VEGETATION CHANGE ANALYSIS AND ECOLOGICAL RECOVERY OF THE COPPERBELT MIOMBO WOODLAND OF ZAMBIA

BY

Stephen Syampungani

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Promoters: Professors Coert J. Geldenhuys and Paxie W. Chirwa

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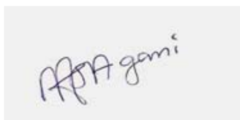
Declaration

I, Stephen Syampungani do hereby declare that the work contained in this thesis is my own original work and has not previously in its entirety or in part been submitted to any University for a degree. I wish also to declare that none of this work has been published by any other person elsewhere. As such, each chapter of this thesis has been prepared in accordance with the guidelines of the target Journal.

Signature  Date : 15/02/2009

Stephen Syampungani (Candidate)

Abstract

The study aimed at developing a new understanding of the Miombo woodland recovery dynamics when exposed to single tree selection, slash & burn agriculture and charcoal production. Five specific studies were conducted to examine different parts of this overall study: Miombo woodland utilization, management and conflict resolution among stakeholders; species-stem curves as a tool in sampling the development of Miombo woodland species richness in charcoal and slash & burn regrowth stands over time; the impact of human disturbance on the floristic composition of Miombo woodland; regeneration and recruitment potentials of key Miombo woodland species after disturbance; and age and growth rate determination using selected Miombo woodland species. Different methods were developed for each specific study. The study of woodland utilization and management employed semi-structured and key informant interviews. STATISTICA statistical package version 6.0 was used for data collation and analysis. Chi-square tests were used to show levels of significance in differences that existed between different user groups. Species-stem curves were used to determine the sample size to assess Miombo woodland dynamics in regrowth stands after slash & burn and charcoal production, and a fixed-area method was used for the mature woodland stands. The study sites in each of three study areas were selected to represent ages ranging from 2 to 15+ years since each disturbance was terminated. The undisturbed woodland was chosen to act as a control. Various analyses using the STATISTICA statistical package and CANOCO version 4.0 were conducted to understand responses of Miombo woodland to these different disturbances. The research revealed that single tree selection, slash & burn agriculture and charcoal production are the main forms of Copperbelt Miombo woodland utilization which will always be there. Additionally, the the Miombo woodland stands were characterized based on the size class profile they exhibit on exposure to human disturbance factors through forest utilization. The characterization has revealed that the woodland is dominated by light demanding species. As such single tree selection harvesting does not support the regeneration and establishment of the timber species which are canopy species under shade conditions. This implies that selection harvesting of timber species, although it appears to be a *non event* in terms of disturbance at stand level may be a *disaster* at population level. The study also revealed that clearing of the woodland for either slash & burn agriculture or charcoal production results in enhanced regeneration and establishment of the dominant Miombo woodland species. The study concludes that charcoal production and slash & burn agriculture are important components to which the woodland ecosystem is adapted. As such these disturbance factors may be considered as *incorporated* disturbances. It is recommended from the study that woodland utilization and management should integrate charcoal production and slash & burn agriculture into forest management. Cutting cycles should be based on growth rate of the selected species. Timber species harvesting should go side by side with these disturbance factors so as to open up the canopy in order that maximum sunlight can reach the regeneration stock. The study also brings out the other management and utilization opportunities (such as managing for *Uapaca kirkiana* and *Anisophyllea boehmii* fruits) that arise from different development stages of the woodland. Lastly, it is recommended to ascertain the optimum gap sizes for both charcoal production or slash & burn agriculture which would still support the Miombo woodland recovery.

Opsomming

Hierdie studie is gedoen om ‘n nuwe begrip te ontwikkel vir die hersteldinamika van Miombo boomveld na onderwerping aan enkelboomseleksie, kap & brand lanbou en houtskoolproduksie. Vyf spesifieke studies is gedoen om verskillende komponente van die total studie te ondersoek: benutting, bestuur en konflikresolusie tussen gebruikers van Miombo boomveld; species-stam kurwes as ‘n instrument in die bemonstering van die ontwikkeling van Miombo boomveld species-rykdom oor tyd na afloop van houtskoolproduksie en kap & brand landbou; die impak van menslike versteuring op die floristiese samestelling van Miombo boomveld; verjongingspotensiaal van sleutelsoorte in Miombo boomveld na versteuring; en bepaling van ouderdom en groeitempo in ge-selekteerde Miombo boomveldsoorte. Verskillende metodes is ontwikkel vir elke spesifieke studie. In die studie van boomveldgebruik en –bestuur is semi-gestruktureerde en sleutel-informant onderhoude gebruik. Die STATISTICA statistiese packet weergawe 6.0 is gebruik vir dataverwerking en -ontleding. Chi-kwadraat toetse is gebruik om vlakke van betekenisvolheid te toon wat bestaan tussen verskillende gebruikersgroepe. Species-stamkruwes is gebruik om monstergrootte te bepaal vir die evaluering van Miombo boomvelddinamika in hergroeiopstande na kap & brand en houtskoolproduksie, terwyl vaste-grootte persele gebruik is vir volwasse boomveldopstande. Die studieplekke in elk van drie studiegebiede is geselekteer om verskillende ouderdomme tussen 2 en 15+ jaar na be-eindiging van die versteuring te verteenwoordig. Onversteurde boomveld is gebruik as kontrole. Verskeie ontledings, met die STATISTICA statistiese pakket en CANOCO weergawe 4.0 is gedoen om die reaksie van Miombo boomveld op die verskillende versteurings te verstaan. Die navorsing het getoon dat enkelboomseleksie, kap & brand landbou en houtskoolproduksie is die hoof vorme van Copperbelt Miombo boomveld benutting wat altyd daar sal wees. Verder is die Miombo boomveldopstande gekarakteriseer gebaseer op die grootteklasprofiel wat hulle vertoon na menslike versteuringsfaktore in die vorm van boomveldbenutting. Die karakterisering het getoon dat die boomveld gedomineer word deur ligeisende soorte. Daarom ondersteun enkelboomseleksie nie die verjonging en vestiging van die dominante houtsoorte wat kroonsoorte is onder skadutoestande. Dit impliseer dat selektiewe inoesting van houtsoorte, alhoewel dit voorkom as ‘n *onbelangrike gebeurtenis* in terme van versteuring op opstandsvlak, ‘n *ramp* is op populasievlak. Die studie het ook getoon dat skoonmaak van die boomveld vir of kap & brand landbou of houtskoolproduksie, lei tot verbeterde verjonging en vestiging van die dominante Miombo boomveldsoorte. Die studie lei tot die gevolgtrekking dat houtskoolproduksie en kap & brand landbou belangrike komponente is waarby die boomveldsisteem aangepas is. Daarom kan hierdie versteuringsfaktore beskou word as *ingeslote* versteurings. Vanuit die studie word daarom aanbeveel dat boomveldbenutting en –bestuur houtskoolproduksie en kap & brand landbou binne die bosbestuur integreerd moet word. Kapsiklusse moet gebaseer word op die groeitempos van geselekteerde soorte. Inoesting van houtsoorte moet saamloop met hierdie versteuringsfaktore sodat die kroondak oopgemaak kan word sodat maksimum sonlig die verjonging bereik. Die studie bring ook na vore die bestuur en benuttingsgeleenthede (soos bestuur vir die vrugte van *Uapaca kirkiana* en *Anisophyllea boehmii*) wat voorkom in verskillende ontwikkelingstadiums van die boomveld. Laastens word aanbeveel dat die optimum openinggroottes vir beide kap & brand en houtskoolbereiding wat herstel van Miombo boomveld ondersteun, bepaal.

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Dedication

This work is dedicated to my son and all the young members of my family with a hope that this will be a source of inspiration to them.

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1 GENERAL INTRODUCTION

1.1 Background to the study

Travelling through the Copperbelt Miombo woodland of Zambia takes one through tall, almost closed-canopy stands and many areas of cleared woodland for slash & burn agriculture or for charcoal production. This causal observation gives an idea of how the woodland is utilized by different user groups. Additionally, it also gives an idea of how the woodland responds over years to disturbances arising from utilization by different user groups.

The demand for woodland products both in Zambia and the Miombo ecoregion in general has increased over years. Additionally, charcoal production and slash & burn agricultural activities have also increased. This is because the ecoregion's economy is growing slowly with the per capita income growth rate of as low as 0.1% between 1990 and 1999 (Kaimowitz, 2003). In Zambia, the privatization program which was undertaken in the early 1990s has left many people out of employment and hence making their means of survival difficult. The result has been high levels of unemployment and continued dependence on relatively cheaper and easy to access traditional sources of energy, food, medicines and many products.

This has forced many people to resort to charcoal production, timber harvesting and land clearing for agriculture. As a result, deforestation in Zambia, which is already high (see Chidumayo, 1997) has further increased. FAO (2005) estimated deforestation in Zambia to be at 445, 000 hectares per annum.

In the Copperbelt Province, forest degradation stands at 40.7% and 52% for forest reserves and open areas respectively (Table 1.1) which has resulted in decrease in forest conditions. This shows considerable pressure on the woodlands and forests which will continue as long as unemployment and poverty levels remain high in the Country. As such, it is important to understand the dynamics of Miombo woodland ecosystems under different forms of utilization in order to provide for the formulation of policies and strategies for their sustainable management. Such policies should provide for the incorporation of charcoal production, timber harvesting and slash & burn agriculture into the management of the Zambian Miombo woodlands.

Table 1.1 Status of forests in the Copperbelt Province

District	Forest reserves		Forests in open areas		Total
	Good/fair	Degraded	Good/fair	Degraded	
	Hectares				
Luanshya	3,400	19,600	14,200	53,900	91,100
Ndola	9,000	22,600	3,700	42,300	77,600
Mufulira	7,800	15,400	18,100	50,800	92,100
Kalulushi	26,800	13,000	6,500	28,800	74,900
Chingola	7,400	15,900	52,100	77,600	153,000
Chililabombwe	18,100	9,900	30,400	26,100	84,500
Kitwe	9,000	6,300	21,900	38,400	75,600
Ndola rural	243,200	58,900	1,310,000	454,200	2,066,300
Total	**324,500**	**161,600**	**1,456,900**	**772,100**	**2,715,100**

Source GRZ, 1998

1.2 Importance and impact of utilization of Miombo woodlands

Miombo woodlands cover Angola, Zimbabwe, Zambia, Mozambique, Tanzania and most of the southern part of the Democratic Republic of Congo (Campbell *et al.,* 2008). They support the livelihoods of millions of rural and urban dwellers in these countries through the provision of non-wood products which include bees wax, honey, edible fruits, edible insects, mushrooms and traditional medicines (Bradley & Dewees, 1993; Brigham *et al*., 1996). Miombo woodland dwellers also depend on the woodland as a source of agricultural land, firewood, charcoal and timber (Ranta, 1988; Luoga *et al*., 2000; Malimbwi *et al*., 2005). Most Miombo species such as *Brachystegia boehmii, Brachystegia floribunda, Brachystegia longifolia, Brachystegia spiciformis, Erythrophleum africanum, Julbernadia paniculata* and *Pterocarpus angolensis* are very important for timber for both medium and heavy construction.

