University of the Witwatersrand, Johannesburg

SCHOOL OF ANIMAL, PLANT AND ENVIRONMENTAL SCIENCE

IMPACT OF CHARCOAL PRODUCTION ON POPULATIONS OF SELECTED SAVANNA TREE SPECIES ON CLAY SOILS IN CATUANE, SOUTHERN MOZAMBIQUE

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Declaration

I declare that this thesis is my own, unaided work. It is being submitted for the degree of Master of Science in Resource Conservation Biology at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

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(Signature of candidate)

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Abstract

The impact of charcoal production on populations of selected savanna tree species was investigated on clay soils in Catuane, southern Mozambique. The study focused on answering questions related to the contribution of charcoal production to the local economy, the way populations of selected species were changed by the activity and the way in which they recover. *Acacia nigrescens*, *Acacia nilotica* and *Ziziphus mucronata* were identified as being amongst the most utilised species for charcoal production due to their hard wood quality. The charcoal production is being done by individuals from outside the local community. They are able to generate relatively high revenues from their product, which they sell to external markets, notably Maputo. The local community do not share in the benefits of the production. Interviews with members of the local community, indicated that they would prefer the activity to be stopped or more rigourously controlled. A comparison was made between adjacent harvested and un-harvested areas to assess the effects of charcoal production on the tree populations. Population structure by stem circumference classes were broadly similar in all three study species being characterised by a high frequency in the smallest circumference class. All other classes had considerably lower frequencies. With regards density, *Acacia nigrescens* and *Acacia nilotica* showed significantly lower densities in the harvested area. *Ziziphus mucronata* showed no significant difference. The frequency of stump circumference classes of *Acacia nigrescens* and *Acacia nilotica* were normally distributed with the class 81-90 cm being the most common. *Ziziphus mucronata* data were skewed to the left, with most stumps in the class 52-60 cm. Stump heights were mostly in the region of 20 cm. Circumferences of stumps were similar across the study species, being in the region of 90 cm. Coppicing in stumps was relatively poorly developed, with the majority of stumps having no successful coppice shoots. Kilns had an average density of two kilns per hectare. There was an inverse relationship between species abundance and mean harvesting radius. The results of the study indicate that harvesting has had an effect on species abundance and population structures. With decreases in density and a shift in age distribution towards a predominance of juvenile trees. However, the results are not unequivocal, since the area is not pristine and may have been subjected to other activities

before harvesting for charcoal. The charcoal producers appear to harvest all sizes of tree. Their production data, approximately 1300 kg of charcoal produced per hectare, indicate the potential for over utilisation of the woodland resource. Futhermore their practice of cutting at low height subjects the stumps to growth retarding elements such as herbivory and fire, possibly contributing towards relatively unsuccessful coppicing and exacerbating the sustainability issue. To address these issues, along with the socio-economics issues, appropriate structures need to be implemented by government, in consultation with communities.

Dedication

To my daughter Neida Gizela Manjate (Isa) and my wife Neusa for enduring my absence, and to my extended family for support. Especially to the memory of my late father Samuel Maluvane Manjate.

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Ac ng …………………………………………………………………*Acacia nigrescens*

Ac nl…………………………………………………………………..*Acacia nilotica*

Zm……………………………………………………………………*Ziziphus mucronata*

H …………………………………………………………………….....Harvested

U ………………………………………………………………………Unharvested

%…………………………………………………………………………Percentage

Std……………………………………………………………..Standard deviation

SE………………………………………………………………….Standard error

K…………………………………………………………………Carrying capacity

< ……………………………………………………………………Lower than

>……………………………………………………………………….Higher than

m^3………………………………………………………………….Cubic meter

Kg………………………………………………………………………Kilograms

m……………………………………………………………………………….Meter

ha……………………………………………………………………………Hectare

US$ ……………………………………………………………United State Dollar

Mt ………………………………………………… Mozambican currency (Metical)

CHAPTER ONE-INTRODUCTION

1.1. General Introduction

Fuelwood, in particular charcoal, is an important source of energy for many rural and urban households across the developing world. Charcoal production from the Amazon tropical forests in Brazil and Peru provide good examples of this. The activity employs around 250 000 people in Peru and makes the greatest contribution to household income when compared to agriculture, non-timber products, livestock and other natural resource activities (Coomes and Burt 2001). In 1995, charcoal was responsible for 47% of Brazilian wood energy use (Muylaert *et al.* 1999). The product is used mainly for industry, further emphasizing its important role in the economy of the country. However, the studies in Amazonia have also shown that uncontrolled forest harvesting has resulted in massive destruction of the tropical forests and is clearly an unsustainable activity.

Studies conducted in savanna woodlands in African countries, such as Zambia, Kenya and Tanzania, have also shown that charcoal production plays an important role in the provision of energy, although in a less formal manner (Okello 2001, Chidumayo and Kwibisa 2003, Kituyi 2004 , Luoga *et al*. 2004). As in Brazil, the activity is considered to be practiced in an unsustainable manner. Besides having implications for the charcoal production 'industry', unsustainable harvesting has implications for a variety of other economic activities and products associated with the savanna woodlands (Chapin III *et al.* 2000). Furthermore, sustainability issues also have major ecological implications, since savanna trees play an important role in a variety of ecological processes.

As in other African countries, the unsustainable utilization of woodland ecosystems has become a matter of concern among scientists and policy makers in Mozambique. The increased utilisation of fuelwood and concomitant increase in charcoal production can be related to the increased urbanisation in Mozambique, notably Maputo. This has resulted in high density slums where electricity is not affordable and fire-wood and charcoal offer a cheaper energy alternative (MADR 2000). Mozambican consumption of charcoal and fuel wood has been estimated at about 12 million tons per year, and the urban consumption (at least 2.9 million tons/year) accounts for 24% of the total (MADR 2000). Furthermore, studies done in terms of fuel-wood consumption indicate that from 1980 the domestic consumption in Maputo, the capital and largest city in Mozambique, has increased by approximately 10% per annum. Domestic consumption in Maputo is now between 0.9 and 1.0 m^3 of woody biomass per capita (Brouwer and Falcão 2004). In terms of energy per unit mass, charcoal has about twice that of wood and makes for a more viable economic option when transporting fuel from rural areas to the urban market (Biggs *et al.* 2004). This harvesting represents a great pressure on the rural savanna woodlands in southern Mozambique. Furthermore, it is predicted that the number of people needing wood energy in Africa is predicted to rise by 50% by 2030, and that the consumption of charcoal will double during this period (Biggs *et al*. 2004). As such, sustainability issues become even more critical.

This study investigates the production of charcoal from rural woodlands in southern Mozambique, with the aim of understanding the socio-economic and ecological issues, in order to allow the formation and application of policies towards sustainable utilization of woodland resources. The study focuses specifically on answering the following questions.

1) To what extent is charcoal production contributing to the sustainable livelihood and poverty alleviation in the identified rural community?

2) To what extent the populations of selected species of tree have changed by the harvesting for charcoal production?

3) To what extent the selected tree species have responded to harvesting, with a focus on coppicing?

1.1.1. Study area

1.1.1.1. Location

Catuane is located about 150 km south of Maputo city in southern Mozambique (Fig. 1).The study area is about 16 km north of Catuane village, in extensive private concessions for livestock and agricultural practices. The area forms part of an area rich in endemic species is classified as the Maputaland Centre floristic unit (Van Wyk and Smith 2001) (Fig. 1). This area is bounded by the Inkomati-Limpopo river in the north, by the Indian Ocean in the east, by the western foothills of the Lebombo Mountains in the west and St Lucia Estuary in the south (Van Wyk and Smith 2001).

1.1.1.2. Social Structure

Catuane is an administrative post of Matutuíne district. There are five communities surrounding this post, namely: ChuCha, Zikhale, Maduvula, Ndlala and Manhangane (Fig. 1). Governmental structures and traditional leadership both play an important decision-making role in the communities. Most of the local communities live in poverty, still depending on forest resources for subsistence, construction materials, wood fuel, livestock initiatives and medicine.

1.1.1.3. Climate

Van Wyk and Smith (2001) recently classified the climate of southern Mozambique as basically tropical/subtropical, with no frost in winter. Mean annual temperature in the Maputaland area diminishes from 22°C in the north to 17°C in the south. The southern boundary of Mozambique seems to follow the 18 °C mean midwinter isotherm quite closely and marks a zone where the fauna (and to a lesser extent the flora) changes from predominantly tropical/subtropical to temperate in nature (Van Wyk and Smith 2001).
Relative humidity is generally high on the plains, even away from the coast. In terms of rainfall, the coastal regions have a moderately high and well-distributed rainfall owing to

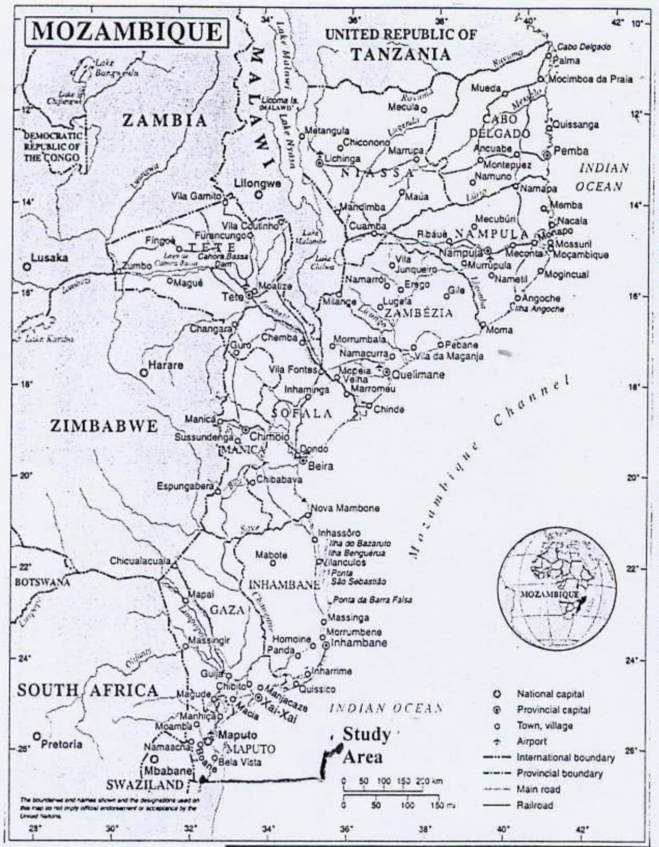
the ameliorating effect of the warm Mozambique current (White 1983) . Annual rainfall averages about 1100 mm along the coast, but declines progressively inland, due to the influence of dessicating ‘berg’winds, to as low as 500-600 mm on the western plains (Van Wyk and Smith 2001). There is a pronounced dry season in winter and Fires are a natural phenomenon in the region and are important for maintenance of some vegetation types (Van Wyk and Smith 2001).

1.1.1.4. Soil structure

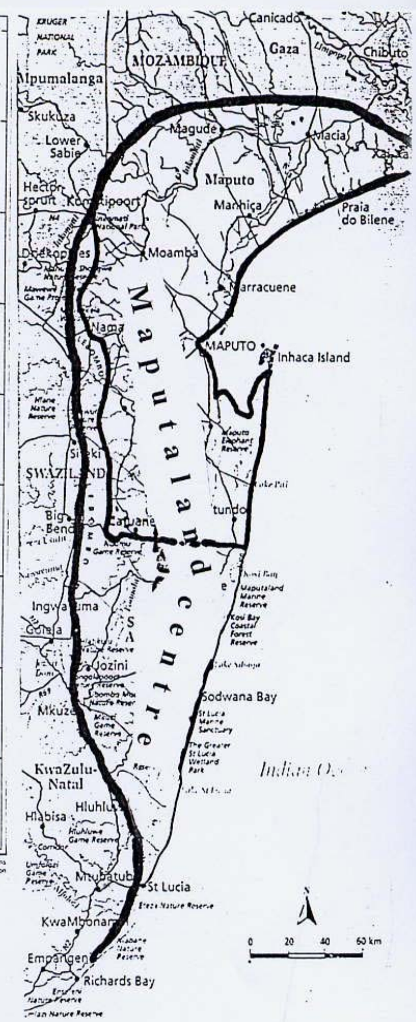
Over most of the southern Mozambican coastal plain the soils are infertile, geologically recent, fine-grained aeolian sands. Fertile soils are restricted to the clayey, alluvium deposits associated with the floodplains of the larger rivers. This is in contrast to the western interior where weathering of the rhyolite lavas of the Lebombo Mountains has produced relatively fertile soils with high clay content (INIA 1991, Van Wyk and Smith 2001). The study area is underlain by these clay rich soils (Fig. 1). They cause an undulating topography that in turn has an effect on the vegetation distribution. It was noted that the vegetation differs between valley, slope and hilltop, with denser thickets occurring in the valleys.

1.1.1.5. Vegetation

The vegetation in the area is essentially subtropical, occurring as a mosaic of forest and coastal grassland inter-fingering with elements of the Afromontane Region (White 1983). According to Van Wyk and Smith (2001) the vegetation of southern Mozambique is diverse and includes different types of grassland, bushveld, thicket, forest and swamp vegetation. Forest canopies generally vary in height from 10 to 30 m and most stands approach rain forests in terms of structure (White 1983). Two unusual and endemic vegetation types in the area include Sand Forest and Woody Grassland. The study area may be classified broadly as savanna woodland, with scattered trees, generally varying in height from five to ten meters, in grasslands. Within this general structure patches of more dense accumulations of bushes and trees or thicket vegetation occurred. In the unconceded areas the vegetation is markedly different in terms of canopy structure. There are fewer large trees and more thicket vegetation and grassland, in which numerous stumps may be found.



(United nations 2004)



(Van Wyk and Smith 2001)

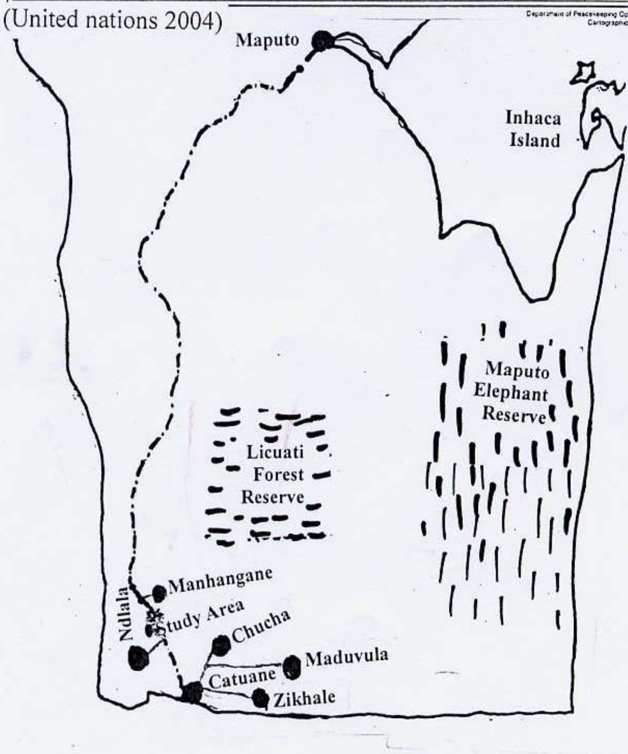


Fig. 1: Study area located in Southern Mozambique

1.2. OBJECTIVES

1.2.1. To understand the system of production and some of the key socio-economic aspects of charcoal production in Catuane

- To identify the species selected for charcoal production and reasons for selection by charcoal makers in Catuane.

- To identify the origin of the charcoal makers in the area.

- To determine the costs and benefits of charcoal production in the area.

- To identify the local attitudes and perceptions about the abundance of tree species, impact of charcoal production, and possible solutions relating to charcoal activity in Catuane.

1.2.2. To quantify the impact of charcoal production on populations of selected savanna tree species in Catuane

- To quantify the density and population structure of selected harvested species in two zones of different harvest intensity in Catuane.

- To quantify harvesting intensity, by size class, of selected species in two zones of different harvest intensity in Catuane.

- To quantify the coppice re-growth of cut stumps per study species.

- To quantify production variables: such as density of kilns and harvesting radius across kilns.

1.3. Literature review

The literature review is divided into two main sections. The first section discusses charcoal production in terms of the process itself, production and consumption statistics and socio-economic details and issues. The second part of the review focuses on ecological aspects. General population concepts and dynamics are discussed before reviewing in more detail the ecology of savanna woodlands. The effects and the responses of savanna woodlands to harvesting are then discussed.

1.3.1. Charcoal production

1.3.1.1. The process

The earth kiln charcoal production system has been a traditional practice across many African countries (Chidumayo 1979, Luoga *et al*. 2000, Okello *et al.* 2001), and is often found practised in southern Mozambique. The traditional method of production of charcoal involves tree felling and the cutting of stems into appropriate sizes. These are then placed in piles and partially dried before being burnt under a cover of soil for a number of days. A limited oxygen supply results in the incomplete carbonization of the wood to produce charcoal (Chidumayo 1979, UEM 1999, Chidumayo and Kwibisa 2003**,** Luoga *et al*. 2004, Biggs *et al.* 2004). According to Okello *et al.* 2001, from 43 to 69% of the biomass for trees with diameters greater than 4 cm can be utilised for charcoal production and the remainder is used as fuel for kilns, kiln spacers, and firewood (<2cm diameter). Most twigs and leaves are used to cover denuded areas to encourage re-vegetation. The utilisation of larger trees for charcoal and smaller trees for kiln fuel was also reported in other studies (Chidumayo 1979, Chidumayo 2003). Studies in Tanzania also reported that more than 56% of the harvested trees in the Kitulanghalo forest reserve, ranged between 2.4 and 68.6 cm trunk diameter at the breast height (Luoga *et al*. 2000). In Mozambique, the producers select diameters above 20cm (UEM 1999).

