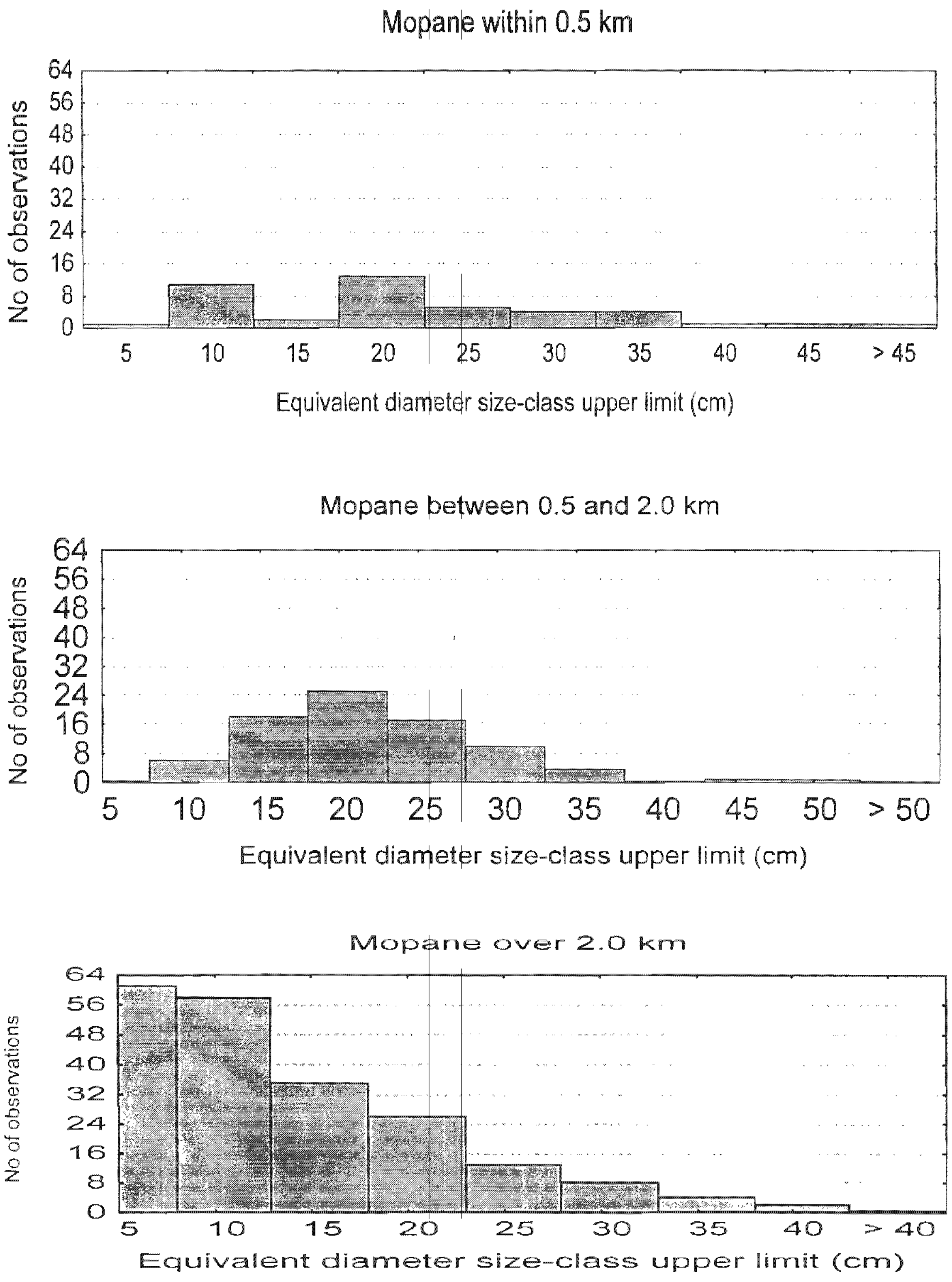


Figure 2.2 Size class distribution for *C. mopane* in communal land. Equivalent diameter is the diameter of a multi-stemmed tree.

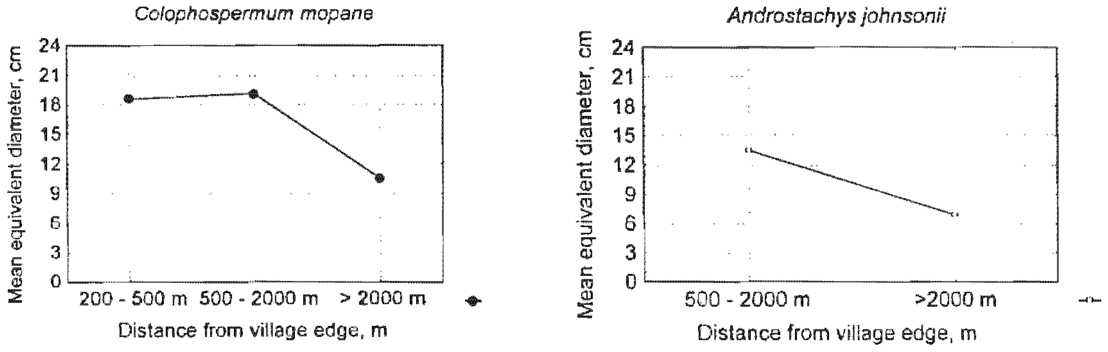


Figure 2.3 Mean equivalent basal diameters for both *C. mopane* and *A. johnsonii* located at some distance levels from village edge. An equivalent basal diameter is the diameter of a multi-stemmed tree, calculated as the square-root of the sum of the square of each individual stem basal diameter.

However, there is no significant difference between the sizes of trees located at 0.5 - 2 km and 2 km or more distances from the village edge. Graphical analyses show that within 0.5 km, *C. mopane* has a bimodal size-class distribution while the bell-shaped and inverse j-shaped curves characterize the 0.5 - 2 k and 2 km and more stands respectively (Figure 2.2). Also, there is no significant basal diameter size difference between trees located 0.5 - 2 km and 2 km or more distances from a village edge. There were no *A. johnsonii* stands within 0.5 km from the village edge. However, the size-class distributions of this species at 2 km or more distance from village edge indicates that this species is characterized by many young individuals and very few big trees while it is characterised by a bell-shaped curve at the 0.5 - 2 km distance level (Figure 2.4).

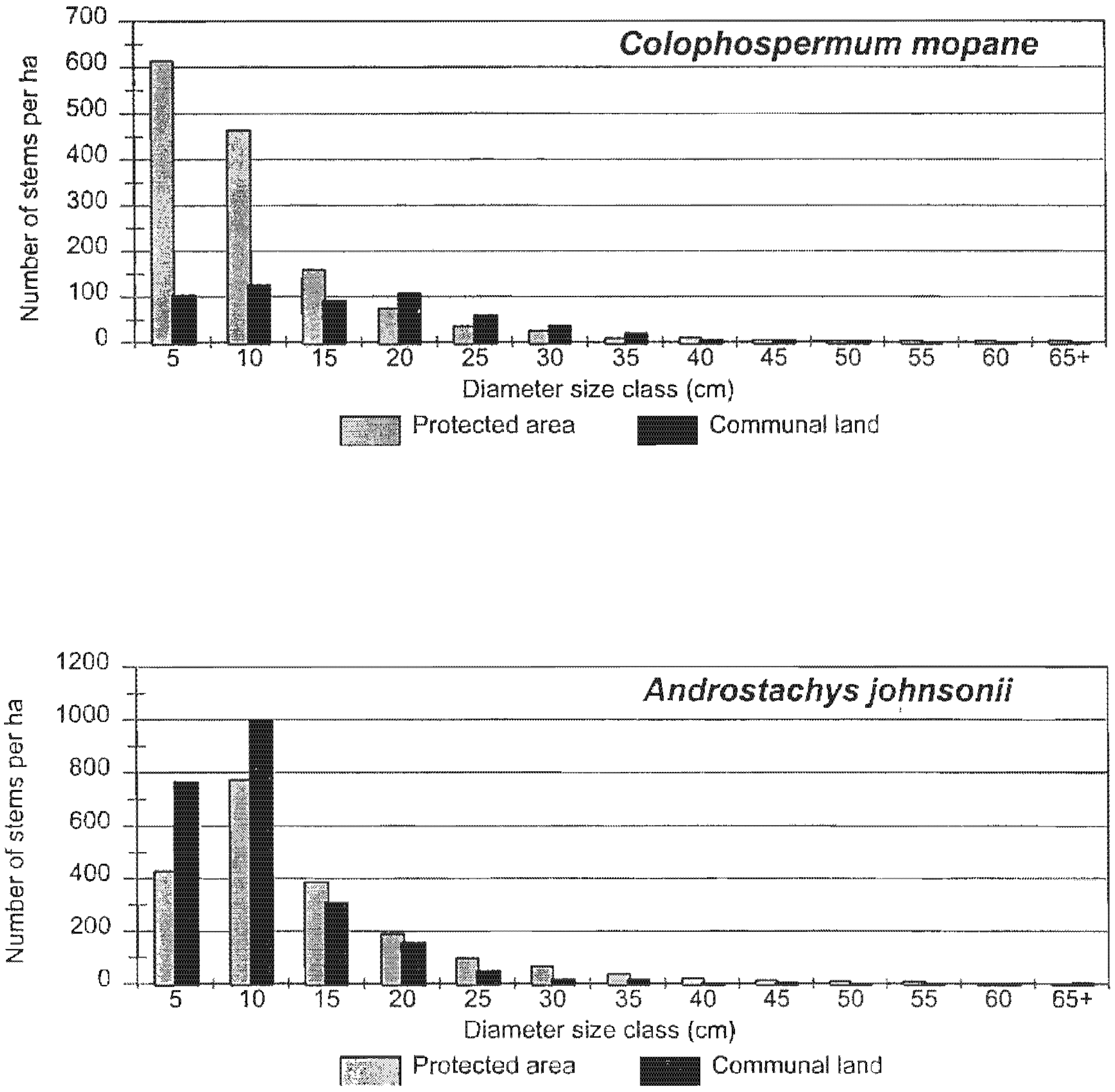


Figure 2.4 Basal diameter size-class distribution for *C. mopane* and *A. johnsonii* under two contrasting management regimes.

2.5 DISCUSSION

2.5.1 Socio-economic patterns

About 6 (15.7%), 17 (44.7%) and 15 (39.5%) of the household owners are less than 30 years old, between 30 and 50 years old and 50 or more years old, respectively. The mean household size of 5.66 (Appendix 1) is quite high in relation to the low household economic conditions. Yet this is still below the 6.8 - 8.4 household size range reported for the Namibian and some South African rural communities (Conroy 1996; Banks *et al.* 1996). Also, 73.0% of the family heads (twenty eight household heads) did not pass Standard 5 at school (Table 2.1), which may be an explanation for the high unemployment rate in this community. However, the mean monthly income per household looks much better for men but very low for women (Table 2.1).

The significant difference in educational standard passed, employment status, type of employment and total income between male and female household heads does not appear to have an impact on the way people know and use plants in this community. It was expected that socio-economic differences across gender should be influencing differences in the way people know and use their plant resources but the results show that there is no significant difference number of plants mentioned by males and females. Plant species knowledge may, in this community, have resulted from sharing and utilising resources and other cultural practices which are still prevalent.

With such low monthly income, people may be forced to depend on the surrounding vegetation for their sustenance. It is not surprising that there are many extended families in this community. The social importance of extended family observed in this area may be based primarily on the provision of social and economic support. The tendency towards female-headed households (about 48% of the families are headed by women compared with 52% headed by men) implies additional burdens on women who must assume responsibility of generating income as well as raising children under such high unemployment rates, low educational levels, low income conditions and large family sizes.

In such cases, woodlands around the communities can be seen as sources of income as well as other household needs. However, correlation results (Section 2.4.1) suggest that knowledge of plant species and dependence of this rural community is not influenced by the age, income, educational levels and type of employment. This is an area of concern since it indicates socio-economic changes will not influence resource use patterns in the future. It is possible that this is due to lack of alternative resources needed in this community such as electricity for energy and woodlots for building and fencing poles. Thus, the dependence of this community on plants is not driven only by the socio-economic conditions but also by lack of service delivery to the area.

According to Gregersen *et al.* (1995) there are no values other than those in the perceptions of individuals and that these perceptions are dynamic, changing as circumstances and situations change. Such changes influence cultural dynamics which entails cultural evolution and adaptations (Griggs 1997). The perceptions of people with regard to goods and services needed for the betterment of life in this community include for example clean tap water, household energy (electricity), better roads, houses and then jobs (Table 2.2). This suggests that pressure on woodland resources can be reduced by providing the community with the above social services but this is unlikely in the near future.

The RSA Statistic in Brief (1996) indicates that about 15.6% of the Africans get their water from either river, dam or spring. Therefore, this pattern of water acquisition is more likely to be common in most rural communities like this one than in urban or semi-urban areas. This has a detrimental impact on the health and hence financial status of rural people. Most trees are likely to be seen as sources of remedies and, instead of purchasing alternatives to plant resources needed, the community may be forced to spare some money for illnesses they cannot cure.

Some people also mentioned that they also cut live wood for fire and that this pattern is common in winter when trees are dormant since they cannot distinguish which trees are dead or dying from those that are alive. However, wood is also cut live for selling, where most of the wood is bought by people from semi-urban communities around Thohoyandou to be sold at higher prices. A well-established market at Sibasa, Lwamondo, Ha-Tshisele, Zwerani, Ngovhela and Miluwani was also observed. Given the value of money generated from sales in urban areas, the community may be tempted to manage the resources in the communal land for employment and income generation purposes.

In short, when the socio-economic conditions of people are below acceptable levels and service delivery is minimal within a rural community, there is no variation among people's perceptions of woodlands around them. This then leads to uncontrolled exploitation of the resources around the community by the community as a whole irrespective of the educational standards passed, household income, type of employment and employment status. Unsustainable harvesting of resources will continue in this community even if the socio-economic conditions become better unless if cheaper alternative sources become available. As a result, the following sections attempt to investigate the status and dynamics of the resources within the communal land and the protected area for the development of sustainable management systems for this rural community.

2.5.2 Plant species and uses preferred mostly by the community

2.5.2.1 The influence of socio-economic status on plant knowledge

A complete list of tree species known to people of Mukomawabani consists of one hundred and forty four plant species (Appendix 2). However, this is really surprising since arid savanna woodlands are regarded to be species-poor. There is therefore a possibility that many common names referring to the same plant species might have been used. To avoid this confusion, plant names given were treated as such and some scientific names were obtained from Von Breitenbach (1981), Mabogo (1990) and Evans (1994). The law of diminishing returns (Martin 1995; Cotton 1996) did not prove to be a useful indicator of the completeness of the plant species list in this survey (Figure 2.1). No expected flattening-off of the total species with number of households did occur. I consider the sample size to be adequate and suggest that the lack of flattening off has another cause. This may be due to people mentioning tree species which do not occur within the study area but mentioning all species known to them. This is likely true because many of the respondents were born in other places and came to this village for farming. Since many ethnobotanists have limited human, financial and time resources, it is suggested that this law be applied and tested over a wide range of rural communities to assess its suitability in studies relating to rural patterns of plant preferences and uses, considering only local plant species.

The insignificant relationships between number of plant species mentioned and sex, age, standard passed, employment status, type of employment or total income suggest that the dependence of people on plant species resources is not influenced by the socio-economic conditions in this community, but that people are naturally dependent on these natural resources most probably as a result of lack of cheaper alternatives or lack of services. It generally argued that old people know many more plants than young ones (Cotton 1996) but results from this study do not support this theory. Thus, there are effective methods of transferring plant knowledge from the elderly people to the young ones which, according to Griggs (1997), might have been brought about by the activity of sharing, exploiting, utilising and dividing the area and its resources. The activity of sharing, exploiting and utilising the resources is possible because all people depend entirely on the wild plants for their household energy and to a larger extent on food, roofing, fencing and building materials. This dependence of people on wild plant resources has also been detected from the importance value (IV_1 vs IV_2) results (Table 2.4) which indicate that people are still dependent on wild plants for most of their needs ($r^2 = 0.83; p < 0.001; N = 36$).

2.5.2.2 The most important uses related to plants in the community

The high level of dependence on *C. mopane* and *A. johnsonii* as sources of fuelwood and construction materials respectively (Table 2.5) by this community is of ecological significance since these two plant species dominate the surrounding vegetation. Any slight shift on the availability patterns can be interpreted differently by the different interest groups, sometimes leading to conflicts.

Of the forty-two minor uses identified in this community (Table 2.6), *C. mopane* is associated with thirteen uses while *A. johnsonii* is associated with eight (Table 2.4). The significant positive relationship between mean importance values and number of uses of a species ($r^2 = 0.49$; $p < 0.001$) suggests that the importance of a species is also based on the number of uses relating to a particular plant species. Thus, species with many uses are more likely to be regarded highly important than species with few uses (Table 2.5). It is therefore not surprising that a different set of most preferred species has been generated from this approach (Table 2.5). Number of uses alone cannot fully explain this high preference for the two species since the durability, easy to work with, resistance to microbial or insect attack, resilience and ecological apparency properties of species also determine its suitability for certain purposes.

Nine major use-categories relating to the preferred species have been identified in this community (Table 2.6). The most important ones in order of their importance are food, construction and household energy respectively. Construction, which is divided into kraals, homestead and farm fencing, roofing and building houses is one of the major destructive practices in this community due to the need to harvest both dead and live materials. Energy entails fire for making beer and for general household purposes such as warmth, light, cooking and boiling water and, according to the respondents, this use category relies mainly on dead wood but sometimes on live wood which is cut and left in the veld to dry. Drought has been mentioned as the most disastrous disturbance which kills most trees which are then used as fuelwood. Thus, fuelwood collection causes little disturbance to the living woody plants and hence the dynamic of the woodland system. However, fuelwood collection has become one of the economic activities of the community and this is where major concerns regarding availability and dynamics of the system stem from: people are not gathering dead wood only but also live wood since the resources are becoming scarce.

Food items needed by this community include fruits, kernels, worms, vegetables, honey and condiments and, according the respondents, there is no apparent change of resources after harvesting. However, if some of the species recruit from seeds it is more likely that most of the fruit-trees used will be represented by many adult trees and few, if any, young individuals than many young trees and few adult ones. This is of ecological significance: if the adult trees are knocked off by some sort of a disturbance, then there will be local extinction of those resources. Also, large trees also suppress the young trees such that the productivity of the whole system is also affected. Monitoring and evaluation of the harvesting and responses of the trees to harvesting is crucial for sustainable fruit production and hence resource supply to this community.

Most of the construction materials are derived from *A. johnsonii* and *C. mopane* respectively, while those of energy are derived from *C. mopane* and a few more other species. Food materials are obtained from a range of plant species, the most important ones being *A. digitata*, *B. discolor* and *S. birrea* subsp. *caffra*. The main focus remains on construction and energy needs. It can be argued that people at this community see *A. johnsonii* and *C. mopane* as the only two most important plant species for construction and *A. digitata* and *S. birrea* subsp. *caffra* as most important for food.

2.5.2.3 Species regarded highly important by the community

Tables 2.4 and 2.5 give contradicting results about the important species for this community. Table 2.5 indicates that the second and third most important plant species after *C. mopane* are *S. africanum* and *A. johnsonii* respectively. The importance of species in this case is based on the uses of each species and hence its overall use value (UV_s). *A. digitata* is no longer the second most important plant species. This is not surprising since UV_s is the mean number of uses of a species based on the number of people who mentioned that plant species. Species which have been mentioned and given many uses by very few people will tend to be the most important ones than species which have been mentioned by many people but given many few uses. It is therefore recommended that the importance value of a species be used to assess its cultural importance instead of the UV_s. Contrary, Table 2.4 indicates the importance of plant species based on the sequence of mentioning and the number of respondents who mentioned that species. Thus the importance of species within a given area in time can be inferred efficiently from the sequence of mentioning and number of people involved as a function of the total number of people interviewed.

Conroy (1996) also found that *C. mopane* is used in many different ways in Namibia and that gradual expansion by the communities have led to deforestation and degradation. While there were no external people responsible for the declining trends of the species in his study area, there are reported cases in this study area where people from other areas come with trucks to purchase firewood. Also, there is a local market for fuelwood in this area such that not only local "ecosystem" people are depleting the resources but also their economic activities and the effects of firewood purchases by "biosphere" people are responsible for the declining trends.

2.5.3 Resource availability patterns

Wood for construction is cut live through selective felling methods where only straight poles of certain basal diameter sizes are cut. Also, poles that are cut live and some dead wood for fire is sold to people coming from other resource-poor areas. This practice may be promoting degradation and vigour of certain plant species. The prevailing conditions are not only a result of the harvest method used but also of the intensity and season of harvesting and climatic conditions. Most people mentioned that they cut wood for building in winter. Since most plants are dormant during this period, we expect them to produce many shoots during the growing season and hence to grow fast. However, results indicate that in heavily used *C. mopane* stands (i.e. those within 0.5 km from village edge) plants are not recruiting as expected compared to the hardly used stands (Figure 2.2) . Maybe this is an indication of the demand on *C. mopane* for both fuelwood and construction wood or an indication of the effects of livestock on the shoots. Similarly, there are no more *A.*

johnsonii stands within 0.5 km from the village edge. However, this species is recruiting well in stands located far away from the village (Figure 2.4). People interviewed indicated that these two plant resources are no longer within reach and that this is due to the harvesting regimes and partly due to environmental conditions after harvesting. It can be deduced that people need plant stems of small to medium (anything between 2 cm and 12 cm basal diameter) size classes. This is not surprising since most of the big stems are only used in corners during fencing, while none of them are used for roofing. Similarly, people prefer small wood over big logs for fire because they are easy to collect and process.

Results from both *C. mopane* and *A. johnsonii* stands suggest that a moderate selective felling regime is important to secure a healthy status of these valuable resources. Such a harvest regime may be based solely on the number of stems cut, size of stems cut and season of cut. However, this is an ecological field of study on its own.

2.5.4 Summary

The community is still highly dependent on woodland resources most probably as a result of low educational levels and hence high unemployment rates. It is also possible that lack of alternative sources of energy, building, roofing and fencing are contributing to this dependence of people on plant resources. The most important plant species resources needed by the community are *C. mopane* and *A. johnsonii* for the provision of firewood and construction materials respectively. Harvesting in communal land is depleting *C. mopane* resources but not *A. johnsonii* resources. The lack of *A. johnsonii* within 0.5 km distance from village edge is probably due the unsustained methods used during the establishment of the village. Results of Chapter 5 support this assumption. Thus, present low and selective use of *A. johnsonii* is sustainable.

CHAPTER 3. POPULATION SIZE CLASS DISTRIBUTIONS PATTERNS UNDER CONTRASTING MANAGEMENT SYSTEMS

3.1 INTRODUCTION

The knowledge of the structure of woody communities and populations is of great importance for practical management since this indicates whether a population is recruiting or not (Meyer & Stevenson 1943; Taylor & Walker 1984; Shackleton 1994). This is usually achieved by the characterization of the size of woody species and by using the quotient *q* (Meyer 1952; Taylor & Walker 1984; Shackleton 1994). The latter is a useful mechanism for the projection of population trends and past perturbations. Projections of future states of the population also facilitate inferences regarding the stability of woody communities and populations (Shackleton 1993), and hence sustainability of the most commonly used plant resources.

If harvesting of resources by local people is sustainable, we would expect woody populations to have more or less similar size class distribution patterns under contrasting management regimes (e.g., protected areas and communal lands). However, it should be expected that populations in protected areas may also behave differently in different communities as a result of environmental heterogeneity.

The long life and large size of trees make many of the conventional methods of studying plant trees impossible or unrealistic. This is certainly true for population dynamics or demography (Harper 1977). As a result the study of tree demography is a study of short cuts. Harper suggested three short cuts to discovering the population dynamics of a forest or woodland.

The first one involves a detailed census procedure which can be applied to strictly defined age-class in a population such as seedlings and saplings. In practice, this is impossible since most arid savanna trees spend most of their life as seedlings, usually referred to as the suffrutex stage (Boaler 1967; Desmet *et al.* 1996), before they can quickly grow into saplings and then mature trees. The second approach entails the dating of trees to obtain an indication of the age of the trees (Van Daalen *et al.* 1993). If the age structure is known, both past and future states of the population can be inferred (Harper 1977; Walker *et al.* 1986). The characteristics of growth rings can reveal more details about the past history of the individuals such as the times it was suppressed by or released from the influence of a neighbour, attacked by a pest or disease, suffered from drought or other hazard. Thus this second approach is useful in predicting past perturbations but fails to quantify the actions of the present and past management regimes. The difficulties associated with these two methods make the two approaches unsuitable for short-term population dynamics studies where both the biotic and abiotic factors are influencing the population structure of trees.

The inherent problem of mapping of seedlings and sapling as well as dating approaches' can be overcome by the third approach in which one make an assumption that size class reflects age (Harper 1977). When the size structure of a population is known, the future states of the population can be inferred (Walker *et al.* 1986; Shackleton 1993) but little can be said about the past (Harper 1977). This approach seems to be more effective where future predictions about the structure of the populations are warranted but where long-term data are scarce. It is easy to obtain a measure of the size of trees in a population, e.g., the diameter of trees at predetermined height above ground. If the assumption is true, it becomes easy to determine the demographic structure of the forest or woodland. In fact, the assumption is false. For example, Harper (1977) noted that differences in the size of individuals develop quickly as a result of genetic differences.

There is, however, an important way in which the size distribution of trees in a forest or woodland can be studied. This is achieved by describing the condition of a population in terms of life states (Harper 1977). The most common approach has been to use the quotient (*q*) between the number of trees in successive diameter classes (Harper 1977; Walker *et al.* 1986; Shackleton 1993). According to Meyer (1952), the forest or woodland over any large area tends to approach a balanced condition in which the quotient (*q*) between the number of trees in successive diameter classes approaches a constant value. The size structure of a population of trees is then some estimate measure of its future changes and is therefore useful to a forester who needs to make predictions about yields or to plan thinning (or harvesting) operations. In view of this notion, the real age of trees may then not be very important. In fact, much of the reproductive behaviour of perennial plants appears to be more related to size than age, and it may be that predictions about the future of a population are best obtained by studying the size rather than age distribution (Harper 1977).

Shackleton (1993) has noted that managers and researchers have little knowledge of the effect of contrasting management practices on the structure and stability of local tree populations in southern Africa. Changes in structure occur before compositional changes, and are therefore useful indicators of the management impact before the loss of valuable species occurs. They may also alert managers to situations of declining recruitment (Walker *et al.* 1986; Shackleton 1993).

3.2 OBJECTIVES

The objectives of this study are:

1. To identify communities in protected area and the dominant canopy species.
2. To assess and compare size structures of some selected species in different communities in protected area and under different harvesting - browsing combination regimes in a communal land.
3. To assess the establishment requirements of *Colophospermum mopane* and *Androstachys johnsonii* seedlings.

3.3 MATERIALS AND METHODS

Sixty-three 0.04 ha circular plots were randomly laid down in four different vegetation types in the protected area: in *Colophospermum mopane* community, *Colophospermum mopane-Androstachys johnsonii* community, the *Androstachys johnsonii* community, and *Commiphora mollis-Acacia nigrescens-Kirkia acuminata* community. The objective of this task was to obtain data representative of all the vegetation types in the protected site which could then be subjected to TWINSPAN for vegetation classification. In communal area fifteen more 0.04 ha circular plots were laid in *Colophospermum mopane* stands and ten more 0.04 ha circular plots in *Androstachys johnsonii* stands. Five 0.04 ha circular plots were laid randomly at each of three distances from the village edge: area within 0.5 km from a village edge, area between 0.5 - 2 km from village edge and area located two or more kilometres from a village edge in order to assess the impacts of harvesting on the size structure and stability of populations in these zones.

Within each plot all trees whose basal diameter was ≥2 cm were identified and recorded. Within the plot, the equivalent basal diameter (i.e. the square root of the sum of basal diameter of both multi-stemmed and single-stemmed trees squared) of each tree was measured ≤30 cm above ground level and recorded. The stem basal diameter was chosen as the most appropriate single measure of tree size, since height may have been modified by fire in the past or herbivory. The characteristics of each plot such as rock cover and grass cover were also noted and recorded.

In order to get a larger sample size of rarer species, a transect survey of the dominant tree species in the *Commiphora mollis - Acacia nigrescens - Kirkia acuminata* community was conducted. A transect was identified and all individual trees of *Commiphora mollis, Acacia nigrescens, Kirkia acuminata* and *Lannea stuhlmannii* within the transect were identified and their basal diameters measured and recorded. A random search for seedlings of both *C. mopane* and *A. johnsonii* was conducted to investigate their location and position relative to canopies (shade/light) of adult trees.