Miombo woodland utilization has resulted in continued decline of the woodland cover (Chidumayo, 1997; Luoga *et al*., 2005). The key drivers of woodland cover loss or deforestation are mainly land clearing for agriculture and wood extraction for energy (Chambwera, 2004; Campbell *et al.,* 2008). Fuelwood is the primary source of energy throughout the SADC region, for most rural and urban populations (Shackleton & Clarke 2007). It accounts for the highest percentage of the national energy budgets for the Miombo ecoregion countries namely 85% in Mozambique (Brigham *et al*., 1996), 91% in Tanzania (SADC, 1993) and 76% in Zambia (Chidumayo, 1997). The high levels of fuelwood energy in the national energy budgets for the Miombo ecoregion countries, like in many African countries, makes fuelwood consumption a major local and global environmental issue (Agyei, 1999; Chambwera, 2004). This also makes the urban areas significant contributors to deforestation (Karekezi & Majoro, 2002). Biodiversity and nutrient losses are considered to be the major impacts of deforestation in the Miombo ecoergion (GRZ, 1998; FAO, 2000; Sileshi *et al.,* 2007). Unfortunately, wood energy will continue to dominate energy production and consumption in decades ahead (Ejigu, 2008). In fact IEA (2006) projected that the trend will continue over the next decades and that by 2015 there will be 54 million more Africans depending on traditional wood energy.

Trade in fuelwood represents a source of income and employment for many rural dwellers of the Miombo ecoregion. Campbell *et al.,* (2008) observed considerable trade networks of charcoal from rural areas to urban areas. As such, the proximity to markets and accessible routes are a significant factor in the harvesting levels and the resulting impacts on the Miombo woodland structure and productivity (Malimbwi *et al.,* 2005).

Miombo woodlands are also important sources of non timber forest products which provide a range of products for subsistence consumption and trade. Medicinal plants, exudates, forage, bee products, woodcrafts, mushrooms and bush meat are some of the main items in this group. For example, Garrity (2004) estimated that more than 80% of the rural dwellers in sub-Saharan Africa depend on medicinal plants for most of their health needs. Additionally, the rural dweller also trade in these non timber products. Diederichs (2006) reported an informal trade of medicinal plants and products in Southern Africa. The woodcraft industry is also an important source of employment to many people in Africa. The industry has been reported to sustain the livelihood of many rural poor people not only in the Miombo ecoregion (Standa-Gunda, 2004) but also in other developing countries (Campbell *et al.,* 2005; Mikolo *et al.,* 2008). The utilization and marketing of fruits, mushrooms and other non timber products are integral components of the local economies in the Miombo ecoregion. The sale of these products is one of the strategies to meet specific cash needs in case of crop failure among the Miombo dwellers (see Sorensen, 1993; Akinnifesi *et al.,* 2008). Harvesteing of indigenous fruits can substantially boost rural income and create employment (Saka *et al.,* 2007; Akinnifesi *et al.,* 2008).

Miombo woodlands are also important for soil erosion control, shade provision, modifying hydrological cycles and soil fertility maintenance. They also support religious and cultural customs which relate to designated woodland areas and certain tree species are vital to the spiritual well-being and effective functioning of the rural communities (Clarke *et al.,* 1996). A number of studies have reported species use and preference for various purposes by different users in many parts of the Miombo ecoregion (McGregor, 1991; Lowore *et al*., 1993).

Therefore, the Miombo woodland is important for food security, agricultural and woodfuel production, religious and cultural values and many other values, and conservation of the forests is a great challenge for the Miombo ecoregion countries.

1.3 Motivation and philosophical argument

Deforestation, not only of the Zambian woodlands but many forests the world over, is an emotional topic of the popular environmental debate today. This is because many people concerned about the environment have been persuaded by graphic images of either the burning forests, or the sight of complex ancient forests being felled in minutes by commercial loggers or slash & burn agriculturalists and charcoal producers who seem to care less for losses to global heritage, biodiversity and impact on global climate change (Forsyth 2003). Many authors have outright condemned deforestation and associated it with massive loss of fauna, flora and some high productive forest ecosystems (Richards 1952; Myers 1984; Mather 1992; Bradley & Dewees, 1993; GRZ 1998; Mather and Needle 2000; Brown 2001). Such commentaries assume a direct relationship between area of forest lost and the species lost (Forsyth 2003) and tend to over-generalize the problem. For example, Mearns (1995) observed that poor data and poorly informed analyses of the impacts of wood extraction on Savanna woodlands tend to over-estimate the problem. This belief has led to the formulation of a variety of policies that seek to protect forests and their ecosystems against interference from the local communities yet charcoal production and slash & burn agriculture (also called shifting cultivation) are forms of forest utilization. Charcoal production and slash & burn agriculture are condemned in preference to single tree harvesting which is perceived to result in minimal negative impact on forests and woodlands. However, many authors have reported the impact of single tree selection harvesting system on species richness in the Miombo ecoregion: Malawi (Makungwa & Kayambazinthu, 1999); Mozambique (Grundy & Cruz, 2001); Zimbabwe (Mudekwe, 2006) and in Tanzania (Nduwamungu & Malimbwi, 1997; Mbwambo, 2000; Luoga *et al*., 2002). These studies have revealed that the commonly harvested species namely *Pterocarpus angolensis, Erythrophleum africanum, Brachystegia boehmii* and *Afzelia quanzensis* exhibited unstable population structures with reduction in absolute densities and also species richness. The decline or reduction in timber species is attributed to lack of controls over the location of harvesting which have resulted in harvesting of the most accessible wood first (Moore & Hall, 1987). This is compounded by the fact that single tree selection harvesting of timber allows very little to no regeneration of the canopy species under canopy. The timber species do not regenerate well under canopy because they require high light intensities to develop and grow (Lees, 1962) and also reduced competition for nutrients. Other studies (Boaler, 1963; von Breitenbach, 1973; Werren *et al*., 1995; Graz, 1996) have reported that *Pterocarpus angolensis* tend to perform well in previously cleared areas. Therefore, the important questions that need to be answered in relation to woodland/forest management are as follows: what kind of resource use management is good for the Zambian woodlands/forests? Is it selective tree harvesting of timber species that allows very little to no regeneration of the canopy tree species under the remaining canopy? Or is it slash & burn agriculture and /or charcoal production that results in maximum light intensities, reduced competition for moisture and nutrients, which enhance the growth of stumps/root suckers and recruitment?

Undeniably, forest loss causes a number of impacts. But the key contentions of such a belief and other commonly heard generalizations about deforestation impacts are increasingly being challenged, not only in the Miombo woodlands (see Grundy *et al*., 1993) but in other parts of the Savanna woodlands namely East Africa (Medley, 1993) and West Africa (Fairhead & Leach, 1995; Leach & Mearns, 1996; Fairhead & Leach, 1998). These studies have challenged population driven models of deforestation impacts by documenting the way in which local populations enrich and manage their environment. Additionally, such models may also overestimate the relationship between the area of the forest lost and the number of species lost. Many studies in other parts of the world (Schmidt-Vogt, 1998; Sillitoe, 1998; Fox *et al.,* 2000) have shown the occurrence of a wide range of species over areas previously deforested. Studies in several parts of the Miombo ecoregion have also revealed woodland species survival and consequent recovery of the woodland once charcoal production or slash & burn agriculture ceases namely Zambia (Fanshawe, 1971; Chidumayo, 1988, 1993a,b, 2004); Tanzania (Boaler & Sciwale, 1966); Zimbabwe (Strang, 1974) and Mozambique (Geldenhuys 2005). Neke *et al.* (2006) and Nyerges (1996) also reported the recovery of South African and Kenyan Savannas, respectively on cessation of the disturbance. This is because woodland regeneration consists of stumps/root suckers and recruitment from old stunted seedlings present at the time of the clearing (see Chidumayo & Frost, 1996). The ability of many Savanna woodland species to regenerate through coppicing mitigates against the degrading effects of local harvesting practices (Medley, 1993; Nyerges, 1996). They have both the vertical and horizontal extensive root systems which support rapid recuperation after cutting (Mistry, 2000). Strang (1974) observed that the horizontal root systems tend to produce root suckers once the parts which are above-ground are removed. Species, plant size and age, stump height and percentage of the cleared woodland have been reported to influence coppicing effectiveness of Miombo woodland (see Grundy, 1995; Luoga *et al*., 2002). Grundy (1995) also showed that the site characteristics, cutting angle and sharpness of the cutting tool have an influence on the coppicing effectiveness of some Miombo woodland tree species. Furthermore, Chidumayo (1993a) reported that exposure to sunlight enhances coppice effectiveness of most of the Miombo woodland species. However, Stromgaard (1986) reported that Miombo woodland could not necessarily revert back to the original Miombo after disturbance cessation in areas which were previously under slash & burn agriculture in northern Zambia. The variation in response is because disturbances vary in frequency, space and magnitude, and therefore in effect as well. Apart from the variation in disturbance frequency, space, magnitude and effect, different species respond differently to various disturbances**.** Each species tends to exhibit a specific size class structural profile which may vary from one woodland/forest type to another and also from one disturbance to another. However, the structural size profile may fall into either of the profiles shown in Figure 1.1 (Peter, 2005).

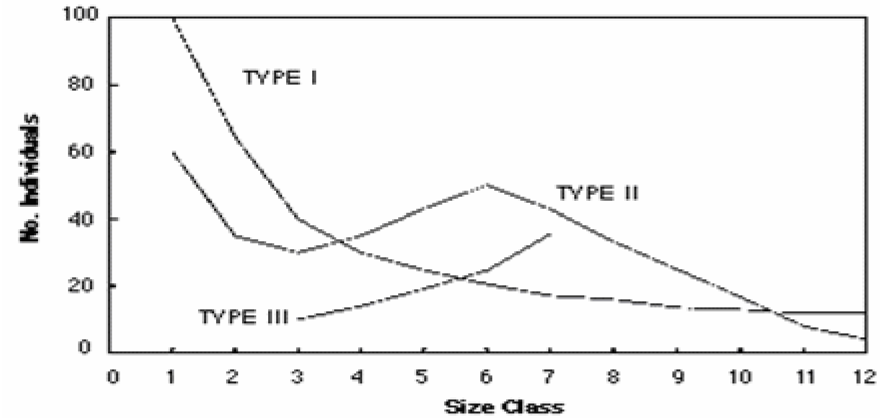

Figure 1.1 Idealized size class distributions exhibited by tree populations (Peter, 2005).

Type I or Inverse J-shaped size class (DWAF, 2005): The inverse *J*-shaped size class profile has a higher abundance of individuals in smaller size classes than in larger classes. This characteristic size class structure is indicative of a stable and expanding population (Geldenhuys, 1993). In the natural evergreen forest the shade-tolerant canopy species, such as *Podocarpus latifolius*, typically has this stem diameter because they continuously regenerate under the canopy (DWAF, 2005). However, in fire-adapted woodlands this type of curve is typical of the fire-tolerant species (Geldenhuys, 1993). According to Peter (2005), it is safe to assume that the death of an adult tree will, at some point, be replaced by individuals growing up from the smaller classes. This therefore implies that such a size class profile represents the ideal of a stable and self sustaining population (Mudekwe, 2006). It may be used for planning yield regulation for woodlands such as Miombo to ensure sustainable supply of raw material.