A wide variety of trees are utilised in Africa. For example, in the miombo woodlands of the Kitulanghalo area in Tanzania, about 42 species were utilised for charcoal production, a higher number than for any other use (Luoga *et al*. 2000, Chidumayo and Kwibisa 2003). The commonly utilised species were *Combretum molle, Julbernardia globiflora, Brachystegia spiciformis and B. boehmii* (Luoga *et al.* 2000). In comparison, in the Amazonia area, it was reported that about 27 tree species have been used for charcoal production (Muylaert *et al.*1999). In terms of charcoal production in Mozambique, the most commonly utilized trees in the south of Maputo province are *Combretum hereroense, C. imberbe, C. molle, Acacia nilotica, A. senegal and A. tortilis* (UEM 1999). In the Gaza province *Colophospermum mopane* is predominantly utilized (UEM 1999). These species may also be utilized for fuelwood, along with a number of other species such as *Brachystegia speciformis, B. boehmii, Antidesma venosum, Terminalia sericea, Afzelia quanzensis, Balanites maughamii*, *Strychnos madagascariensis*, *C. mopane*, *Hirtella zanguebarica*, *Lecaniodiscus franxinifolia*, *Lonchocarpus capassa*, *Piliostigma thonningii, Millettia stuhlmannii, Erythropheleum lasianthum*, *Newtonia hildebrandtii, Albizzia forbesii, Dolichandronealba*, *Fernandoa magnifica* and *Dichrostachys cinerea* (BTG 1990, Saket 1994, Adamo *et al.* 1997, Muchanga *et al.* 1997, Mangue 1997, Howell and Convery 1997, Mangue and Wate 1998, Vilanculos 1998).

1.3.1.2. Production data

In terms of the traditional process of charcoal production, studies in Tanzania in 1997 reported that on average each kiln required 10.2 ± 2.02 (SE) m^3 of wet wood and had a mean production of 1.28 ± 0.26 tonnes of charcoal, the equivalent of 44.2 ± 8.67 bags (Luoga *et al*. 2000). Each household of five people constructed a mean of five kilns per year. This translates into a mean production of 1320 kg (44.2 ± 8.67 bags) per person. In comparison, in a study in Mozambique, one production unit (4-5 people) produces 4740 kg charcoal or approximately 1185 kg charcoal per person (Biggs *et al.* 2004). In terms of a general production statistic per unit area, a total of 283 650 kg of charcoal were produced from a 17000 ha forested area in central Mozambique between the high demand months of April to August. In other words, a hectare of forest produced 16 kg of charcoal.

These production statistics can be compared to consumption statistics. In terms of consumption, a distinction between non-domestic and domestic can be made (Brouwer and Falcão 2004). In Maputo, non-domestic charcoal consumption typically comprises fast food outlets and restaurants. The consumption of fast food outlets in Maputo city were responsible for about 88% of the 60 100 m^3 of the wood burned in the form of charcoal. In terms of domestic use consumption figures are much higher, with approximately 648 000 m^3 being consumed per annum. Maputo (urban) households consume on the average 2.99 (2.42 – 3.56) kg per day per household or 1100 kg per year. This requires the utilisation of approximately 69 ha of forest based on the production statistics above.

1.3.1.3. Socio-economic cost and benefits from charcoal production

As stated in the introduction, charcoal production activity can play an important role in a countries socio-economic development, as in Brazil and Peru. The pressure placed on natural ecosystems such as tropical forests and savannas trees is basically driven by a need to address fuel-wood demands. Many people, especially in poor and rural households, utilize trees as a primary source of energy across developing countries (Luoga *et al*. 2000, Shackleton 2001, Coomes and Burt 2001, Chidumayo and Kwibisa 2003 and Dovie *et al*. 2004). Charcoal production plays an important role in poverty reduction, forming an important source of revenue in most of the rural households involved actively in the business. Secondly it provides an affordable source of energy for those not able to access or afford electricity.

In terms of generating revenue, studies done in Tanzania in 1997 showed that the gross income from charcoal was approximately US$88 per person per year (Luoga *et al.* 2000). Profit equates to about half of this figure. This was at a selling price of US$2 per bag of charcoal and annual production of 42 bags per year per person. The profit margins are enhanced by the fact that the activity may be informal and taxes are not paid. In these instances the producers are usually from within the local communities. In other cases, wholesalers need to be licensed and are normally taxed by government. Village authorities are assisted by forestry guards in collecting the fees for the local government from commercialized wood products, which fall under their jurisdiction (Luoga *et al.* 2000). In Tanzania, therefore, charcoal production usually contributes towards social development. In terms of Mozambique, studies indicate that gross revenue per person per month is approximately US$35. Of this 25% covers costs such as licensing fees. Net profit is approximately to US$22 per person per month. The activity is confined to the dry period (April to August) because conditions are not conducive to charcoal production in summer (e.g. high rainfall) and other activities such as agriculture take precedence. Profit equates therefore to about US$110 per producer per year.

The above indicates that charcoal production can contribute towards an individuals livelihood. However problems arise because the resource being utilised is usually a communal resource. A primary value of savanna woodlands lies in domestic and subsistence uses by local households (Luoga *et al*. 2000). Communal uses of woodlands include fuelwood, shade and fodder for livestock, windbreaks, medicine and material for construction. When the motive of personal profit triggers individuals to use environmental resources more heavily and contribute less to their protection, a concept known as “externality” (Luoga *et al.* 2000), a conflict of interests results. Ecological costs are not taken into account in the process of profit maximisation, leading to unsustainable practices (Luoga *et al*. 2000, Okello 2001, Chidumayo and Kwibisa 2003, Kituyi 2004). The conflict is exacerbated by the fact that the market for charcoal is situated mostly in the urban areas. Informal trading in savanna woodlands products, is more economically rewarding near cities and along main roads than it is in villages, due to lower purchasing power in rural areas. All these factors contribute towards a complex socio-economic situation, involving a number of role-players. Governments may also become involved. For example changing political and regulatory frameworks may influence the situation. A study in Bushbuckridge in South Africa identified socio- economic changes, such as institutional control of access to resources on communal land, unemployment and poverty, and perceptions of rights and responsibilities, as contributing to vegetation changes (Twine 2005). Firstly, during the colonial and Apartheid eras, the access to natural resources on communal lands was controlled by chiefs and their headmen. The new system introduced a control of natural resources by the prevailing government based on bureaucratic schemes (Laws and permits). This resulted in weakness and marginalization of the traditional structure in their role in resource management. Secondly, the level of unemployment was pervasive in this area, and vegetation becoming important as a buffer against poverty, as it provided households with free or a cheap source of resources for local consumption or commercialization for their livelihood. This resulted in a growing number of commercial harvesters of fuel-wood and other commercial ventures. Unemployment also contributed to the increase in harvesting of resources by outsiders, as vendors harvest resources wherever they were available. Declining availability of fuel-wood around some villages has forced vendors to travel further a field to find other resources. Thirdly, a social phenomenon has emerged in many rural areas, including Bushbuckridge, since democratic change in South Africa. There is a widespread perception among rural communities that freedom and democracy implies the right of free and unrestrained access to natural resources on communal land. This has not been accompanied by a sense of responsibility for the natural resource base. There has been a rise in the exploitation of resources by outsiders, who feel that they have the right to harvest resources wherever they like. The increasingly complex situation with regards natural resource utilization requires the application of regulatory forces. These are considered below.

1.3.1.4. Institutional control of forestry resources in Mozambique

The Mozambican act number 10/99 of July 1999 acknowledges the overall economic, social and scientific importance of forestry and wildlife resources to the Mozambican society.

The current forestry and wildlife laws apply to the following areas:

- disturbed areas through pollution, desertification, habitat loss, erosion and deforestation;
- biodiversity loss (genes, individual, organisms, species, populations, aquatic and terrestrial ecosystems) as well as the loss of ecological functions as a whole;

- the promotion of local community participation in protecting their habitation areas, agricultural farming, livestock, catchments, forestry, wildlife, hunting areas and expanding zones;
- Conservation that encompasses sustainable management of resources without endangering the biodiversity;
- sustainable development, which includes an environmental management that considers the basic needs of present and upcoming generation;
- the monitoring and estimation elements or indicators of environmental quality during planned programs, so that such impacts caused by humans in natural resources are adequately assessed, and
- The enforcement of laws such that infringements are penalised accordingly (DNFFB 1999).

Thus the required regulatory environment discussed previously is reasonably well represented in legislature. However, although reasonably legislated, the laws appear to be poorly implemented and controlled and attention needs to be paid to implementation.

1.3.2. Ecological aspects

1.3.2.1. Population concepts

The main aim of ecology is to describe, explain and understand the distribution and abundance of organisms. In all cases ecologists are interested in the number of individuals, distributions of individuals, the demographic processes such as birth, death and migration which influence these and the ways in which these demographic processes are themselves influenced by environmental factors (Begon *et al.* 1996a). Within areas of distribution it can be said that plants or animals occur at varying densities, meaning that species are common in a particular area and rare in another area. However, if we want to be more precise to support such statements, one obviously needs to quantify density and interpret the differences (Case 1992, Krebs 1994).

Populations may be defined as a group of organisms of the same species occupying a particular space at a particular time and ultimately capable of interbreeding and perpetuating that species (Case 1992, Krebs 1994). A population study includes four groups of statistically measurable characteristics that affect its density, namely natality, mortality, immigration and emigration. Also of relevance are age distribution, genetic composition and distribution of individuals in space (Krebs 1994, Begon *et al.* 1996b).

Because of the difficulties in determining the absolute density of populations, usually a researcher must be content to count only a small proportion of the population and use this to estimate the total. The common method of sampling vegetation is to make use of quadrates. This involves counting all the individuals in several quadrates of known size and extrapolating the average to whole area. It is important to choose representative samples by application of random sampling methods (Krebs 1994, Begon *et al.* 1996b).

1.3.2.2. Population dynamics

Each organism, for at least part of its life, is a member of a population composed of individuals of its own species (Begon *et al.* 1996b). Individuals of the same species have very similar requirements for survival, growth and reproduction. The combined demands for a resource may exceed the immediate supply. As a result, individuals compete for the resource and at least some of them become deprived. Ultimately, this competition results in a decrease in reproductive output and an increase in mortality that results in a decline in population size. The competition however, does not necessarily result in a decrease in individual fitness (Begon *et al.* 1996b, Crawley 1998). The likely effect of intra-specific competition on any individual is greater the more competitors there are. The effects of intra-specific competition are thus said to be density dependent. However, the intensity of intra-specific competition experienced by an individual is more specifically determined by the extent to which it is crowded or inhibited by its immediate neighbours.

Theoretically, as density increases, the per capita birth rate eventually falls and per capita death rate eventually rises (Silvertown 1992, Begon *et al*. 1996a, Begon *et al*. 1996b). At the densities below the certain point, the birth rate exceeds the death rate and it said that the population increases in size. Whereas at densities above the cross over point, the death rate exceeds the birth rate and the population declines. At the cross over point itself, the two rates are equal and there is no net change in population size. Indeed this represents a stable equilibrium, in that all other densities will tend to approach it (Begon *et al.* 1996b). Consequently intra-specific competition, by acting on birth rates and death rates, can regulate populations towards a stable density. This is known as the carrying capacity (K) and represents the population size that the resources of the environment can just maintain without a tendency to either increase or decrease (Silvertown 1992, Krebs 1994, Begon *et al*. 1996a, Begon *et al*. 1996b, Case 2000). In natural ranges, the populations undergo a self-thinning, which consists of the suppression of young trees by large ones, in order to regulate their populations. For example, in a long term study done with *Albies balsamea,* a reciprocal relationship between mean plant trunk diameter and the density of surviving plants was often observed. Denser populations exhibited lower mean trunk diameters (Silvertown 1992, Crawley 1998). Some idea of what happens to individual plants during the self-thinning process can be obtained from changes in the frequency distribution of individual size with time. Initial density of *Albies balsamea* had an approximately normal distribution of the trunk diameter size during 3 to 6 years. Self-thinning began and selectively removed the smallest plants resulting in a higher diameter dominating at 10 to 59 years. These higher diameters were also evenly distributed in the population. With the passage of time deaths occurred in a pattern which left survivors evenly distributed in space. Thus in tree ecology there is a natural tendency for small trees to be suppressed by the large ones (Silvertown 1992, Crawley 1998), conferring a stable equilibrium (Silvertown 1992, Krebs 1994, Begon *et al*. 1996a, Begon *et al*. 1996b Crawley 1998, Case 2000). The self thinning process is also relevant to coppicing trees (where a cut or broken stem produces new shoots). The process occurs at two levels. Firstly, in miombo woodlands in Tanzania (Luoga *et al*. 2004), less dense populations coppiced more readily than denser counterparts. Secondly, in *Acacia drepanolobium* savanna woodlands in Kenya, a reduction in the number of coppicing stems with increasing age was observed (Okello *et al.* 2004). Large shoots continuously and increasingly suppressed the success of smaller shoots.

1.3.2.3. Savanna function and disturbance

Southern African studies have shown that there is a strong association between savanna vegetation and climates with a hot wet summer and warm, dry winter providing the first clue that water availability is a key factor of savanna ecology. It was reported also that the dominance of water availability as a determinant of savanna structure and function is particularly strong at the dry end of the savanna structure (Scholes and Walker 1993). The patterns of water supply in relation to demand of the plants, influences both the physical vegetation structure of dry savannas and their ecological composition. Moist savanna receive approximately 1000 mm rainfall per annum and desert shrubland or grassland receive 300 mm per annum. These determine a progressive decrease in the height and density of the trees, and consequent change in the proportion of trees to grasses. Similar tendency occur when passing from sandy to clayey soil under the same climate (Scholes and Walker 1993).

Recent human activities are especially important in creating disturbed habitats include: extensive clearing of natural vegetation for agricultural purposes, including plantation forestry and abandonment of less productive land (Bazzaz 1998) as well as harvesting of populations for economic gain (Krebs 1994, Begon *et al.* 1996a). Disturbances of different types can modify resource fluxes in specific ways, especially the degree of heterogeneity in the resource (Silvertown 1992, Bazzaz 1998). Forces of nature and human intervention lead to innumerable local, regional, and sometimes global changes in plant community patterns. Irrespective of the causes and the intensity of changes, ecosystems are often naturally able or not to recover most of their attributes through natural processes (Silvertown 1992, Bazzaz 1998). Plants respond primarily to changes in their resource base and to the fluxes of chemical and physical factors in their environment. Disturbances alter the resource base of a site consequently changing the patterns of distribution and density.

Savanna ecosystems are characterised by disturbances such as fire, herbivory and droughts which play and important role in shaping their structure and function (Frost *et al.* 1986). The Southern African Study, in Nylsvley, indicated that during the period of study occurred an increase of woody plant biomass with an increase of fire frequency (Scholes and Walker 1993). The historical fire frequency, or intensity, was higher than at present. Alternative explanations for the increase in woody biomass are that large herbivores, such as elephants combined with harvesting of trees by the previous inhabitants for fuelwood and timber occurred in the area, and would have depressed the woody biomass (Scholes and Walker 1993).

Krebs (1994) and Begon *et al.* (1996b) suggested that to manage a population effectively requires some understanding of its dynamics, as the central problem of economically oriented fields such as forestry, agriculture, fisheries and wildlife management is how to produce the greatest crop without endangering the resource being harvested. In all predator – prey interactions the predator will profit by maximizing the prey taken while ensuring that the prey does not become extinct. In the instances involving man as the harvester, the problem is of ensuring neither over-exploitation (hastening extinction) nor under-exploitation (cropping less than the prey population can sustain). The first immediate consequence of harvesting is to reduce the size of the population, and this in turn, will generally affect the life expectancy and fecundity of the survivors in the harvested population. However, it is also important to consider that to some extent the act of harvesting has an important effect on the rate of regrowth of the population by removing the potential competitors.

1.3.2.4. Importance of savanna tree species

Savanna trees play an important role in providing ecosystem goods and services (Chapin III *et al*. 2000). In terms of savanna ecosystem goods, savanna tree species can play an important role in the local economy if harvested in a sustainable way. Savanna woodland goods include commercially exploitable timber products and non-timber products (such as mopane worms), foods, medicine, and wood fuel. The latter is the principle source of energy in most southern African households. Ecotourism is another increasingly important source of income (Cowling *et al.* 1997). In terms of ecological services, savanna trees play an important role in the maintenance of nutrient cycling, since the structure, function and composition of southern African savannas are highly influenced by nutrient availability (Cowling *et al.* 1997). For instance, the leguminous savanna tree species are important in term of nitrogen fixing through their association with soil microorganisms. Maintenance of the water cycle is another important service, where the annual potential evaporation greatly exceeds the annual precipitation in savannas (Scholes and Walker 1993, Cowling *et al.* 1997). The photosynthetic process can also play an important role in CO_2 sequestration from the atmosphere, functioning as a carbon sink, storing carbon in the woody biomass (Graves and Reavey 1990, Scholes 1999). This process also releases O_2, important in the respiration processes and production of energy in other organisms. Savanna trees are important as a habitat for other species such as reptiles, birds, insects etc. In the coastal areas, trees can serve as windbreaks. Thus, the unsustainable use of trees has important ecological and socio-economic implications.