Due to the concern raised earlier about the stability of populations in different communities, all plots from the protected area were subjected to COMPOSE (Mohler 1987) which prepared the data for community classification using TWINSPAN (Hill 1979). The objective was to differentiate communities and species compositions of each community for further assessment of the stability patterns of populations of the same species in different communities. TWINSPAN is a computer program which analyzes data sets so that samples as well as species are classified. All the parameters in TWINSPAN were set to default so that the results obtained are a grouping of species in different communities based on the density and composition of species in different plots.

Within each community, the importance values, IV, (IV = (RD + RF + RBA)/3 where RD is the relative density; RF is the relative frequency; and RBA is the relative basal area, all calculated for each species and expressed as a percentage of the total of all species in the community) were calculated to determine the dominant species in each community.

The frequency distributions of individuals of the dominant canopy species within each community were calculated on a proportional basis. To establish whether the population is stable or not, a method first developed by De Liocourt (1889, in Harper 1977) was used. Meyer (1952) suggested that in stable populations the quotients between the *ln* number of trees per area (ln density) in successive size classes remain essentially constant over the range of sizes found. The quotients *q's* between the ln density of successive size classes were calculated and plotted against size class.

For species in the *Commiphora mollis - Acacia nigrescens - Kirkia acuminata* communities, frequency distributions of the dominant tree species were calculated and assessed graphically.

A search for seedlings of *C. mopane* and *A. johnsonii* was conducted in the protected area. A seedling was regarded as a single-stemmed tree less than 30 cm in height. For each seedling found, it was recorded as found in shade (S) if under the canopy of the adult tree or light (L) if away from the canopy of the adult tree. A total of 96 and 92 seedlings were found for *C. mopane* and *A. johnsonii* respectively. For *C. mopane* 15 and 81 of the 96 seedlings were found in shade and light respectively. For *A. johnsonii*, 50 and 42 of the 92 seedlings were found in shade and light respectively.

Chi-Square analyses were performed to test for micro-site preferences of seedlings of *C. mopane* and *A. johnsonii* species. The frequency distribution of seedlings from the bole of adult trees for *C. mopane* and *A. johnsonii* species was assessed graphically.

3.4 DATA ANALYSIS AND RESULTS

3.4.1 Classification and community compositions

Within the protected area, there were four major communities identified by the TWINSPAN analysis (all parameters set to default): 1. The shrub *C. mopane* community; 2. *C. mopane* - *A. johnsonii* community; 3. Woodland *C. mopane* community; and 4. *Commiphora mollis* - *Combretum apiculatum* - *Boscia albitrunca* community (Table 3.1). The shrub *C. mopane* community is dominated by *C. mopane* in the canopy (IV = 84.28, Table 3.2).

Table 3.1 TWINSPAN output indicating the plant communities at Makuya Park/Nature Reserve. The first two rows indicate the plot numbers.

```
              1    2   11556 2263566522233322333444333  2211111 11 5 444455445455
              25968023403892 3809713646901357567012482  121784615975 346512890734
17 Dypl con   -------------- ------------------------2  ------------ ------------  11111
 6 Arta bra   -------------- ------------------------1  ------------ ------------  11111
 4 Afze qua   -------------- ------------------------1  ------------ ------------  11111
25 Scle bir   -------------- ----1--------------------  ------------ ------------  11110
 5 Andr joh   -----------455 5555555455555555555555555  ------------ ------------  11110
40 Unkn sp4   -----------1-- -------------------------  ------------ ------------  1110
 3 Acac spl   2------------- -------------------------  ------------ ------------  1110
32 Rhiz zam   -------------- -11-1--------------------  ------------ ---1--------  110
23 Mani moc   1------------- -1-----1----------------1  ------1----- ------------  110
14 Comm mer   -----------1-- -----------1--1----------  ------------ ---1--------  110
41 Xant spp   -21-12-21-2222 --1----------------------  ----------2- ------------  101
31 Nezw iul   -44-12-----312 -------------------------  1--------131 ------------  101
42 Xime spp   ----------2--- ----------------1--------  ----1-1---1- ------------  100
35 Term pru   -------------- -2-----------------------  ----2------- ------------  100
 9 Colo mop   45555555555455 3334445422222211---------  553554554553 43------1212  100
28 Muts hal   1------------- -------------------------  ---11---1--- ------------  011
18 Gard res   2------------- --1----------------------  --223------- ------------  011
16 Comm ten   --1------1---- -12--1-------------------  22122-1--1-2 ---1-----32-  011
 1 Acac kar   1------------- -------------------------  ----1------- ------------  011
37 Unkn sp1   -------------- -------------------------  -1---------- ------------  0101
30 Unkn sp5   -------------- -------------------------  11---------- ------------  0101
36 Tshi pas   -------------- -------------------------  -1------1--1 ------------  01001
29 Muun gad   -------------- -------------------------  -----------3 ------------  010001
26 Mund cer   -------------- -------------------------  -----------1 ------------  010001
39 Unkn sp3   -------------- -------------------------  -------1---- ------------  010000
38 Unkn sp2   -------------- -------------------------  -------1---- ------------  010000
24 Mark acu   -------------- -------------------------  ------1----- ------------  010000
34 Stry dec   -------------- -------1-----------------  31-2223----- ------322-12  0011
10 Comb api   -------1------ ------------------------2  -----2311234 5545555222-1  0011
 2 Acac nig   -----1-----1-- -------------------------  -11---1----1 -----2222--1  0011
13 Comm edu   -------------- -------------------------  ----------2- ------11-22-  00101
27 Muru nga   -------------- -------------------------  ------------ --1--1-112--  001001
20 Kirk acu   -------------- --------------1----------  ------------ ----22----23  001001
19 Hete nat   -------------- -------------------------  -----------1 211-12231321  001001
33 Ster rog   -------------- -------------------------  ------------ ----1-221212  001000
12 Comb sp2   -------------- -------------------------  ------------ -------1----  001000
11 Comb sp1   -------------- -------------------------  ------------ -----------1  001000
 8 Cass tra   -------------- -------------------------  ------------ -------1----  001000
22 Maer ang   -1------------ -1---------------1-------  ------------ 112------1-1  000
21 Lann stu   -------------- --1------11--------------  ------------ -22----15-22  000
15 Comm mol   ---111-------- 111-------1---11------1--  --121-1----2 334224342212  000
 7 Bosc alb   -1------------ -------2--------------11-  -----21----1 1221--2122-2  000

              00000000000000 0000000000000000000000000  111111111111 111111111111
              00000000000000 1111111111111111111111111  000000000000 111111111111
              01111111111111 0000000000000000000000001  000001111111 000000111111
```

KEYS: Acac kar = *Acacia karroo*; Acac nig = *Acacia nigrescens*; Acac sp1 = *Acacia sp1*; Afze qua = *Afzelia quanzensis*; Andr joh = *Androstachys johnsonii*; Arta bra = *Artabotrys brachypatalus*; Bosc alb = *Boscia albitrunca*; Cass tra = *Cassine transvaalensis*; Colo mop = *Colophospermum mopane*; Comb api = *Combretum apiculatum*; Comb sp1 = *Combretum sp1*; Comb sp2 = *Combretum sp2*; Comm edu = *Commiphora edulis*; Comm mer = *Commiphora merkei*; Comm mol = *Commiphora molis*; Comm ten = *Commiphora tenuipetiolata*; Dypl con = *Dyplorhynchus condylocarpon*; Gard res = *Gardenia resiniflua*; Hete nat = *Heteropyxis natalensis*; Kirk acu = *Kirkia acuminata*; Lann stu = *Lannea stuhlmannii*; Maer ang = *Maerua angolensis*; Mani moc = *Manilkara mochisia*; Mark acu = *Markhamia acuminata*; Scle bir = *Sclerocarya birrea*; Mund cer = *Mundulea cericea*; Muru nga = *Murunganzie*; Muts hal = *Mutshalimela*; Muun gad = *Muungadaka*; Unkn sp5 = *Unknown sp5*; Nezw iul = *Nezwiuluni*; Rhig zam = *Rhigozum zambeziacum*; Ster rog = *Sterculia rogersii*; Stry dec = *Strychnos decusata*; Term pru = *Terminalia prunioides*; Tshi pas = *Tshipashi*; Unkn sp1 = *Unknown sp1*; Unkn sp2 = *Unknown sp2*; Unkn sp3 = *Unknown sp3*; Unkn sp4 = *Unknown sp4*; Xant spp = *Xanthoxylum sp*; Xime spp = *Ximenia sp*.

Table 3.2 Importance values for the different species in four different communities. IVs ≥20 are underlined. IV = (RF + RD + RBA)/3 where RF is the relative frequency, RD the relative density and RBA the relative basal area.

Species name	Importance values for species in different communities			
	Community 1	Community 2	Community 3	Community 4
Acacia karroo	2.82	-	3.11	
Acacia nigrescens	4.91	-	9.91	15.2
Acacia sp1	2.67	-	-	-
Afzelia quanzensis	-	1.68	-	-
Androstachys johnsonii	16.26	92.43	-	-
Artabotrys brachypatalus	-	-	-	-
Boscia albitrunca	2.43	4.22	9.37	25.11
Cassine transvaalensis	-	-	-	2.63
Colophospermum mopane	84.28	26.61	86.81	31.28
Combretum apiculatum	2.44	1.43	21.10	44.61
Combretum sp1	-	-	-	2.63
Combretum sp2	-	-	-	2.62
Commiphora edulis	-	-	3.20	10.77
Commiphora merkei	2.44	2.78	-	2.64
Commiphora molis	7.28	9.57	16.23	42.23
Commiphora tenuipetiolata	4.84	4.22	25.52	10.68
Dyplorhynchus condylocarpon	-	1.39	-	-
Gardenia resiniflua	2.51	1.36	10.15	-
Heteropyxis natalensis	-	-	3.15	30.73
Kirkia acuminata	-	1.52	-	19.42
Lannea stuhlmannii	-	4.06	-	17.99
Maerua angolensis	2.43	2.71	-	13.27
Manilkara mochisia	2.43	2.76	3.15	-
Markhamia acuminata	-	-	3.11	-
Sclerocarya birrea	-	-	-	-
Mundulea cericea	-	-	3.10	-
Murunganzie	-	-	-	13.27
Mutshalimeia	2.43	-	9.31	-
Muungadaka	-	-	3.57	-
Unknown sp5	-	-	6.20	-
Nezwiuluni	16.47	-	13.15	-
Rhigozum zambeziacum	-	4.34	-	3.19
Sterculia rogersii	-	-	-	19.30
Strychnos decusata	-	1.35	20.44	15.38
Terminalia prunioides	-	1.41	3.17	-
Tshipashi	-	-	9.31	-
Unknown 1	-	-	3.10	-
Unknown 2	-	-	-	2.63
Unknown 3	-	-	-	2.65
Unknown 4	2.42	-	-	-
Xanthoxylum sp	22.39	1.35	3.34	-
Ximenia sp	2.47	1.35	9.3	-

C. mopane - A. johnsonii community is dominated by *A. johnsonii* and *C. mopane.* Table 3.2 shows the dominant species in the other communities. *C. mopane* is found in all the four communities.

3.4.2 Size class distributions and quotients between successive size classes

The size class distribution patterns for *C. mopane* and *A. johnsonii* individuals in different communities and the quotients between successive size classes are shown in Figures 3.1 - 3.2. These variables differ from one community to the other.

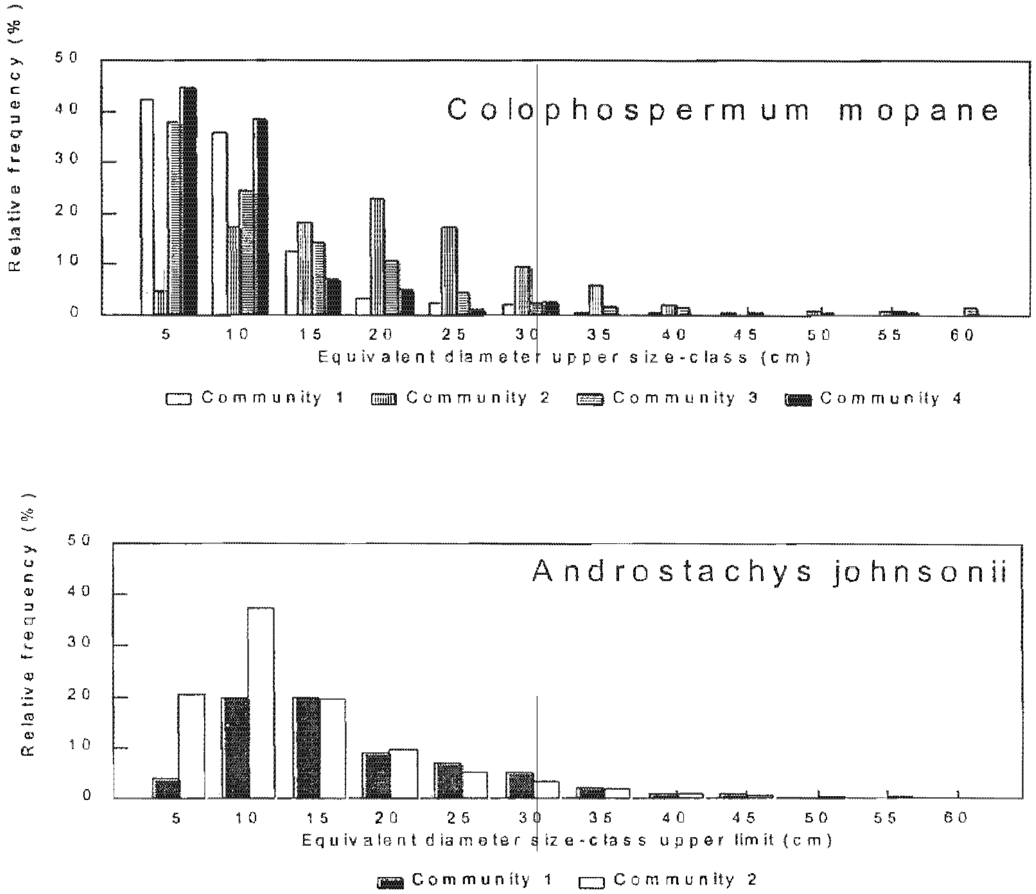
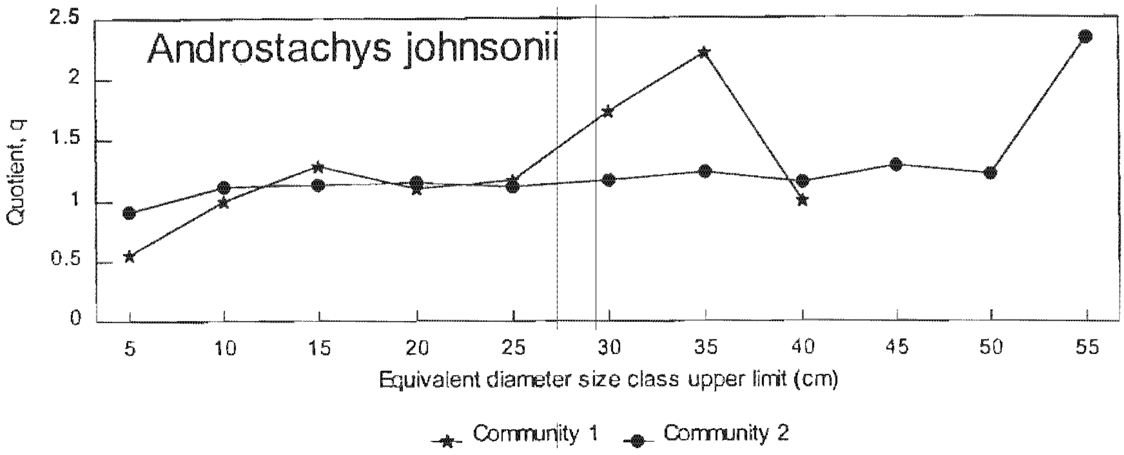


Figure 3.1 Size-class distributions for the two most dominant plant species in different communities in protected area using equivalent basal diameter.



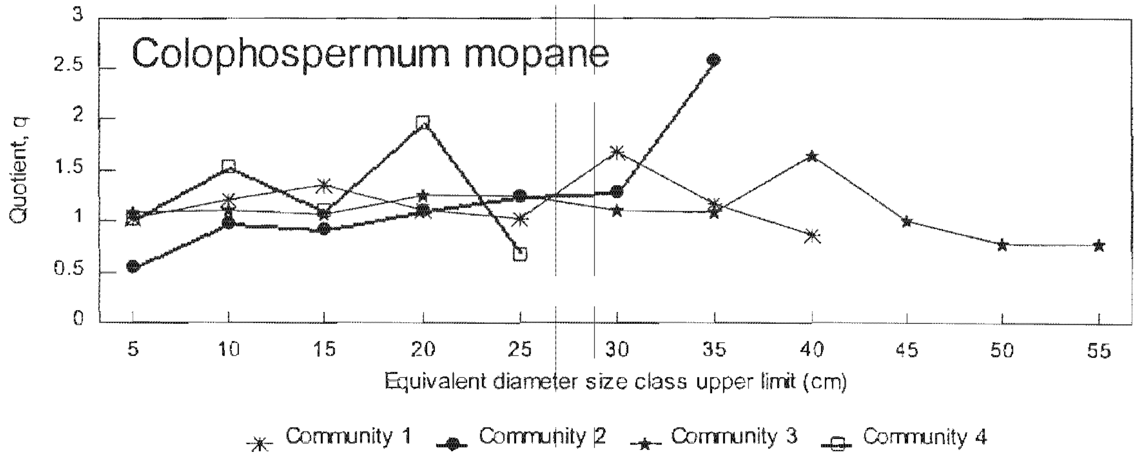


Figure 3.2 De Liocourt curves for both *C. mopane* and *A. johnsonii* in different communities in protected area.

In the communal area the frequency distribution of individuals of *C. mopane* and *A. johnsonii* species within each distance level from the village edge was calculated on a proportional basis and then converted to density ~~per size class. The quotients between the~~

In density of successive size classes were calculated and plotted against size class. The size class distribution patterns for *C. mopane* and *A. johnsonii* individuals in the communal area and the quotients between successive size classes are shown in Figures 3.3 - 3.4.

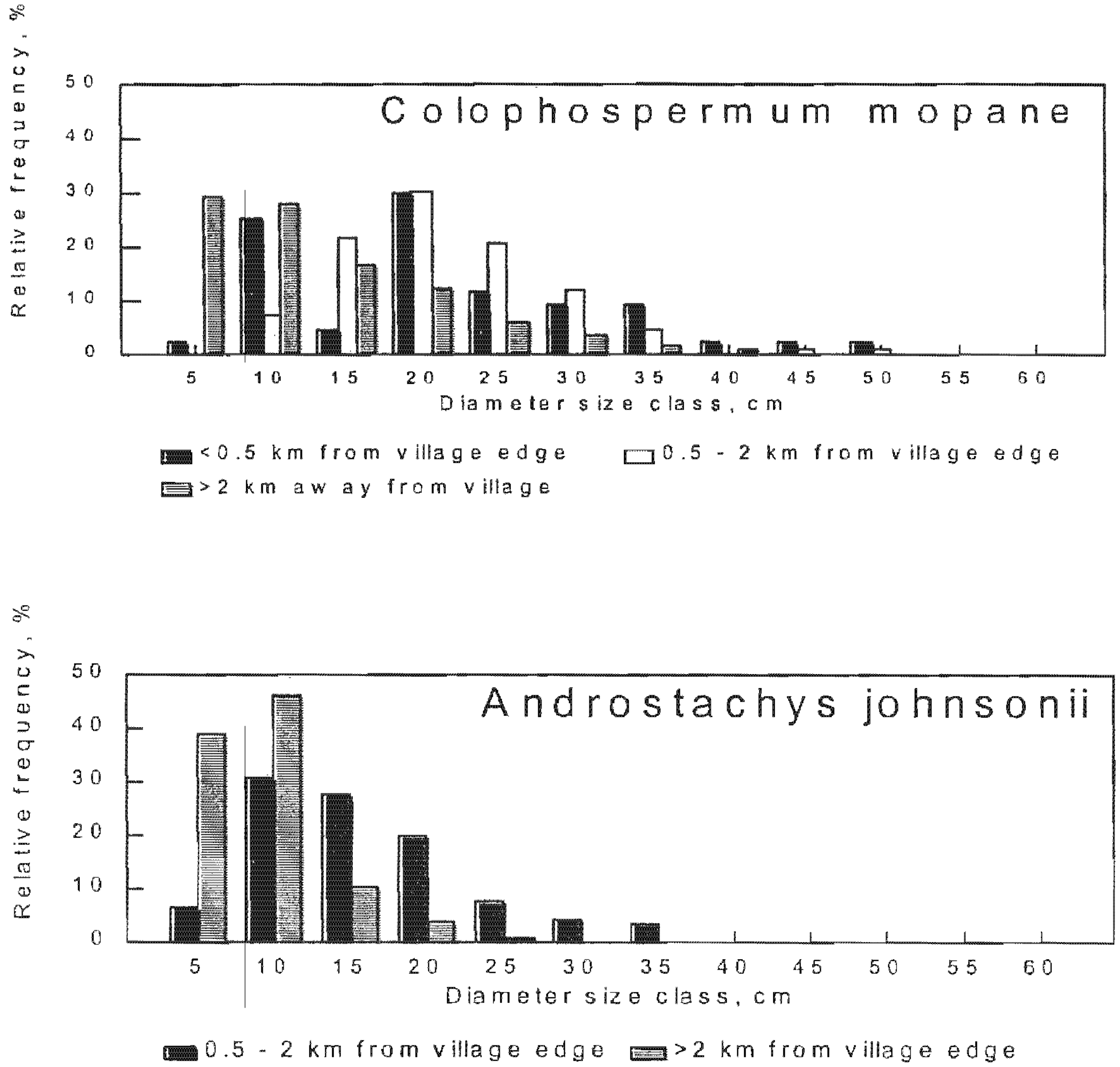
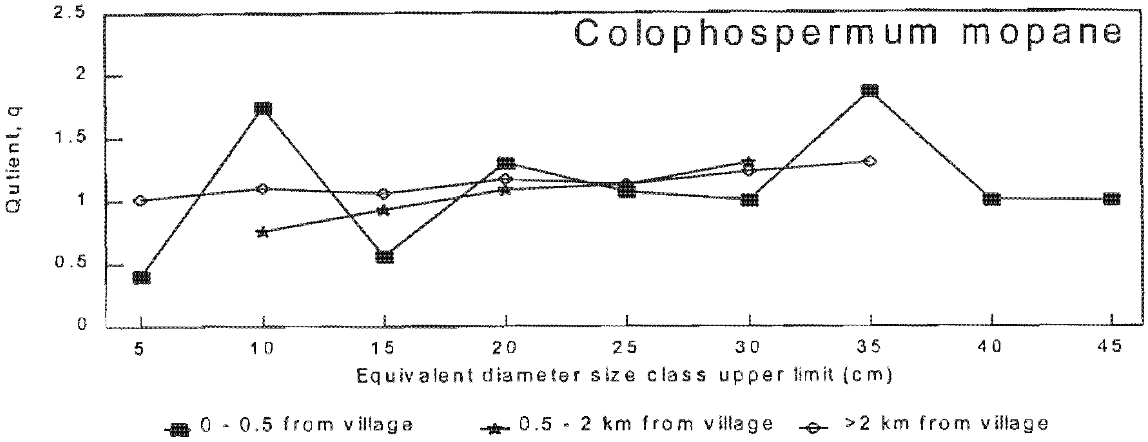


Figure 3.3 Equivalent diameter size class distribution patterns for *C. mopane* and *A. johnsonii* in communal area.

These variables also differ from one distance level to the other in the communal area.



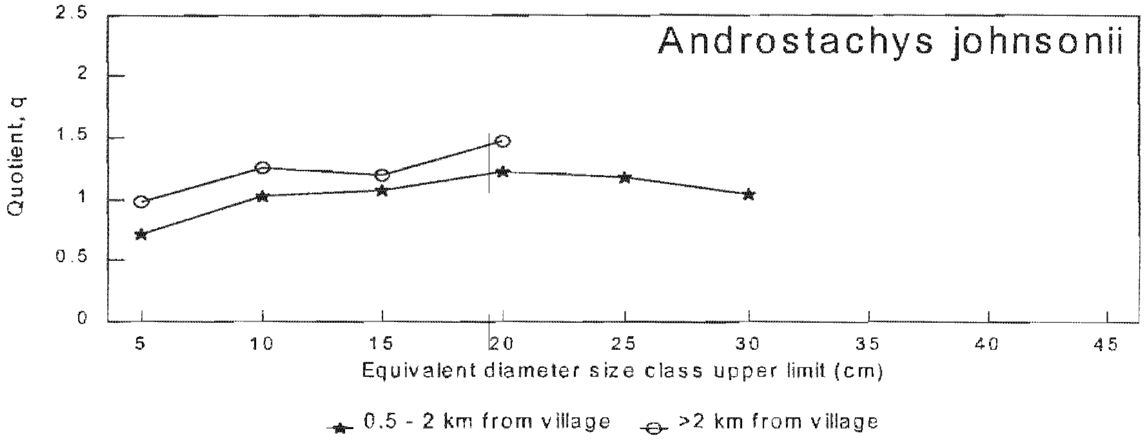


Figure 3.4 De Liocourt curves for both *C. mopane* and *A. johnsonii* species at different zones of resource use from a village edge in communal area.

Size class distributions for *A. nigrescens, C. mollis, L. stuhlmannii* and *K. acuminata*, the most dominant species in *Commiphora mollis - Combretum apiculatum - Boscia albitrunca* community, are shown in Figure 3.5. Again, the species show different size class distribution patterns (Figure 3.5).

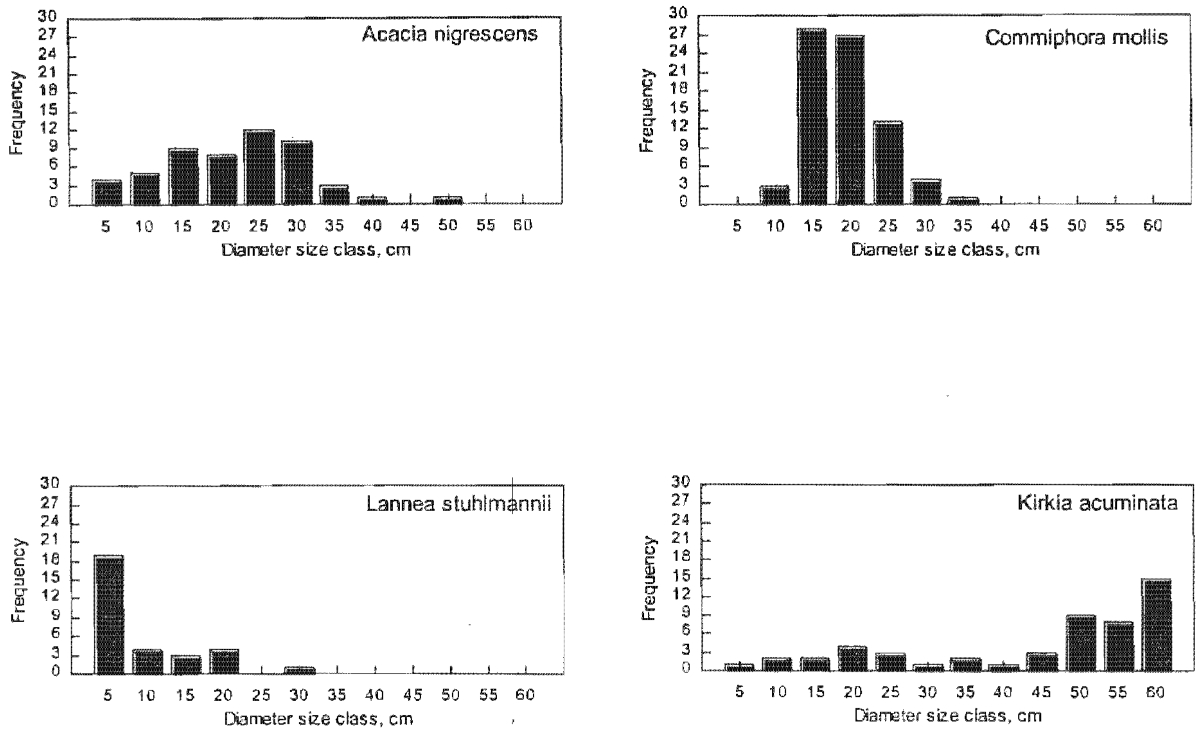
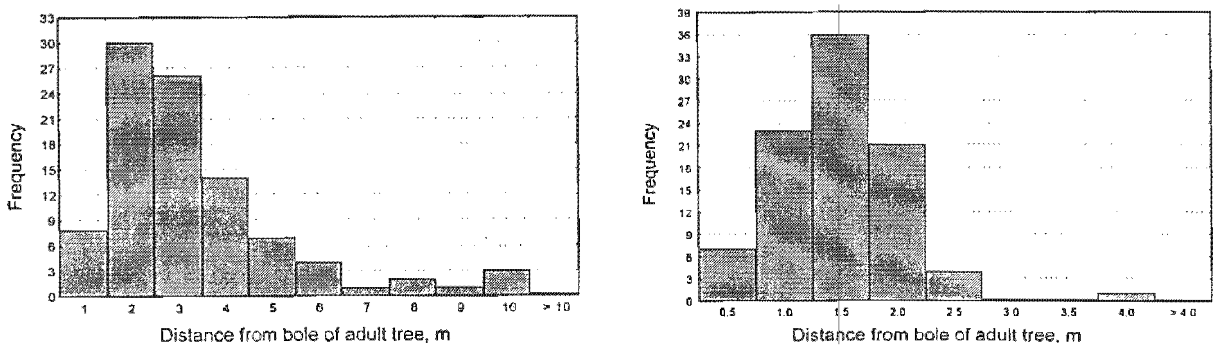


Figure 3.5 Equivalent diameter size class distributions for the most dominant tree species in the *C. mollis* - *A. nigrescens* - *K. acuminata* community in protected area.