Type II or Bell shaped size class (DWAF, 2005): This depicts characteristic populations which experience sporadic or irregular seedling establishment, often related to large-sized gaps in evergreen forest (DWAF, 2005; Peter, 2005). In evergreen forests, the shade-intolerant canopy species, such as *Ocotea bullata*, and invader plant species such as *Acacia melanoxylon*, typically exhibit this size class profile because they can not regenerate in shade (DWAF, 2005). Species that exhibit the bell-shaped size class profile are those that regenerate and develop in cohorts after a window of suitable conditions for regeneration do appear (Mudekwe, 2006). According to Peter (2005) the levels of regeneration for the species may be sufficient to maintain the population, but its infrequency of occurrence causes notable ‘’peaks’’ or ‘’valleys’’ in the size class distribution as the new seedlings grow into larger size classes. The size class profile may also imply that such a species requires a large gap to become established (DWAF, 2005). In some populations, this size class profile may imply that the regeneration is being temporarily interrupted through either excessive harvesting for timber (see Nduwamungu & Malimbwi, 1997; Mbwambo, 2000; Luoga *et al*., 2002; Mudekwe, 2006), fruit or seed (Peter, 2005) or direct physical damage to seedling through infrequent extreme fires (see Trapnell, 1959). Or it may relate to the exclusion of fire in the woodlands that will enable fire-intolerant species to become established (Geldenhuys, 1993).

Type III or Static shape size class (DWAF, 2005): Such a size class profile reflects the population in which there is no regeneration but existing trees increase in diameter (DWAF, 2005). The regeneration of such species is severely limited for some reason (Peter, 2005).

According to Chidumayo (1997), a number of limiting factors of regeneration in Miombo woodlands include fires, water and nutrient stress, insectivory, herbivory, lack of fruit and seed production. Sporadic occurrence of either of or all of these factors in the woodland or forest may result in individual species experiencing sporadic germination, and also establishment of a single or few plants at a time. Over-exploitation of mature timber species may also result in limited regeneration and consequently formation of Type III size class profile for the species that is being exploited (Nduwamungu & Malimbwi, 1997). In the absence of the conducive environment, such species may be severely limited in occurrence (see Swartz *et al*., 2002) or permanently disappear as this has the potential to result in decrease of the likelihood of conspecific replacement and thus increasing the risk of failure of the natural successional pathway (McKenzie, 1988).

Although the three size-class distributions correlate well with the three different regeneration guilds, it is important to remember that the population structure of a species is extremely dynamic and sensitive to changes in the level of regeneration (Peter 2005). It is important to consider that Type I is a build up of Type II (Bell shaped) curves. Each bell is a specific even-aged cohort that establishes in a specific point in time. The stems of this cohort vary in growth rate and some die, then the height of the bell decreases and the base of the bell widens. But if you have regular regeneration, different bells are integrated and then results in an inverse *J*-shaped curve (Type I**).**

The variation in size class profiles due to disturbance among species provides for the classification of disturbance factors based on their influence on any woodland or forest or species population. The classification of disturbance factors helps forest managers to manage the forests/woodland ecosystems and their associated species sustainably based on their response to disturbances. The classification of disturbance factors is possible because each species functions best (regeneration, establishment and productive growth) under an optimum range of conditions related to the primary factors of adaptation (see also Geldenhuys, 2008). Therefore, species dominance changes from early regrowth stands towards mature forest (Geldenhuys, 2008). According to Hansen and Walker (1985), a disturbance can be either a *non-event* or an *incorporated disturbance* or a *disaster* or *catastrophe*: a non-event if it does not alter the functional environment of an entity or may do so with a frequency or intensity too minor to elicit a response; an incorporated disturbance if the event elicits dynamics of a scale to which the entity is adapted and thus necessary to maintain the entity in its present state; or a disaster or catastrophe if it forces the entity into a new state. This could happen at the level of an individual, a population, a community, or the landscape. A disaster to an individual may be an incorporated disturbance to the population of that species and a non-event at the level of the community in which the species is present.

An understanding of the effects of resource utilization on plant dynamics, and more specifically their regeneration ecology, is essential to understanding woodland stability and resilience, with direct implication for both species persistence and for people's livelihoods (Neke *et al*., 2006). The Copperbelt woodlands, in which resource utilization involves timber harvesting, charcoal production and slash & burn agriculture, offer an opportunity for investigating the response of Miombo woodlands to human disturbance. The few studies (Chidumayo, 1988, 1993a, b, 2004) undertaken in Miombo woodland to describe woodland development over time did not look at individual species development and change over time. Additionally, these studies did not compare the impacts of timber harvesting, charcoal production and slash & burn agriculture over time to provide for the integration of these utilization aspects into Miombo woodland management programmes. However, this is not intended to justify and encourage wanton destruction of the forests but should be viewed as a call for attitude change towards the perception of deforestation and its associated impacts. It is a call for a perception change; the general populous propelling such an environmental debate need to be made to understand that slash & burn agriculture and charcoal production, like single tree harvesting, are forms of forest resource utilization which could fall into either of Hansen and Walker's (1985) categories of disturbance.

1.4 Objectives of the study

The overall objective of the study was to develop an understanding of the Miombo woodland recovery dynamics from various disturbance factors through resource use that will help in formulating appropriate strategies for sustainable utilization and management of the Zambian Copperbelt Miombo woodland and its ecosystems.

1.4.1 Specific objectives, related questions and hypotheses

Five specific objectives were formulated, each with related questions.

Specific objective 1: To determine the utilization and management of the Miombo woodland by different users.

Related questions

a. What are the main uses to which the Miombo woodland is put to by different users?

b. What is the likely effect of each use?

c. What are the conflicts between different users?

Specific objective 2: To determine the floristic composition of Miombo woodland that has been under various human disturbance factors (timber harvesting, slash & burn agriculture and charcoal production) in comparison with relatively undisturbed woodland

Related questions

a. What are the species found in each age class category of each disturbance in the Copperbelt Miombo woodland?

b. Do current woodland floristic changes mimic typified Miombo degradation or recovery trends based on the available literature?

Specific objective 3: To determine the suitability of the use of species-stem curves in sampling the development of Miombo woodland species in charcoal production and slash & burn regrowth stands.

Related questions

a. What is the minimum number of stems and plants in each disturbance and age category required to capture the representative species number with minimum effort?

b. What would be the implication of employing fixed area plots in sampling regrowth stands in terms of number of stems or plants measured in each age class and disturbance category?

Specific objective 4: To determine the regeneration and recruitment potentials of the selected species of Miombo woodland when exposed to different human disturbance factors and also relatively undisturbed Miombo woodland.

Related questions

a. What are the diameter and height class distributions of the key species under different disturbance categories and age after disturbance?

b. What are the sources of regeneration under each disturbance?

Specific objective 5: To determine the age and growth rate of selected key Miombo woodland species under different disturbance factors.

Related questions

a. What are the largest diameters for each selected species in each disturbance and age categories?

b. What is the number of growth rings in each diameter?

c. What number of growth rings does each species show in each age class for each disturbance category?

1.5 Scope of the study

This study was implemented in Zambian Copperbelt Miombo woodland to look at the effect(s) of resource use on Miombo woodland recovery. The resource use in this study implies timber harvesting, slash & burn agriculture and charcoal production. At the same time, these are being viewed as human disturbance factors as they result from human use of Miombo woodland.

Theoretically, the study should have included fire, but it was not possible to do so as there were no sites that had been under fire disturbance that could meet the selection criteria. However, casual or opportunistic observations of the occurrence of fire were made and inferred upon if it occurred on the study site.

1.6 Conceptual framework

Conceptually, the study has a continuum of disturbance regimes (frequency, intensity, space) with the vegetation being either i) mature undisturbed woodland, ii) woodland with minimum disturbance (single tree selection harvesting as mainly a *non-event*), iii) woodland with major disturbance through slash & burn and iv) totally cleared woodland for charcoal production as a *disaster.* Additionally, the study determined the ecological processes that impacts the woodland under these different disturbance events and also brings out the true picture of how the majority of the woodland species have become adapted in order that they may be 'equipped' to survive that. Lastly, it also brings out information on how the recovery rate would return the woodland back to the pre-disturbed situation and the characteristic stages of each disturbance event (Figure 1.2**).**

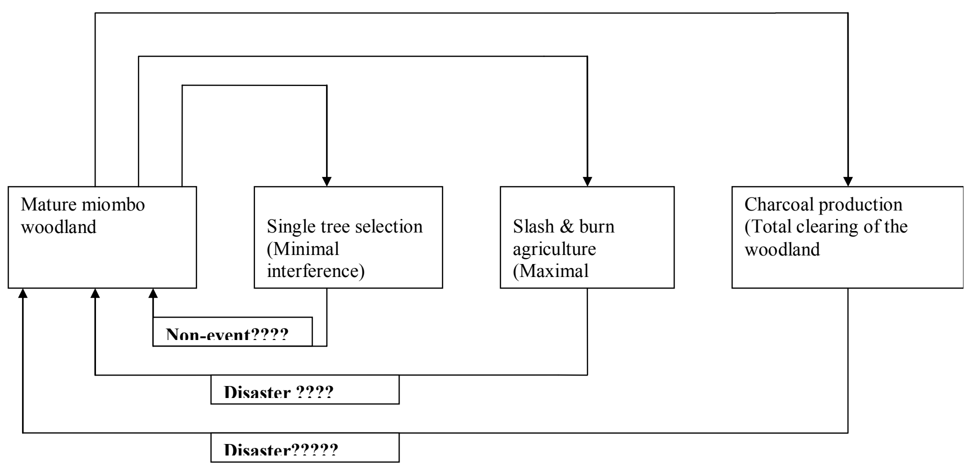

Figure 1.2 Conceptual framework of the study in Zambian Copperbelt Miombo woodland to evaluate woodland response to different disturbance factors

1.6 Approaches to sampling design

The utilization and management of forest resources guided the design of the study. The idea was to find sites in which both the subsistence and commercial users of the forest resources had been operating over years. This was intended to give the different age classes for study.

Site selection criteria

The site(s) selected for the study had the following categories of Miombo woodland occurring in close proximity:

i) Relatively undisturbed Miombo woodland to act as a control in the study;

ii) Slightly disturbed Miombo woodland with sites of different age categories up to 10-12 years old since timber harvesting ceased;

iii) Miombo woodland with sites of up to 15+ years old since slash & burn agriculture and charcoal production ceased.

1.7 Thesis structure

The thesis is divided into seven chapters. Chapter one describes the background to the study, research concept and objectives of the study. The other chapters (chapters two to six) deal with specific components of the study to address stated objectives: (2) Miombo woodland utilization, management and conflict resolutions among stakeholders; (3) The use of species-stem curves in sampling the development of Miombo woodland species in charcoal production and slash & burn regrowth stands**;** (4) Does human disturbance have a negative impact on the floristic composition of Miombo woodland? (5) Recruitment and regeneration potentials of selected Miombo woodland species after a disturbance; and (6) Age and growth rate determination using selected Miombo woodland species. Chapter 7, the last and final chapter entitled *Linking disturbance to sustainable management of the Copperbelt Miombo woodland ecosystems of Zambia,* presents a synthesis of the findings and how the study provides for Miombo woodland management options. Each of these chapters has been prepared according to specific journal requirements to which the articles will be submitted namely Chapter 2 to *Agriculture, Ecosystems and Environment*), Chapter 3 to *Southern Forests*, Chapters 4 and 5 to *Forest Ecology and Management*, Chapter 6 to *Journal of Tropical Ecology*, and Chapter 7 to *Southern Forests*. Chapter 1 has been written according to the requirements of *Agriculture, Ecosystems and Environment.*

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2 MIOMBO WOODLAND UTILIZATION, MANAGEMENT AND CONFLICT RESOLUTIONS AMONG STAKEHOLDERS

Abstract

Miombo woodland is important for both wood and non-wood products. The mostly harvested products are timber, firewood, charcoal, fencing materials and materials for making farm tools and household items. The non-wood products harvested include mushrooms, fruits, medicines etc. Often different user groups namely; timber producers, farmers and charcoal producers, are involved in the exploitation of the woodland resources. With each of the user groups having products of priority from the woodland, their activities have different implications on the woodland resources. The differences in priority products often result in conflicts, with each group attributing the impacts to the other groups; the timber producers accuse the charcoal producers of causing the depletion/decline of the timber species population as they cut them during charcoal production, in stead of concentrating on other species. Additionally, conflicts also arise between these user groups over ownership of land and woodland resources. Once a conflict occurs, the traditionally laid down procedure is followed in trying to resolve it.