1.3.2.5. Recovering of harvested trees by coppicing

Most African savannas are subjected to harvesting of wood, especially for fuel-wood, and construction timber. A key attribute of resilience and productivity of savannas is the ability of damaged trees to re-grow from the remaining stump (Shackleton 2001, Twine 2005). Different species have different coppicing effectiveness. Studies have indicated different coppicing abilities in *Terminalia sericea* (Shackleton 2001), *Combretum molle, Julbernadia globiflora*, *Pterocarpus angolensis*, *Spirostachys africana* (Luoga *et al.* 2004), *Dichrostachys cinerea, Albizia harveyi, and Combretum collinum* (Kashula *et al*. 2005). Miombo tree species generally have both vertically and horizontally extensive root systems which facilitate rapid recuperation after cutting (Malimbwe *et al*. 1994). Shoots grow faster than newly established seedlings, because they already have a well established root system with stored reserves (Chidumayo 1993), Furthermore trees that coppice, still protect the soil since the root stock remains in place. The preservation of root structure is particularly important in nitrogen fixing trees, where fertility is maintained since root nodules are still present (Okello *et al.* 2004). Different degrees of response of species, after being cut for charcoal production, have been reported. Miombo woodland trees in Tanzania, namely *Combretum molle, Julbernardia globiflora, Brachystegia spiciformis and B. boehmii*, show very high rates of recovery by coppicing if they are not uprooted during the initial disturbance (Luoga *et al*. 2000). *Acacia drepenolobium* in Kenya also coppices readily when harvested. Coppice height and stem diameter increased at a mean rate of 28.6 cm per yr and 0.7 cm per yr (Okello *et al.* 2004). In southern Africa, *Terminalia sericea* (Shackleton 2001), *Dichrostachys cinerea, Albizia harveyi*, and *Combretum collinum* (Kashula *et al*. 2005), all used for fuel-wood, show strong recoveries by coppicing.

The degree and rate of recovery may be influenced by a number of factors. These include self-thinning (Okello *et al.* 2004), herbivory, rainfall (Okello *et al.* 2004), fires, species type and stump dimensions (Shackleton 2001, Luoga *et al.* 2004, Kashula *et al*. 2005). The season of the year during which the cutting is done is an important determinant of the number of coppice shoots produced. The best time to re-sprout is just before the onset of the rains when abundant moisture facilitates recovery from harvesting. This was noted in a study done in Tanzania (Luoga *et al.* 2004). In Kenya, another study done on *A. drepanolobium*, also reported that rainfall influenced the coppicing. Coppicing began shortly after the trees have been cut, usually within 3 months, especially if rains fall shortly after the harvest. The mean annual rate of increase in height for the coppicing stands (28 cm) was higher than for non-coppicing stands (18 cm) recorded in a rainfall gradient mean of (550 mm per year) (Okello *et al.* 2004). Self-thinning may also influence coppicing. It was reported as causing a reduction in the number of stems with increasing age, where large shoots continuously and increasingly suppressed the success of smaller shoots (Okello *et al.* 2004). Moreover, Luoga *et al.* (2004) reported that dimensions of stumps influence the mean number of coppice shoots per stump in *Julbernadia globiflora*. Most of the trees showed the highest number of coppice shoots within the 10-20 cm diameter class. In terms of stump height, it was found that the lowest number of coppicing shoots occurred at a stump height of 1.7 ± 1.1 (SE) cm. The general tendency was that tall stumps produced more coppice shoots than short stumps, because of increased surface area, resulting in more buds on the stump. Cutting too low on the stem of the tree may also encourage fungal infection because of moisture from the ground or decay of the stump. Cutting too high may result in loss of sprouting vigour and poor growth. (Luoga *et al.* 2004).

Southern African savanna studies in Bushbuckridge on *Terminalia sericea*, also showed that larger stems (>300mm circumference) produce a greater number of coppicing shoots than smaller stems. Similarly, cutting height appeared to effect the number of coppicing stems. Stems cut at 50 cm produced more shoots than stems cut at 20cm in the large and medium size-classes (Shackleton 2001). Similar results were confirmed in the coppicing response of three key fuel-wood species utilized by local people, namely *Dichrostachys cinerea*, *Albizia harveyi*, and *Combretum collinum* (Kashula *et al*. 2005). Browsing was a factor affecting the number of coppicing shoots in *Terminalia sericea* (Shackleton 2001), especially in the first growing season, where almost 50% of the coppice shoots had been browsed. The greater the cutting height, the lower the potential impact of browsers. Similar results were found in a study in Zimbabwe (Luoga *et al.* 2004). The same can be said for fire, where taller stems are more likely to survive (Shackleton 2001).

1.3.2.6. Impact of harvesting trees

The primary production (NPP) of trees in the Kitulanghalo area in Tanzania was estimated at 3.7 ± 1.3 (SE) tonnes per hectare per year, it means that if the growth is not interrupted by intensive fires, the harvested areas should take less than 5 years to regain the pre-harvested stock of 13.8 ± 1.4 (SE) tonnes per hectare (Luoga *et al*. 2000). However, this biomass would comprise mostly saplings of 3-6 m high, which indicate that the main impact of charcoal production is the change in vegetation structure from woodlands to bushlands. Annual fires were common in Kitulanghalo area. It has been reported that most of smaller trees of <4 cm diameter at breast height are not resistant to the fires, so that fires also affect the recruitment of trees (Luoga *et al*. 2000). The net primary production (NPP) of 3.7 t per ha per year (about 4.35 m^3 per ha) indicated that the removal of wood of 6.38 m^3 ha per year was not sustainable. The sustainable amount of charcoal that could be harvested in order to correspond with the NPP would be 15.5 bags per ha ((4.35 m^3 per ha \ 8 m^3 per tonne) X 1000 kg per tonne \ 35 kg per bag) (Luoga *et al*. 2000)

The ecological functions of trees are difficulty to express in monetary terms (Luoga *et al*. 2000). Sustainable resource conservation has benefits that extend far beyond the profits of commercial resource use. Thus the actual impact of over-utilization of the environmental resource is underestimated because both tangible and intangible functions are ignored. As trees are commercial products, demand will begin to exceed supply. The non-specificity and vast extent of harvesting for charcoal results in the loss of other potential products from woodlands and highlights the possibility of undermining the ecological functions of the woodlands, both of which raise a number of policy issues relevant to the rational use of resources (Norton-Griffiths and Southey 1995).

CHAPTER TWO - METHODS AND MATERIALS

The discussion on methods and materials is divided into two broad sections. The first section details the method of collecting relevant information from the charcoal producers and local communities. The second section describes the method of collecting data on the tree populations. Whilst both methods contributed towards understanding the details of charcoal production process itself, the former focused on assessing socio-economic issues and the latter on assessing environmental/ecosystem issues.

2.1. System of charcoal production and some of the key socio-economic aspects of charcoal production

In order to understand the process of charcoal production and its socio-economic impacts, the interested and affected parties were interviewed. These comprised the charcoal producers themselves and members from communities living in the areas of production. Local authorities were approached to help facilitate the investigation due to its sensitive nature. It was suggested that the research team included members from all the interested and affected parties to allay any fears or suspicions, especially from the charcoal producers. The local authority helped locate and integrate four members into the team: one charcoal maker, one member of the local community and two community conservation agents. Charcoal makers were considered to be all men found in the area producing charcoal and living in temporary camps (as opposed to the more permanent structures of the local communities). Twenty one individuals were located in the area and used as key informants. With regards local inhabitants, the Ndlala community was chosen, due to close proximity to the study area. Twelve households were interviewed.

The required information was obtained by using two standard questionnaires, one for the charcoal producers (Section 7.1) and one for the households (Section 7.2). With regards the former, the questions were aimed at obtaining information about tree species selected, number of trees cut per kiln, kilns production per month, origin of charcoal makers, and economics of production. With regards the latter, questions were aimed at understanding the attitudes of local communities towards the charcoal production as well as details concerning their use of the product.

2.2. Impact of charcoal production on populations of selected savanna tree species

2.2.1. General description of process

To analyze the impact of charcoal production on the ecosystem, an area subjected to harvesting for charcoal production was compared to an area not subjected to harvesting. Numbers and circumferences of trees were recorded at both sites for the three most important species identified through the questionnaire process. These were compared in order to assess the effect of charcoal production on density (in terms of total density of three most important species, and per species of the three most important species) and population structures (in terms of circumference distributions per species of the three most important species). In the harvested area, the number and species of stumps were also recorded. This was done in order to validate and further detail the findings of the questionnaire study, in terms of the species most targeted by charcoal producers. In the harvested area, the circumference and height of stumps were also measured and details of coppice re-growth collected, in order to assess the response of the important species to harvesting. Additional data were also collected from the harvested area in order to further quantify production variables. This included measuring the density of kilns and the harvesting radius around them. The different processes are described in greater detail below.

2.2.2. Sampling Sites

An area affected by charcoal production activity was identified using roads made by the charcoal makers as a general guide (Fig. 2). A more detailed search then identified a region where a harvested area adjoined an unharvested area, and these were chosen as the areas of comparison for the study. It was necessary to choose adjacent sites in order to ensure consistency with regards abiotic factors such as soil type, rainfall etc. The harvested site was characterised by the presence of abandoned kilns and cut stumps. The unharvested site had no kilns or cut stumps and had been protected from harvesting activities, since it was a private concession and was utilised for livestock production (Fig. 2).

2.2.3. Species Selected

The most important tree species in the charcoal making process were identified through the interview and questionnaire process already described. They are shown below in an approximate ranking.

Table 1: Vernacular and scientific species names in Catuane

	Local Vernicular Name	Scientífic Name
1	Nkaia	*Acacia nigrescens*
2	Chihoho	*Acacia nilotica*
3	Passamhala	*Ziziphus mucronata*
4	Sassane	*Acacia gerrardii*
5	Monzo	*Combretum imberbe*
6	Chiwonzwane	*Combretum zeyherii*
7	Ligago	*Acacia luederitzii*

From the above, the three most important species were selected for detailed study viz. *A. nigrescens, A. nilotica and Z. mucronata.* It should be noted that this was further investigated and validated through field identification of stumps in the harvested region, as discussed in more detail below in section 2.2.4.3. These results did not agree entirely with the results of the questionnaire process as is discussed in the results section.

2.2.4. Sampling Techniques

Sampling of the vegetation was done along transects laid out on a north-south compass bearing. A starting point was randomly selected (Knapp 1984, Krebs 1994) in the harvested area (Fig. 2). Sampling of tree populations was then done along a number of N/S orientated transects using quadrates. The quadrate method is a sampling technique in which a number of sampling quadrates are plotted along a determined transect of fixed direction (Mueller-Dombois and Ellenberg 1974, Knapp 1984). A total of 30 quadrates (100 X 4 meters) were sampled per site. Five parallel transects were done, each comprising six quadrates. Each quadrate was separated from the surrounding ones by a 50m interval.

2.2.4.1. Tree densities and circumferences

At each site (harvested and unharvested), and in every quadrate, the number of each species of tree (living only, including coppiced stumps in the harvested area) was recorded and converted to density values. Mean density values for each of the species were then calculated for the harvested and unharvested areas. The circumferences of all the trunks (living only, including coppiced stumps in the harvested area) of the 3 selected species were also measured in every quadrate at each of the sites. The circumference of each stem larger than 5 cm was measured using a tape measure, and estimated for those less than 5 cm.

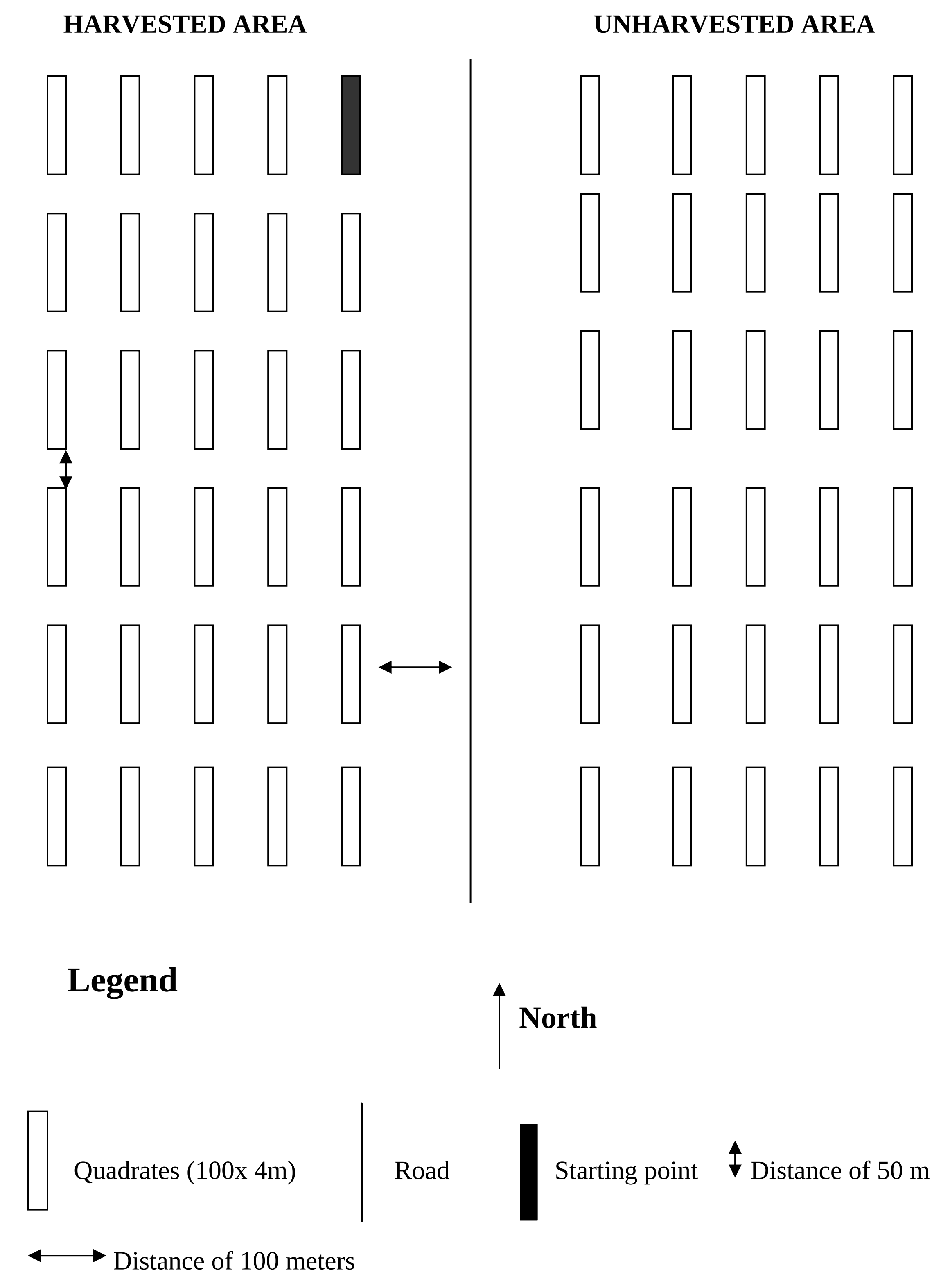


Fig. 2: Quadrates plotted along of North/South transect

2.2.4.2. Coppicing statistics

In the harvested site, wandering transects between each kiln were followed. Every stump around a kiln was identified using (Palgrave 2002) and the number of stumps per species was collated. To avoid double counting of stumps, the charcoal producer assisted in determining to which kiln a particular stump belonged. The circumference, height and numbers of coppice shoots were counted for each cut stump.

2.2.4.3. Kiln statistics – density of kilns, number of stumps per kiln

Kilns were sampled along wandering transects. Starting with a randomly selected kiln, the nearest kiln to that kiln within 180° along a north/south bearing was sampled, and same was done for consecutive kilns along the transect (Fig. 3). The distance was measured between consecutive kilns to calculate the density of kilns. To calculate the mean harvesting radius, the distance from the centre of a kiln to each stump surrounding a kiln was measured.