3.4.3 Seedling recruitment requirements for *C. mopane* and *A. johnsonii*

Seedling recruitment requirements for *A. johnsonii* are not shade or light related, an indication that it is shade-tolerant since the number of seedlings found in shade did not differ significantly from that found in light ($p > 0.05$). Also, Chi-Square results indicate that the number of seedlings of *C. mopane* in light differ significantly than that found in shade, an indication that it is shade-intolerant ($p < 0.01$). The frequency distribution of seedlings of *C. mopane* and *A. johnsonii* from the bole of mature trees is shown in Figure 3.6.



a

b

Figure 3.6 Frequency distribution of seedlings of *C. mopane* (median = 2.35 m) and *A. johnsonii* (median = 1.3 m) from the bole of adult trees. a = *C. mopane* and b = *A. johnsonii*

3.5 DISCUSSION

3.5.1 Classification and community compositions

Visual inspection of the area on the basis of dominance indicated that there are four major communities in the protected area: the *C. mopane* community, *A. johnsonii* community, *C. mopane* - *A. johnsonii* community and *C. mollis* - *A. nigrescens* - *K. acuminata* community (Midgley & Rathogwa - pers. observation). However, TWINSPAN (Hill 1979b) indicates that there are four communities but the species compositions of these communities, although indicator species, are different from those identified visually. For example, when parameters were set to default, TWINSPAN results indicated that there are distinct shrub and tall woodland *C. mopane* communities (Table 3.1). This suggests that the distribution of communities in the protected area is influenced, in part, by environmental conditions and that species populations are more likely showing different patterns of stability. This has serious management implications in communal land since the distribution and hence density and biomass of species will be controlled by the environment. Also, this can influence the responses of species and hence recruitment processes after harvesting.

These findings suggest that a knowledge of environmental conditions influencing recruitment and biomass production is warranted for the development of appropriate management systems in communal lands.

These patterns are the key to understanding the effects of management practices in the communal land. If population size structures in the communal land are similar to those in protected area, this will imply that the supply of the needed resources in the communal land is not affecting the population size structures and hence the harvesting regime is sustainable. The population size class structure variations in the protected area suggest that the stability of populations should also differ even in communal lands as a result of environmental conditions. This is important since harvesting is considered the most important cause of environmental degradation. Thus, harvesting should be confined to areas where species can regenerate and maintain themselves. Harvesting in areas beyond this zone should be discouraged.

The two dominant canopy species in the protected area are *C. mopane* and *A. johnsonii. C. mopane* is distributed throughout the four communities while *A. johnsonii* is confined to Communities 1 and 4. Factors controlling the distribution patterns of these two species were not investigated but it is apparent that soil and some edaphic conditions as well as some historical events have been responsible for the observed distribution patterns. For example, *C. mopane* was dominant in areas without rocks while *A. johnsonii* was confined to the rocky slopes. It is also possible that disturbance in the past, such as fire, could have been common and that rock areas acted as refuges for this species. Fire-induced mortality on deep red soils provided a suitable environment for the establishment and subsequent growth of seedlings of the light demanding species *C. mopane*.

3.5.2 Size class distributions and quotients between successive size classes

Colophospermum mopane

The diameter distribution in any large forest area tends toward the inverse "J-shaped" curve

(Meyer 1952). According to Taylor & Walker (1984) differences in age- or size-distribution patterns are associated with differences in densities of the species and hence edaphic conditions. However, Everard (1993) noted that differences in age- or size-distribution patterns are associated with the grain of the forest or woodland. The frequency distribution of *C. mopane* in different communities in the protected area varies from one community to the other (Figure 3.1a). Two main patterns were distinguished for this species. First, a reverse "J-shaped" pattern typical of stable or growing populations (Taylor & Walker 1984) for communities 1, 3 and 4. In woodlands this would suggest that this species is adapted to regular large scale disturbance regimes such as drought. This size class distribution pattern implies that growth and establishment conditions here are favourable and that the population is self-maintaining. This suggests also that the higher recruitment rates in these communities may be due to favourable establishment conditions. The second pattern was a bell-shaped distribution with the greatest proportion of individuals in the intermediate than in the small size classes detected from community 2 (Figure 3.1a). This pattern is associated with those individuals found on sites located in rocky slopes and recruitment for *C. mopane* in these sites is poor. The recruitment failure in this community can drive species compositional changes and, as a result, the total elimination of *C. mopane* in this community. The causes of this population structure are not known but will potentially lead to the elimination of *C. mopane* on these sites unless there is a disturbance which will minimize the spread of *A. johnsonii* into *C. mopane* stands. Thus, *C. mopane* cannot properly establish itself either under the canopy of *A. johnsonii* or rocky areas.

In Communities 1, 3 and 4 *C. mopane* appears to be stable (Figure 3.2). This indicates that recruitment from seedlings and from one size class into the next is very stable. However, the *C. mopane* population in Community 2 shows wide fluctuations, indicating that recruitment is very variable from year to year with no overall pattern. This is not surprising since this community is dominated by a dense stand of *A. johnsonii*, making it difficult for *C. mopane* seedling recruitment which requires light for their successful establishment. This suggests further that it is the establishment phase that is important in determining the distribution pattern of the arid savanna population.

Communities 1, 2 and 3 have species in the canopy that are also present in the smaller size classes and the species are likely to replace themselves in the future. This is the size class and population stability pattern that we would expect in the communal land where harvesting and subsistence cattle and goat farming is the norm if the system is sustainable. Any slight deviation from the pattern is of concern since it demonstrates that the supply of the valuable resources in the future is uncertain.

Androstachys johnsonii

The frequency distribution of *A. johnsonii* is the same in the two communities (Figure 3.1b). A reverse "J-shaped" pattern typical of a recruiting (stable or growing) populations (Taylor & Walker 1984) for communities 1 and 2 was observed, except that the first size class (i.e., 5 cm size class) tends to change slightly the shape of the curve. This implies that establishment conditions are favourable and that the population is also self-maintaining. The low number of trees in the 5-cm size class suggests that recruitment into that size class is low compared to recruitment from the same size class into the 10-cm size class. This is likely due to episodic recruitment patterns of arid savanna trees or other historical events (Desmet *et al.* 1996).

In communities 1 and 2 *A. johnsonii* appears to be unstable, especially in the higher size classes (Figure 3.2). This indicates that recruitment is very variable from year to year with no overall pattern.

C. mopane and *A. johnsonii* in communal area

The frequency distribution of *C. mopane* at different distance levels from village edge in communal area varies amongst the three distance levels (Figure 3.1a). Three main patterns were distinguished for this species. First, a reverse "J-shaped" curve typical of stable or growing populations (Taylor & Walker 1984) for the > 2 km distance level (Figure 3.3).

The higher recruitment rates may be a function of lower levels of browsing by goats and cattle and also lowered harvesting rates of materials for fire and construction. Second, a bell-shaped distribution with the greatest proportion of individuals in the intermediate than in the smallest size class was detected at the 0.5 - 2 km distance levels (Figure 3.1a). This is undesirable since *C. mopane* is the source of many products for the community (Timberlake 1995; see also Chapter 2), especially the smaller size classes. The issue is that *C. mopane* is not recruiting well in the communal land, especially around the village. This is indicated by the lack of young trees at this distance level, but the abundance of middle sized trees (Figure 3.3). Third, the number of *C. mopane* trees at the 0.5 km distance level reflect a bimodal (Everard *et al.* 1995) or an uneven size distribution (Walker *et al.* 1986) (Figure 3.3). The unevenness may, again, be either due to some historical events or sporadic recruitment events (Midgley *et al.* 1995; Desmet *et al.* 1996) or present harvesting which prevents normal recruitment into the smaller and intermediate size classes. The historical events could be reduced regeneration as a result of unfavourable environmental conditions and/or increased mortality. It is also conceivable that if the events causing mortality were due to humans, regeneration could also have been affected. The unevenness of the size distribution in savannas is reported to be the sort induced by stochastic events (Walker *et al.* 1986). The size distribution of *C. mopane* indicates that the population in communal area is stable at the 0.5 - 2 km and > 2 km distance levels but most unstable at the 0.5 km distance level (Figure 3.4) and will therefore exhibit periods with greater and lesser densities of mature trees as the different cohorts move through to the largest sizes.

The size distribution of *A. johnsonii* at the two distance levels in communal area show the same trend as in the protected area: the inverse J-shaped curve with slightly lower individuals in the 5-cm size class compared with the 10-cm class (Figure 3.3). The inverse J-shaped curve is a characteristic of a stable population (Shackleton 1993). Browsing and harvesting therefore has little impact on recruitment of young trees. This is certainly true because people use a selective harvesting method to obtain materials for building and construction in the communal area. Figure 3.4 also indicates that *A. johnsonii* population in the communal area is stable.

***C. mollis*, *A. nigrescens*, *K. acuminata* and *Lannea stuhlmannii* in protected area.** The size structure of both *A. nigrescens* and *C. mollis* populations are characterized by having a bell-shaped distribution of diameters, a characteristic of episodic recruitment and unstable population (Walker *et al.* 1986) or lack of regeneration (Cohen & Von dem Bussche 1991). Recruitment into the smaller size classes is weak (Figure 3.5). *L. stuhlmannii* population, however, has a J-shape curve (Figure 3.5), a characteristic of a stable or growing population (Taylor & Walker 1984) and a population with a normal regeneration pattern (Cohen & Von dem Bussche 1991). The size structure of *K. acuminata* population is characterized by having a bimodal distribution curve of diameters (Figure 3.5). At present, there is no need to worry about patterns of these species in this community since most of them are not used in the day to day activities of the local communities.

3.5.3 Seedling recruitment requirements for *C. mopane* and *A. johnsonii*

A. johnsonii seedlings were found in both open and shady sites, suggesting that this species recruits well under both shade and light. The mean distance from the bole of parent trees that seedlings can establish themselves is 1.29 ± 0.53 m, with a median of 1.3 m. The frequency distributions of seedling distances from parent trees also indicate that the majority of seedlings are found within 1.5 m from the bole of adult trees (Figure 3.6). Harvesting, which will result in canopy openings, will not affect the recruitment of seedlings since the species is adapted to both open and shade environments for recruitment. No published information on the structure of the seeds is available as well as the mode and agents of dispersal.

C. mopane recruits seedlings better in gaps or canopy openings. These results suggest that *C. mopane* is a light-demanding species, requiring open gaps or land for seedling germination and subsequent establishment. Timberlake (1995) reported this trend by emphasising that the species produces seeds which inhabit light. The mean distance from the bole of parent trees that seedlings can establish themselves is 2.92 ± 2.03, with a median of 2.35 m. Thus, if the vegetation has a more or less closed canopy, seedling recruitment will be minimal whereas opening gaps or clear-felling will result is increased seedling recruitment.

However, Scholes (1990) reported a lowrecruitment rate of 4 seedling/ha/yr in a cleared plot. This suggests that gaps alone do not necessarily lead to high recruitment, but followed by favourable weather conditions will lead to high seedling recruitment. This pattern of low seedling recruitment may be the answer to the observed size class distribution patterns of *C. mopane* in Community 3 where the population is unstable.

The fruit of *C. mopane* is a flattened, wing-like pod, oval or leathery and indehiscent (Palgrave 1977). The name *Colophospermum* is derived from the Greek words meaning "seed inhabiting the light" (Smit 1994) and this possibly refers to the fact that the seed, which is not released from the pod, always remains above the ground and does not germinate in the soil. The pods are compressed and yellowish-brown, about 3.5-6 cm long by 2-3.2 cm wide, reniform or obliquely semicircular with many scattered resin glands on the surface. They are light and papery and readily dispersed by wind while the seeds are large and compressed, 1.4-2.5 cm, with numerous small, sticky, reddish glands (Timberlake1995). According to Boaler (1966) and Vermeulen (1990), the presence of a wing on ripe fruits of some species is an adaptation to be carried on occasion by wind for some distance from the parent tree. High winds detach the winged fruits from the trees. Groeme *et al.* (1957) found that the wind 'rolls the fruits and occasionally lifts them up in dust devils'. These fruits can be found some 3 km or more from the nearest tree in surrounding woodland but generally, they do not travel for any great distance. Therefore, the seeds of *C. mopane* are dispersed by many factors but wind appears to be the primary dispersal agent. Therefore, clear-felling will enhance seed dispersal.

Summary

Assuming that the distribution of *C. mopane* and *A. johnsonii* in the protected site is what could be expected in the absence of major disturbances, it is clear that communal management has markedly altered the size class distributions of *C. mopane*. Populations of *C. mopane* at 0.5 km and 0.5 - 2 km distance levels in a communal site are unstable, with variable transitions from one size class to the next as shown by large fluctuations in the curves. Communal management has, therefore, had a marked impact on the stability of both *C. mopane* and *A. johnsonii* species since there are no longer *A. johnsonii* trees within the 0.5 km distance level from the community edge.

However, *C. mopane* woodlands are known for their low levels of seedling recruitment (Scholes 1990; Shackleton 1997 - unpublished data). Therefore, it is possible that a combination of communal management practices and low recruitment rates are responsible for the observed population size structures and hence stability. The method used to collect and analyse data, the equivalent diameter approach, may be wrong in size structure assessment since it assumes that only one single stem will grow to the full potential on the expense of the other stems.

CHAPTER 4. COMPETITION WITHIN AN ARID SAVANNA SYSTEM

4.1 INTRODUCTION

Savannas include a wide range of vegetation types (Huntley & Walker 1982) which are characterized by a continuous herbaceous layer and a discontinuous cover of shrubs and trees (Huntley & Walker 1982; Vetaas 1992; Scholes & Archer 1997). The relative abundance of these two components is regulated by external determinants such as climate, soil, fire and herbivory (Walker 1987; Scholes & Hall 1996; Shackleton 1997). With increasing aridity the importance of climate increases relative to disturbance factors such as fire and grazing/browsing (Vetaas 1992). Again, with increasing aridity, competition for water becomes an essential element of the arid savanna system (Smith & Goodman 1986).

It is generally argued that at a biome scale productivity is limited by rainfall while within a site it is limited by stand density (Shackleton 1997). This chapter is looking at the argument that production in woodlands is limited by intra- and interspecific competition.

4.1.1 Literature survey

The role of competition in South Africa's arid savannas has received little attention. It is argued that if the biomass of woody vegetation is limited by the availability of soil moisture or nutrients then there is competition for these resources, and that any competitive effect should be reflected in the spacing patterns of woody plants (Smith & Goodman 1986). If competition is taking place in a plant population, the closer two plants of a given size are to each other, the more intense will be competition between them (Pielou 1962). This competition can manifest itself in two ways (Smith & Goodman 1986): (i) the distance between any plant and its nearest neighbour will be positively correlated with the sum of the competing tree sizes, and (ii) each successful established plant may have its own territory within which no other individual can become established.

In stands of natural plant populations, the prevalence and role of a competitive interaction between plants can be inferred from spatial distribution of plants (Yeaton 1977; Shackleton 1997), association analysis (Yeaton 1977), Lorenz curves and Gini coefficients (Weiner & Solbrig 1984; Weiner 1985) and self-thinning dynamics (Weller 1987; Voit 1988). The role of competition in spacing and structuring communities and populations is of great importance in forestry since this determines not only the numbers but also the size of trees that can be found within a given area and presumably growth rates.

4.1.1.1 Competition studies: spatial distribution methods

The most common approach used to assess the prevalence and role of competition is the nearest neighbour method (Pielou 1960, 1961, 1962) which assumes that competitive interference between plants, if present, will be manifested through a reduction in size of one or both the competing neighbours. If there is a significant positive relationship between the distance separating two neighbouring plants and the sum of their sizes, then competition is inferred (Pielou 1962; Smith & Grant 1986; Yeaton 1977). The basic assumption of the nearest neighbour technique is that the closer together two individuals are, the stronger the degree of competition between them. However, this need not necessarily be so since the assumption ignores the influence of other big but distant trees. It has been suggested that more than one nearest neighbour per point tree be measured, for example the nearest trees in each 90^0 quadrant around the base or point tree (Penridge & Walker 1986; Shackleton 1997). In such case, if there is a significant positive relationship between the size of the base tree and sum of the ratios of nearest neighbour sizes to distances separating them, then it is assumed that competition is occurring within such stands (Weiner 1985).

Another approach used to analyse the role of competition involves determination of the distribution patterns of trees as clumped, regular or random distributions (Yeaton 1977; Simberloff 1979; Krebs 1989; Lovegrove & Siegfried 1989; San-José *et al.* 1991; Scholes & Archer 1997). The most common method used for distance analysis is the Clark &

Evans's dispersion index (R): $R = r_a \div r_e$, where r_a is the mean observed nearest neighbour distance and r_e the expected mean nearest neighbour distance given a random dispersion ($\frac{1}{2}\sqrt{p}$), where p is the density expressed as individuals per unit area (Smith and Grant 1986; Krebs 1989). The index R is used as a measure of the degree to which the observed distribution departs from random expectation. In a random dispersion, $R = 1$. Under conditions of aggregation, R values approach 0 whereas values > 1 suggest regular distribution. In this case the significance of departure from randomness is tested using the standard normal variate, $Z = (r_a - r_e) \div \sigma_{re}$, where $\sigma_{re} = 0.26136/\mathrm{sqrt}(NP)$, and N is the number of nearest neighbour measures made.

A search for regular distribution of individuals in plant communities has provided an element common to the exploration of the pattern and of competitive interaction (Yeaton 1977). Regular distribution implies competition is important within the stands while clumped and random distributions suggest facilitation and lack of competition respectively (Yeaton 1977: Smith & Grant 1986; Krebs 1989; San-José *et al.* 1991). However, Smith & Grant (1986) have noted that regular dispersions are rare occurrences in natural plant communities. Thus, even if competition is taking place, a regular dispersion will be found only if the range of plant sizes is small, or if the range of plant sizes is large but density is low. Smith & Grant (1986) warned that the use of regular dispersion should not solely be regarded as evidence of competition since either aggregated or random dispersion does not necessarily indicate a lack of competition.

4.1.1.2 Size inequality (hierarchy) development

Density-dependent patterns of mortality and growth in plant populations have been well studied. Yet the underlying mechanisms of density-dependent phenomena are not well understood. Within a population, plants vary in their sizes. Most natural plant populations consist of relatively few large individuals and many small ones, and the few large ones contain most of the population's biomass. Such size distributions are called size hierarchies or size inequalities (Weiner 1985; Kenkel *et al.* 1989). The ecological and evolutionary significance of size hierarchies are numerous. For example, it is the smallest plants that suffer greatest density-dependent mortality. Also within a population, size appears to be correlated with fitness, and large individuals may contribute inordinately to the gene pool of the next generation. If gene frequencies within the large individuals are different from those of the population as a whole, evolutionary change will occur (Weiner 1985).

Changes in size structures through time reflect the combined effect of the demographic parameters of growth, survival and recruitment (Santos 1995). However, size inequalities may also result from differences in growth rates due to age differences, genetic variation, resource or environmental heterogeneity and competition (Weiner 1985), and the relative importance of each of these factors is not known.

Two basic models have been suggested for quantifying size hierarchy development (Weiner 1985). The first model suggests that size distributions in even-aged monospecific stands are attributed to variation in growth rates due to factors other than competition, and that competition reduces the relative variation in sizes that are generated by these growth rate differences. The second model, the dominance and suppression model, suggests that differences in size distributions are worsened as large plants usurp resources and grow at the expense of small plants (Silvertown & Doust 1995). The hierarchy of sizes then represents a hierarchy of exploitation because large plants will tend to grow larger while small plants hardly grow at all (Weiner 1985). This results in highly skewed, unequal size distributions. When the mean plant size approaches the limit defined by the self-thinning rule (Weller 1987), small plants die. These two models lead to different and incompatible predictions. According to the dominance and suppression model increase in density will result in increased size inequality, since interference increases with density. Increased productivity is also expected to do the same (Weiner 1985).

Weiner (1985) argued that a size distribution is a result of both the growth and mortality of plants. Weiner and Solbrig (1984) and Weiner (1985) then suggested the use of methods developed in economics, the Lorenz curves and the Gini coefficient (*G*) to evaluate size inequality rather than skewness which is used to assess size distributions.

If competition is important in generating size inequality, the spatial patterns of plants are also expected to have an effect on size distributions. That is, plants respond to density as well as local neighbourhood conditions. It is assumed that if plants are regularly spaced there should be less of a size hierarchy than if plants are randomly distributed (Weiner 1985).

4.1.1.3 Self-thinning dynamics

When plants grow in a dense community, they compete for environmental resources (Voit 1988). If competition from other populations and crowding independent stresses such as drought, fire, diseases and herbivory are absent, mortality or thinning is caused by competition within the population, hence the term self-thinning. It has long been known that this competition limits the size of individual plants and that, in turn, the increase in size is accompanied by a decrease in the number of surviving plants as a result of competition-based mortality. Mathematically, this relationship is represented by the equation:

$W = aN^{-b}$ or ($B = aN^{-b}$) or $\log W$ (or $\log B$) $= b \log N + \log a$ (Weller 1987; Voit 1988; Dewar 1993; Kroon & Kalliola 1995; Morris 1996).

where W is average individual size, B is average biomass per tree, N is density of plants (m^{-2}) and a and b are positive parameters that reflect properties of the particular stands and the measure of plant size used (Voit 1988).

Thus, self-thinning studies investigate the relationships between current changes in mean plant mass (or total biomass) and density of plants (Voit 1988; Santos 1995). In crowded even-aged plant stands undergoing self-thinning, the relationship between biomass and density forms a theoretical "self-thinning" line of slope $b = \pm -1.5$ with variable intercepts when mean plant weight and density are plotted on a log scale; an equivalent line of slope *b* = -0.5 and with the same intercept is defined when the log of stand biomass (i.e., biomass density) is plotted against density. This relationship is defined as the general 'law' governing any even-aged plant population (Weller 1987; Santos 1995), the self-thinning rule (Weller 1987; Voit 1988), Yoda's law (Weller 1987) or the $-^{3}/_{2}$ power law (Weller 1987; Voit 1988) and is supported by a wide variety of data from both the artificial and natural stands of land and sea plants. When average mass is used, the value of *b* ranges from 1.3 to 1.8 (Weller 1987).

The other evidence for self-thinning rule is the existence of an interspecific average mass-density relationship of slope *b* = -1.5 that is observed when data from stands of many species are plotted on a single plot of either log *W* vs. log *N*, either as individual mature stands or single species self-thinning lines (Weller 1987). In this way, the growth form of a species becomes less important and we would expect populations from both even-aged and uneven-aged stands to obey this law.

This rule can be used to compare populations growing at different sites, or to draw inferences about the important causes of mortality in a population. As a management tool the rule is considered useful in forestry and other applications requiring predictions of the limits of biomass production for a given species at any plant density (Weller 1987). For example, thinning operations can be based on this "rule". Figure 4.1 shows how populations starting at different combinations of biomass and densities will grow until they reach the self-thinning line. Populations at very low densities, *a*, will grow fast without suffering mortality until they reach the self-thinning line where they will grow in size only if other individuals die. Populations at high densities, *b*, should grow fast but they approach the self-thinning line rapidly and start to suffer mortality. Populations which start above the self-thinning line will suffer crowding-dependence mortality which is not compensated by growth until they reach the self-thinning line where growth can only occur if death occurs.

During the data analysis process, data points from stands that are not undergoing density-dependent mortality (e.g., young populations that have not yet reached the self-thinning line or stands that are understocked because of poor establishment, harvesting etc.) are eliminated a posteriori. That is they are eliminated after identifying points below the self-thinning line through visual inspection of log *W*-log *N* plots (Weller 1987).

The choice of the equation is, however, decided by the data analyst: whether to fit a relationship between average mass and plant density or a relationship between stand biomass density and plant density. The relationship between stand biomass density and plant density has been recommended (Weller 1987) because of the shortcomings related to average mass-density relationships. First, average plant mass increases through two processes: growth of living plants and death of young small plants. Thus, the average mass of the stand increases more rapidly than the sizes of individuals composing it, and the mean plant mass increases when small plants die, even if the survivors do not actually grow. However, stand biomass density increases only through growth and always decreases with mortality, so a correlation of log stand biomass and log density is more clearly interpretable and focuses attention on the extent to which mortality permits a more-than-compensatory increase in the size of the survivors.

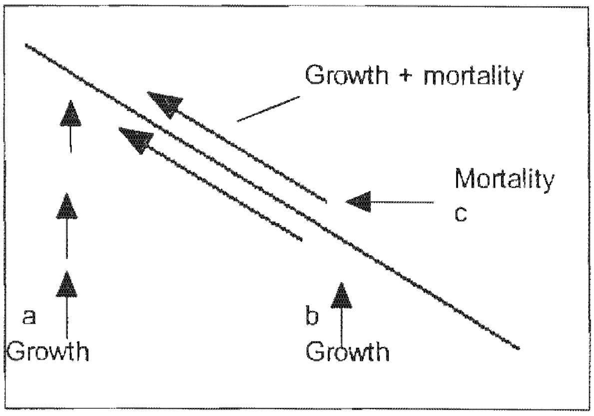


Figure 4.1 Self-thinning trajectories followed by populations at different combinations of biomass and stand densities. The solid straight line represents the population boundary line along which plants can only grow if others die. Populations at *a* should have the highest growth rates until they reach the thinning line where trees can only grow if others die; at *b*, populations grow rapidly and reach the thinning line quickly; populations above the thinning line, *c*, suffer mortality until they reach the thinning line where they can only grow if other trees die.

Secondly, it has been reported that log *W* vs. log *N* analyses give results that are biassed, spurious, artificial and forced (Weller 1987) because average mass is derived from the original measurements by dividing stand biomass by the number of plants. This results in exaggerated correlations since the density is used to calculate average plant weight, and therefore appears on both axes. As a result, stand biomass density versus plant density is recommended.

In practice, a significant relationship between log weight or log stand biomass and log density implies competition and the theory that a carrying capacity keeps the biomass density below a fixed level (Weller 1987). Lack of a significant relationship means that the data does not support the self-thinning rule or other hypotheses about the course of plant mortality since such data do not even show that competition has occurred.

Weller (1987) argued and showed that the slopes and intercepts of thinning lines are variable. That is, even within the same species, different stands might have different dynamic thinning lines. For example, water-logging inhibits plant growth, resulting in small and stunted plants whose mean weight per plant is quite unaffected by density (Harper 1977) while free drainage facilitates the rapid growth of plants, leading to a marked plastic response to density. Thus, restriction on growth is, in this case, water supply and not density per se. Also, soil fertility increases growth and restriction on growth is therefore soil nutrient and not density (Harper 1977). The intensity of competition varies as growth conditions change. It is generally suggested that competition will be more intense in resource-poor habitats because of the greater chance of neighbourhood interference (Morris & Myerscough 1991). To the contrary, Tilman (1987) reported that plants in fertile habitats may have to forage further to acquire resources, and so compete with neighbours more. It has been shown that populations growing in shade or low light intensity tend to thin along lower lines when light is the primary limiting resource (Weller 1987). Also, Morris & Myerscough (1991) reported that the patterns of self-thinning are less clear-cut when soil nutrients are the limiting resources. However, they reported that many species in nutrient resource-poor environments thin along lower lines than those in more fertile ones. This suggests that self-thinning is fastest at high nutrient levels than it is at low levels (Morris &

Myerscough 1991). The lower self-thinning lines observed in shaded and low nutrient soils imply intensification of competition in these stands compared to less-shaded or fertile stands.