Keywords: Priority product, user groups, species availability, conflict resolution

2.1 Introduction

Miombo woodlands, like many other types of woodlands and forests, are important for both wood and non-wood products. The important wood products from the Miombo woodland are timber, firewood, charcoal, fencing materials (poles) and materials for making farm tools and household items while the non-wood products include mushrooms, fruits, medicines and many other essential subsistence goods (Morris, 1995) This is why the rural communities have traditionally been involved in the management of woodland resources in many parts of the Miombo ecoregion (Clarke, 1994; Chidumayo, *et al*., 1996; Kamoto, 1999; Albano, 2001). However, Governments in various parts of the eco-region have used 'interventionism'approach in forest management which according to Albano (2001) is characterized by active involvement of forestry services based on scientific and professional knowledge and 'top down' decision-making process. This approach does not seem to recognize the potential role of forestry products to rural development (Albano, 2001) and also the importance of woodlands as a means of livelihood to rural communities. Additionally, the approach does not recognize the contribution of different woodland user groups to woodland management. The recognition and understanding of the contribution of different user groups towards woodland management are essential elements in achieving sustainability. Several studies (Campbell *et al.,* 1996; Campbell et al., 2003; Mlay et al., 2003) have documented the contribution of various stakeholders to sustainable management of the Miombo woodland. Additionally, other studies (Clarke, 1994; Chidumayo *et al.,* 1996; Kamoto, 1999; Albano, 2001) have documented the existence of indigenous systems in the Miombo ecozone. However, studies on the comparative analysis of the perception of impacts arising from woodland utilization by different user groups are missing. This paper discusses the main uses to which Miombo woodland is put to by different user groups. Additionally, the paper deals with how these user groups perceive each other in terms of the associated impacts arising from their woodland utilization. The paper addresses the following questions: what are the main uses to which the Miombo woodland is put to by the different user groups? What are the likely effects of each use? And what are the conflicts between the different user groups?

2.2 Material and Methods

2.2.1 Study area.

The study area is situated in Masaiti District, approximately 90 km south of Ndola town, towards Kapiri-mposhi, in Zambia. The inhabitants of the area are *lamba* speaking people, although the area has seen an influx of people from other parts of Zambia. The area has an average population density of 58.2 persons per square kilometer (CSO, 2000). Slash & burn agriculture, timber and charcoal production and trade are the main economic activities of the study area (Njovu *et al.*, 2004). Other livelihood systems of the Copperbelt rural include fishing, hunting, fruit trade and bee keeping (Kalaba, 2005). The sites were selected because the area is predominantly a charcoal and timber producing area, while in terms of agriculture; it is mostly slash & burn.

The mean sizes of the fields in the area were estimated to be 1.9±0.9 ha for charcoal production and 3.53±0.4 ha for slash & burn agriculture during the scoping visit. The sizes of twenty fields for each, namely charcoal production and slash & burn agriculture, were estimated from their corner coordinates recorded during the visit. The mean charcoal field was estimated to yield about 176±88 bags of charcoal with a nominal weight of 90 kg/bag (bag size) per cutting cycle. The bag with nominal weight of 90 kg, weighs between 70-80 kg (Ranta, 1988). The average number of years that a person would spend with continuous cropping on the field before moving to another area was 2.7 ±0.8 years.

Timber harvesting takes the form of single tree selection. The main timber species in the area are *Pterocarpus angolensis, Afzelia quanzensis*, *Albizia antunesiana* and *Brachystegia floribunda*. The major vegetation of the study area is Miombo and the dominant species are *Brachystegia spiciformis, Brachystegia floribunda, Julbernadia paniculata* and *Isoberlinia angolensis* with *Pterocarpus angolensis, Pericopsis angolensis, Burkea africana, Swartzia madagascariensis, Albizia antunesiana and Parinari curatellifolia* being the canopy associates. *Anisophyllea boehmii, Diplorhynchus condylocarpon*, *Syzygium guineense* and *Uapaca spp* are the common understory trees found in the study area.

The climate of the area is characterized by an alternation of dry and wet seasons. Based on temperature and rainfall, three distinct seasons are recognized in the area: hot dry season (September-November), hot wet season (December-April) and cool dry season (May-August). The temperatures vary from 18^0C in winter to about 30^0C in summer (Rao & Acharya 1981). The lowest temperatures usually occur in June/July while the highest temperatures occur in October. The average annual rainfall is 1200 mm.

2.2.2 Methodology

2.2.2.1 Data collection

Different user groups i.e. charcoal producers, timber producers and the crop cultivators (or farmers, through slash & burn agriculture) were identified based on records either from the District Forest Offices or the traditional councilors. In total, 155 respondents were interviewed.

The distribution of number of respondents among the different user groups was as follows: timber producers (32), charcoal producers (66) and shifting cultivators (57). This represented 25% of the total population, which is slightly above 20% recommended by Hetherington (1975) as the minimum size that is considered to be a representative sample from which inference can be made about the population. The respondents were randomly selected from a list of households in the study area provided by traditional councilors.

Three techniques were used to collect both qualitative and quantitative data from subsistence and commercial users at both individual and group levels: questionnaire; semi-structured interviews and group meetings. The questionnaire addressed issues relating to the product priorities, species and values preference, extent of woodland utilization, the existent and resolution of conflicts among the user groups.

A semi-structured interview method was used in data collection. This is in line with the recommendation of Chambers (1983) and Babbie (1995) that the best way to learn from the local people is to sit down, ask questions and listen rather than asking respondents to read through the questionnaire and enter their own answers. However, the techniques have some shortcomings as indicated by other authors, such as the danger of the desire of the respondent to please the researcher (Mitchell & Slim, 1991) and the discrepancies between what people report and do (Borgerhoff-Mulder & Caro, 1985). According to Chambers (1983) respondents may provide false information for a variety of reasons such as fear, prudence, ignorance, exhaustion, hostility and hope of benefits. In order to reduce errors arising from such, the researcher employed the service of two research assistants who once worked as community project managers with the local non-governmental organization in the study sites with whom the local communities were familiar.

The interviews were followed by a group meeting under the guidance of the two research assistants at primary schools where facilities like desks and classrooms were available. The group meeting involved dividing community/organization members into user groups and then introducing them to the study objectives. Issues covered related to analysis of woodland resources in terms of value obtained the availability of species and the ranking of disturbance factors with related effects. Additionally, matrix scoring was used to rank species preference and availability in the area.

2.2.2.2 Data analysis

Data analysis involved collating and analyzing responses using STATISTICA statistical package version 6.0. The multiple responses with repeated answers were categorized and tallied using multiple dichotomy method (de Vaus, 1996), in order to obtain the frequency distributions for each variable. The respondents were grouped into their respective user groups to facilitate easy analysis. Chi-square tests (Clewer & Scarisbrick, 2006) were used to show the levels of significance in responses whicht existed between user groups. Additionally, the bootstrap means were used to show the difference in product priority among the different user groups.

2.3 Results

Stakeholders are knowledgeable and appreciative of the value and contribution of the woodland to their welfare. The mostly mentioned values of the woodland from the survey are charcoal, timber, slash & burn agriculture, poles and other values such as food and medicines.

2.3.1 Stakeholder product priority

The preference for products was influenced by the respondent's user group with each group emphasizing the importance of the woodlands for providing their main product (Table 2.1).

Table 2.1 Percentage product priority among producers

Value	Timber producers				Shifting cultivators				Charcoal producers			
	Priority											
	1	2	3	4	1	2	3	4	1	2	3	4
Timber	68.2	31.8	0.0	0.0	0.0	9.3	23.3	67.4	0.0	25.6	25.6	48.8
Charcoal	4.5	4.5	86.5	4.5	9.4	20.9	48.8	20.9	67.5	15	17.5	0.0
Pole	0.0	0.0	31.8	68.2	0	2.3	46.5	51.2	0.0	0.0	40	60.0
Firewood	100	0.0	0.0	0.0	81.4	18.6	0.0	0.0	90.0	2.5	7.5	0.0
Carving	0.0	27.3	40.9	31.8	11.6	2.3	46.5	39.6	0.0	30	32.5	37.5
Ash fertilization	40.0	9.4	12.5	38.1	53.5	41.9	2.3	2.3	22.5	40.0	30.0	7.5
Others eg medicines fruits	0.0	50.0	13.6	36.4	2.3	69.8	23.3	4.6	0.0	0.0	72.5	27.5

(**1**: Very high **2**: High **3**: Medium **4**: Low)

In general, the level of priority for woodland products was significantly influenced by the respondent's user group with each group emphasizing its main product as being of the high priority (Table 2.1). Table 2.1 showed that timber as a woodland resource is more important among the timber producers than to any other user group. Similarly, charcoal is more important to charcoal producers than to timber producers and shifting cultivators while ash fertilization is more important to farmers than to any other user group. However, the preference for firewood, pole and carving was not influenced by the user group of the respondents. Firewood was considered to be of a very high priority among all the user groups.

The importance of woodlands for provision of other products (medicines, mushroom, fruits, etc) was not of high priority among all charcoal producers. However, this was high among the respondents of timber producers and farmers. The user group had significant influence ($P < 0.01$) on the perception of the importance of Miombo woodland in providing other products

2.3.2 Species and value preference among stakeholders

Different Miombo woodland species show differences in importance for use for the different listed products/services (Table 2.2) and the preferences vary among different user groups (Appendix 2.1, 2.2 and 2.3). The importance of species in providing these values varied among user groups; for example the use of *Isoberlinia angolensis* for timber production was significantly influenced by the user group ($P<0.0001$) of the respondent while the user group of the respondents had no significant influence on the use of *Brachystegia spiciformis* for charcoal production. Other species such as *Erythrophleum africanum*, *Pericopsis angolensis, Parinari curatellifolia*, etc were not commonly used for either timber or charcoal production by either of the user groups (Appendix 2.1, 2.2 & 2.3).