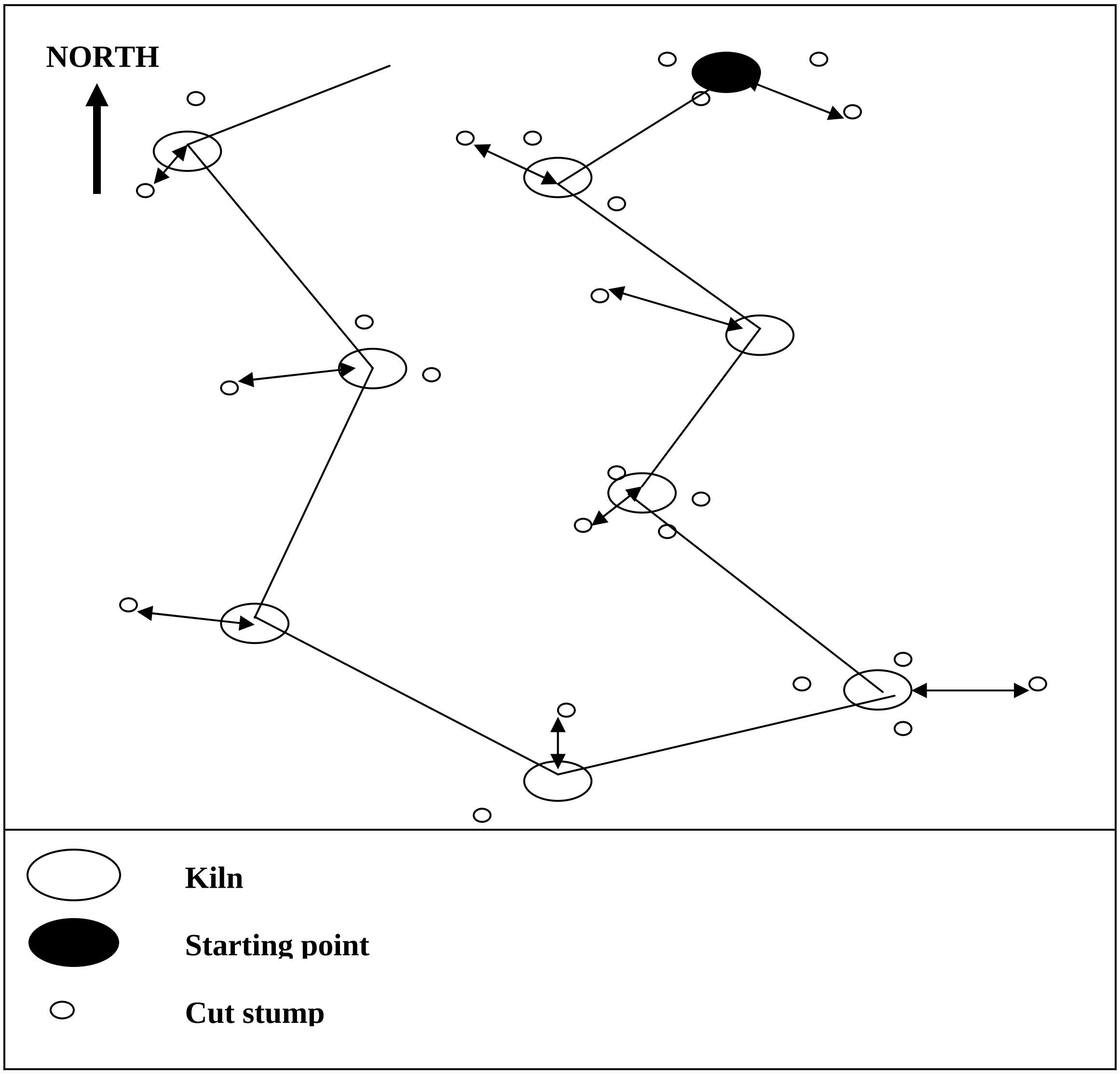


Fig. 3: Schematic diagram of the wandering transect across kilns in harvested area

2.3. Data analysis

2.3.1. System of charcoal production and some of the key socio-economic aspects of charcoal production.

Answers to the various questions were analysed in the following way:

- The most important tree species utilised for charcoal production were identified from the questionnaire. Frequency distributions per species were plotted on pie charts.
- The relative frequency of tree cut per kiln, number of kilns made per month and the number of bags of charcoal produced per kiln were calculated. The most common method of cutting trees down was also identified.
- The origins of the charcoal makers were identified and the relative frequency of 'time in the business' were calculated.
- The selling price of the charcoal was determined, including any variation per season
- Local community attitudes and perceptions about the activity and abundance of trees were considered. The various solutions to problems were evaluated as well as methods of controlling the activity

2.3.2. Impact of charcoal production on populations of selected savanna tree species

- Stem circumference frequency distributions were calculated (10cm wide classes, from 0 to >150 cm) for each of the three important species in the harvested and unharvested areas. Results were plotted on histograms
- Densities of the three species in each quadrate, for harvested and unharvested areas, were determined. The numbers of stems per quadrat (400 m^2) were then converted to per hectare values (multiplied by 25) and a mean density and standard deviation per hectare calculated from this using the SAS statistical package. The data were tested to see if they fitted a normal distribution or not.

The data found to be skewed the Wilcoxon non-parametric test (Conover 1971) was used for the comparison of skewed mean. The significant differences between two means tree densities, were tested using the one sided test at 5% significance levels. The results were then plotted per species in the form of bar graphs with standard error bars.

- The above was also done for total tree densities of the study species and plotted in a bar diagram comparing harvested to un-harvested areas.

2.3.3. Relative frequency of cut stumps per species per kiln

For every kilns encountered in the wandering transect in the harvested area the relative frequency of cut stumps per species was calculated and plotted in a pie diagram. This part of the study identified every species encountered and was not limited only to the three most important species.

2.3.4. Mean stump height and circumference of study species

The mean and standard deviation for stump heights and circumference per study species was calculated. The data were tested to see if they fitted a normal distribution or not. The data were found to be skewed the Kruskal Wallis nonparametric test (Conover 1971) was used to compare the three mean heights of the three study species. The significant differences between the heights were tested using one sided test at a 5% significance level. Bar graphs with standard error were then plotted comparing the study species. Regarding the circumferences, the data were normally distributed; as standard deviations were lower than the mean. ANOVA was used to compare the mean circumferences using a one sided test (Campbell 1989) and the multi-comparison test of Bonferroni at a 5% significance. Bar graphs with error bars were plotted.

2.3.5. Mean number of stumps per species across kilns

Calculated mean and standard deviation for the number of stumps per species across the kilns (n=31). The data were found to be skewed. The Kruskal Wallis nonparametric test (Conover 1971) was used to compare the mean number of stumps between the three study species.

2.3.6. Circumference class frequency for each study species

The number of stumps per circumference class were counted for each of the study species, and expressed as a percent of the total number of stumps for that species. Relative frequencies were compared by bar graphs of three species.

2.3.7. Coppice re-growth of cut stumps per study species.

The frequency distribution of the number of coppice per stumps was calculated for each of the study species. Bar graphs for each species were plotted and assessed visually.

2.3.8. Production variables

2.3.8.1. Density of kilns

The density of the kilns was calculated from the mean distance (Mueller-Dombois and Ellenberg 1974) between kilns with following formula: Mean density of the kilns (Kilns/hectare) = Unit area in m^2 */ (Mean distance between kilns in m)*^{2}.

2.3.8.2. Harvesting radius

The mean and standard deviation of the distance per species across kilns was calculated as well as the overall mean distance. The data were not normally distributed. The Kruskal Wallis nonparametric test (Conover 1971) was used to compare the three mean harvesting radii. This was tested using a one sided test at the 5% significance level. Bar graphs with standard errors were plotted.

3.0. CHAPTER THREE – RESULTS

3.1. The system of production and some of the key socio-economic aspects of charcoal production in Catuane

3.1.1. Selection of species for charcoal production.

The key informants (n=21) supplied information about the most commonly utilised tree species for charcoal production. It should be noted that although the questionnaire allowed for a ranking of importance, this was not used in the final analysis. Only the number of times a species occurred in the list was used to calculate its relative frequency. Figure 4 shows the descending order of preference of the tree species used by the charcoal makers. *Acacia nigrescens* is utilised the most, followed by *Acacia nilotica* and *Ziziphus mucronata.* Although other species are utilised, this study focused on the three most commonly used species. Charcoal producers were unanimous that these species produce high quality, resistant charcoal. In particular, the high quality charcoal produced from *Acacia nigrescens* resulted in high revenue for the producers.

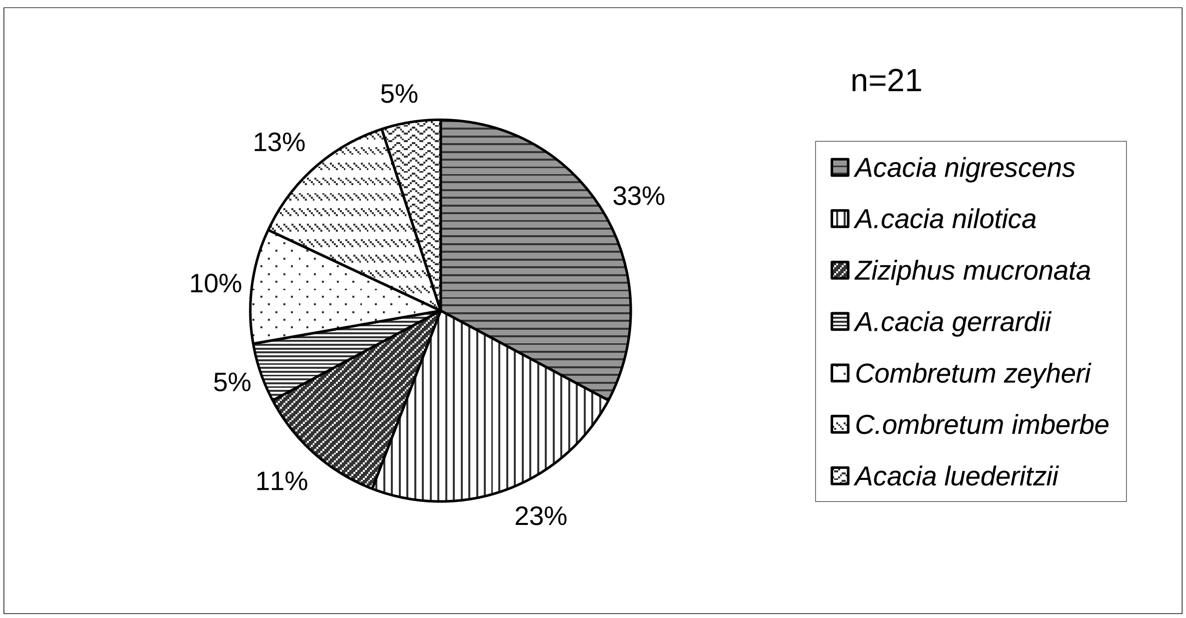


Fig. 4: Relative frequency of the times recorded in the list of the species most utilised by charcoal producers in Catuane.

3.1.2. Origin of charcoal makers

This study showed that the charcoal producers come from outside the Catuane region. Of the 21 charcoal makers interviewed, (18) said that they were from Inhambane, (2) from Gaza and (1) from Maputo provinces located in the north of the region. Regarding time in the business, the majority of respondents (10) had been in the business from one to five years followed by six to eight years (7), nine to ten years (3) and less than one year (1).

3.1.3. Socio - economic costs and benefits of charcoal production

A few relevant production statistics are detailed before discussing the socio-economics. Firstly, the number of trees cut and kilns made depended on the tree density and equipment used to cut trees. With regards the latter, either axes and saws or diesel band-saws were utilised. Band saws were not used very often and have not been included in the analysis. Most (7) of the charcoal makers said that, using axes and saws, they cut approximately 6 to 10 trees per kiln. This was followed by one to five trees (5), sixteen to twenty and twenty-one to thirty and greater than thirty (all 3). All respondents said that they build between one and two kilns per month. In terms of the number of bags of charcoal produced per kiln, (16) produced fifteen to thirty bags, (3) produced ten to fifteen bags and (2) produced more than thirty. The majority of producers (18), reported that production occured predominantly in the dry winter months (April to September), because during the rainy season the kilns are destroyed by the rain and the temperature are too high too work in. Lower humidity in the winter months also allows the kilns to burn more efficiently.

Of the respondents, (19) said that all products are sold to buyers from Maputo or elsewhere at 80,000.00 Meticais (US$ 3.3) per bag whilst (2) sell to everyone at 60,000.00MT (US$ 2.5). Using the average production figures (1.5 kilns per month and 22.5 bags per kiln per month) and the average selling price per bag (80,000.00Mt), a charcoal producer can generate 2700,000.00 Mt month^{-1} (US$112.50). The majority of charcoal is produced and sold in the winter months (April to September). An annual income for a charcoal producer therefore approximates to 16200,000.00 ($675.00). Since the majority of producers have been in the business about 1 to 5 years (i.e. 2.5 for calculation purposes), an accumulated gross capital per producer approximates to 40500,000.00 Mt ($1687.50).

3.1.4. Local community attitudes and perceptions about the activity and its effect on the abundance of trees in the region

The key informants (n=12) supplied information in the local households interviewed in Ndlala. The majority (11) indicated that charcoal production is a recent activity in the region. Most (11) said that this activity has not brought economic benefit or alternatives for local development because charcoal was produced in the area by outsiders and was taken and sold in other regions. The households believed that the charcoal producers did not contribute to the development of the region, mostly because of their transient lifestyle. In terms of the origin of the charcoal makers, (9) of households did not know their origin, whilst (3) said that came from another area because of the language they spoke.

In terms of local utilization of charcoal, the households indicated that they rely predominantly on firewood collected by themselves from their immediate surroundings. Only (1) of the households indicated that they utilized charcoal for cooking. This occurred in winter when firewood utilization for heating purposes increased. Since the local community and the charcoal producers both utilize the trees for their own interests, it is not surprising that (11) of the households regarded charcoal production as a negative activity for the local community, especially with regards the effects on tree populations. They identified damage and destruction of the vegetation caused by the clearing of trees, soil erosion when kilns are built and the burning of large areas resulting from poor control of kilns as problematic. These factors do not only impact on their sources of fuelwood, but also have implications for shade and fodder for livestock, windbreaks, medicine and material for construction. The only (1) of the respondent households that utilized charcoal for cooking believed that the business has benefits because does not have to collect firewood as often and the extra time could be dedicated to other activities. However, acknowledged that the activity had problems associated with it.

In terms of how the problematic situation should be dealt with, (7) of the households believed that charcoal production should be stopped totally, whilst (5) believed that the activity could continue but with a degree of control. In terms of the methods to achieve this, (5) wished to expel the producers, another (5) believed that law enforcement should be applied, (1) believed that the confiscation of materials would solve the problems, whilst another (1) was uncertain as to how to deal with the matter (Fig. 5). With regards who should control or stop the charcoal production (6) of total households interviewed said that the processes require a complete involvement of local government and community. A further (3) said that only the government should be responsible, whilst (2) said that only the local community should be responsible. The remaining (1) gave the responsibility to community based organizations for natural resource conservation
(Fig. 6).

Fig 5: Relative frequency of suggestions by households for the control or elimination of the charcoal activity in Catuane.

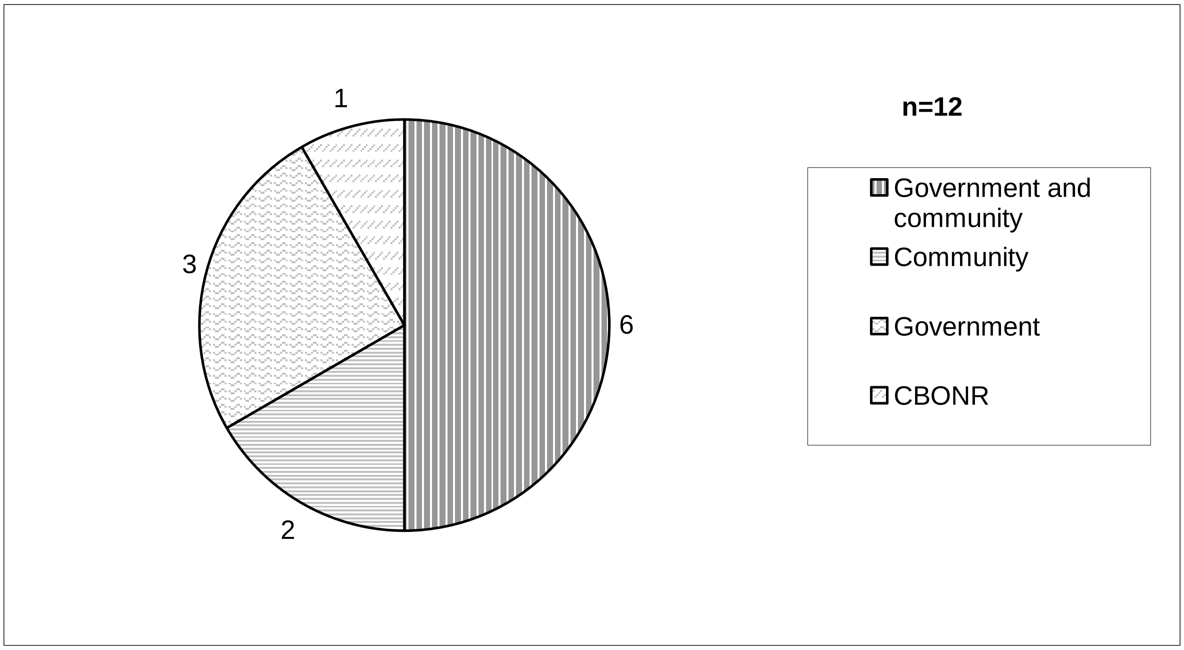


Fig 6: Suggestions as to the agents who could be responsible for the control the charcoal activity in Catuane.

3.2. Impact of harvesting on populations of selected species

3.2.1. Stem circumference class distribution and density of the three study species in harvested and unharvested areas

In both the harvested and unharvested areas, population structure by stem circumference classes for all three species were broadly similar, in that class 1 (0-10cm) has by far the highest frequency. All other classes have considerably lower and similar frequencies (Fig. 7, 8, 9). The difference is less acute but still prominent for *Ziziphus mucronata* (Fig. 9). This species also displayed a different pattern relative to the other two species with regards the comparison between the harvested and unharvested areas. In *Z. mucronata* the size class 1 was slightly more predominant in the unharvested area. In the other two species the situation was reversed, with the harvested areas showing a slight predominance in that class. A further similarity displayed by all the species is a slight tendency of symmetry or normal distribution in the classes 11-20 cm to >150 cm. This tendency is less obvious for *Z. mucronata,* with some of the classes being totally unrepresented.