The intensity of competition in self-thinning stands can be measured by the extent of mortality and by the ground area required to support survivors of a given mass. The former, however, requires monitoring of long-term research sites over a long period. The best approach is then to compare stands at the same time (Morris & Myerscough 1991): stands that have thinned the most have undergone the most intense competition.

Following self-thinning, some populations may achieve the carrying capacity for that environment: mortality may continue but biomass remains constant.

The mechanism of self-thinning phenomenon is only dimly understood. Density-dependent mortality studies suggest that (i) mortality occurs at high but not low densities; (ii) mortality continues with time and is not restricted to a particular growth stage; and (iii) the higher the density the sooner the first deaths occur (Harper 1977). This relationship presents a vivid picture of a population of rapidly growing plants from which individuals are continually lost in the self-thinning process, a population that is dynamic both in terms of numbers and the size of individuals.

Given this range of methods used to study competition, it is more likely that some of the methods will detect competition while others will not, all depending on the nature of the system under study. For example, it was shown in the previous paragraphs that even if competition is taking place, a regular dispersion will be found only if the range of plant sizes is small, or if the range of plant sizes is large but density is low. Again, Smith & Grant (1986) warned that the use of regular dispersion should not solely be regarded as evidence of competition since either aggregated or random dispersion does not necessarily indicate a lack of competition. It is against this background that a range of methods are being employed to determine the effects of competition on biomass production in arid savanna system.

4.2 OBJECTIVES

The objective of this study was to gain an understanding of the role of competition in arid savanna biomass production patterns using spatial distribution methods and self-thinning dynamics approach.

4.3 MATERIALS AND METHODS

4.3.1 Intra- and interspecific competition

4.3.1.1 Intraspecific competition

Twenty-two, twenty and eight 0.04 ha circular plots were randomly sampled from *Colophospermum mopane*, *Androstachys johnsonii* and *Colophospermum mopane-Androstachys johnsonii* stands respectively. Within each plot, a maximum of thirty focal individuals were randomly selected and the distance to the closest nearest neighbour in each of the four 90^0 quadrants was measured for the first three closest neighbours. We considered three neighbours to be sufficient for subsequent analysis. A base tree is a tree whose measure of performance is being assessed. For *C. mopane*, an individual tree refers to all stems within a radius of 0.25 m from the stem in the centre of a multi-stemmed tree. This appeared to be sufficient to include all stems in most cases. For *A. johnsonii*, an individual tree refers to a single-stemmed tree at or below 10 cm above ground. The first three quadrants, from the one with the closest nearest neighbour to the one with the third closest neighbour, were used, and closest tree in the fourth quadrant was ignored. The basal diameters of all base trees and the three nearest neighbours were measured at 30 cm above ground level. The distances between the base trees and nearest neighbours were also measured and recorded. From individual stem basal diameters of both single and multi stemmed trees, equivalent diameters or tree diameters were calculated as the square-root of the sum of individual stem basal diameters squared. This was used to calculate the basal areas of each measured tree. An individual tree was regarded as all stems growing within 0.5 m radius for *C. mopane*. For *A. johnsonii*, an individual tree was regarded as a stem growing from the ground. Where stems branch below 30 cm, individual stems were measured separately and the equivalent tree diameter calculated. An individual tree was considered a neighbour of another tree if it was within the five metres radius from the base tree, otherwise the distances to and sizes of trees located more than five metres away from the base tree were not measured.

4.3.1.2 Interspecific competition

Eight 0.04 ha circular plots from *A. johnsonii-C. mopane* mixed stands were sampled. Within each plot, the basal diameters of each species were measured at 30 cm above ground or above swelling. Fifteen trees of each species were randomly selected and their sizes and the distances to their three nearest neighbours were measured. For example, if the base tree was *C. mopane*, the sizes of the three nearest neighbour *C. mopane* individuals and the distances between this base tree and its neighbours were measured and recorded. This procedure was repeated for the three *A. johnsonii* neighbours. The whole procedure was repeated for *A. johnsonii*.

The index of dispersion *I*, which is based on the number of individual trees per plot (Scholes 1997) was used to investigate the distribution patterns of *A. johnsonii* and *C. mopane* within mixed *A. johnsonii-C. mopane* stands.

4.3.2 Competition, stocking and productivity

4.3.2.1 Self-thinning dynamics

Twenty-two and twenty 0.04 ha plots were sampled from both *C. mopane* and *A. johnsonii* stands respectively. Within each plot all individual trees were identified, their stem basal diameters measured at 30 cm above ground and their equivalent sizes (basal diameter and basal area) calculated. The mean stand basal areas were regressed against the stand density for both species.

In communal area fifteen and ten plots respectively were sampled in *C. mopane* and *A. johnsonii* stands. Within each plot, tree basal diameters were measured ≤30 cm above ground level, or above the basal swelling, using a diameter tape. The objective of this survey was to assess if harvesting of trees promote productivity in communal area. The relationship between the stand basal area and stand density (self-thinning) was established for both *C. mopane* and *A. johnsonii* species.

4.4 DATA ANALYSIS AND RESULTS

4.4.1 Intra- and interspecific competition

Only thirty six percent of the twenty-two *C. mopane* plots indicate that there is intraspecific competition within *C. mopane* trees when using one tree as the nearest neighbour of the base or point tree. However, competition was not detected in any of the plots when two or more nearest neighbour trees were used (Table 4.1). Results of some of the plots which show and did not show competition are given in Figure 4.2. Single nearest neighbour tree approach revealed that in about half (i.e., 50%) of the twenty *A. johnsonii* plots there is competition. Again, results for the multiple nearest neighbour trees approach show that there is intraspecific competition within *A. johnsonii* trees in only fifteen percent of the twenty plots (Table 4.1). Examples of some of the plots which showed and did not show competition are given in Figure 4.3.

Table 4.1. The results of regression of sum of basal area vs. distance, and base tree basal area vs. and sum of nearest neighbour basal area divided by distance. * = significant relationship ($p < 0.05$).

			Colophospermum mopane			
Plot no	Three nearest-neighbours approach			Single nearest-neighbour approach		
	r^2	*p - value*	*N*	r^2	*p - value*	*N*
1	0.03	0.34	30	0.00	0.89	30
2	0.02	0.42	30	0.23	0.01*	30
3	0.00	0.87	29	0.04	0.31	29
4	0.02	0.42	30	0.00	0.82	30
5	0.05	0.23	30	0.02	0.5	30
6	0.06	0.21	30	0.00	0.9	30
7	0.01	0.57	30	0.17	0.02*	30
8	0.01	0.56	30	0.08	0.13	30
9	0.02	0.42	30	0.01	0.65	30
10	0.08	0.12	30	0.07	0.16	30
11	0.03	0.78	5	0.31	0.33	5
12	0.02	0.66	13	0.45	0.01*	13
13	0.00	0.94	30	0.05	0.23	30
14	0.04	0.57	10	0.56	0.01*	10
15	0.18	0.09	17	0.04	0.44	17
16	0.00	0.86	25	0.26	0.01*	25
17	0.00	0.93	21	0.23	0.03*	21
18	0.01	0.54	27	0.01	0.69	27
19	0.00	0.83	30	0.15	0.03*	30
20	0.04	0.27	30	0.21	0.01*	30
21	0.06	0.39	30	0.00	0.99	30
22	0.01	0.65	31	0.00	0.86	31
			Androstachys johnsonii			
1	0.02	0.43	31	0.24	0.005*	30
2	0.00	0.73	30	0.35	0.001*	30
3	0.19	0.02*	30	0.18	0.021*	30
4	0.14	0.05*	30	0.02	0.42	30
5	0.01	0.55	30	0.02	0.51	30
6	0.04	0.31	30	0.05	0.22	30
7	0.00	0.84	30	0.00	0.81	30
8	0.07	0.18	27	0.16	0.04*	27
9	0.02	0.44	29	0.21	0.01*	29
10	0.05	0.23	30	0.01	0.54	29
11	0.03	0.34	30	0.40	0.000*	30
12	0.14	0.04*	30	0.02	0.43	30
13	0.02	0.48	30	0.51	0.00*	30
14	0.01	0.58	30	0.00	0.84	30
15	0.11	0.08	30	0.05	0.22	30
16	0.03	0.39	30	0.31	0.001*	30
17	0.00	0.84	30	0.03	0.4	30
18	0.02	0.47	30	0.10	0.08	30
19	0.05	0.22	30	0.17	0.02*	30
20	0.00	0.92	30	0.25	0.01*	30

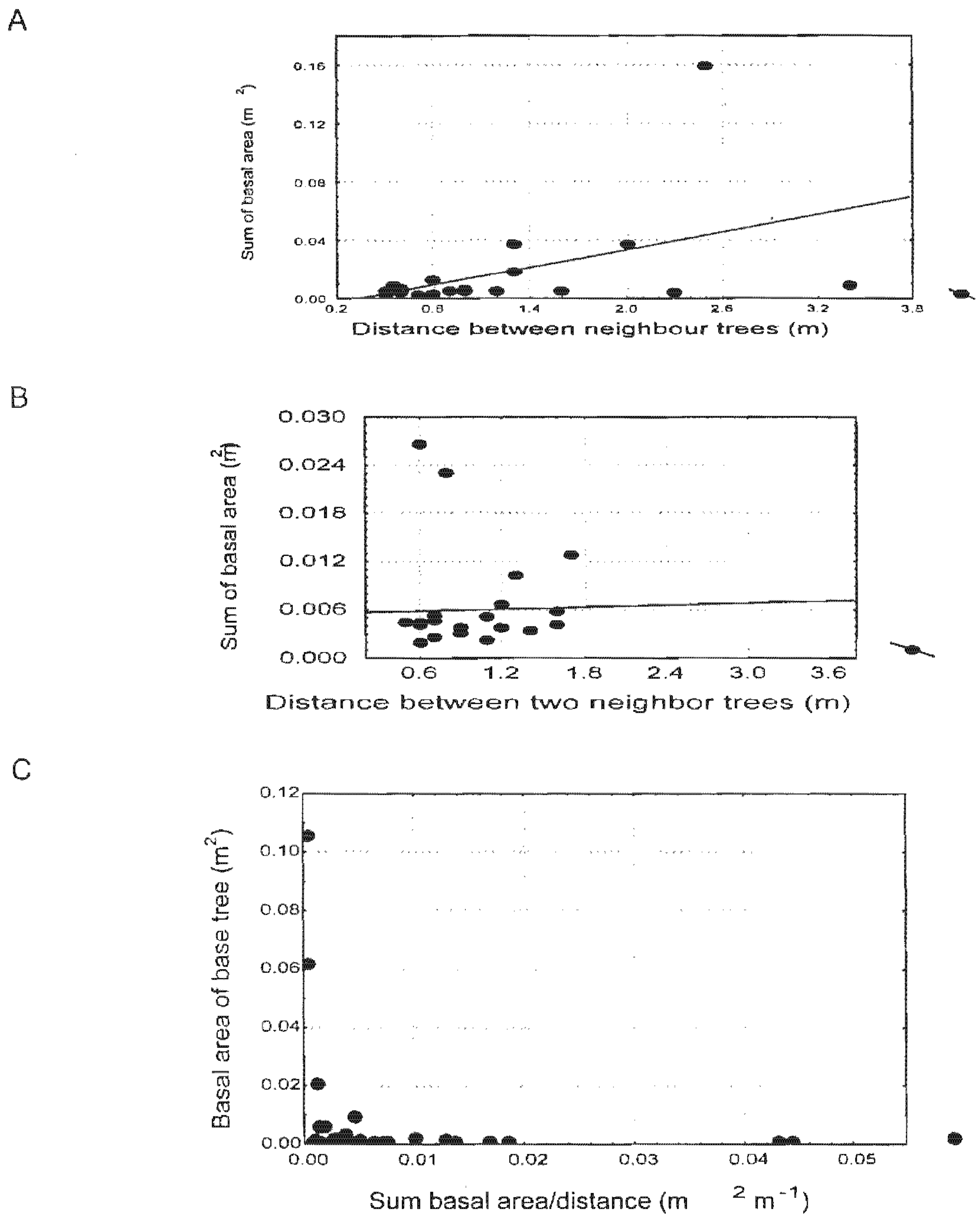


Figure 4.2. Relationship between sum of nearest neighbour pair size and distance between neighbouring trees of *C. mopane*. *A*: example of one of the plots with intraspecific and *B* and *C* from plots with no competition. In *A*, sum of basal area = - 0.0070 + 0.02020 * distance and n = 30, r^2 = 0.23, p < 0.01; In *B*, sum of basal area = 0.0056 + 0.00042 * distance and n = 30, r^2 = 0.00, p > 0.05; In *C*, sum of basal area = 0.0109 - 0.4100 * $\sum$basal area divided by distance and n = 30, r^2 = 0.04, p > 0.05.

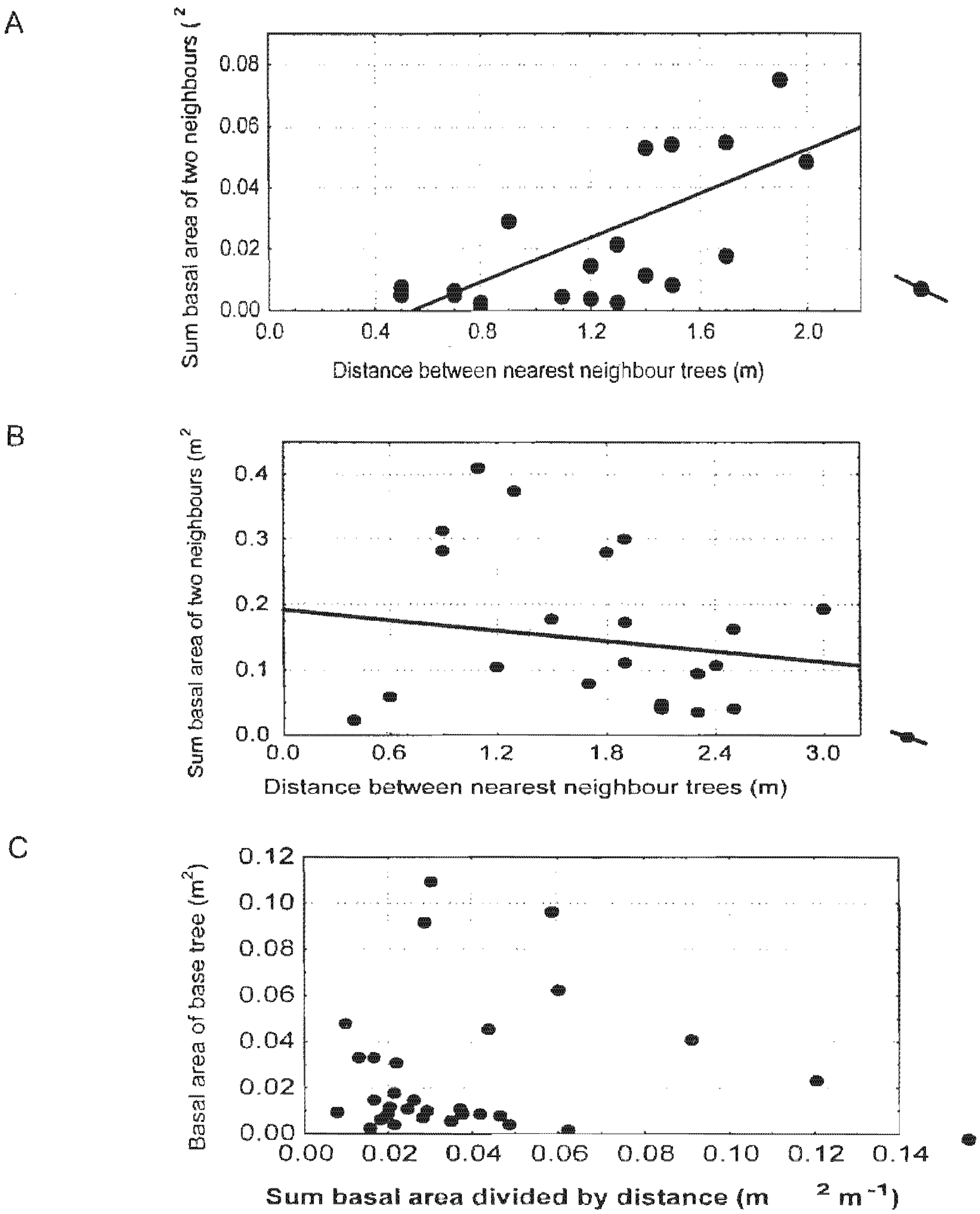


Figure 4.3. Relationship between sum of nearest neighbour pair size and distance between neighbouring trees of *A. johnsonii*. *A* is an example one of the plots with intraspecific competition and *B* an example of a plot with no competition. Also, there was no competition in *C*. In A, sum of basal area = - 0.0195 + 0.03597 * distance and n = 30, r^2 = 0.51, $p < 0.001$; In B, sum of basal area = 0.19208 - 0.0265 * distance and n = 30, r^2 = 0.026, $p > 0.05$; In C, basal area = 0.0197 + 0.17627 * $\sum$basal area divided by distance and n = 30, r^2 = 0.02, $p > 0.05$.

Between species, there is no significant positive relationship between the sum of sizes of nearest neighbour trees and the distance separating the two different neighbouring species

$r^2 = 0.011$; $p = 0.157$; $N = 192$). Thus, there is no interspecific competition between individuals of *C. mopane* and *A. johnsonii* species. Results are shown graphically in Figure 4.4.

Clark and Evans's nearest neighbour distance dispersion indexes (R) (Smith & Grant 1986; Krebs 1989) shows that *C. mopane* trees within monospecific stands are regularly distributed (i.e., thirteen out of twenty plots have uniform distributions), as characterized by $R > 1$ (Table 4.2).

Only six and two plots respectively have a clumped and random distribution patterns. However, eight plots show uniform, eight random and four clumped distribution pattens respectively for *A. johnsonii*. Statistically, only four and one *C. mopane* plots show regular and clumped distributions respectively (i.e. Z-value > 1.96), suggesting that the trees are randomly distributed. Similarly, only two and one *A. johnsonii* plots show regular and clumped distributions respectively (i.e. Z-value > 1.96). Thus, monospecific *C. mopane* and *A. johnsonii* sites have trees which are more randomly distributed than they are either regular or clumped distributed (Table 4.2).

Results indicate that both *C. mopane* ($I = 15.71$) and *A. johnsonii* ($I = 16.17$) have clumped distribution patterns in mixed stands. However, these distribution results are not statistically significantly different from randomness, $X^2_{19,0.05} = 30.144$ and $X^2_{21,0.05} = 32.671$ for both *C. mopane* and *A. johnsonii* respectively. The two species are therefore, again randomly distributed within this site and, according the distribution patterns, there is no intraspecific competition within each species.

Table 4.2 Spatial distribution patterns within *C. mopane* and *A. johnsonii* plots. (* = significant departure from randomness).

Species	Plot No	Trees per plot	Density trees / m²	Mean observed distance (A)	Number of pairs	Expected mean distance (B)	Std error	R = (A/B)	Pattern	Z-Value
Androstachys johnsonii	1	80	0.2 0	1.1	30	1.1	0.1	0.98	Random	-0.2
Androstachys johnsonii	2	106	0.26	1	30	1	0.1	1.03	Random	0.3
Androstachys johnsonii	3	139	0.34	1.1	30	0.8	0.1	1.34	Regular	3.6*
Androstachys johnsonii	4	115	0.28	1.1	30	0.9	0.1	1.13	Regular	1.3
Androstachys johnsonii	5	133	0.33	0.9	30	0.9	0.1	1.05	Random	0.5
Androstachys johnsonii	6	104	0.26	1.0	30	1.0	0.1	1.05	Regular	0.5
Androstachys johnsonii	7	135	0.34	0.9	30	0.9	0.1	1.01	Random	0.1
Androstachys johnsonii	8	69	0.17	1.2	30	1.2	0.1	1.01	Random	0.1
Androstachys johnsonii	9	85	0.21	1.1	30	1.1	0.1	0.97	Random	-0.3
Androstachys johnsonii	10	140	0.35	0.7	30	0.8	0.1	0.78	Aggrega	(2.3)*
Androstachys johnsonii	11	63	0.16	1.6	31	1.3	0.1	1.26	Regular	2.8 *
Androstachys johnsonii	12	43	0.11	1.6	30	1.5	0.1	1.06	Regular	0.6
Androstachys johnsonii	13	59	0.15	1.6	30	1.3	0.1	1.23	Regular	2.4*
Androstachys johnsonii	14	47	0.12	1.6	30	1.5	0.1	1.12	Regular	1.2
Androstachys johnsonii	15	44	0.11	1.6	30	1.5	0.1	1.05	Random	0.5
Androstachys johnsonii	16	119	0.3	0.9	30	0.9	0.1	0.93	Aggrega	(0.8)
Androstachys johnsonii	17	50	0.13	1.3	30	1.4	0.1	0.91	Aggrega	(0.9)
Androstachys johnsonii	18	27	0.07	2.0	27	1.9	0.2	1.02	Random	0.2
Androstachys johnsonii	19	67	0.18	1.3	29	1.2	0.1	1.06	Regular	0.6
Androstachys johnsonii	20	54	0.14	1.2	29	1.4	0.1	0.91	Aggrega	(0.9)
Colophospermum mopane	1	134	0.34	1.0	30	0.9	0.1	1.11	Regular	1.2
Colophospermum mopane	2	71	0.18	1.1	30	1.2	0.1	0.88	Aggrega	(1.2)
Colophospermum mopane	3	83	0.21	1.0	29	1.1	0.1	0.89	Aggrega	(1.1)
Colophospermum mopane	4	32	0.08	1.6	30	1.8	0.2	0.92	Aggrega	-0.9
Colophospermum mopane	5	83	0.21	1.3	30	1.1	0.1	1.22	Regular	2.3*
Colophospermum mopane	6	76	0.19	1.3	30	1.1	0.1	1.12	Regular	1.2
Colophospermum mopane	7	98	0.25	0.9	30	1.0	0.1	0.87	Aggrega	(1.3)
Colophospermum mopane	8	60	0.15	1.4	30	1.3	0.1	1.08	Regular	0.8
Colophospermum mopane	9	92	0.23	1.0	30	1.0	0.1	0.96	Random	(0.4)
Colophospermum mopane	10	91	0.23	1.0	30	1.0	0.1	0.95	Aggrega	(0.6)
Colophospermum mopane	11	15	0.04	3.1	8	2.6	0.5	1.18	Regular	1.0
Colophospermum mopane	12	21	0.05	1.1	13	2.2	0.3	0.49	Aggrega	(3.5)*
Colophospermum mopane	13	51	0.13	1.9	30	1.4	0.1	1.35	Regular	3.7*
Colophospermum mopane	14	18	0.05	2.4	10	2.4	0.4	1.00	Random	0.0
Colophospermum mopane	15	21	0.05	2.7	17	2.2	0.3	1.23	Regular	1.8
Colophospermum mopane	16	48	0.12	2.0	25	1.4	0.2	1.37	Regular	3.5*
Colophospermum mopane	17	31	0.08	2.1	21	1.8	0.2	1.19	Regular	1.7
Colophospermum mopane	18	45	0.11	2.3	27	1.5	0.1	1.51	Regular	5.1*
Colophospermum mopane	19	65	0.16	1.3	30	1.2	0.1	1.02	Random	0.2
Colophospermum mopane	20	46	0.12	1.6	30	1.5	0.1	1.06	Regular	0.7
Colophospermum mopane	21	64	0.16	1.3	30	1.3	0.1	1.07	Regular	0.8
Colophospermum mopane	22	55	0.14	1.4	31	1.3	0.1	1.05	Regular	0.6

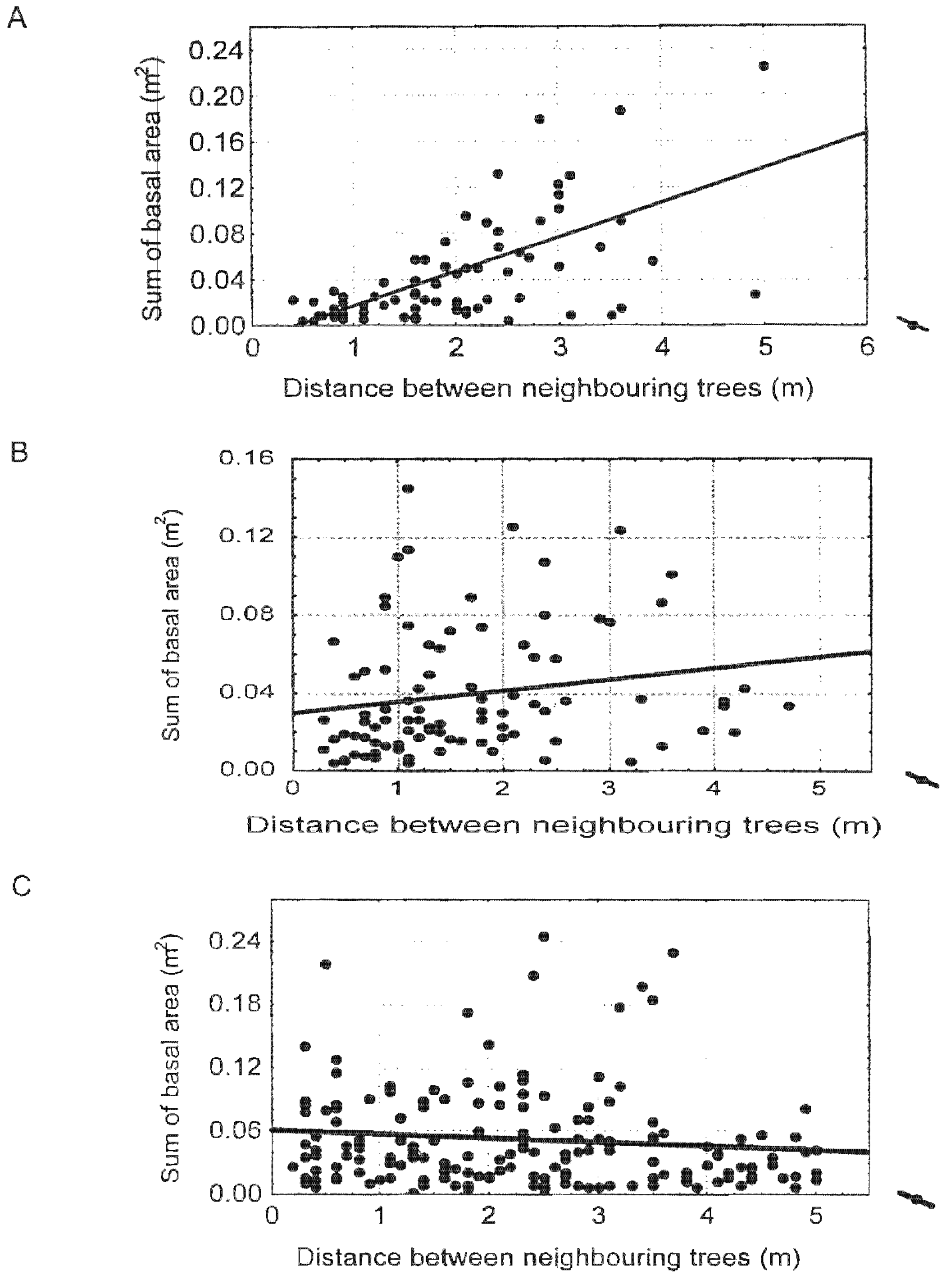


Figure 4.4. Relationship between sum of nearest neighbour pair size and distance between neighbouring pairs. A is for *C. mopane* with sum of basal area = -0.0130 + 0.02995 * distance, n = 101, r^2 = 0.0.39, $p < 0.001$. B is for *A. Johnsonii* with sum of basal area = 0.02964 + 0.00580 * distance, n = 122, r^2 = 0.026, $p < 0.05$. C is for both *C. mopane* and *A. johnsonii* pairs with sum of basal area = 0.06102 - 0.0037 * distance, n = 192, r^2 = 0.011, $p > 0.05$.