Table 2.2 Probability of P < 0.05 of species and their product/value preferences according to Miombo woodland user-groups of the Copperbelt woodlands (The significant values are underlined)

Species	Timber	Charcoal	Pole	Carving	Firewood	Ash fertilization	Other values
Isoberlinia angolensis	0.0001	0.0001	0.0001	0.1781	0.0001	0.0003	0.0001
Pericopsis angolensis	1.0000	0.8411	0.0004	0.0004	0.0019	0.1639	0.1322
Julbernadia paniculata	0.1174	0.0001	0.0001	0.0001	0.0001	0.0178	0.0029
Pterocarpus angolensis	0.0881	1.0000	0.0001	0.0230	1.0000	1.0000	0.0003
Erythrophleum africanum	0.0001	1.0000	0.0001	0.0062	0.1322	0.3868	0.1322
Brachystegia spiciformis	1.0000	1.0000	0.0742	1.0000	1.0000	0.0001	0.0003
Brachystegia boehmii	1.0000	0.0001	1.0000	1.0000	0.0001	0.6084	0.1434
Brachystegia floribunda	0.0001	0.0001	0.0001	0.0125	0.0001	0.0001	0.0479
Parinari curatellifolia	0.0001	0.0002	0.0742	0.0125	0.1862	0.7407	0.0576
Afzelia quanzensis	0.0004	1.0000	1.0000	0.0001	1.0000	1.0000	0.5347
Albizia antunesiana	0.0001	0.0879	0.0001	0.0001	0.0356	0.0054	0.0001
Any other species; Faurea saligna, Swartzia madascariensis	0.2927	0.0001	0.0001	0.0001	0.0125	0.6453	0.3657

Additionally, *Pterocarpus angolensis*, *Erythrophleum africanum* and *Afzelia quanzensis* were seldom considered species suitable for charcoal production among the different user groups. However, all the user groups perceived many other Miombo woodland species such as *Pseudolachnostylis maprouneifolia*, *Swartzia madascariensis* etc as suitable for charcoal production.

Similarly, species such as *Brachystegia floribunda*, *Afzelia quanzensis* and *Albizia antunesiana* were considered to be important timber species by all the user groups although the levels of importance were significantly influenced by the user group of the respondents: *Brachystegia floribunda* (P<0.0001), *Afzelia quanzensis* (P<0.0004) and *Albizia antunesiana* (P<0.0001) (Table 2.2, Appendix 2.1,2.2 and 2.3). The importance of *Pterocarpus angolensis* as a timber species was not significantly influenced by the user group of the respondents. *Pterocarpus angolensis* was perceived to be important timber species by all the user groups.

2.3.3 Availability of preferred species

Each of the user group had its own perception on the availability of the preferred species for various uses from the surrounding woodlands in required sizes, form and quantities. The perception was significantly ($P < 0.001$) influenced by the user group of the respondent. Among the charcoal producers, 70 % considered their preferred species to be readily available while 43% of the slash & burn agriculturalists felt that their preferred species are readily available. However, only 3% of the timber producers felt that their preferred species are readily available from the surrounding woodlands. This implies that 97% and 57% of timber producers and slash & burn agriculturalists, respectively felt that their preferred species are no longer readily available.

The decline in availability of preferred species for various uses has resulted in a shift in species utilization among the few timber producers and slash & burn agriculturalists (Table 2.3). They have found a replacement for those species that are not readily available with those that are readily available. Table 2.3 shows a number of species which are being exploited as replacement for the species that were preferred for various uses in the past. For example, 16.7% and 8.3% of timber producers indicated they are exploiting *Isoberlinia angolensis* and *Brachystegia floribunda* respectively, as a substitute for *Pterocarpus angolensis*. Among the slash & burn agriculturalists, a tendency in shift to species preference and utilization due to decline in availability of previously preferred species is slowly showing. For example, there is now a shift in use from *Pericopsis angolensis* and *Pterocarpus angolensis* to *Swartzia madagascariensis* for pole and carving (Table 2.3).

Most of the respondents were able to give reasons for the depletion of the preferred species. The reasons varied among user groups, with each group attributing the depletion to the other group. The timber producers attributed the depletion of timber species to clearing of woodland for charcoal production and slash & burn agriculture.

2.3.4 Community awareness of Miombo woodland management

Most of the user groups were aware of how the surrounding woodlands were managed; 100%, 97.7% and 90% of charcoal producers, slash & burn agriculturalists (farmers) and timber producers respectively claimed to know how the woodlands were managed. Among the respondents, the commonly mentioned management structures were government and the local community. Occasionally, some respondents would mention the existence of joint management between the Government and the local community as was the case in Katanino/Kashitu area. However, most of the respondents; 62% (timber producers), 65% (farmers) and 83% (charcoal producers) were not aware of the existence of management structures, like village committees at village level for managing the surrounding woodlands. Of the few that claimed to be aware, their user group ($P<0.02894$) significantly influenced their knowledge of the existence of structures for woodland management, with more timber producers (38%) and farmer (35%) claiming to be aware of the existence of management structures, compared to only 17% of the charcoal producers.

Table 2.3 A shift in species utilization due to reduction in availability of the preferred species

Species		Percentage of respondents (%)			Uses
Previous	Current	Timber producer	Charcoal producers	Farmers	
Pterocarpus angolensis	*Isoberlinia angolensis*	16.7	0	4.7	Timber
	Brachystegia floribunda	8.3	0	0	Timber
	Swartzia madascariensis	0	0	4.7	Poles, carvings
Pericopsis angolensis	*Swartzia madascariensis*	0	0	2.3	Poles, carvings
	Any species	0	0	2.3	Poles
Afzelia quanzensis	*Isoberlinia angolensis*	12.5	0	4.7	Timber
	Brachystegia floribunda	4.2	0	0	Timber
Albizia antunesiana	*Brachystegia floribunda*	8.3	0	2.3	Timber
	Julbernadia paniculata	4.2	0	2.3	Timber
Brachystegia boehmii	*Brachystegia spiciformis,*	0	4.7	6.0	Bark rope
	Brachystegia longifolia	0	0	4.7	Bark rope

The existence of rules and bye-laws governing woodland management appeared to be a known fact among the different user groups though, the knowledge of the existence of rules was significantly influenced by the user group ($P<0.0001$). Some of the rules governing woodland management mentioned were as follows:

i) Cutting of trees with permission from the headman;

ii) No cutting down of fruit trees either during harvesting of fruits or for house building;

iii) No opening up of new areas for cultivation before a period of two years elapses;

iv) No setting of fires before and after the burning period-The burning period is May–June when the fuel can burn without adverse effect on the woodlands;

v) No uprooting or burning of stumps during field preparation.

Each of these rules/by-laws was associated with some form of fine or punishment. The fine or punishment was dependant on the nature and magnitude of the offense. The action against the offender could range from paying a fine or confiscation of the tools used and the product to even eviction from the chiefdom.

2.3.5 Conflict management and resolution among different user groups

Among the products harvested in the study area were timber, mushroom, fruits, bark rope and charcoal. Consequently, conflicts existed between either individuals or different user groups or both. The perception of conflicts among respondents was influenced by user groups (P<0.00001), with more timber producers (69%), compared to only 49% and 26% of farmers and charcoal producers acknowledging the existence of conflicts. The causes of conflicts varied among the user groups but the common causes were:

i) Bad harvesting methods: Careless harvesting techniques such as cutting down of trees for caterpillars, fruits and charcoal. This is viewed as showing no consideration for other user groups;

ii) Unclear permit- The permit either from the headman or the forestry authority may not be clear on the quantities and time frame within which such species/products have to be harvested.

iii) Ownership: Resource users have no legal claim over the woodlands

iv) Ill-defined boundaries: either group territories or authority boundaries.

Once the conflict occurred, the traditional hierarchy of authority would be followed in trying to resolve it (Figure 2.2). Conflict resolution started with the complainant approaching the offender to discuss the problem at hand. The case would be referred to the committee of village headman and some selected elders of the village if the two failed to reach a compromise. If the village headman and the selected elders failed to resolve the issue, they then referred the case to the committee of traditional councilors. Cases which the committee of traditional councilors failed to handle were referred to the chief. However, cases which involved Government would not follow the traditional hierarchy but the formal courts as required by the laws of the nation.

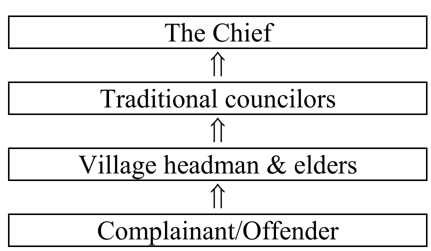

Figure 2.1 A typical traditional leadership hierarchy of the *Lamba* people in Masaiti area, Zambia

2.4 Discussion

2.4.1 Miombo utilization

Different stakeholders in the study sites know and acknowledge the importance of Miombo woodland for providing various uses/products (Table 2.1). They consider the woodland as their source of wood and non-wood products. Many researchers (Grundy, 1990; Tuite and

Gardiner, 1990; Clarke *et al*., 1996; Dewees, 1996) do recognize the importance of the woodlands in supplying many products essential to the well-being of the local communities. The stakeholders have used the woodland as a source of timber, charcoal, poles and carving material, bark rope, ash fertilization and also for other products such as food (e.g. fruits) and medicines. The use of Miombo woodland as a source of the above products has been reported by many researchers (Campbell, 1987; Chidumayo and Siwela 1988; Grundy *et al*., 1993; Clarke *et al*., 1996; Shackleton *et al.,* 1998; Olsen *et al*., 1999) in other parts of the Miombo ecozone and the savanna woodlands. These forest resource users assign different uses to different species but with a lot of overlap, especially when the species has multiple uses. This kind of behavior of assigning different uses to different species was also observed by Mbwambo (2000) among the forest resource users of Tabora region, in Tanzania.

2.4.1.1 Charcoal and firewood

One of the major uses of Miombo woodland is firewood with households in the region using an estimated 5-7 tonnes of dry wood per household per year (Grundy *et al*., 1993; Coote, 1995). Firewood and charcoal appear to be the main products from the woodland among the farmers and charcoal producers in the study area (Table 2.1). Firewood has many uses among the user groups, such as cooking, heating and burning bricks while charcoal is sold for income generation. Many species were considered suitable for firewood in the study area although *Brachystegia* spp., *Isoberlinia angolensis* and *Julbernadia paniculata* are more preferred among the user groups (Appendix 2.1, 2.2 & 2.3). A similar pattern of species preference was reported by Werren *et al*., (1995) in Malawi where a bundle of firewood could have included between 12 and 25 of the most common species in the woodland. However, species and size preference for firewood differs among the users. Species such as *Brachystegia* spp., *Isoberlinia angolensis* and *Julbernadia paniculata* are more preferred for fuelwood production because of their burning qualities, and these are often also the dominants of the woodland (Chidumayo *et al*., 1996) while people may prefer small stems as they require less labour to cut than large stems.

Charcoal is one of the major products in indigenous woodlands and provides an important source of income for the rural dwellers (Chidumayo *et al*., 1996). It is an important product for all the producer groups. Most of the species of the woodland in the study area are suitable for and used in charcoal production by all the forest users (Appendix 2.1, 2.2 & 2.3). This confirms the report by Chidumayo (1990) that 90% of the above ground biomass in Miombo woodland of Zambia is suitable for charcoal production. However, usually only logs with butt girth greater than 3.2 cm DBH are used (Chidumayo, 1990) though the producers may cut smaller stems, and use branches for charcoal production if large sized stems are not readily available.

2.4.1.2 Pole supply

Poles are important for house and barn construction for the communities. Most of the species are used for pole production in the study area (Appendix 2.1, 2.2 & 2.3). This, according to Grundy *et al*. (1993) and Vermeulen (1993), is because the construction works require many poles of many different dimensions, weights and durability. However, the demand for pole sizes may be highest above a certain diameter. Lowore *et al*. (1993) observed that the highest demand for poles around Chimaliro Forest Reserve in Malawi was from stems of above 5 cm in basal diameter and any recruitment into this size was rapidly utilized. However, the importance of

Miombo woodland in supplying poles to different user group ranked lowest (Table 2.1). This could be attributed to the fact that house and barn construction is not a day to day activity of these people and therefore once the house/barn is constructed it takes longer before someone can see the need to replace the poles.