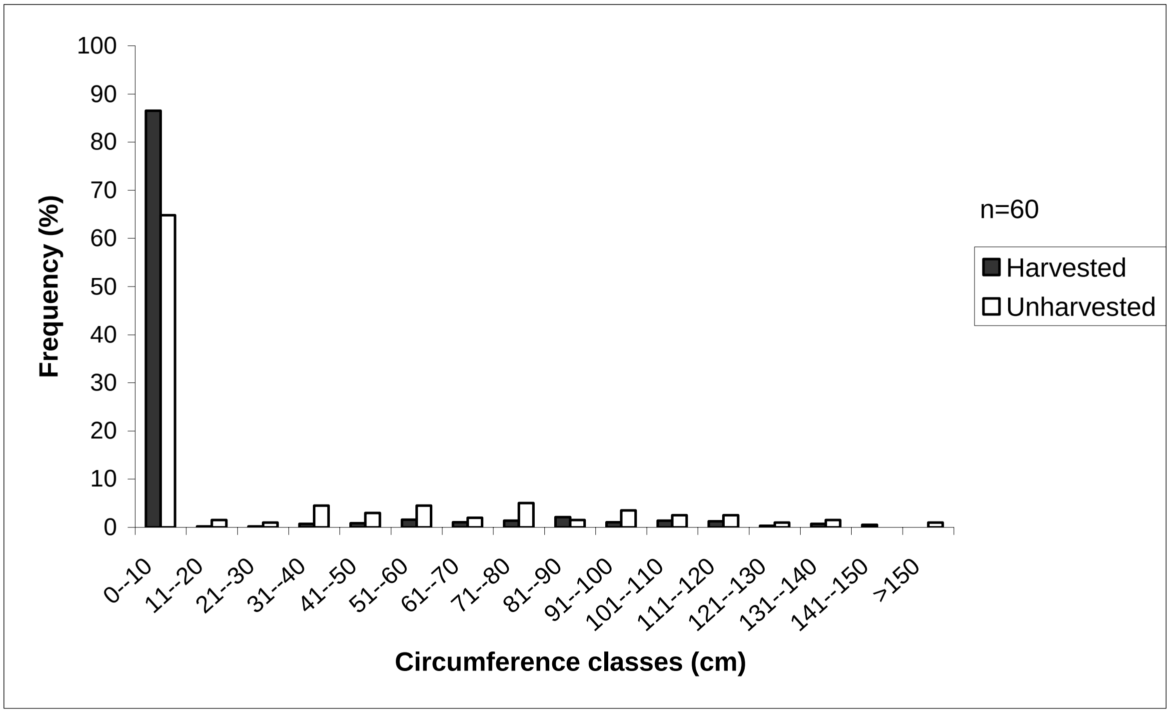


Fig. 7: A comparison of the relative frequencies of the recorded circumferences classes (cm) for the stems of *Acacia nigrescens* in the harvested and uharvested areas.

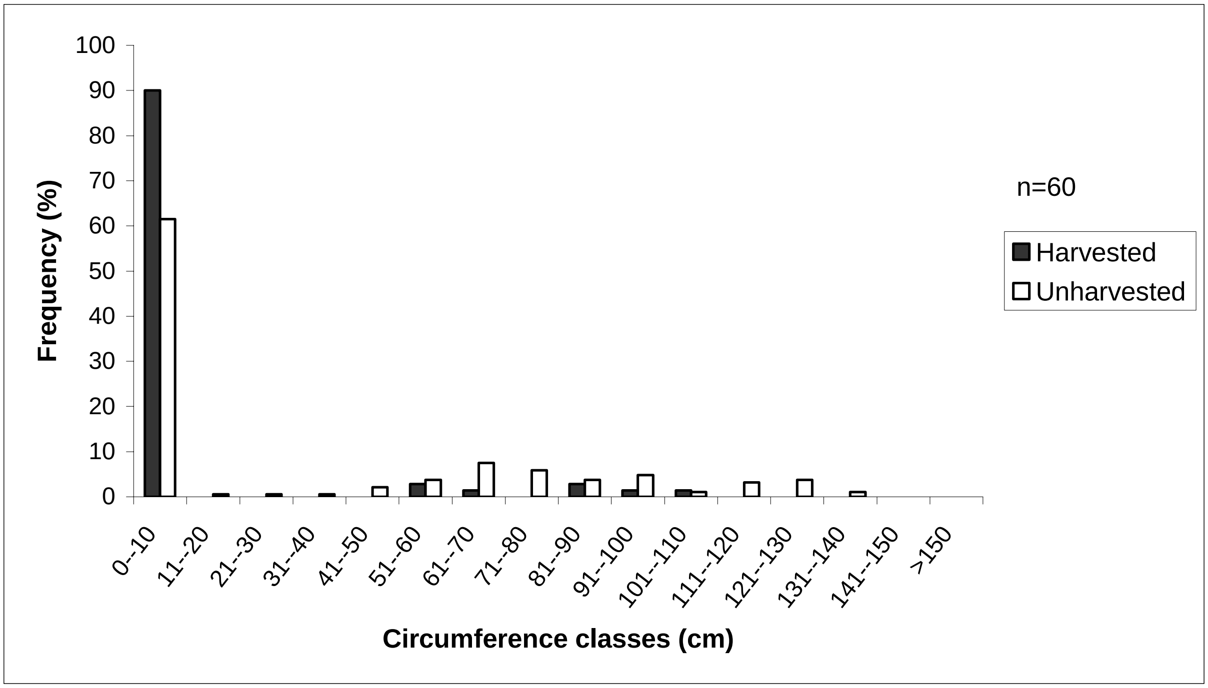


Fig. 8: A comparison of the relative frequencies of the recorded circumferences classes (cm) for the stems of *Acacia nilotica* in the harvested (H) and unharvested (U) areas.

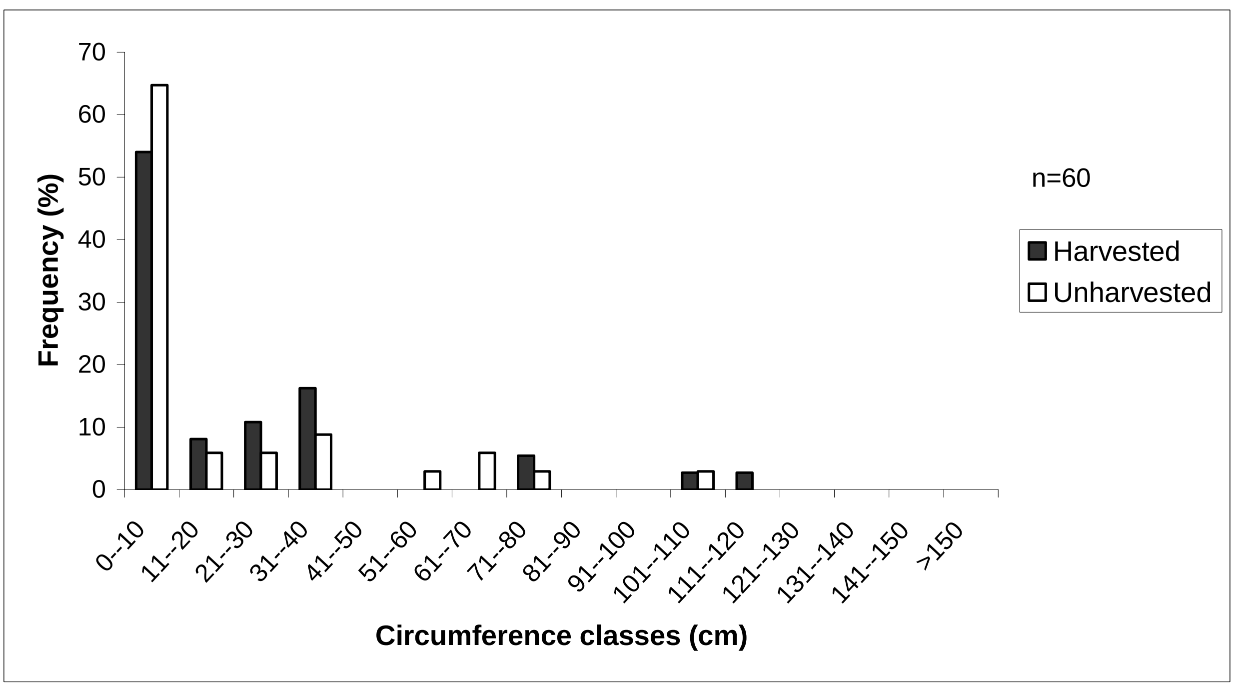


Fig 9: A comparison of the relative frequencies of the recorded circumferences classes (cm) for the stems of *Ziziphus mucronata* in the harvested (H) and unharvested (U) areas.

3.2.2. Density of the three study species in the harvested and unharvested areas

Density of *Acacia nigrescens* stems was significant higher (*p*=0.02) in the unharvested site (762.5 ± 919) than in the harvested site (470.8 ± 789.9) (Fig. 10). Similarly, *A. nilotica* had a significantly higher density of stems (*p*=0.03) in the unharvested site (227.5 ± 263.1) than in the harvested site (213.3 ± 367.3) (Fig. 11). *Ziziphus mucronata* differs from the other two study species, in that density of stems was higher in the harvested site (57.5 ± 90.8) than in the unharvested (37.5 ± 69.4) (Fig. 12). However, these means were not significantly different (*p*= 0.2).

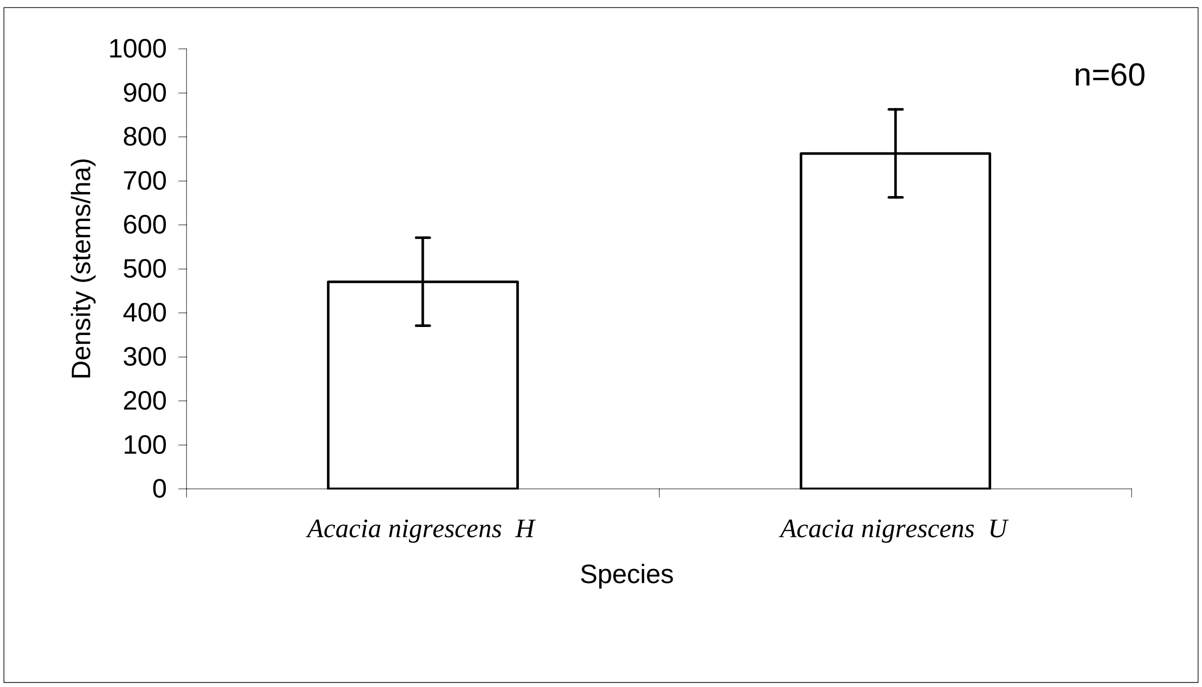


Fig.10: A comparison of the Densities (stems\ha) for the *Acacia. nigrescens* in harvested (H) and unharvested (U) areas.

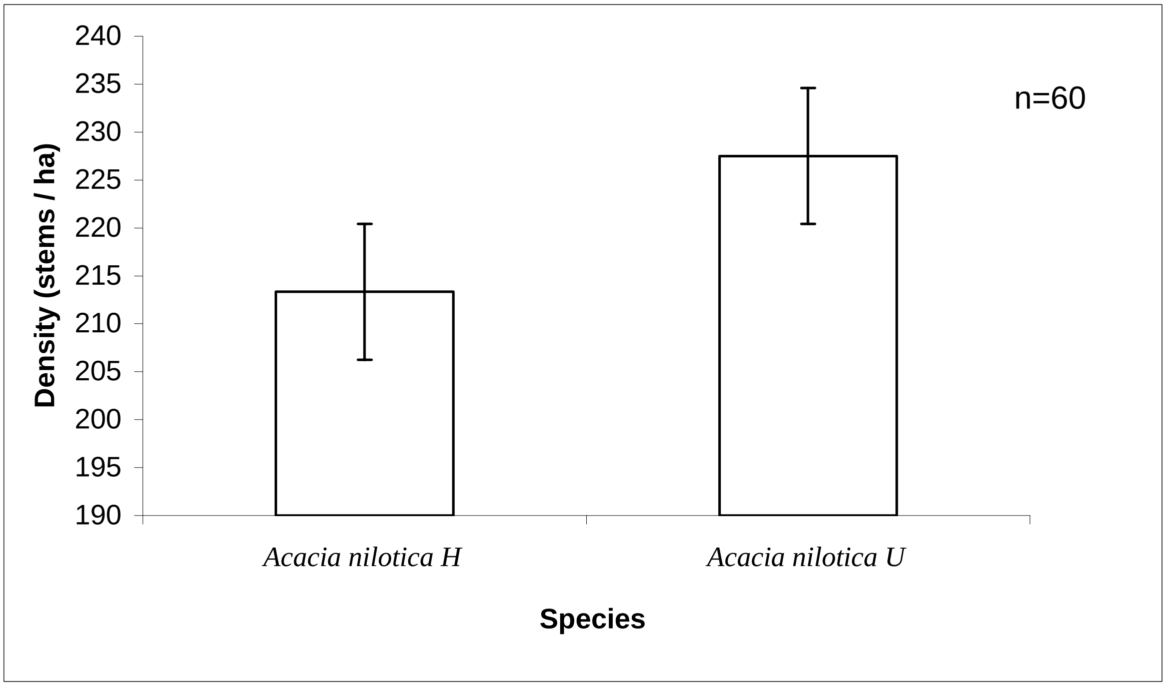


Fig. 11: A comparison of the Densities (stems\ha) for the *Acacia. nilotica* in harvested (H) and unharvested (U) areas

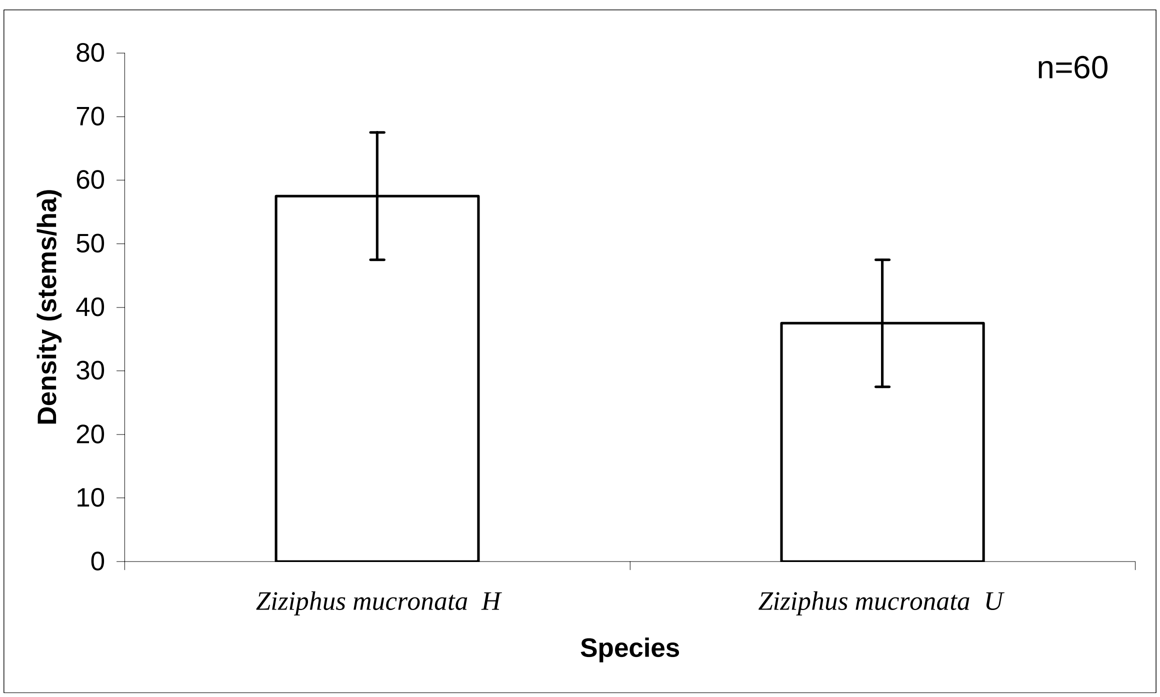


Fig 12: A comparison of the Densities (stems\ha) for the *Ziziphus mucronata* in harvested (H) and unharvested (U) areas.

A further analysis was done in order to look at the combined tree densities of study species between harvested (247.2 ± 528.5) and unharvested area (342.5 ± 628.2). Total density in the harvested area was significantly lower (*p*= 0.04) than density in the unharvested area (Fig. 13).