4.4.2 Stocking and productivity

There is a significant negative relationship between mean basal area and density ($r^2 = 0.87$, $p < 0.001$; slope = -1.47 and $r^2 = 0.81$, $p < 0.001$; slope = -1.41) for *C. mopane* and *A. johnsonii* species respectively (Figure 4.5A and B).

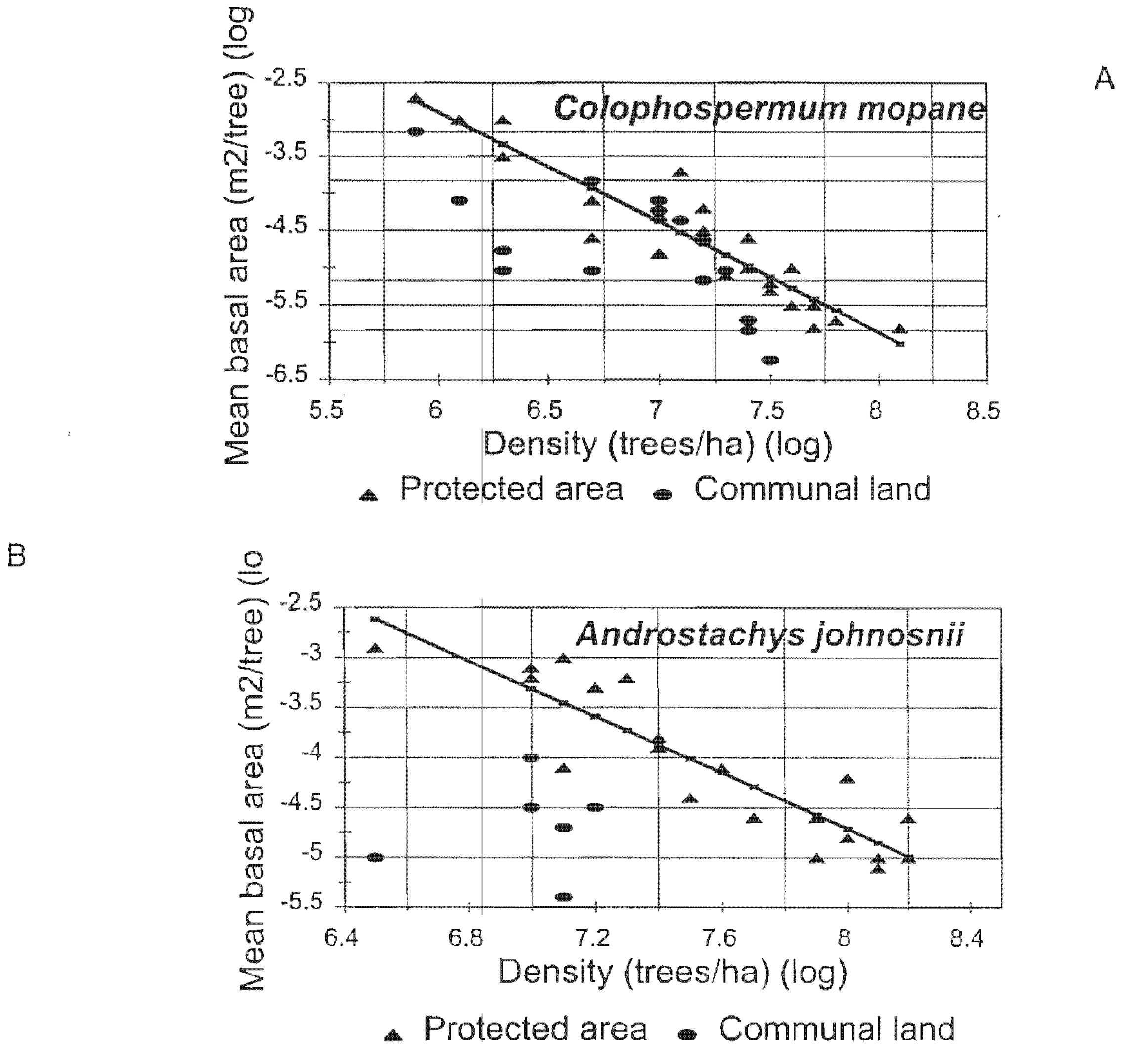


Figure 4.5 The relationship between log$_e$ mean basal area and log$_e$ stand density in protected area. Values for the communal land data were included to investigate the hypothesis that harvesting promotes production. *C. mopane:* $n = 22$, $r^2 = 0.87$, $p < 0.001$, *log$_e$ (basal area)* = *5.9362 - 1.473 * log$_e$ (density)*; *A. johnsonii*: $n = 20$, $r^2 = 0.81$, $p < 0.001$; *log$_e$ (basal area) = 6.5616 - 1.412 * log$_e$ (density)*. Note that plots in communal land were not used for regression and consistently fell below self-thinning lines.

Most of the plots from the communal land for *C. mopane* stands lie below the protected area population boundary (self-thinning) line, suggesting that tree production in communal land may be higher. Four of the plots from within 0.5 km from village edge lie far below the boundary lie, while those from >2 km from village lie along the self-thinning line. While scrutinizing the data from the protected area, it was further established that most of plots lying far below the boundary area come from stands of young, multi-stemmed trees. The same patterns were also evident for *A. johnsonii.*

4.5 DISCUSSION AND CONCLUSION

4.5.1 Intra- and interspecific competition

The absence of detectable competition (Table 4.1) within most of the monospecific plots examined using single nearest neighbour tree approach for both *C. mopane* and *A. johnsonii* sites is contrary to the findings of most previous studies in savannas (Yeaton *et al.* 1977; Smith & Walker 1983; Smith & Grant 1986; Smith & Goodman 1986; Grundy *et al.* 1994). The results however support the findings of a recent study in savannas (Shackleton 1997) that competition is not important in the structuring of communities. The evidence presented here for lack of intraspecific competition by many of the plots do not support the commonly held view that plants in semi-deserts are spaced as a result of competition, probably for water (Yeaton *et al.* 1977). It is also possible that the lack of detectable competition might have resulted from the methods used and the measure of plant performance used. For example, Shackleton (1997) found that there is a significant negative relationship between relative basal area growth and stand density, suggesting that competition is a significant determinant of stand productivity.

The lack of detectable competition within monospecific *C. mopane* stands and in about seventeen *A. johnsonii* plots using multiple nearest neighbour approach may be an indication that the influence of distant neighbours on woody production is minimal. If light is the limiting resource, we would expect the influence of distant neighbours to be high due to shading effect of some individuals with larger canopy areas or volumes. Thus, individual trees are not affected by a multitude of others, but by single close neighbouring individuals. Any method of harvesting that can promote regeneration of the species can be employed since growth is not related to the size and proximity of neighbours.

Very few plots show competition (Table 4.2) using spatial distribution methods such as Clarke and Evans dispersion index (Krebs 1989). Although many plots indicate that both *C. mopane* and *A. johnsonii* species have individuals that are regularly distributed (about 13 and 8 plots respectively, R > 1), only six of the forty-two plots (i.e 14.3%) have individual trees that are significantly regularly distributed. The absence of significant regular distribution patterns further suggests that production in the arid savanna systems is not limited by competition.

The lack of detectable interspecific competition between *C. mopane* and *A. johnsonii* species in mixed stands (Figure 4.4) suggests that the two species use the limiting resources differently. Assuming that water is the limiting resource, lack of interspecific competition between them may be explained by root segregation in space. The spatial distribution of the root systems of *A. johnsonii* have never been studied. Roots of *C. mopane* are shallow with an extensive horizontal spread (Smit 1994; Smit & Rethman 1988b). The fine roots are largely confined to the first 400 mm of soil while the coarse roots extend deep. This allows the species to exploit efficiently limited water resource during rainy season. However, intraspecific competition has been detected within each species in regions of overlap, suggesting that woody production in areas of overlap is limited by competition between species.

In this environment in which the availability of moisture is variable and limited, seasonal growth strategies are important with regard to co-existence of these two species. Penetration of moisture into the soil may be high during the gentle winter rains, but low in summer when thunderstorms, although heavy, are of short duration. Plants with superficial root systems such as *C. mopane* would then require a strategy permitting rapid absorption of and storage of water before it penetrates to lower levels, coupled with the ability to photosynthesize as soon as water and temperature conditions are suitable. This might be an explanation of why *A. johnsonii* is an ever-green plant species. Deciduousness, a characteristic feature of *C. mopane*, may be related to positioning of absorbing roots above those of *A. johnsonii* species in the association because new leaves are produced during the growing, wetter seasons only. It has also been found that leaves remain green during the dry winter months, probably due to the presence of underground water and to a tolerance for winter cold (Wessels *et al.* 1998).

From the findings of this study on competition, it can be concluded that competition is limiting production in *A. johnsonii,* and to lesser degree in *C. mopane* stands in this arid savanna woodland. This conclusion is subject to limitations of the methods used as well as the measures of plant performance in this arid savanna system.

4.5.2 Stocking and productivity

Two major factors limit woodland productivity: between sites productivity is generally limited by water and hence nutrient availability while within stand productivity is limited by density or competition (Von Maltitz & Scholes 1995; Scholes & Hall 1996; Landsberg & Waring 1997; Shackleton 1997). Results from the self-thinning study (Figure 4.5) support the hypothesis that plant productivity in arid savannas is limited by intraspecific competition (Voit 1988). It has long been known that this competition limits the size of plants and that, in turn, the increase in average size is accompanied by a decrease in number of plants, as a result of competition-based mortality, a phenomenon referred to as self-thinning (Yoda *et al.* 1963; Westoby & Howell 1981; Weller 1987; Sackville-Hamilton *et al.* 1995). The slopes of both *C. mopane* and *A. johnsonii* self-thinning lines (= -1.47 and -1.41 respectively) are within the -1.8 and -1.2 ranges assumed to be further evidence for the self-thinning rule and hence intraspecific competition (Weller 1987; Voit 1988). For both these two species, each has its own 'population boundary line' (limit) above which no biomass can be accumulated.

At this limit plants can only grow if others die: growth of large, dominant trees then drives mortality of small, suppressed plants (Harper 1977; Voit 1988; Sackville-Hamilton *et al.* 1995). The self-thinning theory is of particular importance in the prediction of the limits of biomass production for a given species at any given stand density or in drawing inferences about the important causes of mortality in a population. For example, stands which are fully stocked will tend to grow slowly. This is undesirable if the supply of the needed woody plant resources is to be sustainable. Also, the death of young trees results in a loss of biomass within a stand, and reduces the potential stock for the future.

The interpretation of the self-thinning dynamics in this study suggest that stands in the protected area are fully stocked with trees which are not growing to their full potential as a result of high stand density. Growth is only possible if other trees die within the stands. Plots from the communal land lie below the protected site population boundary line, an indication that growth of trees in these stands is not limited by stand density and may probably be higher than in the protected area. The growth of trees above a certain diameter class may be undesirable to the community. For example, within the 0.5 km distance from village edge, plants are characterized by having many big stems and very few small stems. Plots from this area lie far below the self-thinning line and, according to the self-thinning rule, they should have trees with higher growth rates than the rest of the plots. These areas are however, regarded as resource-poor regions by the community. Whether there has been any significant growth of tree after harvesting small stems remains unclear. Therefore, we need comparative long-term growth data from both the communal land and the protected site. Nevertheless, the results support the hypothesis that stand density is limiting productivity and that harvesting, which mimics self-thinning, is promoting production in communal land.

The relationship between basal area and stand density may however be misleading in the sense that average basal area increases even if the plants are not growing (Weller 1987). In such case, the increase in average basal area is a result of mortality, whereas it should be a result of both mortality as well as the growth of surviving plants. That is, changes in average plant mass or basal area can be brought about through both growth of living plants and death of small plants. In such cases, the average stand basal area increases more rapidly than the sizes of individuals composing it, and average mass increases when small individuals dies, even if the survivors do not actually grow (Weller 1987).

It is therefore recommended that stand biomass density be used to test the self- thinning rule since this variable increases only through growth and always decreases with mortality. Nevertheless, the findings of this study indicate that population responses to increased density include the reduction in individual plant size (basal area) to compensate basal area lost through mortality of young trees. Another characteristic of population response to increased density is the development of size inequality among neighbouring plants (Ballare *et al.* 1994), the phenomenon dealt with in the next section.

The observed distribution of basal area-stand density plots from the communal land (Figure 4.5) suggests that harvesting in communal land is influencing the growth of the remaining uncut stems. The result of the greater access to resources for the remaining biomass is generally enhanced woody productivity of the remaining trees (Shackleton 1997). As expected, the graph of biomass-density support this enhanced woody productivity in heavily harvested areas.

The shortage of small individuals within the community suggests that people are using small- to medium-sized stems, live big trees left standing in their fields, which can be incorrectly interpreted as growing due to harvesting. Thus, we cannot currently rely on these findings before a more focussed research into the growth patterns in communal area vs. protected area has been conducted.

In short, as individuals die, due either to competition or to factors extrinsic to the population, the resulting gaps allow the increased growth of neighbouring individuals. These implied dynamics are supported by the self-thinning results. Those individuals whose nearest neighbours may be removed are more likely to show a significant increase in growth rates than those whose neighbours are not removed. Presumably, the removal of neighbouring trees will increase the availability of the limiting resource, allowing the tree to extend its zone of influence (root system) to areas previously occupied by neighbouring individuals.

I found the self-thinning patterns the real persuasive evidence that biomass in arid woodland is regulated by density mass than anything else in *C. mopane* and *A. johnsonii*, and to a lesser extent intraspecific competition in *A. johnsonii*. However, some of the variances between the species and sites might be due to site differences. *A. johnsonii* is found on very rocky sites, needing more space between cracks, and this is an ultimate constraint in getting any more trees on this area. The death of trees might also occur without any growth by surviving plants that are unable to utilize the resources previously unavailable to them.

The main point is that woodland production in Mopane is probably limited by space for trees to grow. So some harvesting should result in higher productivity of the remaining trees. How much harvesting is needed to get more production of the right sized trees will need long-term experimental studies. According to Seydack (1999), the overall production per stand is usually higher that the production of a few remaining individual trees. Thus, stands which are fully stocked are characterized by high biomass but there is no production at such stands. Over harvesting results in stands with low biomass per stand, higher production per tree and low production per hectare. Moderate harvesting will results in stands with intermediate biomass per stand, moderate production per tree and high production per hectare. Depending on the management objective, it is possible that harvesting practices that are based on self-thinning dynamics will lead to the desirable goals for any given woodland system.

CHAPTER 5. RESPONSE OF ARID SAVANNA TREES TO HARVESTING

5.1 INTRODUCTION

Access to fuelwood and construction timber in indigenous woodlands (both forests and savanna woodlands) is one of the primary basic needs of rural communities throughout the developing world. This is also the case in Southern and South Africa where most rural populations are still reliant upon fuelwood for most of their energy needs, and indigenous timber for building houses, roofing, making kraals and fencing (Conroy 1996; Shackleton 1997; see also Chapter 2). The negative impacts of wood collection from woodlands include a decline in the availability of plant resources and hence deforestation (Chidumayo 1987; Goodman 1987; Griffin *et al.* 1993; Banks *et al.* 1996).

Deforestation in developing countries is a problem that increasingly invokes worldwide concern since fuelwood and construction timber shortage remain an important issue in rural areas. Similarly, wood collection by rural people is generally outstripping the vegetation around them (Conroy 1996). Consequently, there is a general perception that there is a resource crisis in rural communities because available supplies are insufficient to meet demand, particularly as the wood-using populations are increasing (Banks *et al.* 1996). In arid savannas, the proposed solutions to deforestation such as the establishment of woodlots and social forestry programs (Goodman 1987; Arnold 1987; Shackleton 1993, 1994) are more likely to fail than succeed, due to slow growth rates of trees (Helliwell 1987), unpredictable weather conditions such as drought (Goodman 1987), and most probably due to institutional set-ups. A complementary approach to the establishment of woodlots and social forestry programs entails the provision of access to sustainable harvesting in neighbouring areas presently unavailable to rural communities, including conservation and private land (Shackleton 1993; Cunningham 1996; Wild & Mutebi 1996). In this case, information on the effects of damage, including felling, lopping and browsing, on yield components of trees is a basic requirement for assessment and management of trees for wood production (Milton 1988). In arid savannas, an understanding of the reproductive strategies of different trees under different harvesting regimes would offer alternatives to resource extraction mechanisms employed by rural communities.

Most savanna trees regenerate vegetatively (Chidumayo 1993). Stumps of most tree species have the ability to produce sucker shoots (Chidumayo 1989). Sucker shoots arise from buds which develop on roots and stem bases. In miombo woodlands the production of sucker shoots is related to age and size of the trees (Chidumayo 1993). Also, it is known that the viability of buds on old and large trees varies with species. Stumps produce many sucker shoots but during regrowth development inter-shoot competition suppresses some of the shoots until a few dominant shoots emerge. These dominant shoots constitute the next generation of regrowth savanna woodland, but the stem density per plant declines slowly with the age of the regrowth.

Most studies on the relationship between felling age and season, and sprouting ability, show shortest sprouts and fewest number of sprouts on stumps felled during the growing period of the year (Johansson 1992a,b). Some studies dealt with the effect of sprouting and suckering of trees cut at different periods of the year with the purpose of decreasing the need to cut sprouts and suckers some years later (Johansson 1992a). In general, the sprouting ability and felling period are correlated. This is so because the seasonal trend of sprouting is believed to be the result of the seasonal fluctuation of carbohydrate reserves (Johansson 1992a). In some instances, carbohydrate concentration in the roots is not a limiting factor for sprouting ability and, as a result, felling time does not influence the sprouting ability of some species. The potential for sprouting by natural regenerated species is important to know when discussing utilisation of biomass on arable land for energy and timber production. Small areas might be used both intensively by plants and extensively by seeding naturally or artificially. In both cases the stumps after felling are sprouting and producing new shoots for fuel wood or other utilities (Johansson 1992a)

It has been shown that woody communities subjected to harvesting are usually characterized by a change in overall population structure (Chapter 3): there is a reduction in mean stem size and range of sizes represented relative to unharvested sites (Shackleton

1993). The alteration of the size class profile also shows different patterns of responses of trees to both harvesting and browsing intensity, frequency and duration. Although harvesting generally leads to a reduction in stem sizes, harvesting does not necessarily mean a reduction in woody productivity (Mc Gregor 1994). Reasons for this increased production appear to be the increase in resources and a decrease in competition associated with a reduction in stand density, basal area and biomass (Smith and Goodman 1986). The result of the greater access to resources for the remaining biomass is enhanced woody productivity of the remaining trees (Landsberg & Waring 1997). We would also expect enhanced woody productivity in heavily harvested areas due to reduction in woody density and hence basal area and biomass, but such trends might be incompatible with local communities' requirements, especially if there is no recruitment into smaller size classes and if harvesting is selective in slow growing tree populations. The resulting size structure may be one of a population of many big unfavourable logs and few medium and small one. Frequent harvesting has marked impacts on recruitment of new stems because vegetative reproduction through coppicing is stimulated from cut stems directly or from the remaining root stock. Also affected by frequent harvesting and browsing is the establishment and subsequent growth of seedlings.

Cutting or lopping of trees occurs throughout all African savannas and is caused by both humans and mammals (Conroy 1996; Shackleton 1997). Felling by humans ranges from selective removal of particular individuals (species and/or sizes) through to almost clear felling of an entire area. Both occur in support of subsistence and commercial endeavours, and both have a significant impact on the status and availability of the plant resources.

C. mopane has numerous uses over its entire range (Conroy 1996; Chapter 2) as does *A. johnsonii* (Chapter 2). These include, among others, construction, browse for goats, and cattle and firewood. Within the rural communities there is a growing scarcity of these plant resources. The reason for this appears to be the gradual increase in the number of homesteads (Conroy 1996) and commercial operations (Chapter 2). The scarcity of these resources is affecting almost all the people in the study area because people are still heavily dependent on plant resources for their household and economic ends. Moreover, obtaining enough firewood and other fuel is particularly an acute problem for all households because this resource is needed every day. As the density of homesteads increases, so will be the demand on plant resources for energy, fencing, hut walls' construction, building kraals and roofing.

A key attribute to the resilience of savannas is the ability of damaged trees to regrow from the remaining stumps (Shackleton 1997). According to Johansson (1992a,b), factors which determine the formation of sprouts are: the species, the season of cutting, the age and hence size, dimensions of stumps and site. Survival of the cut stems and growth rate of the resultant coppice shoots is influenced by the tree size and height of cutting, (Shackleton 1997). Moreover, replacement is faster through coppice growth than through seedling recruitment because coppice shoots grow faster than stems recruited from seedlings and have lower mortality rates (Scholes 1990; McGregor 1994). According to Scholes, survival of stump trees and the coppicing mechanism depends on the cutting method used, the post-cutting management and the biology of the species.

While measures such as the provision of access to sustainable harvesting in neighbouring areas presently unavailable to rural communities (i.e., protected or conservation areas) are continually advocated (Shackleton 1993: Cunningham 1996; Wild & Mutebi 1996), very little is known about the population biology of the species preferred by the rural communities, including their responses to harvesting and subsequent coppice shoot growth patterns. A preliminary survey on resource use patterns by a rural community (Chapter 2) identified *C. mopane* and *A. johnsonii* as the most sought after species for energy and construction respectively. It is against this background that these two species and a few more other species were selected for harvesting.

This study was subsequently undertaken as a preliminary investigation into the effect of tree size, intensity of stem harvesting, height of cutting and season of harvesting on stump survival, coppice production, and coppice shoot growth patterns.

5.2 AIMS AND OBJECTIVES

The main aim of the study was to investigate harvesting methods for arid savanna plant resource and to investigate management interventions that are likely to be sustainable in the long-term. The objectives of this study were:

1. To determine the influence of tree size and intensity of stem harvesting on survival and mortality patterns of cut trees.
2. To determine the effects of stump size on coppice shoot production and growth.
3. To determine the effects of nearest neighbour plants on coppice shoot production and growth.
4. To determine the influence of light availability on coppice shoot production and coppice shoot height and circumference growth.

5.3 MATERIALS AND METHODS

5.3.1 *C. mopane* and *A. johnsonii* responses to harvesting

In a protected area both tall and the shrubby stands of *C. mopane* and *A. johnsonii* species were identified. Within both tall and shrubby stands, ten trees were selected for total harvesting (100% of stems of an individual tree harvested) and another ten trees selected for partial harvesting (25% - 75% of stems of an individual tree harvested) during December 1997 just before the start summer rains. Thus, a total of twenty trees was selected for harvesting for each species in each stand. Before harvesting, each tree was assigned a number and the stem basal diameters of the selected trees were measured ≤30 cm above ground level, or above the basal swelling, using a diameter tape. Each tree was then harvested using a chainsaw ≤30 cm above ground. The number and sizes of stems removed from each tree were noted and recorded. The basal diameters of three nearest neighbours in the first three 90^0 quadrants were also measured and recorded. The trees were left to regrow for a period of one year.

After a year the sites were revisited. Within each site trees that were harvested were assessed to see if they had died or not, and to see if they had produced new shoots (coppice).

5.3.2 The influence of stem size, nearest neighbour and available light on the response vigour of *C. mopane*

For those trees that were still alive and had produced new shoots, the number of new shoots produced were counted and their length and basal diameter measured and recorded. The relationships between the initial stem size and number of sprouts produced, totalled length of a sprouts and equivalent diameter of sprouts were established. The effects of neighbours were assessed by measuring the sizes of the three nearest neighbour trees at each of the three quadrants. The relationships between the sum of nearest neighbour diameters divided by distances and number of sprouts produced, totalled length of sprouts and equivalent diameters of sprouts were established.

5.3.3 *C. mollis, C. apiculatum, K. acuminata, L. stuhlmannii* and *A. nigrescens*

Ten trees of *C. mollis*, *K. acuminata* and *L. stuhlmannii* species were selected for total harvesting (100% harvesting regime) because they grow as single-stemmed individuals. For *A. nigrescens* only five trees were harvested (100% harvesting) and for *C. apiculatum* five trees were selected for partial harvesting (25% - 75% harvesting regime) and another five trees were selected for total harvesting. The trees were left unattended for a period of one year. After a year the sites were revisited. One year later harvested trees were assessed to see if they had died or not, and to see if they had produced new shoots (coppice). The number of shoots produced were counted and the total length of shoots and their basal diameters were measured and recorded.

5.4 DATA ANALYSIS AND RESULTS

5.4.1 *C. mopane* and *A. johnsonii* responses to harvesting

When *C. mopane* is cut at ≤30 cm above ground, it produces many new shoots from stems and stem base, and can therefore be regarded as a strong resprouter. None of the cut trees from either shrubby and tall stands died, but three were removed during road construction (Table 5.1). All the remaining trees of variable pre-harvesting stem sizes produced new shoots when stems were cut close to the ground irrespective of how many stems of an individual tree had been removed. Harvesting intensity did not have any effect on the survival of the cut trees.

A. johnsonii dies when harvested at ≤30 cm above ground and when all stems of an individual tree are harvested, especially the big trees. Seventy percent of the shrubby *A. johnsonii* died when all the stems of an individual were removed and 100% mortality was also observed from the tall stand (Table 5.1). Forty percent and fifty six percent respectively died in the shrub and tall *A. johnsonii* stands when stems of an individual tree were partially harvested (25 - 75% harvesting regime).

Table 5.1 Responses of *C. mopane* and *A. johnsonii* to varying harvesting intensities. For shrubs, canopy ≤3 m, and tall refers to canopy ≥4 m. bd is basal diameter.

Species	Growth form	100% harvest level			25 - 75% harvest level		
		Dead	Live	n	Dead	Live	n
C. mopane	Shrub (≤15 cm bd)	0 (0%)	10 (100%)	10	0 (0%)	10 (100%)	10
	Tall (> 15 cm bd)	0 (0%)	10 (100%)	10	0 (0%)	7 (100%)	7
A. johnsonii	Shrub (≤15 cm bd)	7 (70%)	3 (30%)	10	4 (40%)	6 (60%)	10
	Tall (> 15 cm bd)	10 (100%)	0 (0%)	10	6 (.60%)	4 (40%)	10

5.4.1.1 The influence of initial tree stem size and nearest neighbour on the response vigour of *C. mopane* and *A. johnsonii*

For both these two species there was no relationship between the initial size of the cut tree and number of shoots produced and total length of coppice. However, there was a significant relationship between the initial size of the cut tree and basal diameter of coppice *C. mopane* when all the stems of and individual tree were harvested but not for the 25-75% harvest level (Table 5.2; Figure 5.1). Also, there was a significant negative relationship between the sum of sizes divided by distance and equivalent diameter of coppice shoots (Figure 5.2).

The estimated percent of light available to a tree during the day did not influence shoot production and shoot growth of *C. mopane* sprouts ($n = 20$ both cases, $r^2 = 0.14$ and 0.14 for shoots and total length respectively, and $p > 0.05$ in both cases).

Table 5.2 Relationship between initial tree basal diameter and number of shoots produced, total length of shoots produced and the diameter of shoots produced. N/A = there is no value since most trees had died. The mean number of shoots, mean basal diameter (cm) and mean total length (cm) of shoots and standard deviations are given in brackets.

Species	100% harvest level			25 - 75% harvest level		
C. mopane	Basal diameter vs. number of shoots			Basal diameter vs. number of shoots		
	r^2	p-value	n	r^2	p-value	n
	0	0.935	20 (12.3 ± 10.3)	0	0.97	16 (5.8 ± 5.4)
	Basal diameter vs. total length of shoots			Basal diameter vs. total length of shoots		
	r^2	p-value	n	r^2	p-value	n
	0.042	0.397	20 (665.6 ± 367.8)	0.025	0.56	16 (285.2 ±276.9)
	Basal diameter vs. diameter of shoots			Basal diameter vs. diameter of shoots		
	r^2	p-value	n	r^2	p-value	n
	0.36	0.005*	20 (2.3 ± 0.67)	0	0.95	16 (1.1 ± 0.6)
A. johnsonii	Basal diameter vs. no of shoots			Basal diameter vs. no of shoots		
	r^2	p-value	n	r^2	p-value	n
	N/A	N/A	N/A	0.22	0.147	12 (7.8 ± 8.1)
	Basal diameter vs. total length of shoots			Basal diameter vs. total length of shoots		
	r^2	p-value	n	r^2	p-value	n
	N/A	N/A	N/A	0.103	0.336	12 (82.0 ± 75.7)
	Basal diameter vs. diameter of shoots			Basal diameter vs. diameter of shoots		
	r^2	p-value	n	r^2	p-value	n
	N/A	N/A	N/A	0.007	0.803	12 (0.5 ± 0.3)

There is a positive linear relationship between the percentage light available to sprouts and the equivalent diameter of sprouts for *C. mopane* when all stems of an individual tree are harvested (n = 20, $r^2 = 0.27$, $p < 0.05$; Figure 5.3).