2.4.1.3 Timber production

The main timber species in the study area are *Isoberlinia angolensis, Pterocarpus angolensis, Brachystegia floribunda*, *Afzelia quanzensis* and *Albizia antunesiana*. These species are among the many timber species in the Miombo woodland. They are used for all sorts of timber applications such as mining timbers or sawlogs. The species are preferred among the producers because of their specific attributes. For example, *Pterocarpus angolensis* is preferred because of its durability (Gauslaa, 1989) while *Afzelia quanzensis* is straight-grained and hard, making it suitable for both internal and external joinery (Chidumayo *et al.,* 1996). However, other species may be preferred for other attributes such as fuzziness.

2.4.1.4 Carving

People in the study area use wood for making various implements: hoe and axe handles, pestles and mortars, cooking sticks, plates, bowls and curios. As is the case with firewood, specific attributes are required for each express purpose (see Grundy *et al*., 1993). For example, hunting tools such as knobkerries and arrows are made from heartwood such as *Swartzia madascariensis*, while species such as *Julbernadia paniculata* with interlocked grains at root collar, and also strong, resistant to splitting and can also be sanded to a smooth finish are more preferred (Chidumayo *et al.,* 1996). For utility items a durable wood, with good form and density is desired such as *Pericopsis angolensis* (Chidumayo *et al.,* 1996). This explains why species such as *Julbernadia paniculata*, *Pterocarpus angolensis*, *Erythrophleum africanum, Afzelia quanzensis* and *Swartzia madascariensis* are more preferred for carving purposes among the community members in the study area (Table 2.2, Appendix 2.1, 2.2 & 2.3).

2.4.1.5 Ash fertilization

The importance of Miombo woodlands for agricultural production is well known, in the study area like in many other parts of northern Zambia. The farming systems in this part of the Zambia have been dominated by slash & burn as a strategy for soil fertility enhancement. However, the system has been practically unsustainable (Lawton 1982) due to an increase in population pressure. A good number of respondents among farmers consider Miombo woodlands as of high priority for soil improvement using slash & burn ash (Table 2.1). This is contrary to the results obtained in Tanzania (Mbwambo, 2000) and Zimbabwe (Campbell, *et al*., 1993; Grundy *et al*., 1993) where a lot of the community members did not perceive the woodland to be important for soil improvement. However, elsewhere within Zimbabwe, the local communities have been reported to use Miombo woodland for soil improvement (Nyathi and Campbell, 1993)

2.4.1.6 Other products and services

The local communities also derive some other benefits from the woodlands apart from the above mentioned products. In general, the woodlands provide wild foods which can either be consumed or sold to generate income, and also traditional medicines. The wild foods harvested from the woodlands include fruits, mushroom, insects, wild vegetables and tubers. The common fruits in the study area are *Uapaca spp., Strychnos spp., Syzygium spp., Parinari curatellifolia* and *Anisophyllea boehmii*. However, the importance of woodlands for these products does not seem to be of a high priority among the stakeholders (Table 2.1). Apart from being more important in famine periods (Campbell, 1987; Coote *et al*., 1993), they are most consumed by children (Campbell, 1987). The use of Miombo woodland for wild foods such as fruits has been reported elsewhere in the Miombo ecoregion Miombo namely Zaire (now Democratic Republic of Congo) (Malaise, 1978), Tanzania (Mbwambo, 2000) and Malawi (Akinnifesi *et al*., 2006; Lowore *et al.,* 1995). Additionally, use of woodland products for income generation has also been reported not only in Zambia (Chidumayo and Siwela, 1988) but also in other parts of the region (Campbell, 1987; Shackleton *et al*., 1998; Olsen *et al*., 1999). This, according to Brigham *et al.* (1996) is one of the strategies to meet specific cash needs, as a contingency in case of crop failure.

2.4.1.7 Species preference and availability

Stakeholders in the study site have species preference for various uses. The perception on availability of species for various uses is dependent on the user groups. Charcoal producers considered their preferred species for charcoal production to be readily available. It is not surprising that the charcoal producers have not noticed changes in species availability as most of the above-ground biomass in Miombo woodland of Zambia is suitable for charcoal production (Chidumayo, 1990; 1991). However, a small number of charcoal producers have observed a decline in the population of *Brachystegia boehmii*, a species used for producing bark ropes for making charcoal bag heads (Figure 2.2). *Brachystegia boehmii* is among the species commonly used for fibre production because its fibre is strong and easy to peel (Clarke *et al*., 1996)

Figure 2.2 Bark rope on the charcoal bag head

Additionally, the species for pole production are considered to be readily available among all stakeholder user groups except for a few farmers who have observed a slight change in the availability of species such as *Pericopsis angolensis* and *Pterocarpus angolensis*. This could be because the communities have a number of immature regrowth woodlands in their vicinity which according to Clarke *et al*., (1996) have a high density of poles.

Most of the timber producers (97%) and farmers (57%) have observed a decline in previously preferred species. However, as regards the low proportion of respondents of timber producers indicating that their preferred products are readily available, this could be attributed to the fact that most of the Miombo timber species have always been widely dispersed (Brigham *et al*., 1996). As such the producers have to walk long distances when harvesting such resources and therefore, these respondents may take it as though that is how the resources have been, even when they are being depleted or on a decline. However, concerns among producers that the supplies of some species becoming depleted have been reported in other parts of the ecozone. In Tanzania (Mbwambo, 2000) and Zimbabwe (Bradley and Dewee, 1993) the depletion was attributed to either over-harvesting or agricultural expansion or hot fires. Other authors (Moore and Hall, 1987; White, 1988) attribute the decline or depletion to lack of controls over the location of harvesting which have resulted in harvesting of the most accessible wood first.

2.4.2 Woodland management and conflict resolution among stakeholders

The results of the study indicate the value of the woodland to different stakeholders, and also the various indigenous silvicultural practices among different user groups, which range from controlled utilization, protection and maintenance of regeneration simulation. However, when these practices are compared to the general theoretical framework model on indigenous silviculture (Wiersum and Slingerland, 1997), those practices relating to the production of desired products are normally absent. A similar observation was made by Kamoto, 1999) in the study of indigenous management practices around Chimaliro Forest Reserve, Malawi. This is because indigenous resource management is not as specialized resource management as is the case with professional forestry (Wiersum, 1997). It forms part of the local livelihood strategy, and depending on the strategies of resource use of the local community such as protection of water resources, forest management may be integrated into the local resource use (Gerritsen, 1995). This is why Ostrom *et al.* (1992) suggested that the users of common resources may develop credible commitments to its sustainable use without necessarily relying on external authorities and knowledge. The local communities have rules and laws governing the management of common resources whose enforcement is based on what Niamir (1990) referred to as social ostracism, prestige from being model members, public sanctions and punishments, traditional accountability, informal police force or observance of an informal fairness ethics. However, the fundamental fact confronting all societies is that scarcity of valued things prevails; leading to disputes over their allocation (Cobb and Elder, 1983). Therefore, the higher perception of conflicts among timber producers could be attributed to limitation in availability of their preferred timber species (see Brigham *et al*., 1996) which at times forced them to harvest in other people's fields or even in Government gazzetted forests like *Katanino* local forest. Such conflicts are directly related to the increase in the value of the resources due to increased demand. The abundance in species suitable for charcoal production could explain the low perception of conflict among charcoal producers while land encroachments among the farmers explained the perception of conflicts.

2.5 Conclusion

Most of the user groups in the study area understand the importance of Miombo woodland as the source of various products and services for their daily livelihood. They depend on the woodlands for their wood requirements. However, these user groups differ in product priority from the woodlands, and the choice of species differed according to the intended use or product. Nevertheless, user groups use similar species for the following: building poles, rope and firewood. The use of Miombo woodland among the groups indicated some level of indigenous forest management and commitment to woodland management. Additionally, the groups have been able to notice some decline in species availability. But this has resulted in these groups attributing the negative impacts to the activities of the other. For example the timber producers are attributing the decline in timber species to charcoal production. There is need for these user groups to come together to manage their forest resources on a collaborative basis.

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Appendix 2.1 Percentage distributions of species and value preference among the farmer stakeholder group

Species	Timber	Charcoal	Pole	Carving	Firewood	Ash fertilization	Other values
Isoberlinia angolensis	11.6	48.8	20.9	2.3	95.5	93	69.8
Pericopsis angolensis	0	4.7	2.3	81.4	41.9	9.3	0
Julbernadia paniculata	2.3	93	7	3	100	65.1	34.9
Pterocarpus angolensis	93	0	46.5	81.4	0	2.3	0
Erythrophleum africanum	4.6	0	72.1	69.8	0	2.3	0
Brachystegia spiciformis	0	100	4.7	0	100	34.9	53.5
Brachystegia boehmii	0	100	0	0	100	60.5	34.9
Brachystegia floribunda	46.5	90.7	0	6.8	100	48.8	39.5
Parinari curatellifolia	2.3	11.6	4.7	7	48.8	53.5	58.1
Afzelia quanzensis	74.4	0	0	51.2	0	0	2.3
Albizia antunesiana	32.6	0	34.9	46.5	11.6	11.6	0
Any other species; Faurea saligna, Swartzia madascariensis	32.6	0	34.9	46.5	11.6	11.6	0

Appendix 2.2 Percentage distribution of species and value preference among the charcoal producer stakeholder group

Species	Timber	Charcoal	Pole	Carving	Firewood	Ash fertilization	Other values
Isoberlinia angolensis	74.4	100	0	0	100	69.8	2.3
Pericopsis angolensis	0	2.3	100	97.7	11.7	6.9	2.3
Julbernadia paniculata	0	100	23.3	25.6	100	39.5	7
Pterocarpus angolensis	93	0	86	95.3	0	0	2.3
Erythrophleum africanum	2.3	0	95.3	90.7	0	0	2.3
Brachystegia spiciformis	0	100	0	0	100	34.9	34.9
Brachystegia boehmii	0	100	0	0	100	65.1	34.9
Brachystegia floribunda	51.2	100	0	0	100	88.4	34.9
Parinari curatellifolia	0	37.2	0	0	60.4	62.8	34.9
Albizia antunesiana	34.9	2.3	2.3	7	0	0	2.3
Afzelia quanzensis	90.7	0	0	93	0	0	0
Any other species; *Faurea saligna, Swartzia madagascariensis*	34.9	30	2.3	7	0	0	2.3

Appendix 2.3 Percentage distribution of species and value preference among the timber producer-stakeholder group

Species	Timber	Charcoal	Pole	Carving	Firewood	Ash fertilization	Other values
Isoberlinia angolensis	87	69.6	4.3	0	73.9	65.2	20
Pericopsis angolensis	0	4.3	78.2	100	30.4	21.7	0
Julbernadia paniculata	4.3	69.6	21.7	0	73.9	43.5	26.1
Pterocarpus angolensis	100	0	39.1	78.3	0	0	0
Erythrophleum africanum	43.5	0	60.9	91.3	0	0	0
Brachystegia spiciformis	0	100	0	0	73.9	91.3	7.9
Brachystegia boehmii	0	78.3	0	0	78.3	47.8	21.7
Brachystegia floribunda	91.3	73.9	21.7	0	73.9	65.2	65.2
Parinari curatellifolia	30.4	34.8	0	0	34.8	65.2	0
Afzelia quanzensis	100	0	0	69.6	0	0	0
Albizia antunesiana	100	4.0	13	43	16	4.3	40
Any other species; Faurea saligna, Swartzia madagascariensis	60	4.3	13	43.5	15	4.3	21

Appendix 2.4 Questionnaire structure for charcoal producers/ subsistence farmers/timber producers

A. Background information of the respondent

Name of the local community:……………………..Respondent No......................
Age………………………………Remarks: Charcoal burner ( ) Farmer ( ) Timber dealer ( )

B. Description of the traditional community

1) Describe briefly the history of this traditional community around this forest'
………
……………………………………………………

2) Are the traditional rules and institutions still functioning significantly here?
( ) Yes. Explain…………………………………………………………………..
………………………………………………………………………………………
( ) No. Explain…………………………………………………………………
………………………………………………………………………………………

3) To whom do the traditional rules apply and how are they maintained?
………
……………………………………………………

4) Are there any traditional rules used for protecting the forest?
Yes ( ), if what are traditional sanctions imposed on people who damage the forest?..
....
No ( ) …………….