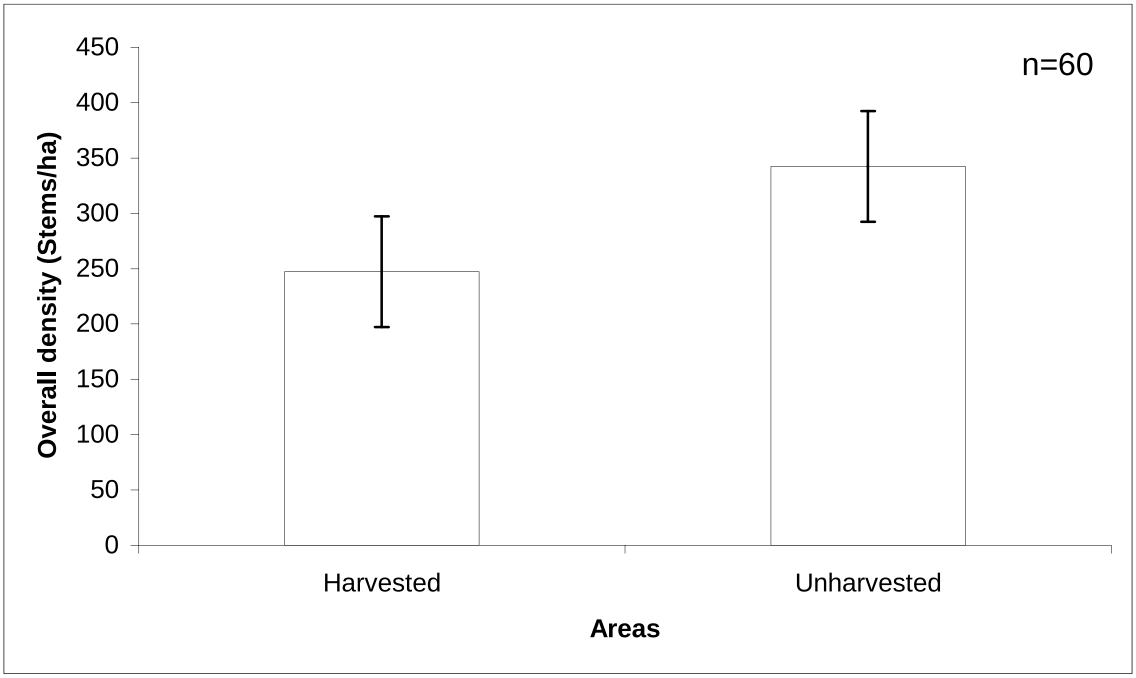


Fig 13: A comparison of the overall Density (stems\ha) for the study species in harvested (H) and unharvested (U) areas

3.2.3. Relative frequency of species, mean number and circumference class of stumps across kilns

Figure 14 shows the relative frequency of cut stumps per species (calculated from observations around 31 kilns). *Acacia nigrescens* and *Acacia nilotica* remain as the two most important species for charcoal production, as determined from analysis of the questionnaires. However, the field investigations identified *Acacia gerrardii* as the third most commonly utilised species, as opposed to *Ziziphus mucronata* identified in the questionnaires. However, the study maintained an emphasis on the three species identified by the questionnaire.

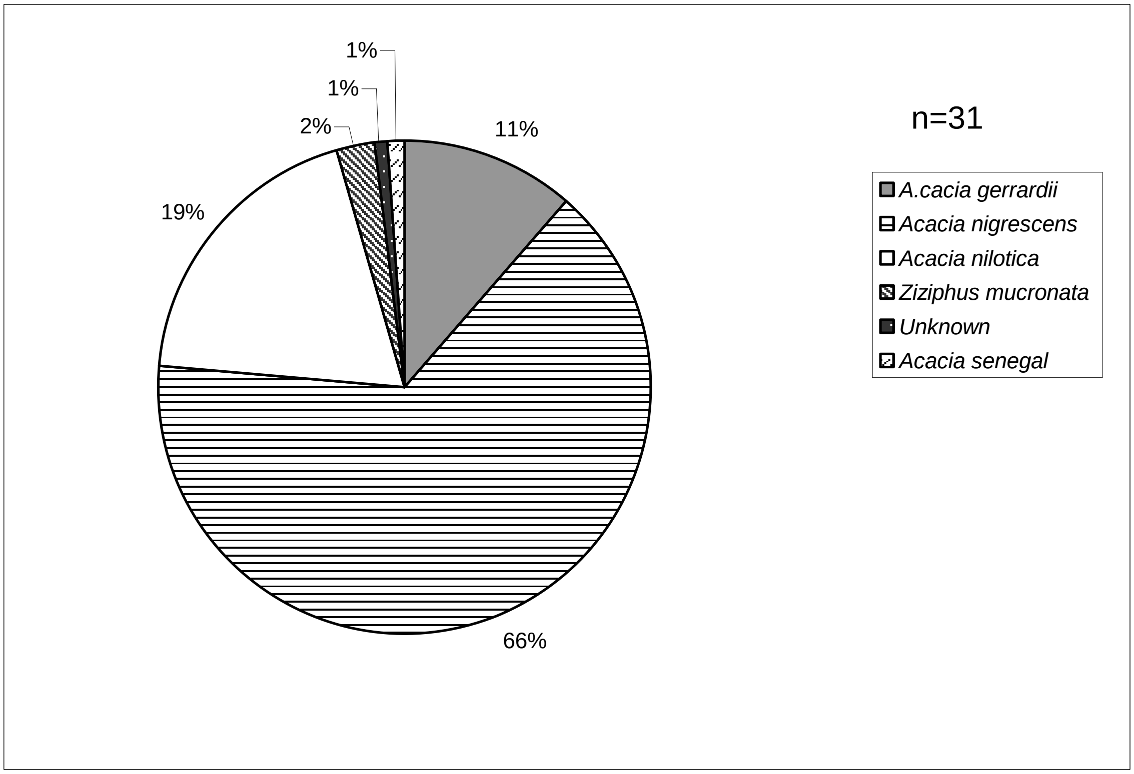


Fig. 14: A comparison of the relative frequencies of the recorded cut stumps per species across kilns

In terms of the mean number of stumps per kiln per species and standard deviations, the following were calculated (Fig. 15):

- *Acacia nigrencens* - (14.9 ± 18.3)

- *Acacia nilotica* – (4.3 ± 3.7)

-*Ziziphus mucronata* – (0.5 ± 1.2)

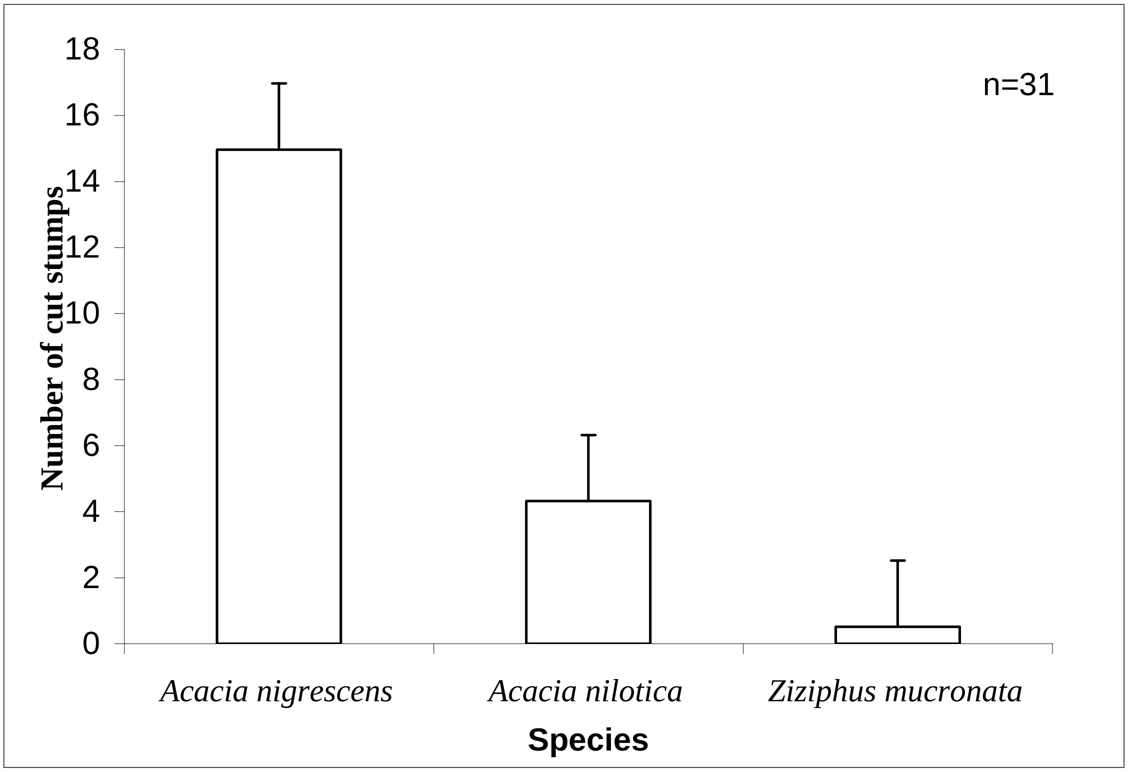


Fig. 15: A comparison of the recorded number of cut stumps of *Acacia nigrescens* (Acng), *Acacia nilotica* (Acnl) and *Z. mucronata* (Zm) across kilns.

The mean number of stumps were significantly different, using the Kruskal Wallis one-sided test at the 5% significance level ($p<0.0001$).

With regards stump circumferences (Fig. 16), *Acacia nigrescens* and *Acacia nilotica*, showed a normal distribution, with class 9 (81-90cm) being the most common. Distribution for *Ziziphus mucronata*, was skewed to the left, with most stumps in class 6 (51-60cm).

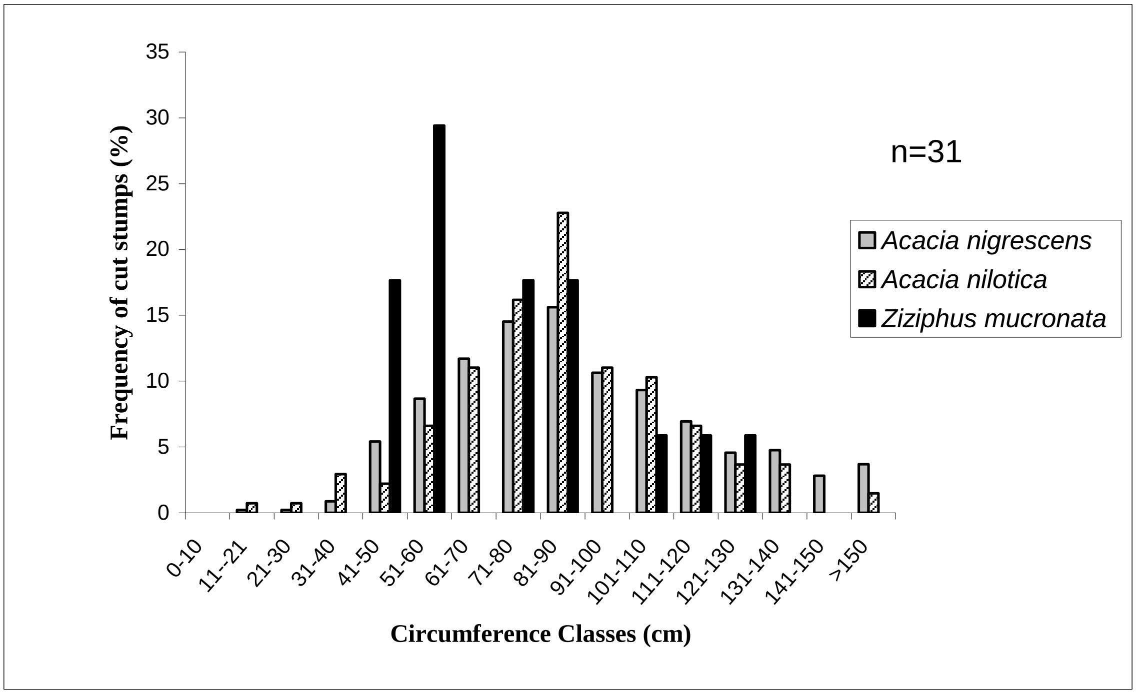


Fig. 16: A comparison of the relative frequencies of cut stumps circumferences classes of the three study species across kilns

3.2.4. Mean height, circumference and coppicing re-growth of cut stumps across kilns

Mean stump heights (calculated from observations around 31 kilns) of *Acacia nigrescens* (21.5 ± 20.9), *Acacia nilotica* (24.5 ± 17.4) and *Ziziphus mucronata* (16.8 ± 18.1) did not differ significantly from each other (p=0.08) (Fig. 17).

Mean stump circumference (calculated from observations around 31 kilns) are normally distributed. The means of *Acacia nigrescens* (91.1 ± 33.4), *Acacia nilotica* (85.8 ± 25.9) and *Ziziphus mucronata* (76.2 ± 24.9) (Fig. 18), are only slightly significantly different from each other (p=0.048). However, the multiple comparison test of Bufferoni for *Acacia nigrescens-Acacia nilotica*, confidence interval: (-2.1, 12.7), *Acacia nigrescens* - *Ziziphus mucronata*, confidence interval: (-3.9, 33.7) and *Acacia nilotica*- *Ziziphus mucronata* confidence interval: (-9.9, 29.2*)* showed no significant difference of mean stumps circumferences between the study species, as confidences intervals include zero.

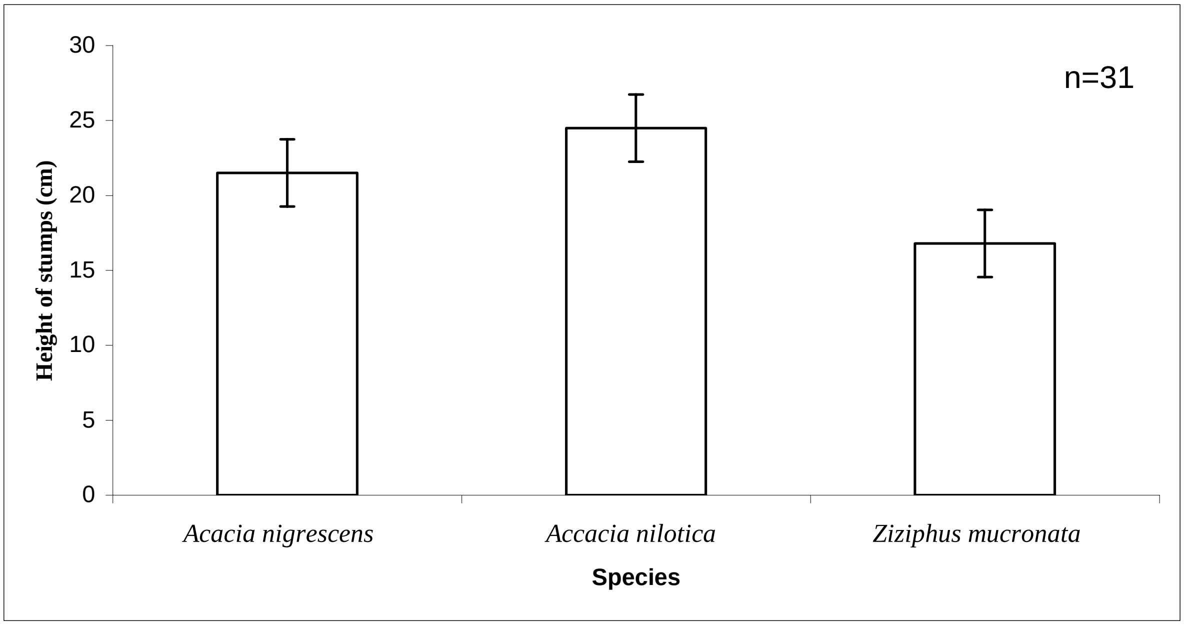


Fig. 17: A comparison of the heights of cut stumps of *Acacia nigrescens* (Acng), *Acacia nilotica* (Acnl) and *Ziziphus mucronata* (Zm)

Fig. 18: A comparison of the circumferences of cut stumps of *Acacia nigrescens* (Acng), *Acacia nilotica* (Acnl) and *Ziziphus mucronata* (Zm) across kilns.

The analysis of the relative frequency of coppice shoots (classes 0, 1-10, 11-20 and >20 cm) for the three study species indicated that they have a high frequency of stumps not coppicing (Fig. 19). *A. nilotica* had the highest frequency not coppicing. With regards coppiced stumps, *Z. mucronata* coppicing appears to be restricted to low values in terms of the number of shoots per coppicing stump. *A. nigrescens* is relatively well represented across the spectrum. *A.nilotica* is also represented in all the classes, but at lower relative frequencies).

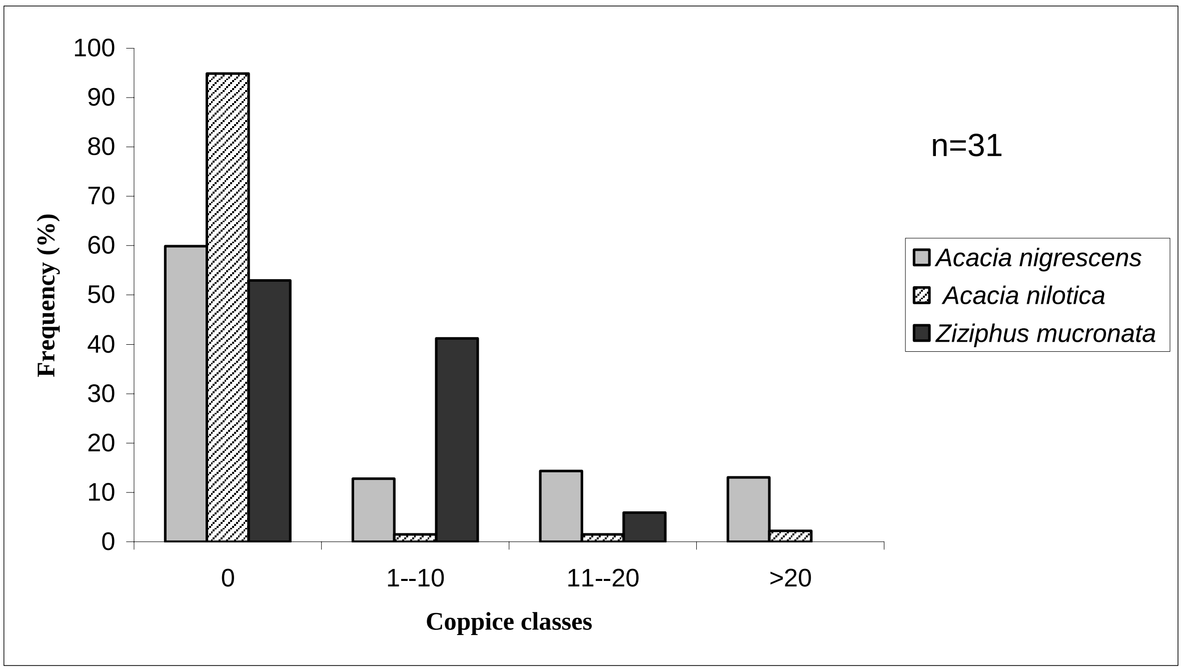


Fig. 19: A comparison of the relative frequencies of coppicing of the three study species (calculated from stumps around 31 kilns)

3.2.5. Density of the kilns and harvesting radius per species

The distance between kilns, as measured between 31 kilns in meters had (72.2 ± 36). This translates into an average density of 2 kilns per hectare (using the formula described in the methods section). The harvested area was about 30 hectares and would therefore contain approximately 60 kilns (30ha X 2 kiln).