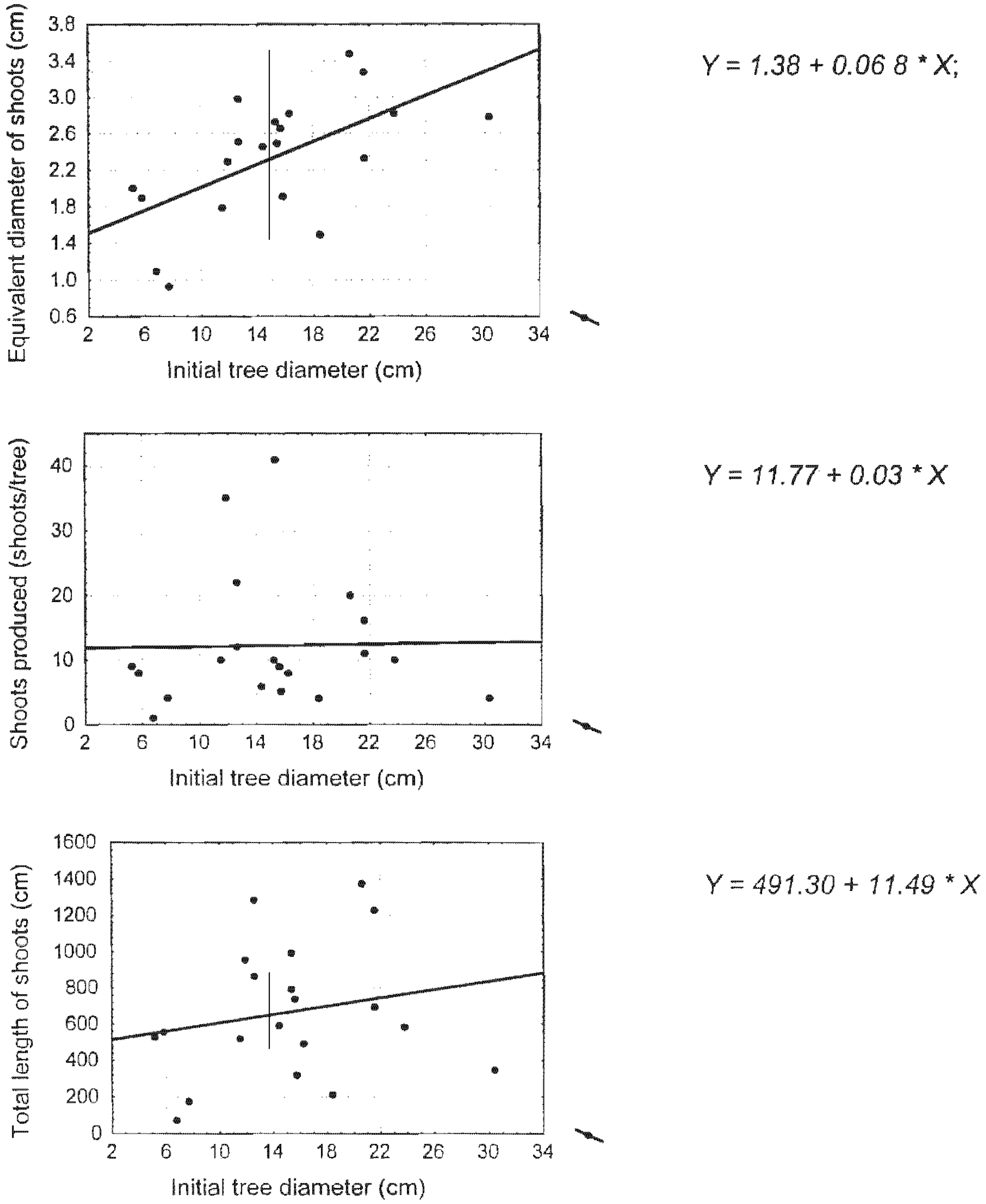


Figure 5.1 Relationship between the initial tree (stump) size and i) equivalent diameters of shoots, ii) number of shoots produced and iii) total length of shoots produced for *C. mopane* under 100% harvest level. Sample size, r^2 and *p* values are shown in Table 5.2.

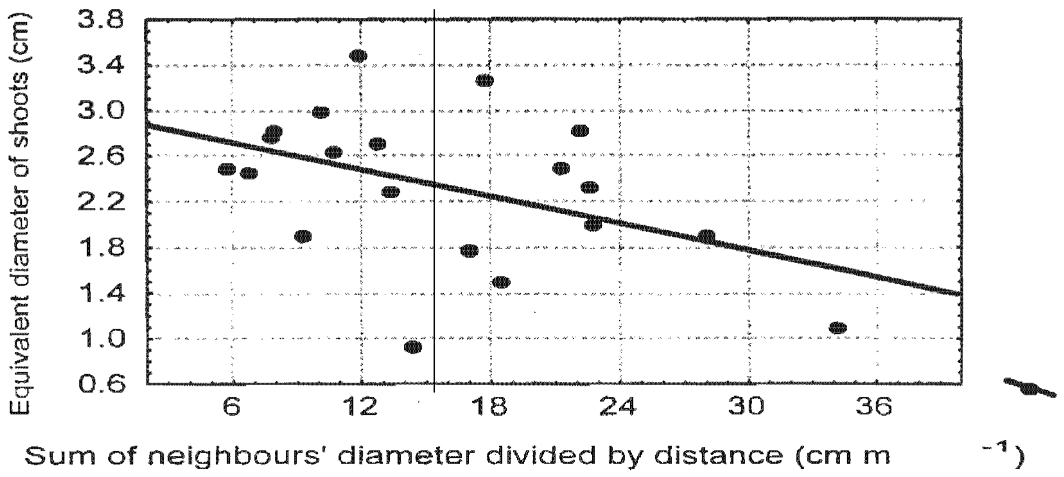


Figure 5.2 The relationship between equivalent basal diameter of shoots and sum of nearest neighbour diameters divided by distance for *C. mopane* under 100% harvest regime. Shoot basal diameter = 2.952 - 0.039 x sum of nearest neighbour diameters divided by distance (n = 20, $r^2 = 0.20$; $p < 0.05$).

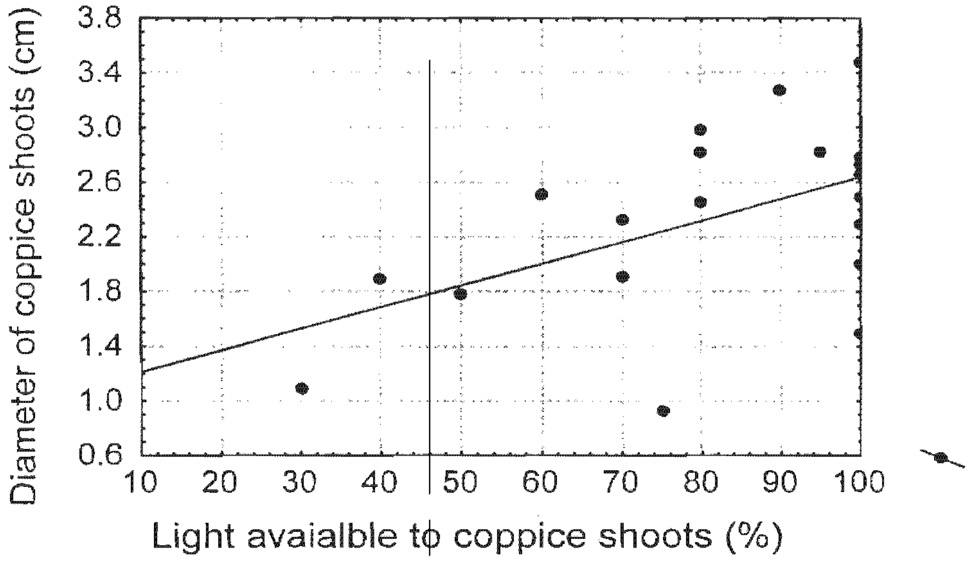


Figure 5.3. Relationship between light available to shoots and equivalent diameters of shoots (shoot diameter = 1.0514 + .01586 * % light; n = 20, $r^2 = 0.27$, $p < 0.05$).

5.4.2 *C. mollis, C. apiculatum, K. acuminata, L. stuhlmannii* and *A. nigrescens*

C. apiculatum, K. acuminata, L. stuhlmannii and *A. nigrescens* are all strong resprouters when cut at ≤30 cm above ground. However, *C. mollis* died soon after being cut and is therefore not a resprouter (Table 5.3). Table 5.3 shows the mean number of shoots produced per year, the mean total length of shoots and mean basal diameters of coppices.

Table 5.3 Mean total length and equivalent basal diameter for the five biggest shoots produced plus mean number of shoots produced for some selected species.

Species	Mean total height ± SD (cm)	Mean equivalent basal diameter ± SD (cm)	Mean number of shoots produced ± SD	Dead	Live
A. nigrescens	345 ± 117 (n = 4)	1.7 ± 0.7 (n = 4)	8.8 ± 4.0 (n = 4)	1 (20%)	4 (80%)
C. apiculatum	486 ± 259 (n = 10)	1.4 ± 0.2 (n = 10)	24.6 ± 14.5 (n = 10)	0 (0%)	10 (100%)
C. mollis	All dead	All dead	All dead	10 (100%)	0 (0%)
K. acuminata	245 ± 53 (n = 7)	1.6 ± 0.4 (n =7)	18.3 ± 11.0 (n = 7)	3 (30%)	7 (70%)
L. stuhlmannii	404 ± 91 (n = 8)	1.9 ± 0.3 (n = 8)	24.0 ± 11.2 (n = 8)	0 (0%)	8 (80%

5.5 DISCUSSION

5.5.1 *C. mopane* and *A. johnsonii* responses to harvesting

Results indicate that *C. mopane and A. johnsonii* respond differently to particular harvesting regime. The survival rate of both big and small *C. mopane* trees is higher than the death rate irrespective of the harvesting intensity. On the other hand, the death rate of *A. johnsonii* is generally higher than the survival rate irrespective of the harvesting intensity, except for the small trees under partial harvesting of stems (Table 5.1).

C. mopane

It seems that pre-harvest stem size does not have much influence on the survival of cut *C. mopane* trees. Thus, a range of size classes of this species can be harvested and they will persist under such harvesting pressure. Johansson (1992b), while studying the resprouting of 10- to 50-year-old *Betula pubescens*, found a mean survival percentage of stumps of 84% one year after felling. In this study almost 100% of cut stumps are still living one year after cutting. Johansson (1992b) also noted that large stumps of *B. pubescens* do not survive as well as smaller stumps but this study showed that the two size classes survive in a similar fashion after they are cut. Higher mortality rates in large trees are said to be due to the fact that the older trees have fewer buds has and hence their sprouts depending, among other things, on the thicker stump bark on older trees than on young trees. There are also reported cases of poorest sprouting from old stumps in *B. pubescens* (Kauppi *et al.* 1988 in Johansson 1992b; Johansson 1992b). The high survival rate of *C. mopane* may be due to the fact that buds are located over the whole tree in which case stumps seem to have overcome the difficulties with which any individual bud will have in developing independently of the cluster. Physiologically, the explanation for this high survival rates of *C. mopane* trees may be that trees were felled during the late dormant season when the carbohydrate reserves are high. This assumption is based on the findings of Johansson (1992b) and Vila & Lloret (1996) on other tree species. The effects of the season of cutting were not investigated.

The period that can be used for cutting with the aim of yielding a high percentage of living stumps with sprouts is also during the November - December period, more especially if the emerging sprouts are to be used for biomass production for local people. In practice, silvicultural recommendations on the best felling period to promote living stumps should not be based on the size of the tree but on the species itself and season of harvesting, including habitat quality.

A. johnsonii

Small and big trees are sensitive to both the height of cutting as well as the harvesting intensity applied in this study. The high mortality rate of big stems appears to be due to the old age of buds because it is known that buds on old and large trees lose viability and die (Chidumayo 1993). I observed stem swellings on which buds are concentrated. These swellings (or bud clusters) are close to the ground in young trees but as the tree grows, the clusters only occur higher up the stems (Figure 5.5), suggesting that as the tree stems elongate, the swellings tend to be located higher up the stems.

It seems that stem size has much influence on the survival of cut *A. johnsonii* trees. Thus, a range of size classes of this species cannot be harvested since some will not persist under such harvesting pressures (Table 5.1). It is common that less than 50% of the cut stumps are living 1-5 years after felling (Johansson 1992b). In this study almost 100% of large 100%-harvest-intensity-level stumps died after one year. Johansson (1992b), working on *Betula pubescens*, also noted that large stumps do not survive as well as smaller stumps. This study proved that the two size classes of *A. johnsonii* indeed do not survive in a similar fashion after they are cut.

Higher mortality rates of large trees in this study may be due to the fact that the older trees have fewer buds and sprouts are produced depending among other things on the thicker stump barks on older trees than on young trees. There are also reported cases of poorest sprouting results from old stumps (Kauppi *et al.* 1988; Johansson 1992b).

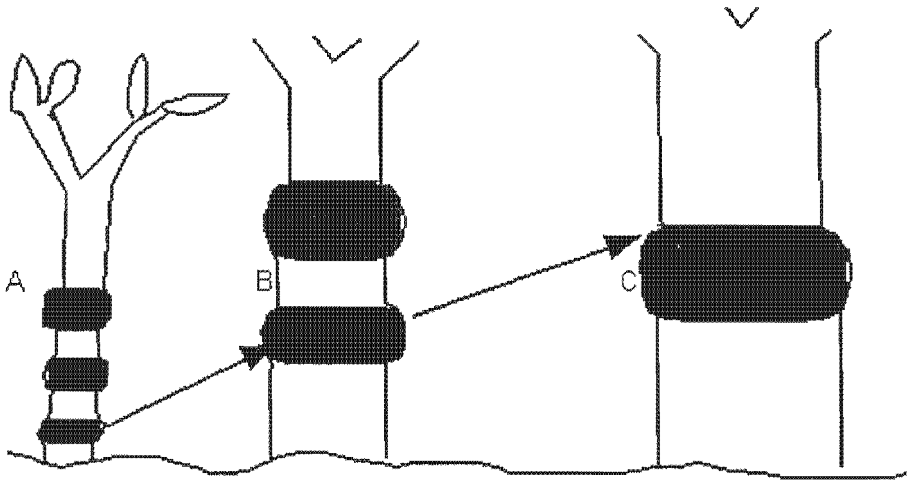


Figure 5.4 The swellings of stems in *A. johnsonii* from which sprouting occurred. Black areas indicate swellings (=bud clusters). A to C are different sizes of a tree from the small to large individuals. The arrow indicates hypothesized variation in the location of swellings with tree age.

The location of buds of *A. johnsonii* as clusters above the stem base seems to be causing difficulties as to which individual bud must develop independently of the cluster. The high mortality rate may also be due to the fact that the stems were cut too far the level where buds are located or during the season when carbohydrate reserves were too low. Johansson (1992b) also noted that if buds on stumps are located in clusters, there is a correlative interaction within the bud cluster which then prevents buds from sprouting and hence higher mortality. The physiological explanation for this high death of trees may be that trees were felled during December season when the carbohydrate reserves are low (Johansson 1992b), resulting in higher death rates and producing few coppice shoots if any. Subsequent observations on *A. johnsonii* indicated that trees generally died if cut below a bud cluster and survived if cut above a bud cluster.

If the emerging sprouts are to be used for biomass production, then more focussed research into the response of this species is warranted. In practice, silvicultural recommendations on the best felling period to promote living stumps should be based on the size of the trees and height of cutting for *A. johnsonii* (and possibly season, which was not studied).

5.5.1.1 The influence of an initial tree stem size and nearest neighbour on the response vigour of *C. mopane* and *A. johnsonii*

The initial size of a tree did not influence resprouting and height growth of sprouts in *C. mopane* and *A. johnsonii* trees irrespective of harvest treatment applied (Table 5.2). However, there is a positive correlation between the initial size of a tree and the equivalent diameter (see Chapter 4) of sprouts for *C. mopane* when all stems of an individual tree are harvested (Figure 5.2).

The percentage light available to a tree during the day did not influence number of shoots and length of *C. mopane* sprouts ($n = 20$ both cases, $r^2 = 0.14$ and 0.14 for shoots and total length respectively, and $p > 0.05$ in both cases). This indicates that shoot production and height are not influenced by the size and proximity of uncut neighbouring trees. However, there was a significant positive linear relationship between the amount of light available to sprouts and the equivalent diameter of sprouts for *C. mopane* when all stems of an individual tree are harvested ($n = 20$, $r^2 = 0.27$, $p < 0.05$; Figure 5.3) suggesting that competition between coppice shoots and adult trees is limiting shoot growth. These findings are contrary to the results of some studies in the Mediterranean vegetation (Vila 1997) where competition and light availability were found to reduce sprout recruitment and sprout density.

5.5.2 *C. mollis, C. apiculatum, K. acuminata, L. stuhlmannii* and *A. nigrescens*

The response results after harvesting *C. mollis, C. apiculatum, K. acuminata, L. stuhlmannii* and *A. nigrescens* suggest that it is possible to cut stems of *C. apiculatum, K. acuminata, L. stuhlmannii* and *A. nigrescens* partially or fully but the stems will survive and produce many new shoots of variable heights and basal diameters (Table 5.3). This suggests that these four plant species are strong resprouters which can persist under harvesting. According to Kruger *et al* (1997), we would expect all the four species except *C. apiculatum* to have died after cutting since they are single-stemmed trees (reseeders). This is a result of allocating much of the resources to sexual reproduction. *C. mollis* seems to be a reseeder and therefore, cannot tolerate harvesting. Whether this is due to bud problems or carbohydrates allocation patterns is unknown. The findings of this study suggest that if the strong resprouter species are useful resources to the community, clear-felling operations can be applied. In such instances, care should be exercised to minimize damage to *C. mollis* mature trees and seedlings to avoid changes in species composition and hence local extinction of this species.

Other studies on the resprouting and productivity patterns of sprouts (e.g., Huang *et al.* 1994; Hytonen 1994; Cobbina 1995; Sennerby & Zsuffa 1995; Vila & Terradas 1995; Wirthensohn *et al.* 1996; Misra *et al.* 1996) have indicated that the height of cutting, season of cutting, competition within shoots and between stumps and uncut adult tree, size of stumps as well as soil nutrient regimes all play an important role in stump survival patterns and subsequent coppice shoot production and growth. However, the effects of these factors vary among species. For example, Cobbina (1995) observed greatest stump survival rates and rapid shoot growth when trees were cut in winter. Sennerby & Zsuffa (1995) reported a strong correlation between number of sprouts formed and the structure and number of buds and their position on the stools. *A. johnsonii* response to the harvesting regime used in this study is similar..

While removal of neighbours in other studies have resulted in increased number and biomass of sprouts (Vila & Terradas 1995) which is an indication of the effects of competition, the same pattern of biomass accumulation was detected suggesting that competition is a factor in regrowth. This is contrary to previous results in the same study area (Chapter 4). Thus, competition is limiting diameter growth but not stem production and height growth. If this competition between cut stumps and uncut trees was influencing coppice shoots production and height growth, we would expect to find a significant positive relationship between number as well as height of coppice and sum of sizes divided by distances of neighbouring trees and the amount of light available to cut stumps (Tschaplinski & Blake 1989; Grundy *et al.* 1993; Vila 1997). The high rate of sprouting in all these trees may be due to the fact that trees had adequate starch reserves in roots which are believed to be important during the early phase of resprouting in coppice systems (Von Fircks & Sennerby 1998).

Other reports suggest that the height of cutting is related to number of stems produced and inversely related to stem length (Hytonen 1994; Wirthensohn *et al.* 1996) while others report that height is unimportant with regard to coppice shoot production and growth (Misra *et al.* 1996). These suggest that the responses of trees to harvesting are quite different and depend on the biology of the species.

Summary

This chapter has shown that Mopane is very resistant to injury and coppices well across all size classes, an indication that different size classes can be harvested to meet local needs. *A. johnsonii* does not survive well after harvesting and can be killed if harvested below bud swellings. In practice, *A. johnsonii* is usually felled at heights which permit sprouting in the communal area and the community should be encouraged to use the same approach in the future. The productivity of Mopane resprouts is influenced by competition from remaining trees in protected area since the area had low browsing pressure relative to woodlands in communal land. Survival of resprouts may be strongly impacted by browsers is communal land where recruitment has been shown to be low.

CHAPTER 6. MODELLING *C. mopane* POPULATIONS IN COMMUNAL LAND

6.1 INTRODUCTION

Studies on *C. mopane* in the recent past have concentrated mainly on investigating the effects of tree thinning (Scholes 1990; Smit 1994; Smit & Rethman 1998a,b) on subsequent coppice production and growth, herbage production and reproduction dynamics of the species and to a lesser extent on socio-economics of the species (Timberlake 1995; Conroy 1996). While measures like this are important in understanding the population dynamics of the species, investigations into the role and effects of local rural population on the dynamics of the species have been ignored. With increasing human populations in rural areas, the demand for this species will also increase. In Chapters 2, 3, and 5, patterns of resource utilisation were established in this community, the stability of *C. mopane* populations under two contrasting management regimes were also established, and the responses of this species to harvesting were investigated. Results suggest that the species is not stable in communal area, while harvesting in protected area suggests that the species is capable of recruiting well through resprouting after harvesting.

Results from my survey conducted in 1997 at Mukomawabani community (Chapter 2) indicate that *C. mopane* is one of the most important species for this rural community. The wood of this species is regarded highly important for fire, roofing, fencing and building houses, while its leaves are a source of browse for both cattle and goats, especially during the dry season (Irvine 1937). Much of the wood is harvested either live or dead and sold in the urban areas. As a result, local communities' perceptions of this resource in communal land suggest that *C. mopane* is no longer available around the community. Reasons for the declining trends given by the community during the survey include drought, burning of live trees with the aim of increasing the amount of dead wood for fire, harvesting of live trees for both household consumption and building houses, and economic activities related to this species.

Other most possible explanations for the declining trends in communal land may be the combination of harvesting and browsing pressures by goats and cattle. However, this assumption was not tested during the 1997/98 study period. It is against this background that a study of sustainability in one of the rural communities which rely heavily on this species was undertaken. The approach followed was to use a matrix model to simulate the impacts of harvesting regimes, browsing pressures and a combination of these two factors.

6.1.1 Literature survey

Acocks (1988) distinguishes between two blocks of Mopani veld within the borders of South Africa. The first of these lies in the wide, gently sloping undulating valley of the Limpopo, north of the Soutpansberg. The second lies within a broad belt running south from the eastern part of Soutpansberg to beyond the Olifants river. The latter block is wetter, rainfall being over 400 mm per annum, and the altitude is from under 300 m to 400 m (Smit 1994). This chapter reports on a study conducted within an area representative of the former block at Mukomawabani village next to Masisi in the Northern Province.

In the rest of southern Africa, Mopane veld covers large areas of Botswana, Zimbabwe, Mozambique and northern Namibia (Smit 1994). The total area in southern Africa under *C. mopane* vegetation types is estimated at 555 000 km^2 (Mapaure 1993).

While inherently arid with limited potential for intensification, the Mopani veld is almost exclusively used for extensive cattle and game farming (Smit 1994). The major direct economic uses of *C. mopane* trees include its use as firewood and as rough construction timber, while the mopane worm, the edible larva of the Saturnid moth *Gonimbrasia belina*, is much sought after as a delicacy (Timberlake 1996; Smit & Rethman 1998a,b). According to Smit (1994), the grazing capacity of the area is overestimated and as a whole is very low.

6.1.1.1 An introduction to matrix models

The general form of the population projection matrix as demonstrated by Lefkovitch (1965) is:

$$An(t) = n(t + 1)$$

where $n(t)$ is the population vector in the form of a matrix consisting of a single column of numbers, whose elements are $n_i(t)$, which describe the size class distribution of the population at time t. A is a square matrix of dimensions i rows and j columns and is termed the population projection or transition matrix. The matrix contains transition probabilities that describe the number of offspring born to each size class that survive time period t, as well as the proportion of individuals in each size class that survive and remain in that size class, and those that survive and enter another size class. By multiplying the present size class distribution by a matrix of transition probabilities, one can obtain the expected population size class distribution after one time period has elapsed, $n(t + 1)$.

The transition matrix contains values for the size class specific fecundity (F) on the first row of the matrix; values for the probability of surviving and remaining in the same size class per time period (R) on the diagonal; and the probability of surviving and growing into the next size class per time period (G) on the sub-diagonal or any other cell in the matrix not occupied by F and R values (Table 6.2). The elements of Matrix A characterize the nature of a population by incorporating elements of fecundity, mortality and growth rates or ingrowth/regeneration (= number of stems growing into the next size class) for each size class in a population's life history (Alder & Synnott 1992; Vanclay 1994, 1995, 1996; Silvertown & Doust 1995). In the Lefkovitch matrix, there is no necessary relation between life-history size classes or states of the model and age (Desmet *et al.* 1996) as required in the Leslie matrix (Leslie 1945, 1948; Caswell 1989). The assumption ~~is that all~~ individuals in the same size class are subjected to the same mortality, fecundity and growth schedules, as specified in the transition matrix.

The state variables for any population must fulfill some very distinct requirements (Werner & Caswell 1977). That is, they need to be biologically relevant to the organism concerned (Desmet *et al.* 1996). A population can be projected for any number of time periods, k, into the future:

$$n(t+k) = A^{k}n(t).$$

In a constant environment, as the value of k increases, the predicted population size distribution approaches stability, such that, eventually, the proportion of individuals in each size class become constant. This is known as the stable-stage distribution (SSD). Once the population stage distribution has stabilized, the rate of population change from one time period to the next must also be stable, for both the individual size classes and the population as a whole. This rate can be calculated as:

$$\lambda = n(k)/n(k - 1)$$

where λ is the finite rate of natural increase, and $n(k)$ denotes the projected distribution vector k time periods into the future such that a stable stage distribution has been reached. The value of k required to reach this may vary markedly. The finite rate of increase, λ, has a value of 1.0 when the total population remains constant through time; is >1.0 when the population is increasing; and is <1.0 when the population is declining.

6.2 METHODS

In Chapter 2, community people indicated that there is a resource crisis in communal land due to pressure imposed on the resource by local as well as urban people, as a result of harvesting, browsing and burning of trees and climatic conditions which prevail after harvesting. However, the study failed to quantify these problems. Results of harvesting experiments (Chapter 5, Table 5.1) indicate that harvesting does not results in mortality of the harvested trees, irrespective of the size of the tree harvested. Results from Chapter

3, Figure 3.3, support the community's argument that the resource crisis in communal land is a real issue, but no possible explanations could be suggested. During a 1998 survey in the communal area by myself and William Bond, it was apparent that the effects of browsing, mainly by goats, are more detrimental to the populations of *C. mopane*, especially the seedlings and young tree populations in the vicinity of the community. It should also be expected that goats will also have the same impact on coppice shoots.

Which factors are influencing the sustainability patterns of *C. mopane* in communal land? To understand the population dynamics of this species, a matrix model incorporating the effects of browsing, harvesting and a combination of browsing and harvesting regimes was constructed to simulate populations patterns over time.

6.2.1 *C. mopane* population survey in communal land

During December 1997, data from fifteen 0.04 ha circular plots, five located within 0.5 km from village edge, five located between 0.5 km and 2 km from village edge, and five located more than 2 km from village edge, were gathered in *C. mopane* stands in communal land. Within each plot, all *C. mopane* stems ≥2.0 cm in basal diameter were measured ≤30 cm above ground level or above the basal swelling. The data from all the fifteen plots were pooled. Population structure was examined by constructing a histogram of equal-diameter size classes (5 cm). Diameter was chosen over height as the means of analysing population structure for two reasons: (1) it is known that older trees develop canopy volume and increase in diameter, as opposed to height (Desmet *et al.* 1996) and (2) diameter is the most important measure in determining which tree is liable to be harvested.