C. People's understanding of the value of the *miombo* resources around them?

5) Are the *miombo* woodlands around your community important for your daily life
Yes ( )
No ( )
Don't know ( )

If yes, for which values are they important in order of priority?

Value	Priority			
	1	2	3	4
Timber				
Charcoal				
Poles				
Firewood				
Carving				
Ash fertilization				
Others e.g. fruits				

1: 1st priority 2: 2nd priority 3: 3rd priority 4: 4th Priority

6) Which trees do you normally get these values from?

Species	Timber	Charcoal	Poles	Carving	Firewood	Shifting cultivation
Isoberlinia angolensis						
Pericopsis angolensis						
Julbernadia paniculata						
Pterocarpus angolensis						
Erythrophleum africanum						
Brachystegia spiciformis						
Brachystegia boehmii						
Brachystegia floribunda						
Parinari curatellifolia						
Afzelia quanzensis						
Any other species						

7) What are these products for? ( ) Personal consumption ( ) Sale.
If for sale, who are your main buyers?
……
…………………………………………………………

8) Do you know how the woodland from which you get your products is managed?
Yes ( )
No ( )
If yes, what type of management is applied?
Government only ( )
Community participation ( )
Jointly ( )
I do not know ( )
Are there any rules set for the management of the woodlands in this area?
( ) Yes ( ) No ( ) I do not know. If the answer is yes
explain……
……
…………

C The extent of miombo woodland resources utilization in the area

Do you depend entirely on the woodland for all your wood requirement? Yes ( ) No. If no, indicate the other sources
……
……………………………………………

Do you still get tree species you prefer for most of your various uses? ( ) Yes
( ) No ( ) Do not know: If no, which species with their respective uses previously preferred but not available?

Use	Species

Which species have replaced the ones you preferred in the past?

Previous species	Current species	Uses

D. Conflicts among forest user groups

Do other people from outside your community come to harvest forest produce from this forest? ( ) Yes ( ) No ( ) Do not know. If yes, name the products they come to harvest:……

Are there conflicts among the different forest user groups?
( ) Yes
( ) No. If yes, proceed to question 14.

Which one of these do you perceive to be the sources of conflict among different user groups?
( ) Land ownership

Explain……

( ) Private and communal forest resources
Explain
………

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3 THE USE OF SPECIES-STEMS CURVES IN SAMPLING THE DEVELOPMENT OF MIOMBO WOODLAND SPECIES IN CHARCOAL PRODUCTION AND SLASH AND BURN REGROWTH STANDS

Abstract

The use of fixed-area plot methods was considered unsuitable for sampling regrowth stands to generate data for comparing species recovery over time. This paper explains why variable sampling is an ideal method for sampling regrowth stands. The research questions were: i) What is the minimum number of stems and plants in each disturbance and age category required to capture the representative species number with minimum effort? ii) What would be the implication of employing fixed area plots in sampling regrowth stands in terms of number of stems or plants measured in each age class and disturbance category? Different major land use practices in Miombo woodland impact on the recovery potential of the woodlands. Timber harvesting does not result in significant change in stocking of the woodland compared to changes in regrowth after vegetation clearing for either charcoal production or slash & burn agriculture. After such clearing the woodland regrowth changes from an initial high stocking to a much lower stocking over time. In this study in Zambian Copperbelt Miombo woodland species-stems curves were used to determine the optimum number of stems or plants to record at a sampling point to compare species recovery over time in slash & burn and charcoal production regrowth stands of 2 to 15 years after ending the resource use activities. The study has revealed that 34 and 31 stems or plants for slash & burn and charcoal production regrowth stands respectively would adequately capture the representative number of species to describe the plant community of these regrowth stands. The research has also revealed that the use of fixed area methods would result in measuring of too many plants in one category (younger stands) with too few in the other category (advanced stands). Therefore, the study concludes that variable plot size is an appropriate method for sampling species recovery in regrowth stands.

Key words: Variable sampling, fixed area method, Species-stem curves, charcoal and slash and burn regrowth stands.

3.1 Introduction

How can we compare the responses of different species to different land use practices when young regrowth stages have many stems and the older more advanced stages have fewer stems? Can we use plots of variable size to collect information in regrowth stands that provides for comparison of species recovery over time? The comparison in terms of species recovery through fixed plot size may give many stems in the younger stands and fewer stems in more advanced stages. It is possible to miss out on the representative number of species in older stages and too much time may be spent in younger stages than necessary. Timber harvesting does not involve clearing of the woodland and stem density does not change much from pre-harvesting stands. However, both slash & burn agriculture and charcoal production result in clearing of the current woodland. The recovery results in dense regrowth of small stems which gradually grow taller with self-thinning of the stand and a decrease in stem diameter and possibly change in species composition. In the mature woodland the same size categories of plants are present in addition to the mature trees, but the number of stems and number of species vary greatly. In essence, a sampling approach is required to make adequate and fair comparisons, either by fixed area of plots or by fixed number of stems, of most of the species in the relevant size categories of plants in the different disturbance-age categories.

Forest inventories have generally used fixed plots of variable sizes: 0.4 ha (Lees, 1962; Edmonds, 1964, Chidumayo, 1987), 20 m by 20 m (Lawton, 1978; Stromgaard, 1985; Araki, 1992) and 40 m by 40 m (Scholes, 1990) and circular sample plots (Zimba, 1991). Their relevance together with their suitability in measuring species recovery over time is questionable as they may be very large and time consuming and therefore impracticable (Mark and Esler, 1970). They are not adaptable for use in rapid reconnaissance as well as in intensive studies of stands with high variation in density (Shanks, 1954). Additionally, these techniques are not suitable for measuring regrowth stands of variable age after either charcoal production or slash & burn (shifting cultivation). Such stands tend to be variable in both plant stocking and species composition over time (see Strang, 1974; Stromgaard, 1985). Other studies have employed sub-sampling techniques (Shea *et al*., 1993; Geldenhuys, 2000): a larger plot for measuring the fewer bigger trees, and a smaller sub-sample plot within the bigger plot to sample the smaller stems. For example, Geldenhuys (2000) used a sub-sample plot of 0.01 ha within the main plot of 0.04 ha while Shea *et al*., (1993) used a sub-sample plot of 0.00003 ha within the bigger plot for measuring smaller stems. However, other studies (Shanks, 1954; Cottam and Curtis, 1956; Cooper, 1963; Ashby, 1972; Collins *et al*., 2002; Keeley, 2003) have used plotless sampling techniques for the enumeration of trees in extensive and variable forests and woodlands. Plotless sampling involves the use of a certain number of plants to define the size of the plot. Such plots tend to vary in radial distances and are therefore referred to as variable samples.

An adoption of variable sampling in measuring Miombo regrowth stands is necessary in order to determine the minimum number of plants that would adequately be used to describe the vegetation composition of the sampled stand. Variable sampling derives the number of plants from species-stem curves. The species-stem curve method is a modification of the species-area curve method (see Huston, 1994; Rosenzweig, 1995).

This study forms part of a larger study to determine and compare the regeneration (recovery) potential of target Miombo woodland species over time after the specific resource harvesting activity within three land use categories (timber harvesting, slash & burn agriculture and charcoal production) has been terminated. The earlier regrowth stands have dense regrowth of small stems which gradually become taller but less dense. Stands used for timber harvesting were excluded from this specific sampling study because they do not have dense regrowth of different age and species composition. The need is to record enough stems or plants that would represent the species and stem sizes typical of each regrowth stage.

The objective of this particular study was to determine the number of plants that would be used to define the size of variable sized plots. The research questions were: i) What is the minimum number of stems and plants in each disturbance and age category required to capture the representative species number with minimum effort? ii) What would be the implication of employing fixed area plots in sampling regrowth stands in terms of number of stems or plants measured in each age class and disturbance category?

3.2 Materials and methods

3.2.1 Study area

The study area is located approximately 90 km south of Ndola Town towards Kapiri-mposhi in Masaiti District which lies between latitudes 13^{o} 25' 00"S and 13^{o} 45' 00"S and longitude 28^{o} 25' 00"E and 28^{o} 40' 00"E (Figure 3.1). The climate of the area, based on temperature and rainfall is characterized by three distinct seasons: hot dry season (September-November), hot wet season (December-April) and cool dry season (May-August). The temperatures vary from 18^{0}C in winter to about 30^{0}C in summer (Rao & Acharya, 1981). The lowest temperatures usually occur in June/July while the highest temperatures occur in October. The average annual rainfall is about 1200 mm (Rao & Acharya, 1981).

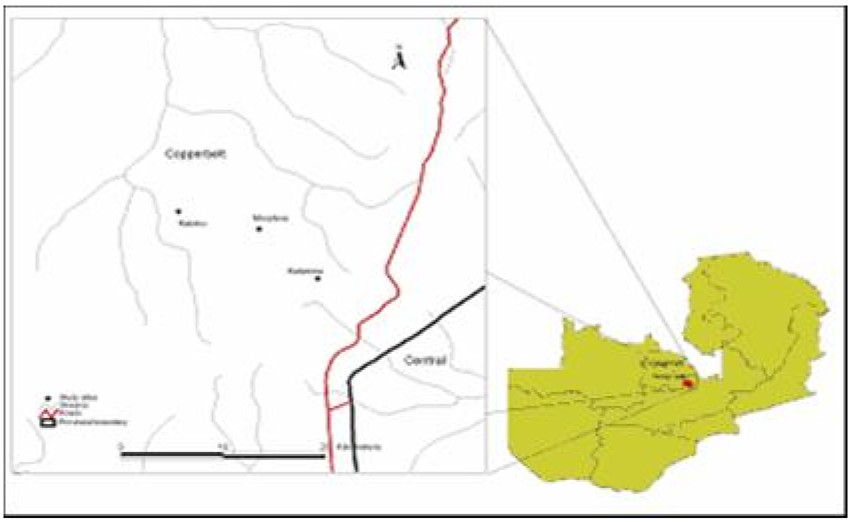

Figure 3.1 Map of Zambia showing study area in Masaiti District

It occurs on the Katanga rock system at an altitude of 1200 m. The soils of the study site are of eluvial origin occurring on basement quartzites, schists and granitic rocks. Such soils are Oxisols and Ultisols which are acidic (pH 4-5), sand rich and highly leached with sandy-silty-clayey textural composition (Chidumayo, 1997).