The overall harvesting radius for all species combined, calculated from 31 kilns, had a (27.5 ± 23.9). Mean harvesting radius for the three study species was significantly different (p=0.0013). The value was highest in *Ziziphus mucronata* (36.6 ± 14.3) and lowest in *Acacia nigrescens* (26.2 ± 25.2) (Fig. 20).

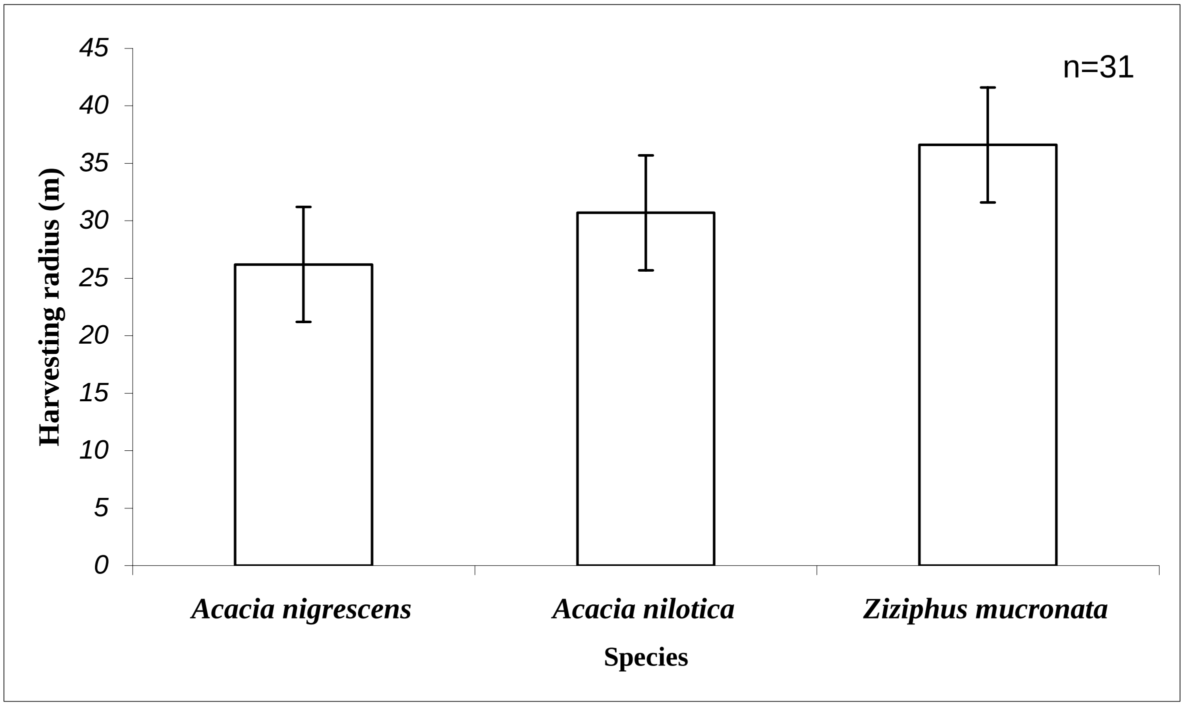


Fig. 20: A comparison of the harvesting radius of *Acacia nigrescens* (Acng), *Acacia nilotica* (Acnl) and *Ziziphus mucronata* (Zm) around kilns.

CHAPTER FOUR: DISCUSSION

In the discussion, the two main topics of the study are considered, namely the system of production of charcoal and the key socio-economic aspects followed by the impacts of charcoal production on selected tree species.

4.1. The system of production and some of the key socio - economic aspects of charcoal production

The system of charcoal production in Catuane is practised in a similar way to the traditional kiln method employed across many countries. The system requires little outlay, production costs are low and markets exist, making it an attractive venture in impoverished areas, of which Catuane is an example. Relative to other rural activities such as agriculture and livestock farming, charcoal production has been seen to be competitive in terms of profits generated (Coomes and Burt 2001). Catuane provides a good example of this. The study has shown that a charcoal producer can generate approximately US$675 during the six month production period (April to September). In terms of profit, this study shows more profitability since the producers in Catuane sell a bag of charcoal for US$3.3 as opposed to US$2 in Kitulanghalo, Tanzania (Luoga *et al*. 2000) and US$ 1.1 in Nhamatanda, in the centre of Mozambique (Biggs *et al*. 2004). It is also noteworthy that this income is generated in winter when other activities such as agriculture are less productive. Furthermore, the main market for the charcoal lies outside Catuane. The activity therefore has potential to inject capital into the community from external sources, providing a catalyst for local economic growth, but this was not observed in this study.

All these potential economic benefits, however, also require a suitable regulatory system or framework to be in place. Of particular importance in determining an appropriate system, is the relationship between charcoal producers and the community in which the activity takes place. In some instances, for example in Tanzania, charcoal producers originate from within the community and often comprise family units (Luoga *et al*.

2000). Economic benefits therefore accrue to the community. In other instances licensed co-operatives are regulated by local or central governments and pay taxes that would indirectly benefit the communities in which the work is done. An example of this is the community association licensed to manage a forested area in Nhamatanda, in the centre of Mozambique (Biggs *et al.* 2004). In Catuane, however, all charcoal producers are from outside the area and operate as one-man enterprises in an informal, transient manner. This may be partially related to the fact that many of the local male inhabitants work in other countries. Furthermore, many of the inhabitants left the area as refugees in the civil war period and have only recently returned. The producers enter a region during the production months, living in temporary structures, and exploit the woodland resources to produce charcoal, which is then transported and sold mostly to the settlements around Maputo. Local inhabitants do not benefit economically from the procedure. In fact, the community incurs an expense, in that the charcoal producers exploit the woodlands that the local community itself relies upon as a resource for fuel, food, medicine, fodder and construction.

The situation is further exacerbated by 'externalisation'. Luoga *et al.* (2000) describes this as '…the motive of personal profit triggering individuals to use the environmental resource more heavily and contribute less to their protection…' The local inhabitants recognise the value of the woodlands and the study has revealed their feelings of anger towards the charcoal producers' exploitation of their resources. The charcoal producing activity seems to be relatively new to the area with most of the producers indicating that they have been involved in the activity for less than eight years. Twine (2005) described how socio-political and economic changes can influence resource use patterns. Mozambique has experienced relatively extreme socio-political changes in recent years as it changed from a colonial era to a new democracy by way of civil war. Previous traditional attitudes towards natural resources, which include a sense of sustainable utilisation, have survived much of these changes, as is obvious from the local communities attitudes. The remoteness of the area may have played a role in the preservation of these values. However the values have recently become threatened by outside forces. The civil war in Mozambique has resulted in a high degree of unemployment and poverty. Former combatants familiar with the remote regions have recognised the economic potential of the woodlands. Being unemployed, the motive of personal profit is foremost in their attitudes i.e. externalisation, and their unsustainable exploitation of the woodland resources brings them into conflict with the more conservative ways of the local inhabitants. The situation is exacerbated by the lack of institutional controls.

The lack of institutional controls is reflected in the local inhabitants' responses to the question of possible solutions to the unsustainable exploitation of their natural resources. Although many of the local inhabitants felt that the activity should be stopped altogether, an almost equal number believed that the activity could continue, but with appropriate controls. Both camps believed that changes needed to be implemented by various combinations of government and community alliances.

However, it should be noted that even if the local inhabitants became part of the process of charcoal production, there would probably still exist the problem of profit driving unsustainable utilisation. The lack of a local market would still see the exportation of the charcoal to other areas as is the case in Nhamatanda, where they produce in the area strategically located with high accessibility to Beira, Chimoio (EN6) highway and inchope-Gorongosa (EN1) highway (Biggs *et al*. 2004).

Finally, when moving towards sustainable forest resource utilisation, lessons from other African countries have to be taken into account where households participated effectively and are moving to sustainable production, such as in Kenya (Okello *et al.* 2001), and Zambia (Chidumayo and Kwibisa 2003). It is urgently required that Mozambican forestry and wildlife law obtains adequate legislation, coordination and capacity of institutions to manage resources. This would provide important tools for sustainable management of savanna tree resources and enhancement of the households vision found in this study, to control or stop the activity in the region. Without these tools, charcoal production will continue to be an illegal and destructive activity contributing to the unsustainable depletion of natural resources, despite the potential profitability of the process.

4.2 Impact of charcoal production on populations of selected savanna tree species

4.2.1 Selection of species for charcoal production

The species of tree considered to be the most utilised by the charcoal producers themselves differed slightly from what field evidence indicated. In both instances, *A. nigrescens* was indicated to be the most utilised followed by *A. nilotica*. However field investigations indicated that *A. gerrardii* was the third most utilised species, not *Z. mucronata*, as indicated by the charcoal producers. Field investigations placed the latter in the fourth most utilised place. Other species identified by the charcoal makers included *Combretum zeyheri, C. imberbe,* and *A. luderitzii*. These were not identified in field investigations. *A. senegal* however was, although it was not mentioned by the charcoal producers. Discrepancies between field investigation and reports from charcoal producers are likely the result of the fact that the field observations were made in an area smaller than the area in which the interviewed producers worked. It may also be a function of availability. Perhaps they prefer *Ziziphus mucronata* to *A. gerrardii*, but *Z. mucronata* may be far less abundant than *A. gerardii*, so they harvest species that give most benefit for effort. Both investigations however highlighted the relative predominance of only two species, namely *A. nigrescens* and *A. nilotica*. This is similar to other areas in which, although there may be a wide variety of species available, those producing relatively high quality charcoal are preferentially exploited. In Tanzania, for instance, of the forty two miombo species, only four were commonly utilised (Luoga *et al*. 2000). The focus on a high quality product (as opposed to mass production of a low quality product) is dictated by the wholesalers who transport the product. Furthermore, the relatively unsophisticated methods of production require a relatively high quality product. The utilisation of particular species and the non-utilisation of others have definite consequences for population distributions. In harvested areas for instance, it was noticed that numerous marula (*Sclerocarya birrea*) trees occurred. This tree produces poor quality charcoal and is also held in high regard for its use as a food source and probably because of folklore aspects (personal observation).

4.2.2. Population structure and density of the three study species in harvested and unharvested areas

Theoretically, natural population structure and density have an approximately normal distribution of the trunk diameter size. With age, higher diameters predominate (Silvertown 1992, Crawler 1998, Okello *et al.* 2004). However, most tree population structures are with most individuals in small size classes, similar to this study (Shackleton 1993a, Shackleton 1993b). A normal distribution was expected to be found in unharvested areas whereas, as this area should have natural stands, composed by the mature and reproductive stands, as should not being harvested. Whilst, it was not necessarily expected in areas subjected to harvesting for charcoal production, as the trees probably being harvested, composed by new individuals in the populations and also it would be expected a similar size class shape but a higher frequency of smaller stems in harvested site due to recovery of trees by coppicing and seedling**.** Regarding the former, for instance, a severe alteration of woody biomass, in terms of a reduction of population structure by size class, of *Brachystegia. spiciformis and Julbernardia globiflora* (miombo) in Zambia (Chidumayo 2003) as a result of charcoal production activity was reported. Similar consequences were reported regarding *Acacia drepanolobium* in Kenya (Okello *et al*. 2001). The study however showed a distribution of trunk circumference heavily skewed towards a younger population in both of the areas, albeit more so in the harvested area (Fig. 7, 8). Three factors need to be taken into account when considering the unusual results for the unharvested area. Firstly, although stumps and kilns were not found in the unharvested area, it is a non-protected, communal land that has been subjected to different types of uses. According to local authorities it was conceded to private intensive livestock and agriculture farming. Secondly, representative sampling was made difficult due to the fact that the trees were not evenly distributed in the study area, but rather occurred as irregularly distributed thickets and patches in grasslands. It should also be noted that the *Ziziphus mucronata* data displayed a further peculiarity in that the unharvested area had a greater predominance of stem circumference in the small size class, than that in the harvested area (Fig. 9).

As has been found in previous studies (Okello *et al*. 2001) it was considered likely that the densities should decrease when comparing harvested to unharvested areas. *A. nigrescens* and *A. nilotica* showed this decrease. In both cases the differences were statistically significant (Fig 10, 11). This implies that the cutting of trees in the harvested region increases mortality rates and/or the reproductive ability of trees in the harvested region has been negatively affected. This could arise from the preferential harvesting of mature trees that reproduce through seed dispersal methods. As with the circumference data, *Ziziphus mucronata* gave contrary results, with the harvested area having a higher density than the unharvested area (Fig. 12). The difference between the mean values was, however, not statistically different. A possible reason for the result is that the relatively minor harvesting of *Z. mucronata* is made up by enhanced regenerative capabilities of *Z. mucronata* due to a reduction in competition from the preferentially harvested Acacias. In terms of combined density values, the decrease in density from harvested to unharvested areas, as displayed by the Acacias, is borne out.

The results of this study in terms of the affects of charcoal production on population structures and density are generally similar to previous studies, however further work needs to be done on population structures of indigenous species in protected areas.

4.2.3. Harvesting intensity by circumference class and height of stumps of selected tree species

Analysis of the number of cut stumps per species for only the three study species (Fig. 15) further validated their relative importance in the production process. *A. nigrescens* was significantly more utilised. From Figure 18, it is obvious that no matter what the species of tree, a similar size of tree (in terms of circumference) is harvested. Although it might be concluded that the producers specifically focus their efforts on this size of tree, observations of their activities indicated that they were not doing this. The distributions of the circumference data of harvested trees per species for *A. nigrescens* and *A. nilotica* were normally distributed whereas the data for *Z. mucronata* were skewed to the left (Fig. 16). The distributions show, therefore that the producers appear to utilise all sizes of tree. This is in keeping with the general method of kiln production. According to Okello *et al.* (2001) from 43 to 69% of the biomass for trees with diameters greater than 4 cm can be utilised for charcoal production and the remainder is used as fuel for kilns, kiln spacers, and firewood (<2cm diameter), most twigs and leaves are utilised for covering denuded areas to encourage re-vegetation. Other studies also reported the utilisation of a range of tree sizes (Chidumayo 1979, Luoga *et al*. 2000, Chidumayo 2003). Mean stump height did not differ significantly between the species and averaged close to 20 cm. The heights of cut stumps indicated that the producers cut as low down as possible to utilize as much of the tree as possible (Fig. 17).

In terms of the mean harvesting radius per species (Fig. 20), *A. nigrescens* (the most utilised tree species) has the lowest harvesting radius. A likely interpretation is that the producers site their kilns in an area that has a relatively high abundance of the preferred species.

4.2.4. The effect of various factors on the number of coppice shoots in the harvested area

The stump circumferences and heights were measured, since these could play a role in the recuperative abilities of the harvested trees, as discussed in the review.

Many African studies reported that savanna species subjected to harvesting, showed a high ability of recovering by coppicing from the remaining stump (Shackleton 2001). The analysis of the relative frequency of coppicing (Fig. 19) indicated that most of the stumps were not coppicing. *A. nilotica* was particularly unsuccessful, followed by *A. nigrescens* and *Z. mucronata*, which had similar success rates. However, it was noted that many of the stumps which were included in the class of ‘no coppice shoots’, had shoots which had died. Possible reasons for this include factors such as, self-thinning (Okello *et al.* 2004), herbivory, rainfall (Okello *et al.* 2004), fires, soil type, species type and stump dimensions (Shackleton 2001, Luoga *et al.* 2004, Kashula *et al*. 2005), as discussed in the literature review.

In terms of soil type, it has already been mentioned that the study is situated in a generally fertile area. As such, the soil is unlikely to have affected the coppicing abilities. Herbivory may have affected the number of coppice shoots. Studies of foraging behaviour of cattle and goats in oak forest stand showed that goats foraging behaviour includes woody species coppice shoots (Papachristou *et al*. 2005). The study area is dominated by livestock and few game which probably could have browsed coppicing shoots. In terms of rainfall, it has been shown that rainfall amounts in the region of 550 mm per year can negatively affect coppicing (Okello *et al.* 2004). The study area has similar rainfall amounts 500-600 mm (Van Wyk and Smith 2001) and may well have influenced the coppicing ability of the study species. Circumference of cut stumps may also affect coppicing effectiveness. Southern African studies showed that *Terminalia sericea*, has the highest coppicing effectiveness at the highest circumference (Shackleton 2001). This study, in Southern Mozambique, has indicated that the stumps have a relatively large circumference (Fig. 18). It is unlikely therefore that the circumferences play a role in preventing coppicing success. In terms of stump height, southern African savanna species (*T. sericea)* showed that cut stumps of less than 20 cm height produced few coppicing shoots (Shackleton 2001). In this study, harvested trees are cut at a height very close to this figure (Fig. 17). This may well have played a role in influencing coppicing ability since the greater the cutting height the lower the potential impact of browsers and fire (Shackleton 2001). Fires in southern Mozambique have been reported as a regular natural phenomenon (Van Wyk and Smith 2001). Therefore the relatively short cutting height probably exposed the cut stumps to burning. This would be exacerbated in the low density harvested areas due to enhanced wind movement.