6.2.2 Modelling harvesting and browsing

A stage-based model was developed to gain some quantitative insight into the dynamics of the population in communal land. A simple matrix, based on life-history of *C. mopane* being divided into four stages was used: (1) trees ≤3.9 cm, mostly not harvested but more likely to be browsed by goats and cattle; (2) trees ≥4.0 cm but ≤9.9 cm, mostly used for roofing, fencing and firewood; (3) trees ≥10.0 cm but ≤19.9 cm, used mostly for building houses, firewood, and fencing; and (4) trees ≥20 cm, used for fencing and firewood. Shackleton's five years of unpublished data on growth (Table 6.1) were used to quantify fecundity, survival and growth rates of the species in protected area. The data come from a stand which was fully stocked (3795 trees per ha; basal area = 32.23 m^2/ha) suggesting that growth rates may be slower than in the communal land under study. No temperature records for the study area were available but the area is known for its high summer temperatures. The mean annual rainfall over a five-year period (1991/1992 - 1995/1996) was 500 mm. The soil is typical deep sandy soil.

Table 6.1 Data used to construct the matrix model for *Colophospermum mopane*. (Source: Shackleton - unpublished Hans Merensky Top plot data).

		Number of stems per 0.0664 ha					
Variable	Size class range, cm	Year: 1992	1993	1994	1995	1996	1997
Population	2.0-3.9 cm	105	102	91	83	73	67
	4.0-9.9 cm	83	83	88	95	101	102
	10.0-19.9 cm	17	17	17	17	16	19
	20.0+ cm	12	12	12	12	13	12
Mortality	2.0-3.9 cm		3	5	1	0	1
	4.0-9.9 cm		0	1	0	4	2
	10.0-19.9 cm		0	0	0	0	0
	20.0+ cm		0	0	0	0	0
Ingrowth	From ≤3.9 to >3.9 cm		2	4	7	10	5
	From ≤10.0 to >10.0 cm		0	0	0	0	2
	From ≤20.0 to >20.0 cm		0	0	0	1	0

The life-stage table (Table 6.2) represents all the possible transitions an individual can make in any of the stage classes in one time. The population vector (Table 6.2) was derived from the data collected in communal land at Mukomawabani village. The limit between the smallest size class and the next one was set by the minimum observed utilisable stems in the village.

The derived transition matrix for the population was analysed following the method outlined in the introduction. The time period for the model is 1 year. Consequently, the calculated transition probabilities are expressed as the probability of a transition occurring during that time period. The calculated probabilities for the transition matrix are presented in Table 6.2a with the corresponding symbols in Table 6.2b. The population vector, based on the observed size class distribution in the communal land, is presented in Table 6.2c.

Table 6.2 (a) The derived transition matrix for *C. mopane* using Shackleton's unpublished data. (b) The matrix cell reference labels for the transition matrix for *C. mopane*. (c) The population vector matrix (stems per ha) as derived from a survey in communal area.

a		< 4.0 cm	< 10 cm	< 20 cm	≥ 20 cm
	< 4.0 cm	0.91	0	0	0
	< 10 cm	0.07	0.981	0	0
	< 20 cm	0	0.004	0.99	0
	≥ 20 cm	0	0	0.01	1
b		R1	F2	F3	F4
		G1	R2	0	0
		0	G2	R3	0
		0	0	G3	R4
c		Stems per ha			
	< 4.0 cm	163.3			
	< 10 cm	276.6			
	< 20 cm	300			
	≥ 20 cm	100.0			

The transition values *F*2, *F*3 and *F*4 were all set to zero since no seedling recruitment information was available. The transition matrix therefore assumes that seedling recruitment is not a key limiting stage in population growth. The transition values *G*1, *G*2 and *G*3 were calculated as the mean number of stems that grew from the one size class into the next over a five-year period, as a proportion of stems in that size class during the previous year. *R* values were calculated as 1 minus the stage-specific mortality and growth probability, *G*.

The derived transition matrix was used to explore some harvesting, browsing and a combination of harvesting and browsing scenarios. The harvested populations were tracked through time and subjected to one harvesting strategy: a fixed percentage across size classes irrespective of trees available. This was used for trees 4.0 cm and bigger. After harvesting, all the harvested stems were allocated to the smallest size class one year after harvesting because of the ability of harvested stems to coppice and grow fast to reach the smallest size class (2.3 ± 0.67 cm in basal diameter; Chapter 5, Table 5.2).

To simulate the effects of browsing, it was assumed that goats would only affect the smallest size class since trees ≥4.0 cm in basal diameter have reached a stage where goats can no longer feed on them. The transition values for *G*2 and *G*3 as well as *R*2, *R*3 and *R*4 were then not changed but the values for *G*1 and *R*1 were changed according to the level of browsing simulated. For example, to simulate a 10% browsing regime resulted in values of *G*1 changed to *G*1*(1-0.1) and *R*1 changed to *R*1*(1-0.1). The same procedure was repeated for browsing regimes of 50 and 100%. To simulate the impact of a combination of harvesting and goats together, the proportion of trees that could become the stock of the smallest size class after one year was calculated as trees in the smallest size class plus the proportion of harvested trees, multiplied by one minus browsing regime used.

6.3 RESULTS

6.3.1 *C. mopane* population survey in communal land

A total of 504 stems (or 840 stems per ha) of *C. mopane* in fifteen 0.04 ha circular plots were recorded during a survey in communal land. Of the 504 stems per 0.6 ha or 840 stems per ha, 98 stems per 0.6 ha (or 163 stems per ha) were less than 3.9 cm in basal diameter. Of the remaining stems, 166 (or 276.7 per ha), 180 (or 300.0 per ha) and 60 (or 100 per ha) were ≥4.0 cm but <10.0 cm, ≥10.0 cm but <20.0 cm and ≥20.0 cm respectively.

The stem size structure of the population in communal land is characterized by having an inverse J-shaped distribution of diameters (Figure 6.1).

6.3.2 Modelling harvesting and browsing

The calculated probabilities for the transition matrix with the corresponding symbols and the population (column) vector are given in Table 6.2a-c. Table 6.3 shows the number of stems produced in different size classes under different harvesting and browsing regimes.

Table 6.3. Production of stems by *C. mopane* woodland in communal land as predicted by the model.

Harvesting and browsing scenarios	Size class	Initial stems / ha	Stems per ha after 60 years of projection. 15 yrs	30 yrs	45 yrs	60 yrs
No harvest & goats	4.0 - <10 cm	277	289	237	182	138
	10.0 - < 20 cm	300	274	251	228	205
	20+ cm	100	143	183	219	251
1% Harvesting	4.0 - <10 cm	277	283	254	222	194
	10.0 - < 20 cm	300	237	189	152	123
	20+ cm	100	124	136	141	140
5% Harvesting	4.0 - <10 cm	277	256	251	222	185
	10.0 - < 20 cm	300	129	61	34	21
	20+ cm	100	67	41	24	14
10% Harvesting	4.0 - <10 cm	277	221	202	163	126
	10.0 - < 20 cm	300	59	17	8	6
	20+ cm	100	31	9	3	1
10% Browsing	4.0 - <10 cm	277	252	191	143	108
	10.0 - < 20 cm	300	273	248	222	198
	20+ cm	100	143	182	218	249
50% Browsing	4.0 - <10 cm	277	216	162	121	91
	10.0 - < 20 cm	300	272	245	218	194
	20+ cm	100	143	182	217	248
100% Browsing	4.0 - <10 cm	277	207	156	117	88
	10.0 - < 20 cm	300	272	244	217	193
	20+ cm	100	143	182	216	247
1% Harvesting and 10% browsing	4.0 - <10 cm	277	237	179	136	105
	10.0 - < 20 cm	300	235	185	145	113
	20+ cm	100	123	136	140	138
5% Harvesting and 50% browsing	4.0 - <10 cm	277	112	45	19	8
	10.0 - < 20 cm	300	126	53	22	9
	20+ cm	100	67	40	22	12
10% Harvesting and 100% browsing	4.0 - <10 cm	277	41	6	1	0
	10.0 - < 20 cm	300	55	10	2	0
	20+ cm	100	30	8	2	0

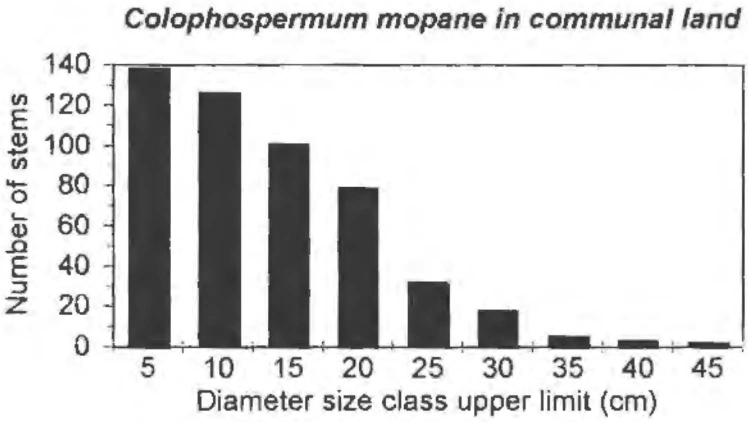


Figure 6.1 Stem size class distribution for *C. mopane* in communal land.

The finite rate of increase of the population (λ) for the 110-year simulation period with no harvesting and browsing pressures is 0.9958, indicating that the population is slowly decreasing in size as shown in Figure 6.2.

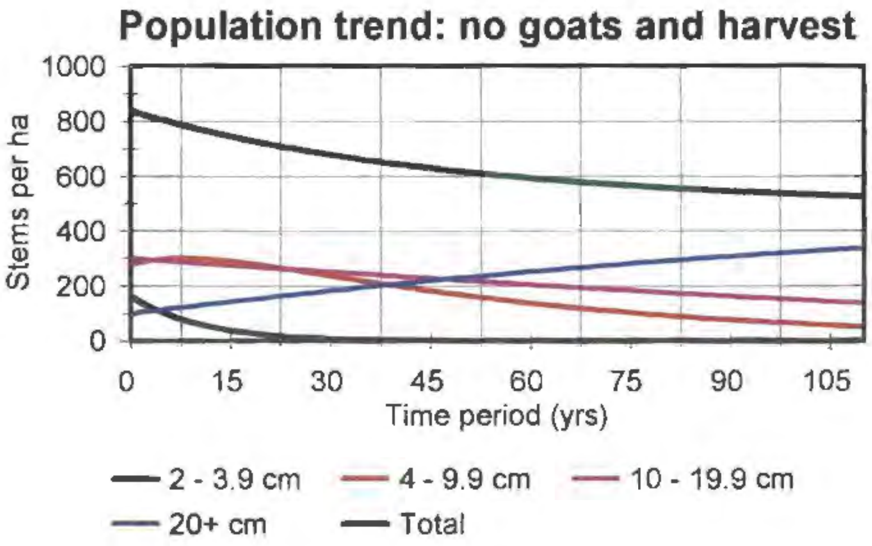


Figure 6.2 Simulated population growth trends with no harvesting and browsing.

The finite rate of increase of the population (λ) for the 110-year simulation period with 100% browsing pressure is 0.9952, indicating that the population is decreasing slightly faster than when there is no browsing. Figure 6.3b indicates that browsing alone, is reducing the population very slowly since the figure looks more or less to Figure 6.2 (no browse) and Figure 6.3a for the mild browse regime. This is not surprising since browsing affects stems in the smallest size class only.

A harvesting regime of 1% across each size class, with the exception of the smallest size class, appears to be sustainable on a short as well as long-term basis as indicated in Figures 6.4a (λ = 0.99). Harvesting regimes of 5% and 10% across the three larger size classes appears to be unsustainable regardless of the fact that harvested stems become part of the smallest size class population (Figure 6.4b,c). λ is 0.985 and 0.983 respectively for Figure 6.4b and Figure 6.4c.

A combination of low levels of browse (10%) and harvesting (1%) results in a population of about 220 stems per ha after 110 years, suggesting that it is sustainable (Figure 6.5a, λ = 0.988).

High levels of browse (50 - 100%) and harvesting (5 - 10%) are unsustainable (Figure 6.5b,c) irrespective of the resprouting ability and subsequent growth after harvesting. λ is 0.948 and 0.896 for the 50% browse : 5% harvesting combination and for the 100% browse : 10% harvesting combination respectively.

a

b

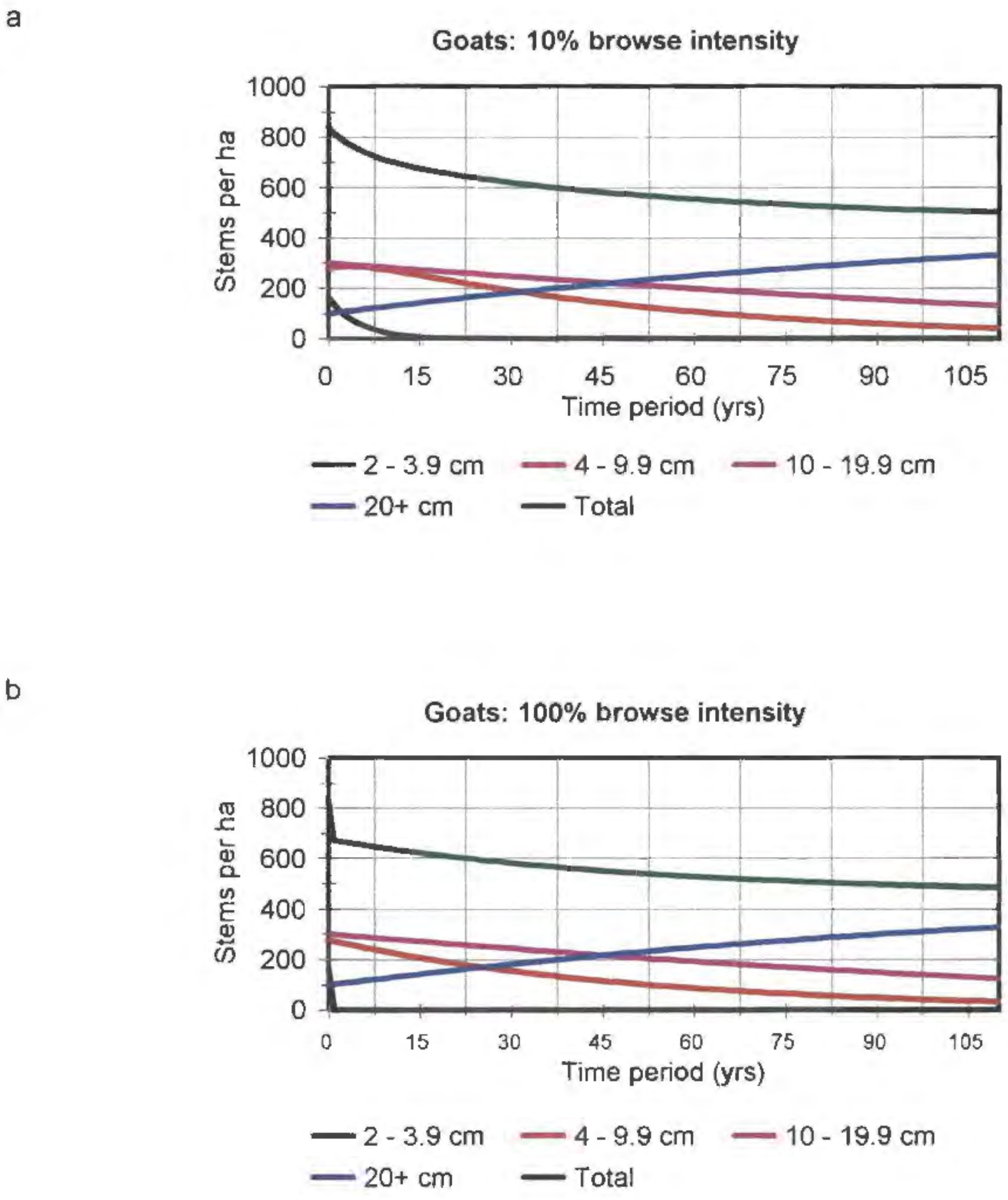


Figure 6.3 Simulated population growth trends under mild and heavy browsing.

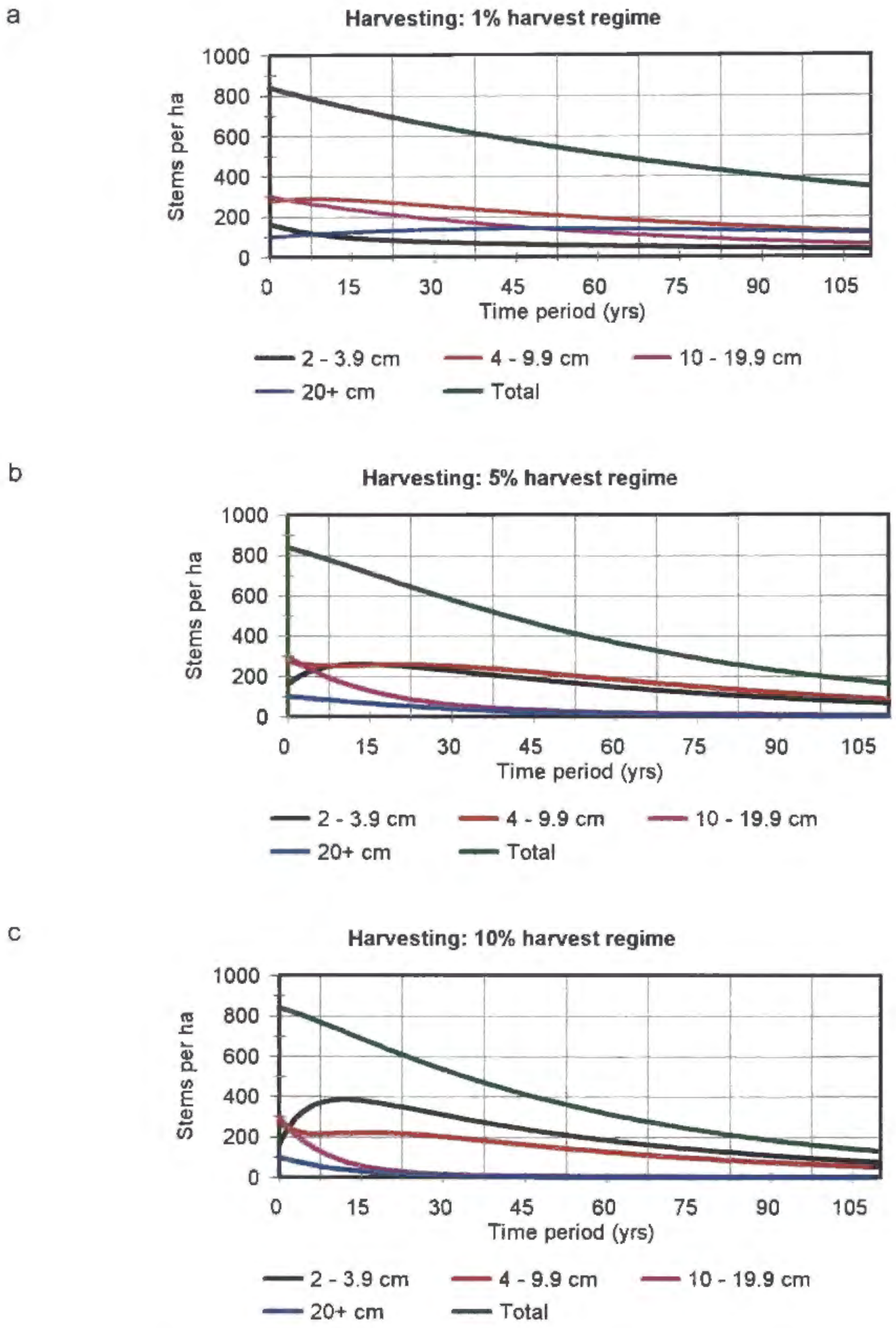


Figure 6.4 Simulated population growth trends with varying degrees of harvesting.

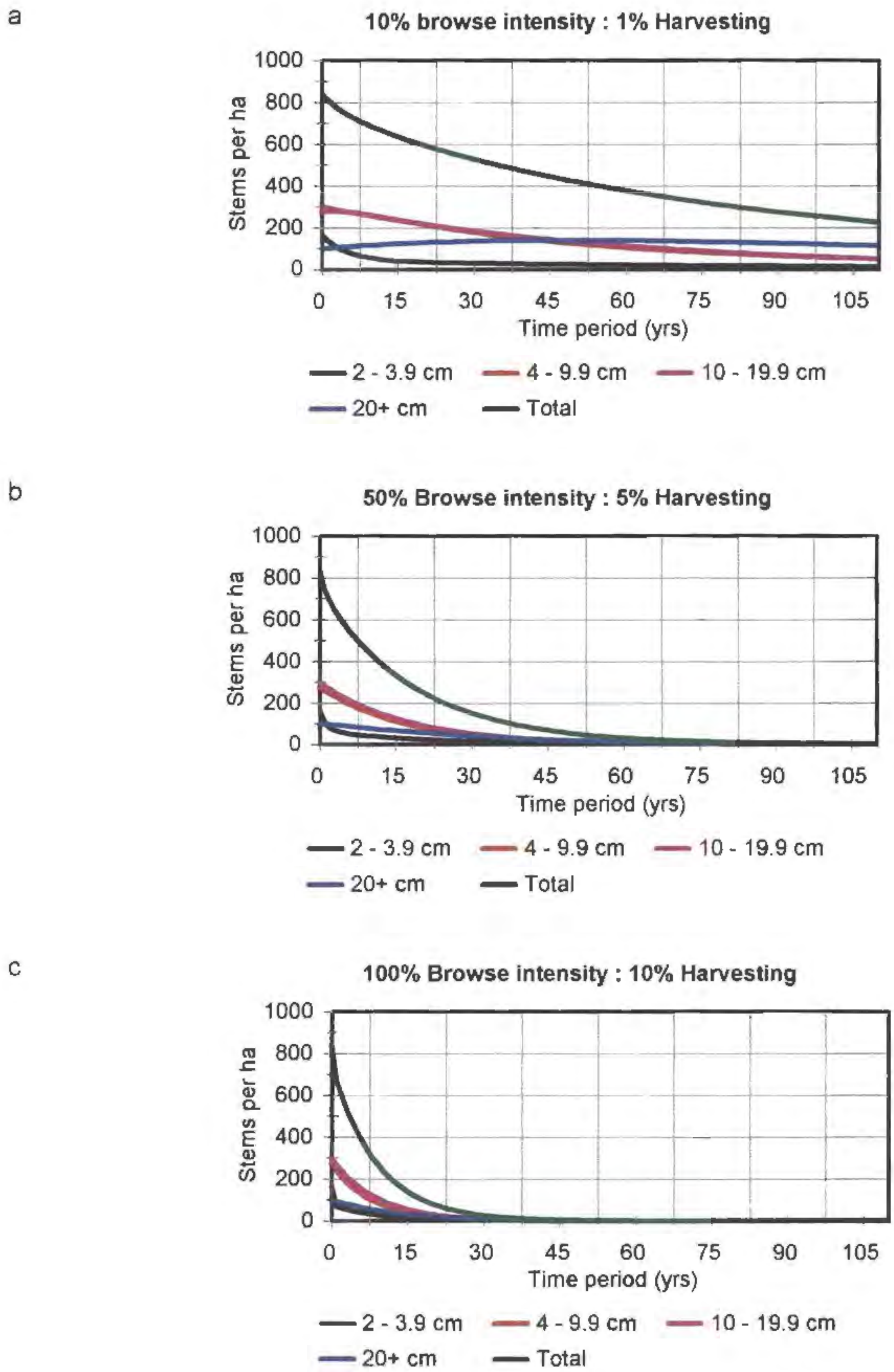


Figure 6.5 Simulated population growth trends with browsing and harvesting.

6.4 DISCUSSION

6.4.1 *C. mopane* population survey in communal land

This population of *C. mopane* in communal land is characterized by having an inverse J-shaped distribution of diameters (Figure 6.1). This is an indication that the population is recruiting or regenerating well in communal land (Harcombe 1987; Meyer 1952). This finding is misleading since it demonstrates that mild harvesting and browsing do not have an impact on recruitment processes whereas it has been shown that the populations of this species are not recruiting well in communal land, especially in areas within 2.0 km from village edge (Chapter 3, Figure 3.3). Thus, the pattern observed here is a result of plots sampled in areas located far away from village edge where there is low intensity of browsers, and where people are allowed to harvest dead material only.

6.4.2 Modelling harvesting and browsing

The pattern of decline in population size over time (Figure 6.2) suggests that recruitment is unimportant for the stability of the population ($\lambda = 0.99$ for 110 years). By adjusting *F*2, *F*3 and *F*4 to 0.005 (Table 6.2), λ changed to 1.00 after 107 years, again suggesting that seedling recruitment is unimportant. This patterns supports the general trend observed for this species in previous studies. For example, Shackleton (pers. comm) while searching for seedling recruitment of this species from 1993 to 1997, recorded only four seedlings during the first year and none during subsequent years. However, it was not clear as to when the seedlings were recruited. Scholes (1990) reported a recruitment rate of four seedlings per ha per year, but failed to quantify mortality patterns of seedlings. It is well known that *C. mopane* seedlings cannot establish well on soils with good grass cover, and that factors such as low and erratic rainfalls, tend to favour seedling establishment (Thompson 1960). These suggest that seedlings are not important, as predicted by the model. However, this prediction is only possible if recruitment is episodic, occurring only during favourable conditions (Desmet *et al.* 1996). The species suffered high mortality rates after the 1991/2 drought in the Kruger National Park (Viljoen 1995). It is possible that seedlings could have suffered the highest mortality during this drought period and that even if seedling recruitment is high after during favourable years, drought will probably cause high mortality.

The model suggests *C. mopane* populations can persist for hundreds of years even if no seedling recruitment takes place. This assumption only holds if the individual trees can live for 100 and more years. But it must be expected that unfavourable conditions, such as drought (Mukomawabani - pers. comm.), will cause some mortality. If this happens, and no recruitment takes place, the populations will persist for a shorter than the predicted time. Nevertheless, the model indicates that these populations have been maintaining themselves even under harsh conditions that are unfavourable to seedling recruitment. Thus, the populations of *C. mopane* in communal areas will be stable under no browse and harvest pressures, as indicated by the model.

The model suggests that the effects of browsing alone are very minimal (Figure 6.3). This is interesting since Figure 3.3 indicates that populations very close to the village are not recruiting well, possibly leading to a decline in population size. We would expect populations in communal land to be affected heavily by goats through their browsing effects on seedlings, but the model predicts similar trends to those where there are no goats and harvesting. This is, however, not surprising since the impacts of browsing are confined to the smallest size class. Grazing/browsing of *C. mopane* leaves has been reported to be confined to winter (Irvine 1937), most probably so because this species can retain some of the leaves during the dry season (Potgieter *et al.* 1997).

The model further suggests that the population of *C. mopane* in communal land is declining as a result of harvesting pressure (Figure 6.4). This prediction seems true because *C. mopane* is the most preferred species for energy, building houses and roofing (Chapter 2). The combined effects of harvesting the materials for these commodities justify the observed trends predicted by the model. As the human population increases in the communal land, it is highly likely that the demand for this resource will increase.

Consequently, the sustainability of this resource will be affected negatively. The previous findings (Chapter 5, Table 5.1) that trees which are cut live survive, grow and become part of the smallest size class stock during the second year appears to be inadequate to replace the harvested trees. Nevertheless, harvesting one percentage of the population appears to be sustainable (Figure 6.4a). Harvesting above this level, with no goats, will be sustainable on long-term basis since the population tends to stabilise as a result of recruitment through coppicing. This is supported by the simulated results shown in Figure 6.4b,c and Table 6.3. The harvesting regimes used in the model may be inflated, overshadowing the exact nature of harvesting practices in communal land. For example, materials needed for roofing should be of good quality and it is possible that these resources are longer abundant in the communal land.

A combination of high levels of browsing and harvesting has the most influence on the sustainability of the species in communal land (Figure 6.5). With mild browsing and harvesting regime (Figure 6.5a), the population can persist for over 100 years in communal land. However, with a combination of intermediate levels the population will crush or become extinct in communal land after just 75 years (Figure 6.5b). A combination of high levels of browsing and harvesting has the most detrimental effects on the persistence of the population and hence the sustainability of this population in communal land. Under these levels, the population becomes extinct after just 45 years (Figure 6.5c, Table 6.3). With increasing human populations in communal land, coupled with the demand for this resource for income generation and through purchases by urban people, and the need to build more houses and roofing, and a shortage of dead wood for energy, it is more likely that people in this community will use most of the available resources in ten years' time. As the model predicts, this pattern of resource use is unsustainable and will lead to local extinction of the resource in communal land.

Managers of the communal land need to recognize that what they are dealing with is inherently unstable due to harvesting and browsing pressures. Post harvesting grazing management has been suggested to have a decisive effect on the rate of woody plant establishment for *C. mopane* (Smit & Rethman 1998). As a management option, where trees are cut live, the sites can be enclosed to reduce the effects of browsing until such time that browsers cannot fully utilise the growing shoots. Such action is unlikely to succeed given the small area available for subsistence goats and cattle farmers. The area is earmarked for stock farming and balancing woody demand for local as well as urban people with stock farming by local and urban people will not be easy. Results (Chapter 5) indicate that the species can grow very fast from coppice shoots. Thus, a coppice management system can be applied in this community for the production of fuelwood materials, wood for building, roofing and fencing. For stock farmers, the same does not necessarily apply: they cannot manage coppice *C. m*opane for the production of fodder since the growth of coppice is dependent upon the prevailing climatic conditions. If drought can kill mature young and adult unharvested trees (Viljoen 1995), then cutting trees during drought period will probably cause death to the cut trees, or cut trees will resprout but the shoots may die soon after their emergence (Braam Dekker - pers. comm.). Also, the presence of browsers will reduce the availability of resources needed for building and roofing, which, according to the community, are coppice shoots because of their good shape. Thus, the ultimate goal of managing *C. mopane* in communal land will depend on several social as well as ecological factors. Stopping harvesting is unrealistic due to high unemployment rates in the community, unless cheap alternative sources of energy become available. While reducing goat browsing is also problematic, the sustainability of this woodland resource (*C. Mopane*) in communal land can be assured by reducing the stocking rates of goats.

It is recommended that further harvesting experiments be conducted during different seasons, and that the trees be cut at different heights above ground and that the coppice shoots be pruned at different levels as these aspects were not covered during the study period. Most important, the number of cut trees should be increased. Further more, permanent sample plots should be laid to monitor survival, growth and ingrowth patterns of the species in its natural habitat.

This model assumes no strong climatic effects on population growth and hence stability. For example, drought may be a factor but is not included in the model. Also, the effects of competition were not modelled but it is well known that reducing crowding may increase growth and reduce mortality. Monitoring the effects of these variables on tree populations will enable the development of appropriate tree population models that can generate ideas about populations trends under different climatic and management regimes.

CHAPTER 7. A SYNTHESIS OF THE FINDINGS

Sustainable plant resource utilisation requires the development of resource management plans which guide all resource management activities, including the level of timber production (Worthington *et al.* 1996). A key element in developing these plans is a thorough analysis of the plant resource system's ability to supply goods and services in response to society's demands.

The appropriate level of plant resource harvesting from the resource systems has been and continues to be a contentious issue in management planning for communal forest lands, most probably due to institutional issues and a wide range of resources preferred by the different user groups with their varied socioeconomic backgrounds. Consequently, the resources needed are different and the methods used to gather them differ significantly and, as a result, the responses of the plant resources to harvesting also differ significantly.

7.1 PLANT RESOURCES NEEDED BY THE RURAL COMMUNITIES

In this study, I explored resource use patterns in a rural village, Mukomawabani, as a case study of rural community resource use. This study (Chapter 2) has demonstrated that the most needed resources in this area, in order of their importance, are: fruits, firewood, roofing poles, fencing poles, trees for shade, browse for goats and cattle, poles for building hut walls, and medicinal plants. Harvesting fruits and medicinal materials has little impact on the status of the resources since most of these are still obtainable from within the village. However, wood for energy and construction purposes is no longer within easy reach and this is an area of concern. Village people are aware of this problem but due to lack of alternatives, they keep on using whatever is available around the community. Species most favourable for energy and construction purposes are *C. mopane* and *A. johnsonii* respectively.

As the demand for plant resources increases, the only source of wood would be the conservation areas. If these protected sites are too far from the villagers, the provision of access to harvest in conservation areas will not solve the problem due to lack of transport and possibly money to pay for transportation from the protected area to the village. Assuming that one household uses one load of a van for three weeks (Author - this study), and that one van costs R60.00 to R120.00, the current overall transport cost per household is about R1020.00 to R2040.00 per year. If all the households will need transport to bring their fuelwood to the village, the value associated with activity is about R77 520.00 to R155 040.00. These values are a good indication of the potential for business in this community which can result in job creation. If transport cost for building, roofing and fencing materials is included, the overall income from this activity could be higher than predicted. Thus, the protected areas have much to gain in the future to cover some of the costs of maintaining them through the sales of these resources.

This study (Chapter 2) has further demonstrated that some rural communities in South Africa are characterized by high levels of unemployment, low educational status, low income and large family sizes. As a result, these communities are highly dependent upon the woodland around the villages for subsistence and economic ends. Contrary to expectations that there is a general resource crisis in communal land, the pattern at the village I studied was that resources are still available since there are still many plants within the 10-km radius from the village edge. Grundy *et al.* (1993) also reported this trend in Zimbabwe, where people advocate that there is a resource crisis in communal land whereas scientific investigations do not support this argument. It is possible that resource scarcity is not as bad as it is thought (Grossman & Gandar 1989) but due to lack of scientific evidence, people will remain convinced that there is a resource crisis.

The survey has shown that this dependence on wild plant resources is under threat since, from a community perspective, there is a resource crisis close to the village. This crisis will probably influence people in the future as to where the resources should be collected. There is a possibility that a nature reserve may be targeted in the future. As shown in the previous section, there is a potential for good business through transport of the harvested resources from the protected area to the village. If access is allowed without a good understanding of the responses of trees to harvesting, there is a potential threat to sustainability of conservation and development initiatives. Possible solutions to the problems in the village, more especially regarding fuelwood, can be overcome by the development of appropriate and transfer of technology for harvesting resources around the village. This can be in the form of a communal property or given to few individuals who will be hired by the community for the provision of services. However, the transfer of technology can lead to unsustainable methods of resource use (Gadgil 1987) such as the destruction of the resource base. As a result, operational, monitoring and evaluation mechanisms should be developed and transferred to the community before the deployment of this technology.

According to the community, harvesting methods and intensity of harvesting are influencing the dynamics of these two plant resources in the communal land. Studies of stand structure showed that stands located far away from the village edge are characterized by the inverse J-shaped size class distribution curves, indicating that the species are recruiting well in those environments, whereas recruitment is poor adjacent to the village. This should be expected since people are allowed to harvest dead only wood in this area.

The high unemployment rate, most probably as a result of lower educational levels, and larger family sizes, is a contributing factor with regard to rural communities' dependence on woodland resources. The fact is: there is a resource crisis which may persist for a longer time. Where will the next generation get these resources? One possible solution would be to embark on the establishment of woodlots and social forestry programs (Goodman 1987; Arnold 1987; Shackleton 1993, 1994) but this approach is more likely to fail than succeed due to slow growth rates of trees (Helliwell 1987) and unpredictable weather conditions such as drought (Goodman 1987). A complementary approach may be to provide them with access to sustainable harvesting in neighbouring areas presently unavailable to rural communities, including conservation and private land (Shackleton 1993; Cunningham 1996; Wild & Mutebi 1996).

If this becomes a reality, some comparative studies which characterize populations in communal land and protected area is crucial as was shown in this study (Chapter 3). Not only did this study approach tell us about patterns of resource abundance under contrasting management systems, but it also highlighted the effects of contrasting management on the population dynamics of the species under study.

7.2 POPULATION DEMOGRAPHY OF *C. mopane* AND *A. johnsonii*

I searched for plant communities in the study using some multivariate technique to gain insight into the dynamics of populations of he same species under different environmental and management regimes. The observed communities identified by the analysis (Table 3.1) suggest that the distribution of plant communities in the protected area is influenced, in part, by the environmental conditions. This finding can be a basis for the assessment and management of populations of specific trees. Tree species may respond differently to harvesting under different environments. Given the same environmental conditions in communal land, the choice of areas that can be used for harvesting can be made easier, and the resource abundance patterns can be understood better. This is important since the sustainability of resource utilisation may depend not only on resource use, but a combination of resource use and environmental factors as indicated in Chapter 3. However, this assumption was not tested in communal land and needs further research on its own. Nonetheless, the study has indicated that population demography and size class distribution patterns vary not only with communal management practices, but also with differences in environmental conditions.

7.2.1 *Colophospermum mopane*

The frequency distribution of *C. mopane* in different communities in protected area varies from one plant community to the other (Figure 3.1a, Chapter 3). Given the same environmental conditions, this information could be used to quantify abundance and size class distribution patterns in communal land and hence resource crisis patterns. Unfortunately, such information was not collected in the communal land. However, the area close to the village where heavy harvesting pressures were observed appears free of stones. Thus, size class distribution pattern in communal land is more likely caused by high levels of harvesting than by environmental conditions.

7.2.2 *Androstachys johnsonii*

The size class frequency distribution of *A. johnsonii* under the contrasting management systems is the same, suggesting that growth and establishment conditions are favourable and that the populations are also self-maintaining. Even if the species recruits well under both shade and in open space, recruitment into smaller size classes may be higher after some clear felling operations. This harvesting method is, however, undesirable since local people need poles of certain sizes and shapes. Thus, a selective harvesting system may be employed in the protected area for sustainable utilisation of the species.

7.3 COMPETITION AND WOODY PRODUCTION

The presence of competition within many of the monospecific plots using single nearest neighbour tree approach for both *C. mopane* and *A. johnsonii* sites suggest that competition is also a factor that is limiting productivity of this arid savanna woodland. These findings are very important with regard to resource harvesting in communal land. That is, if people are harvesting some trees, thereby reducing competition within trees, the remaining trees will grow fast.

Self-thinning results from this study support the hypothesis that woody production of the two species is limited by competition (Voit 1988). The evidence of the self-thinning in these two species is an indication that plants are stocked with trees that grow if others die. From this, it is evident that harvesting of the big trees will lead to faster growth of the remaining trees. However, this is not possible due to the facts that there are no people with machines to cut the big trees. Also, big trees are not highly preferred over young ones most probably so because of the time and energy required to process them before use. With the availability of relevant and appropriate technologies, the availability of big trees will offer local communities with much of the desired wood, and this technology can be used to generate income for some local communities. This is possible, there are many big trees available around the community, but due to the fact that they cannot use them, people regard them as unwanted resources. It is against this background that I support that resource crisis is overemphasized in communal land. This perception may change as soon some relevant and appropriate technologies become available.

7.4 RESPONSE OF TREES TO HARVESTING

The high survival rates of *C. mopane* stumps after cutting suggests that harvesting intensity does not have any effect on the survival of the cut trees. Why then are there few small and many big *C. mopane* trees in the communal land? One possible reason might be that heavy browsing, largely by goats and to a lesser extent by cattle in winter (Irvine 1937), is responsible for the lack of desirable poles in the communal land as shown in Chapter 6. Reducing browsing pressure at this moment is not a viable option since this area is earmarked for subsistence goats and cattle farming, even though the model suggests that browse alone does not have any detrimental effects on the stability of the population. However, such heavy browsing is absent from the protected area and, as such, harvesting inside the park will not lead to gradual depletion of the resources due to the observed high resprouting rates of this species.

The observed high growth rates (both diameter and height) after one year (Table 5.1) suggest that *C. mopane* may be ready for harvest within five years provided the growth rates do not decline with age of sprouts as reported in some other studies (Chidumayo 1993). It seems that stem size does not have much influence on the survival of cut *C. mopane* trees. Thus, a range of size classes of this species can be harvested but they will persist under such harvesting pressure. The high survival rate of *C. mopane* may be due to the fact that buds are located as individuals all over the whole tree (Potgieter *et al.* 1997) in which case the stumps seem to have overcome the difficulties with which any individual bud will have in developing independently of the cluster. Therefore, it can be concluded that the size of *C. mopane* trees does not influence the survival of this species after cutting. However, subsequent data analysis indicated that 25%, 73% and 100% of the cut stems in the < 10 cm class, < 10 cm class and ≥20 cm size class respectively can grow 2.0 cm or more in equivalent diameter one year after they are cut. Thus, the size of the cut stump influences, although insignificantly, the diameter growth rates of the coppice shoots. This is important since cutting trees in the bigger size classes will result in rapid growth of coppice shoots.

Cutting trees during December resulted in the production of many coppice shoots. This is undesirable since most of them will ultimately die due to inter-shoot competition. It is recommended that the harvesting season which will result in few shoots formed be used as a management tool to avoid the expensive exercise of shoot pruning.

For *A. johnsonii*, it seems that stem size has much influence on the survival of cut stumps. Thus, a range of size classes of this species cannot be harvested since some will not persist under such harvesting pressures. Higher mortality rates in big stems suggest that the season of cutting employed in this study is not the appropriate one, and that harvesting during this season will be unsustainable. It is possible that mortality was high as a result of the height of cutting which was too low or that the species does not respond well to the removal of many stems of an individual tree. It can only be suggested that people should employ selective stem-harvesting methods to reduce mortality of the cut stumps and that trees should be cut higher up above bud clusters.

7.5 MODELLING HARVESTING AND BROWSING IN COMMUNAL LAND

The matrix model suggests that high levels of *C. mopane* resource harvesting are causing a decline in population size in communal land. Harvesting appears to be the overriding factor as was also suggested by the community. However, it is the combination of heavy browsing and harvesting that is highly responsible for the observed population trends in communal land. The sustainability of *C. mopane* populations in the communal land requires an effective management system to reduce the rate at which the species is currently harvested. This may entail a complete halt to wood sales in the area and a reduction in browsing pressure, far enough by reducing the number of livestock units. All these suggestions seem unrealistic given the overall high unemployment rates, low educational levels, high family sizes and overall family income. Stock farming provides income for the unemployed as does fuelwood sales. Being unemployed, most people rely on the woodland around them for their daily needs and survival. There is no short cut to the problems experienced in this community. Unemployment rates will increase and, if *C. mopane* is well managed, this woodland can be used as a source of income for most of the community when appropriate harvesting technologies become available to some of the local people.

7.6 SUMMARY

Clearly, harvesting disturbance has a significant impact on *C. mopane* community structure in communal land. However, despite harvesting disturbance, the regenerative potential appears strong, and vigorous coppicing was evident. It was noted from the protected site that *A. johnsonii* does not respond favourably to harvesting regimes, more specifically the bigger trees when all the stems are harvested. Why then is the species regenerating so well in communal area? This is likely so since most of the needed stems by the community are of small to medium size classes which, when cut, respond by producing coppice shoots from the stems and stem bases. Also, the height at which the stems are cut in communal land is larger than the 30-cm height applied in the protected site. Another possible reason is that *A. johnsonii* grows in rocky areas far from the villages where goats can hardly reach the area.

For *C. mopane*, the harvesting method that can counter the impacts of browsing in communal land is pollarding. However, it remains to be seen if this method will yield the desirable poles. Potgieter *et al.* (1997) reported that cutting trees at 1.5 m above ground results in faster growth of the coppice shoots relative to stems cut at the ground level. Thus this method can be employed to counter the effects of goats but it is highly unlikely that communities will follow this method where most of the desired biomass is left during harvesting. Stronger action and self-discipline among the community members are required if the woodlands are to persist for a long time. People should stop exploiting the resources for short-term economic gains such as fuelwood harvesting for other people coming from urban areas where these resources are sold at high prices at the expense of local people.

A complementary approach to woodlots and social forestry entails the provision of access to sustainable harvesting in neighbouring areas presently unavailable to rural communities, including conservation and private land (Shackleton 1993; Cunningham 1996; Wild and Mutebi 1996). Information on the effects of harvesting disturbance on yield components of trees indicates that *C. mopane* and *A. johnsonii* respond differently to harvesting and browsing regimes. These findings can be used as a basis toward sustainable resource utilisation in protected areas. In such cases, the responses of these two different species to harvesting regimes should be used as guidelines toward harvesting methods.

Analysis of rural socio-economics, plant utilisation and plant dynamics in this study has proved to be a worthwhile exercise in unearthing drivers of plant resource use and dynamics within an arid savanna system.

7.7 RECOMMENDATIONS

It is recommended that:

1.1 Studies be conducted to investigate the effects of subsistence livestock farming on tree seedlings recruitment and coppicing patterns.

1.2 Comprehensive studies on resource availability patterns be conducted to quantify resource crisis patterns in communal lands.

1.3 Research be conducted to investigate the effects of browsing on coppice growth in communal land.

1.4 Studies be conducted to investigate the influence of seasons of harvesting, initial tree size and height of cutting on the response vigour of different species to harvesting regimes.

1.5 Permanent sample plots be established over a wide range of site conditions to establish growth, mortality and regeneration, and overall population dynamics of the species with and without harvesting and browsing.

1.6 Different measures of plant performance be used to investigate competition within and between species in arid savanna.

1.7 The effects of coppice shoots pruning on subsequent growth and photosynthetic rates be investigated across a wide range of arid savanna species and sites.

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Appendix 1. Socio-economic conditions at Mukomawabani community.

Family No	Trees listed	Sex(1=male; 0 = female)	Age	Standard passed	Employment status	Employment type	Salary, R	Total Income, R	Size of family	Others3	Others2	Others1	Pension	Brooms	Selling firewood	Local beer	Sheep	Chicken	Crops	Spaza	Overall income
1	29	1	50	4	0	5	2500	2500	9	0	0	0	0	0	0	0	0	0	0	0	2500
2	21	0	55	0	1	3	1200	1211	13	1500	0	0	0	11	0	0	0	0	0	0	2711
3	9	1	32	7	1	3	1974	1998	9	1900	0	0	0	24	0	0	0	0	0	0	3898
4	18	1	61	0	0	0	0	20	1	0	0	0	0	20	0	0	0	0	0	0	20
5	23	0	61	0	0	0	0	0	7	0	200	0	0	0	0	0	0	0	0	0	200
6	20	1	38	4	1	4	2000	2000	7	0	0	0	0	0	0	0	0	0	0	0	2000
7	25	0	80	0	0	0.5	0	460	3	0	300	0	460	0	0	0	0	0	0	0	760
8	16	1	32	7	1	3	1138	1138	6	1500	0	0	0	0	0	0	0	0	0	0	2638
9	15	1	29	10	1	1	800	1260	4	0	0	0	460	0	0	0	0	0	0	0	1260
10	7	0	34	0	1	2	100	100	7	0	100	0	0	0	0	0	0	0	0	0	200
11	23	0	23	7	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
12	8	0	35	5	1	2	300	300	4	0	0	0	0	0	0	0	0	0	0	0	300
13	33	0	40	0	1	2	100	100	6	1000	0	0	0	0	0	0	0	0	0	0	1100
14	19	0	60	3	0	0	0	0	3	1200	0	0	0	0	0	0	0	0	0	0	1200
15	16	0	26	3	1	1	300	300	5	0	0	0	0	0	0	0	0	0	0	0	300
16	41	1	48	0	1	3	1800	1800	8	0	0	0	0	0	0	0	0	0	0	0	1800
17	35	0	46	4	0	0	0	150	5	0	0	0	0	50	100	0	0	0	0	0	150
18	14	0	60	0	0	0.5	500	650	5	0	0	0	0	0	0	150	0	0	0	0	650
19	47	1	61	0	1	3	855	1355	3	0	0	0	500	0	0	0	0	0	0	0	1355
20	48	1	60	0	0	0	0	560	4	300	500	1800	0	0	0	0	180	180	200	0	3160
21	48	1	32	13	1	3	5100	5100	10	500	0	0	0	0	0	0	0	0	0	0	5600
22	16	0	39	0	0	0	0	0	12	1800	0	0	0	0	0	0	0	0	0	0	1800
23	11	0	39	0	1	2	200	200	6	0	0	0	0	0	0	0	0	0	0	0	200
24	25	1	31	9	1	1	800	800	4	0	0	0	0	0	0	0	0	0	0	0	800
25	7	1	28	10	1	3	1600	2200	5	0	0	0	0	0	0	0	0	0	0	600	2200
26	26	1	37	3	1	3	1000	1000	6	0	0	0	0	0	0	0	0	0	0	0	1000
27	13	1	37	9	0	0	0	0	4	160	0	0	0	0	0	0	0	0	0	0	160
28	23	0	64	0	0	0	0	0	8	120	0	0	0	0	0	0	0	0	0	0	120
29	17	1	33	4	1	1	720	1255	5	0	0	0	0	0	400	135	0	0	0	0	1255
30	29	1	55	0	0	0.5	500	500	8	200	0	0	0	0	0	0	0	0	0	0	700
31	11	1	34	15	1	3	7000	10000	7	1500	0	0	0	0	0	0	0	0	0	3000	11500
32	17	0	28	2	1	3	350	350	4	30	0	0	0	0	0	0	0	0	0	0	380
33	18	1	56	5	1	3	1300	1600	9	0	0	0	0	0	0	0	0	300	0	0	1600
34	35	1	25	9	1	3	1625	1625	7	400	0	0	0	0	0	0	0	0	0	0	2025
35	37	0	30	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0
36	31	0	72	0	0	0.5	500	500	1	0	0	0	0	0	0	0	0	0	0	0	500
37	24	0	51	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
38	28	0	62	0	0	0.5	500	500	2	0	0	0	0	0	0	0	0	0	0	0	500
Min	7		23					0	1												0
Max	48		80					10000	13												11500
Mean	23.3		44.32					1092.95	5.66												1488

Keys: Standard passed: 13 = degree and a diploma, 15 = two degrees and a diploma; Employment status: 1 = employed, 2 = unemployed; Type of employment: 0 = not employed, 0.5 = pensioners, 1 = contract formal employment, 2 = full-time informal employment, 3 = full-time formal employment, 4 = informal business, 5 = headman. Others 1, 2 and 3 refers to other working people in the same household.

Appendix 2. List of trees listed during the r-mops survey.

Tree No	Local name	Scientific name
1	Balabutwa	?
2	Dzaluma	*Tragia sp.*
3	Gukhunu	?
4	Gwambadzi	*Toddalia asiatica*
5	Luanakha	?
6	Ludedede	?
7	Masinya	?
8	Mubalauta	?
9	Mubobo(li)bo	*Commiphora edulis*
10	Mububulu	*Mimusops sp.*
11	Mubungaselo	?
12	Mubvumbangwena	*Acacia robusta*
13	Mudoro	*Opuntia sp.*
14	Mudzidzi	*Artabotrys brachypetalus*
15	Muembe	*Annona senegalensis*
16	Mufhalakhwali	*Albizia brevifolia*
17	Mufhanda	*Lonchocarpus capassa*
18	Mufhandulakhali	?
19	Mufhulu	*Burkea africana*
20	Mufula	*Sclerocarya birrea subsp. caffra*
21	Mugwiti	*Comnretum molle*
22	Muhataha	*Pterocarpus rotundifolius*
23	Muhatu	*Tabernaemontana elegans*
24	Muheri / Muzwiri	*Combretum imberbe*
25	Muhoto	*Faidherbia albida*
26	Muhuhuma	*Hexalobus monopetalus*
27	Muhuyu	*Ficus sp.*
28	Mukakate	*Sterculia rogersii*
29	Mukangala	*Strychnos decussata*
30	Mukhalu	*Ziziphus mucronata*
31	Mukhwikhwi	?
32	Mukokole	*Rubus sp.*
33	Mukolokote	*Piliostigma thonningii*
34	Mukonde	*Euphorbia ingens*
35	Mukopokopo	*Combretum paniculatum*
36	Mukukuna	*Grewia hexamita*
37	Mukukushi	?
38	Mukululu	*Ficus ingens*
39	Mukundandou	*Ormacurpum trichocarpum / Mundulea sericea*
40	Mukunguvhuti	?
41	Mukuvhazwivhi	*Cassine transvaalensis*
42	Mukwakwa	*Strychnos madagascarensis*
43	Mukwatule	*Maytenus peduncularis*
44	Mulakholomo	*Markhamia acuminata*
45	Mulala	*Hyphaene coriacea*
46	Mulelu	?
47	Mulivhadza/Muswina	*Lannea stuhlmannii*
48	Mulolo	*Musa sp.*
49	Mulondo	*Acacia erubescens*
50	Mulumanaman	*Cassine sp.*

Tree No	Local name	Scientific name
51	Munadzi	*Rauvolfia caffra*
52	Munambo	*Manilkara mochisia*
53	Munanga	*Acacia nigrescens*
54	Munembenembe	*Senna petersiana*
55	Munengeledzi	?
56	Munganingani	*Cordia ovalis*
57	Munie	*Berchemia discolor*
58	Munombelo	*Englerophytum magalismontanum*
59	Munungu	*Xanthoxylum sp.*
60	Mununzwu	*Schotia brachypetala*
61	Munyasela	?
62	Munzhelenga	*Acacia xanthophloea*
63	Munzhounzhou	*Entandrophragma caudatum*
64	Muonze	*Spirostachys africanum*
65	Mupane	*Colophospermum mopane*
66	Mupaulula/Mutambanamme	*Maerua angolensis*
67	Mupesu	*Securidaca longipeduncularis*
68	Mupfuka	*Grewia microthyrsa*
69	Mupfumbadzi	*Albizia forbesii*
70	Mupfumbadzi-bane	*Albizia sp.*
71	Mupfure	*Ricinus communis*
72	Muphuga	?
73	Mupimbi	*Garcinia livingstonei*
74	Mupondoki	?
75	Mupumbulu	?
76	Murabvapfene/Muparasheni	*Grewia flavescens*
77	Muramba	*Strychnos spinosa*
78	Murapfa(bva)	*Grewia bicolor*
79	Murenzhe	*Dichrostachys cinerea*
80	Murenzhebani	*Rhizogum zambeziacum*
81	Muruthu	*Croton megalobotrys*
82	Musalamarubini	?
83	Muserenga	*Melia azedarach*
84	Musese	*Peltophorum africanum*
85	Mushashandau/Mutwari	*Terminalia prunioides*
86	Mushato	*Xanthocercis zambeziaca*
87	Musimbiri	*Androstachys johnsonii*
88	Musinwa	?
89	Musu	*Acacia tortilis*
90	Musuma	*Diospyros mespiliformis*
91	Mususu	*Terminalia sericea*
92	Muswoswo	*Synadenium cupulare*
93	Mutafa	?
94	Mutaladzi	*Mimusops zeyheri*
95	Mutalu	?
96	Mutamvu	*Ficus sp.*
97	Mutanaunga	?
98	Mutangauma	*Flueggea virosa*
99	Mutangilanguvha	?
100	Mutangule	*Euclea divinorum*
101	Mutanzwa	*Ximenia caffra*
102	Mutasiri	*Rhus pentherii / pyroides*
103	Mutate	*Cyperus sexangularis*

Tree No	Local name	Scientific name
104	Mutavhatsindi	*Brakenridgea zanguebarica*
105	Mutenze	?
106	Mutepe	*Ehretia rigida*
107	Muthobi	*Boscia albitrunca*
108	Muthobi musekene	*Boscia sp.*
109	Muthowa	*Diplorhynchus condylocarpon*
110	Mutokota	*Afzelia quanzensis*
111	Mutololwe	?
112	Mutondo	*Pterocarpus angolensis*
113	Mutonyombidi	*Commiphora merkei*
114	Mutovuma	*Ekebergia capensis*
115	Mutshetshete	*Ziziphus mucronata*
116	Mutshevho	*Phoenix reclinata*
117	Mutshikili	*Trichilia emetica*
118	Mutsingidzi/Mukhwirir|	*Combretum apiculatum*
119	Mutswiriri	*Bauhinia galpinii*
120	Mutu	*Syzygium cordatum*
121	Mutulume	*Breonadia microcephala*
122	Mutungu	*Euphorbia tirucalli*
123	Mutunu	*Dovyalis caffra*
124	Mutupa	*Strychnos potatorum*
125	Mutwari	*Tarchonanthus trilobus*
126	Muukhuthu	*Commiphora mollis*
127	Muumo	*Ficus sp*
128	Muunga/muswi(u)	*Acacia tortilis*
129	Muvevha	*Kigelia africana*
130	Muvhazwi	*Obetia tenax*
131	Muvhola	*Albizia amara*
132	Muvhongwe	?
133	Muvhungo	*Landolphia kirkii*
134	Muvhuyu	*Adansonia digitata*
135	Muvumela	*Kirkia acuminata*
136	Muzwilu	*Vangueria infausta*
137	Ntsasilambe	?
138	Phungaluselo	?
139	Tshidedede	*Gardenia resiniflua*
140	Tshiphandwa	*Maytenus heterophylla*
141	Tshiralala	*Gardenia sp.*
142	Tshitahadzi	*Commiphora tenuipetiolata*
143	Tshivhuyudumbu	*Adenia spinosa*
144	Vhuswavhutswu	?