4.2.5. Sustainability of charcoal production in the study area

To obtain an idea of the sustainability of charcoal production in Catuane, production figures need to be compared to re-growth figures in harvested areas. Some of the required data to make these estimations was not available for the study area and reasonable estimates from other studies have been utilised. In terms of production, an average kiln produces approximately 660 kg of charcoal. Each harvested hectare contains approximately two kilns, making the production for a hectare equal to approximately 1300 kg of charcoal. Luoga *et al*. (2000) recorded biomass production, after harvesting, of 3.7 tonnes per ha per yr for miombo woodlands. This equates to 4.35 m^3 per ha per yr. Using a conversion of 8 m^3 producing 1000 kg of charcoal, it can be calculated that the re-growth can be converted into 560 kg charcoal. Therefore if you are producing more than this amount of charcoal from a hectare of African woodland, you will be testing the boundaries of sustainability. This is obviously the case in the present study where twice the amounts are being produced. However the sustainability question also requires temporal evaluation. If you allow the harvested area to grow for two or more years, it is possible that it can replace the biomass removed. Such details of intensity of harvesting are not available for this study and should be further investigated. Whether or not the Luoga *et al.* 2000 data are a reasonable reflection of re-growth rates and wood to charcoal conversion factors in this study is also debatable. However the analysis provides a starting point for further investigation. Also of importance in the analysis would be to quantitatively evaluate the effect of harvesting procedures, such as height of stem cuts, on re-growth abilities.

CHAPTER FIVE – CONCLUSIONS

5.1. Ecological and Socio – economic impacts of charcoal production

Studies considering the socio-economic role of charcoal production from natural resources have shown varying degrees of benefits and costs. Most studies indicate that markets exist for the product, especially in terms of it being a relatively cheap alternative energy source for impoverished areas. This study has confirmed that this general situation is applicable to southern Mozambique where charcoal producers are able to make a livelihood from the process. However, ideally the utilisation of natural resources should not be motivated by profit alone. The concepts of sustainability, economic growth and social development, that are particularly pertinent to third world development, need to be considered and incorporated into the process. This study has identified that in Catuane, problems exist with regards these concepts. Considering one of the fundamental requirements for continued success of charcoal production, namely sustainability, the following problems have been identified. First and foremost, the amounts of charcoal being produced (approximately 1300 kg per ha) requires the harvesting of approximately 10 m^3 of wood per ha. Other studies in African woodland have indicated that harvested areas replace biomass at the rate of approximately 4.35 m^3 per ha per year. In other words, if a hectare of woodland is harvested, it would require two to three years to replace the harvested biomass. One problem is that harvesters remove mature trees, and with them the reproductive ability of the system through seed dispersal. Certainly, this study has shown that the charcoal producers utilise all sizes of tree and are not discriminating when it comes to reproductive conditions. Another possible problem arises in that certain species are preferentially exploited, such as *Acacia nigrescens*, and *Acacia nilotica* identified in this study. The obvious result is a change in the species structure of the woodlands i.e. a fundamental alteration of the ecosystem that may have implications for long term balances and sustainability issues. It is generally identified that African savanna trees have the potential to regenerate from cut stumps through the process of coppicing. The study has indicated that this potential is being stunted in the study species, as is evidenced by the number of stumps not coppicing, or having failed to do so successfully. Previous studies have shown that the height of cutting can play an important role in affecting the success of coppicing. This study has shown that average cutting heights are in the region considered to have potential negative effects, with damage of coppicing shoots by herbivory and fires being identified as likely candidates. Other factors such as low rainfall amounts may also be playing a role. The study has therefore indicated that sustainability of charcoal production in Catuane may be a problematic issue. However, the system needs to be studied in more detail to obtain a better quantification of the problem. For instance, the exact recuperative potential of the woodlands in Catuane need to be measured. With regards how much time a particular area is allowed to recover before it is re-harvested need to be detailed. These details would then ideally need to be incorporated into formal plans for sustainable harvesting, with the aim of maximising the profitable exploitation of the interesting market for charcoal identified in southern Mozambique.

The idea of the formalisation of the process arises from a number of considerations. A fundamental driver of the charcoal production process is the profit motive. However, at the same time that it acts as an initiator and driver. Luoga *et al*. (2000) described the concept of externality as being relevant to charcoal production in their study in Tanzania. This idea of "personal profit triggering individuals to use common environmental resources more heavily and contribute less to their protection" is relevant to this study as well. Charcoal producers in Catuane are transient individuals from outside the region. They sell their product predominantly to outside markets and retain all profits for themselves. The local community receive no benefits from the process, since it is informal and taxes are not paid. The community has recognised that not only do they not receive any benefits, but that the activity is a potential threat to their woodland resources, for which they rely on for various products. Their animosity towards the charcoal producers was evident in interviews, with the majority of interviewed households indicating that the production must either stop or be regulated. The lack of a common property regime in the area is not surprising considering the socio-political upheavals in Mozambican recent history, with disruption and displacement of communities. Community property rights need to be re-fostered in order to address the socio-economic issues. Only then can scientific knowledge be utilised to address ecological and sustainability issues. Therefore local government should bring together a variety of stakeholders in order to involve them in woodland management, with government institutions providing a broader enabling environment. Government needs to act along with traditional leadership to establish appropriate frameworks to motivate the profit maximisation from agriculture, livestock and eco-tourism. In the meantime, charcoal producers could be educated and encouraged to integrate with local development programs.

The key message of this study is that the integration of indigenous and scientific knowledge requires careful evaluation, as it has shown some inconsistencies. However, it is a useful and important method to allow an understanding of the system of production and some key socio-economics aspects of charcoal production in Catuane. The success of forest natural resource management programs in the area requires the integration of different stakeholders. This is evidenced by the findings of the social study guiding subsequent application of ecological methods. In spite of some inconsistencies in incorporating indigenous knowledge into scientific methods, it had proved relevant in this study, determining exactly the impact of charcoal production on selected savanna species in Catuane, southern Mozambique. The interaction with local communities allowed an understanding of their visions, and incorporation of these visions in ensuring their effective participation in the sustainable utilization of savanna species. The study has shown that it is appropriate and useful to incorporate social and ecological variables in research. Social sciences and economics have a role to play in the process of moving into a new paradigm, one which incorporates a multidisciplinary approach towards the better understanding of the importance of the human dimensions on vegetation change in rangelands, and sustainable savanna resource management at the local level.

5.2. RECOMMENDATIONS

5.2.1. Further study

A more detailed economic viability study of charcoal production, from the producers to consumers, needs to be completed. It should incorporate an analysis of biomass per bag of charcoal that can sustain continued production in southern Mozambique.

A similar study in savanna species in other areas is required in order to determine the pattern of savanna species utilisation, identifying potential natural resources which can be alternatives for poverty alleviation.

A study of the population structure of woodlands in protected areas needs to be completed to augment the data collected here. This is in light of the finding that the unharvested area in this study had probably been utilised for agriculture in the past.

5.2.2. Conservation and management

The fact that these forests require a period of recovery is often overlooked in current management practices. Forests often occur in rural areas, where use is high and scientific knowledge and management is poor, placing them under compound threats (Lawes *et al.* 2004). There is a perception that sustainable use can proceed in the absence of the understanding of forest dynamics. Indeed the notion that ecological research is time consuming, and is a hurdle to social transformation and the use of natural resources, has promoted the recent emphasis of implementing strategies of forest use in advance of our understanding of the system. While there is no denying the urgency of the many social issues associated with forest resource use, and the need for some very quick practical solutions, perhaps the most serious consideration is to develop long-term management strategies that will prove that by understanding forest ecology, we can more carefully implement methods for managing forest use in a sustainable manner (Lawes *et al*. 2004).

CHAPTER SIX - REFERENCES

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CHAPTER SEVEN - APPENDIX

7.1. Questionnare for charcoal makers

Name____________________________M/F______________

Date___/___/____time of the day__________________

1. Which type of trees do you utilize most for making charcoal? Or give me 3 trees names most utilized for charcoal in decreasing order. // que tipo de arvores cortas para fazer carvão ou indique em ordem decrescente, três arvores que mais utilizam
   - ☐ Sp.1. ____________________________vernacular name_____________
   - ☐ Sp.2. ____________________________vernacular name_____________
   - ☐ Sp.3. ____________________________vernacular name_____________
   - ☐ Sp.4. ____________________________vernacular name_____________
   - ☐ Sp.5. ____________________________vernacular name______________

2. Why do you use these trees than other // diga a razão de preferires estas arvores para o carvão.
   - ☐ Burns easly // queima facilmente
   - ☐ Easier to cut // fácil de cortar
   - ☐ It is abundant // facil de encontrar
   - ☐ It makes good charcoal and more requested by buyers // produzem bom carvão, mai preferido pelos compradors.
   - ☐ None of above reasons // nenhuma das razões acima mencionada

3. How many trees do you cut per kiln? // quantas arvores cortas por forno?
   - ☐ 1 - 5
   - ☐ 6-10
   - ☐ 11-15
   - ☐ 16-20
   - ☐ 21-30
   - ☐ > 30

4. How many bags do you produce per kiln? // quantos sacos produzes por forno?

   ☐ 5-10
   ☐ 10-15
   ☐ 15-20
   ☐ 20-30

5. How many kilns do you produce per month // quantos fornos produzem por mês?

   ☐ 1-2
   ☐ 3-4
   ☐ 5-6
   ☐ 7-8
   ☐ 9-10
   ☐ >10

6. Are the kilns produced permanent? // os fornos produzidos são permanents?

   ☐ No
   ☐ Yes

7. For how long are you in this busness? // a quanto tempo estás neste negocio?

   ☐ 1-5 y
   ☐ 9-10 y
   ☐ 11-15y
   ☐ 16-20y
   ☐ > 10y

8. Where do you sell the charcoal produced? // onde é que vendes o carvão produzido?

   ☐ Catuane
   ☐ Boane
   ☐ Intermediary
   ☐ Maputo city
   ☐ I am a worker
   ☐ Changalane
   ☐ Matola

☐ Other /specify___________________

9. How much do you sell a bag? // quanto custa um saco de carvão?(1r=+/-3500.00mt)

10. Where do you get the empty bags? // onde apanhas os sacos vazios?

11. Where do you come from? // de onde vens?
    - ☐ South africa
    - ☐ Catuane
    - ☐ Changalane
    - ☐ Maputo city
    - ☐ Inhambane
    - ☐ Gaza
    - ☐ Other. Specify___________________

12. Which month or season do you produce more charcoal? Specify // qual é o mês ou epoca que tens mais produção de carvão? Especifique.

13. Why do you produce more or less particularly in this month or season? // porquê produz mais ou menos neste mês ou epoca?

7.2. Questionnaire for households

Date___/___/____male___female___husband___wife___children

1. What kind of energy do you use at home? // que tipo de energia utilizam?
   - ☐ Wood fuel
   - ☐ Charcoal
   - ☐ Electricity
   - ☐ Gas
   - ☐ Other specify___________________

2. How much does the energy cost in meticais per day/week/month // quanto custa a energia por dia/semana/mês?

3. Which month or season do you use more energy // qual é o mês que tens energia em abundancia?

4. Why // porquê?

5. Do you think the charcoal production brings benefits to this area? Achas que a produção de carvão trás beneficios nesta região?

6. Why? // porquê?

7. Do you think the harvesting of charcoal creates any problems? If so, explain. // achas que a exploração do carvão cria alguns problemas? Se sim quais.

8. Where do most charcoal makers come from? Donde são originarios os produtores de carvão?

9. Do you think they should be controlled or stopped? // pensas que podem ser controlados ou proibidos?

10. Why/why not? // porquê / porquê não?

11. If yes, who should control them? // se sim quem deve controlar ou proibir a exploração de carvão?

12. What do you think has to be done to minimize or stop the charcoal production? O que pensas que deve ser feito para reduzir a produção do carvão?

7.3. Table 2: Data collection sheet for population structure of selected tree species

Plot Number	**Species Code**	**Number of individuals**	**Circumference (cm)**	**Coppice**

7.4. Table 3: Data collection sheet for density and harvesting radius around kilns

Kiln Nr	Specie code	Distance between kilns (m)	Distance of Stump (m)

7.5. Table 4: Data collection sheet for size class and coppice shoots of stumps around kiln

Kiln Number	Species code	Height of stumps (cm)	Circumference of stumps (cm)	Nr of coppice shoots

7.6. Table 5: Relative frequency of stem circumference classes for *Acacia nigrescens* (Ac ng), *Acacia nilotica* (Ac nl) and *Ziziphus mucronata* (Zm) in harvested (H) and unharvested (U) areas

	Acacia nigrescens		***Acacia nilotica***		***Ziziphus mucronata***	
Circumfer. classes	***Freq.* H (%)**	***Freq* U (%)**	***Freq H* (%)**	***Freq U* (%)**	***Freq H* (%)**	***Freq. U* (%)**
0---10	86.50	64.82	90.00	61.50	54.05	64.71
11---20	0.18	1.51	0.00	0.53	8.11	5.88
21---30	0.18	1.01	0.00	0.53	10.81	5.88
31---40	0.71	4.52	0.00	0.53	16.22	8.82
41---50	0.89	3.02	0.00	2.14	0.00	0.00
51---60	1.60	4.52	2.86	3.74	0.00	2.94
61---70	1.07	2.01	1.43	7.49	0.00	5.88
71----80	1.42	5.03	0.00	5.88	5.41	2.94
81----90	2.13	1.51	2.86	3.74	0.00	0.00
91---100	1.07	3.52	1.43	4.81	0.00	0.00
101---110	1.42	2.51	1.43	1.07	2.70	2.94
111---120	1.24	2.51	0.00	3.21	2.70	0.00
121---130	0.36	1.01	0.00	3.74	0.00	0.00
131---140	0.71	1.51	0.00	1.07	0.00	0.00
141---150	0.53	0.00	0.00	0.00	0.00	0.00
>150	0.00	1.01	0.00	0.00	0.00	0.00
	100	100	100	100	100	100

7.7. Table 6: Stem density per hectare of *Acacia nigrescens, Acacia nilotica and Ziziphus mucronata* in Harvested and Unharvested Areas

Plots	Ac ng H	Ac ng U	Ac nl H	Ac nl U	Zm H	Zm U
1	2450	700	650	0	300	0
2	25	300	50	1125	0	100
3	400	425	325	1025	0	0
4	125	275	0	175	0	75
5	900	1575	250	250	0	0
6	650	150	25	0	150	0
7	300	400	0	550	0	0
8	375	325	25	50	0	0
9	0	400	50	0	100	125
10	0	125	200	175	125	0
11	25	75	650	175	50	150
12	625	175	750	125	275	325
13	225	175	300	100	50	25
14	125	150	25	75	75	75
15	175	2925	1550	200	0	0
16	575	850	550	275	0	0
17	425	800	0	100	0	0
18	75	600	0	225	25	50
19	325	725	0	300	25	0
20	250	3225	75	400	0	0
21	0	3425	0	0	0	0
22	900	1025	925	200	300	25
23	225	175	0	75	0	50
24	50	1375	0	150	125	0
25	300	150	0	275	0	25
26	250	200	0	75	25	0
27	125	1325	0	275	75	0
28	125	425	0	0	0	0
29	250	400	0	225	0	0
30	3850	0	0	225	25	100

7.8. Table 7: Density of *Acacia nigrescens, Acacia nilotica and Ziziphus mucronata* in Harvested and Unharvested Areas

Species	Harvested				Unharvested				Pvalue
	Means	**STD**	**SE**	**Total**	**Means**	**STD**	**SE**	**Total**	
A. nigrescens	470.8	789.9	144	14125	762.5	919	167.7	22875	0.02
A. nilotica	213.3	367.3	67.1	6400	227.5	263.1	48	6825	0.03
Z. mucronata	57.5	90.7	16.5	1725	37.5	69.4	12.7	1125	0.2
Overall	247.2	528.5			342.5	628.2			0.04

7.9. Table 8: Frequency, mean number of stumps, mean stumps height and mean stumps circumference for study species across kilns

Species	Freq (%)	Mean Height (cm)	STD	Pvalue	Mean Circ. (cm)	STD	Pvalue.	Mean. Nr Stumps	STD	Pvalue.
Acacia nigrescens	62.02	21.5	20.9	0.086	91.1	33.4	0.093	14.96	18.31	<0.0001
Acacia nilotica	19.2	24.5	17.4		85.8	25.9		4.32	3.7	
Ziziphus mucronata	2.4	16.8	18.1		76.2	24.9		0.52	1.23	
Others	13.4									

7.10. Table 9: Harvesting radius for *A. nigrescens A. nilotica* and *Z. mucronata*

Species	**Mean distance(m)**	**STD**	**Pvalue**
Acacia nigrescens	26.22	25.15	0.0013
Acacia nilotica	30.7	19.5	
Ziziphus mucronata	36.6	14.3	
Overall	27.5	23.9	

7.11. Table 10: Relative frequency (%) of stump circumference class of study species

Class Numbers	**Circumfer. classes**	***Acacia nigrescens***	***Acacia nilotica***	***Ziziphus mucronata***
1	0---10	0	0	0
2	11---20	0.3	0.7	0
3	21---30	0.2	0.7	0
4	31---40	0.9	2.9	0
5	41---50	5.4	2.2	17.7
6	51---60	8.7	6.6	29.4
7	61---70	11.7	11.0	0
8	71----80	14.5	16.2	17.7
9	81----90	15.6	22.8	17.7
10	91---100	10.6	11.0	0
11	101---110	9.3	10.3	5.9
12	111---120	6.9	6.6	5.9
13	121---130	4.6	3.7	5.9
14	131---140	4.8	3.7	0
15	141---150	2.8	0	0
16	>150		1.5	0
16	**16**	**100**	**100**	**100**

7.12. Table 11: Relative frequency (%) of coppice of three study species

Class Numbers	Coppice Classes	*Acacia nigrescens*	*Acacia nilotica*	*Ziziphus mucronata*
1	0	59.9	94.9	52.9
2	1--10	12.8	1.5	41.2
3	11--20	14.3	1.5	5.9
4	>20	13.0	2.2	0
		100	**100**	**100**