The major vegetation of the study area is Miombo. Miombo is a *Kinyamwezi* term for *Brachystegia boehmii* (Mansfield *et al*. 1976) but has been accepted to refer to the woodland types dominated by *Brachystegia* spp., *Julbernadia* spp. and *Isoberlinia angolensis*. It is a single tree-story woodland with a light, closed canopy, dominated by Papilionacae and Ceasalpiniodeae, especially of the genera *Brachystegia, Isoberlinia* and *Julbernadia.* The dominant canopy species of the study area are *Brachystegia spiciformis, Brachystegia floribunda, Julbernadia paniculata* and *Isoberlinia angolensis* with *Pterocarpus angolensis, Pericopsis angolensis, Burkea africana, Swartzia madagascariensis, Albizia antunesiana and Parinari curatellifolia* being the canopy associates while *Anisophyllea boehmii, Diplorhynchus condylocarpon*, *Syzygium guineense* and *Uapaca spp* are the common understory trees found in the study area.

This area is being used for timber harvesting through a single-tree selection system, slash & burn agriculture and charcoal production. Regrowth stands of less than two years to over 15 years after cessation of the particular land use practice are present in the study areas.

3.2.2 Methodology

3.2.2.1 Sampling design

Initially, five sites previously under slash & burn agriculture and charcoal production were selected for the study. These sites had different age classes represented from the time slash & burn agriculture and charcoal production ceased (see Table 3.1). These age classes were estimated using records from the District Forest Office, Kaloko Trust, Traditional Councilors (*ba filolo*) and by interviewing the local farmers and charcoal producers. Three sites were randomly selected for the study. Then the site map for each site was developed from coordinates collected with the use of a global positioning system (GPS). A grid system with latitudes and longitudes of 50 m by 50 m was superimposed to give the potential number of points from which a random selection of sampling points was made. A total of 16 sampling points (only 12 for charcoal regrowth stands which had no site for the 15 + year old stand category in Katanino/Kashitu) were randomly selected in each of the disturbance categories. This implies that four points were established in each age category (Table 3.1). A total of 92 sample points were selected for the study. This study formed part of the sampling design for the larger study to determine the regeneration potential of target species within the three land use practices.

Table 3.1 Distribution of sampling points per site per age class

Site	Slash & burn re-growth stands				Charcoal re-growth stands			
	Age, years							
	2-3	5-6	10-12	15+	2-3	5-6	10-12	15+
Kaloko	4	4	4	4	4	4	4	4
Mwaitwa	4	4	4	4	4	4	4	4
Katanino/Kashitu	4	4	4	4	4	4	4	-
Total	12	12	12	12	12	12	12	8

3.2.2.2 Data collection

Sample points were located in the field with the use of a GPS. Data collection involved the measuring and recording respective distances of individual plants from the sampling point. The maximum sample size for this study was defined by 60 plants (not stems) whose distances were measured from the centre point clockwise starting with nearest plant until the furthest plant was measured (Figure 3.2). The number 60 was determined based on the initial assessment which indicated that 40-50 plants in a sample plot would adequately describe the species composition at the sampling plot.

The 60 plants to be measured are those closest to the sampling point as indicated in Figure 3.2. A plant in this study refer to a either a single stemmed plant or a group of stems with a common base (Figure 3.3 a & b).

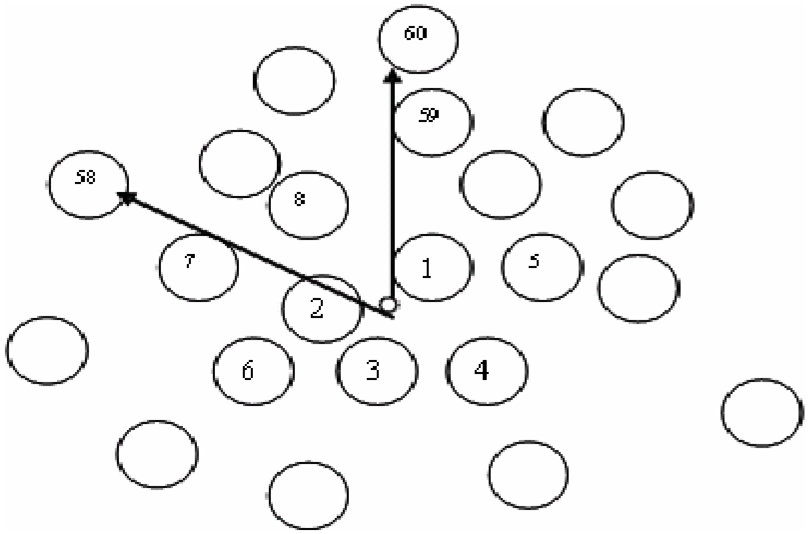

Figure 3.2 Sequence of recording up to 60 plants around the sampling point to develop species-stem curves in regrowth Miombo woodland near Ndola, Zambia**.**

(a) (b)

Figure 3.3 Multistemmed plant (a) and a single stemmed plant (b)

However, it may be difficult to determine the 60th closest plant, and as such the distance was measured from the sampling point to the 58 to 60th plant. In that way, the 60th plant was determined. The size of the sampled area was determined by the radius of a circular plot, defined by the distance from the sampling point to the mid-point of the 60th plant defining the boundary of the variable plot.

3.2.2.3 Data analysis

The species names and their respective distances from the sample point were entered into an Excel spreadsheet. Data for the 60 plants recorded at each point were arranged according to their respective distances from the centre point using Excel version 2003. Then, starting with the plant closest to the centre point, the number of species was recorded after every plant up to the 60^{th} plant (Table 3.2).

Table 3.2 Consecutive plants/stems by species with respective distances from the center point (up to 60 plants per sample point, but not shown here).

Species	Distance, m	Plant number	Stem number	No of species
Julbernadia paniculata	0.6	1	1	1
Julbernadia paniculata	0.9	2	2	1
Julbernadia paniculata	0.9	2	3	1
Diplorhynchus condylocarpon	1.5	3	4	2
Diplorhynchus condylocarpon	2.2	4	5	2
▼	▼	▼	▼	▼
Brachystegia floribunda	15	**31**	**84**	**15**
Etc, until 60th plant				

The number of species found at every distance from the centre point was plotted on the vertical axis (**O-Y**) against the number of stems (or number of plants) on the horizontal axis (**O-X**) to produce the resulting sigmoid species-stems or species-plants curves (Figures 3.3 & 3.4). This was done for every plot separately.

The desired minimum number of stems/plants was determined by locating the point on the curve where the line takes a horizontal course, and then joining it to the horizontal axis to indicate the minimum number of stems/plants required to capture the minimum number of stems/plants needed to adequately describe the species composition for that sample point.

The minimum number of stems/plants required to sample the minimum number of species with minimum effort for each sample plot was read from excel spread sheet (e.g. Table 3.2) against the total number of stems/plants at which the sigmoid curve began to form (Figures 3.3 & 3.4). The average number of stems/plants desired to sample the minimum number of species with minimum effort was calculated as follows:

$$\text{Average number} = \frac{\text{Total number of stems/plants for all plots per disturbance and age class}}{\text{Number of plots per disturbance and age classes}}$$

Additionally, the average radial distances (m) were calculated for each disturbance and age category. The average radial distances for each disturbance were compared across age classes to determine the implication of using fixed area plot as opposed to variable sampling.

3.3 Results

3.3.1 Species-stems relationship and the required number of plants

The study of the species-stems relationship in both charcoal and slash & burn regrowth stands showed that as the number of stems increases the number of species also tend to increase up to a point when the curve begins to flatten.

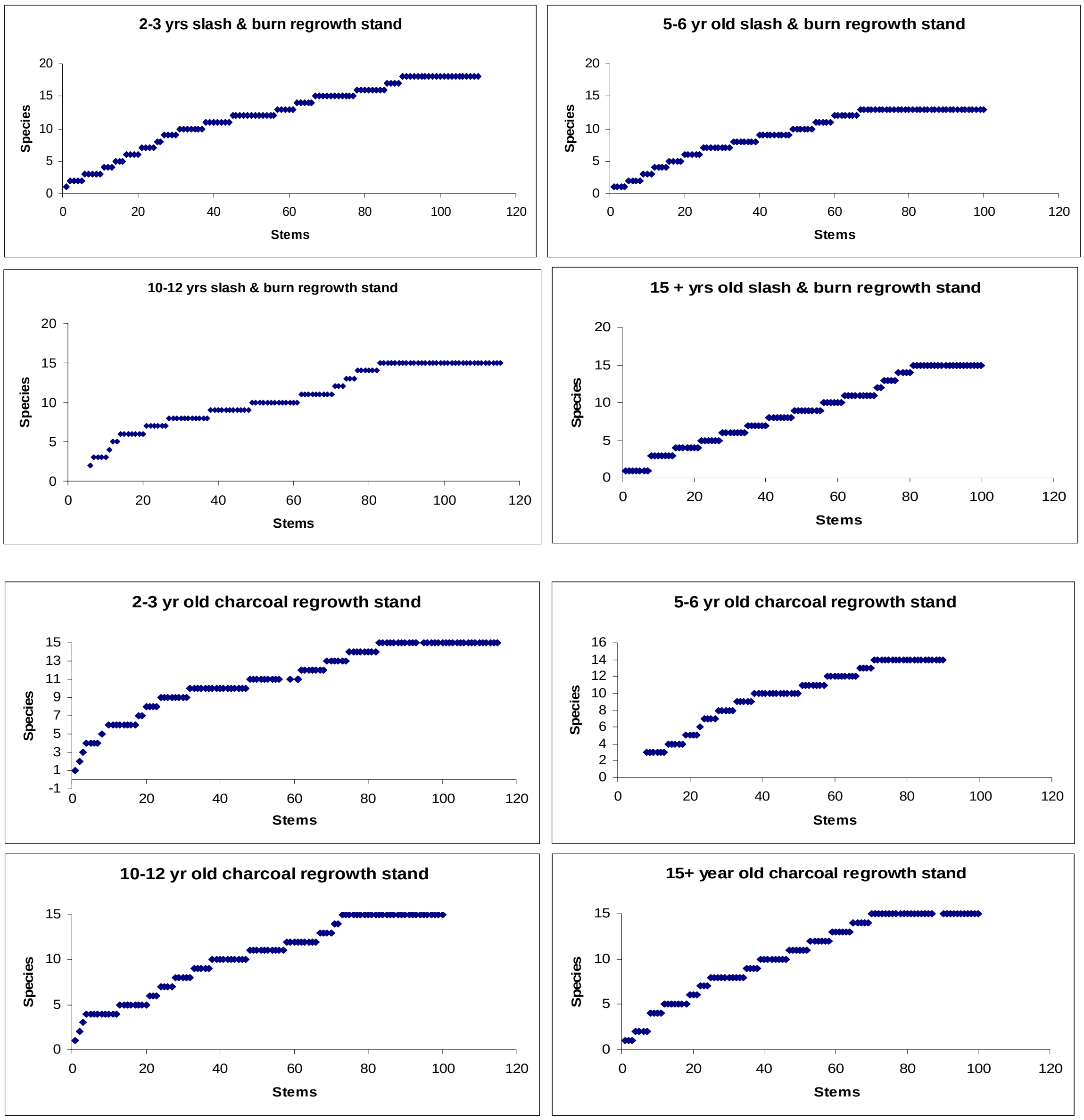

Figure 3.4 Species-stem curves for various age classes for some of the slash & burn and charcoal regrowth stands

This results in the formation of a sigmoid curve (Figure 3.4). This is the common trend obtained in all the age class categories of each disturbance. A similar curve is observed from species-plants relationships (Figure 3.5).

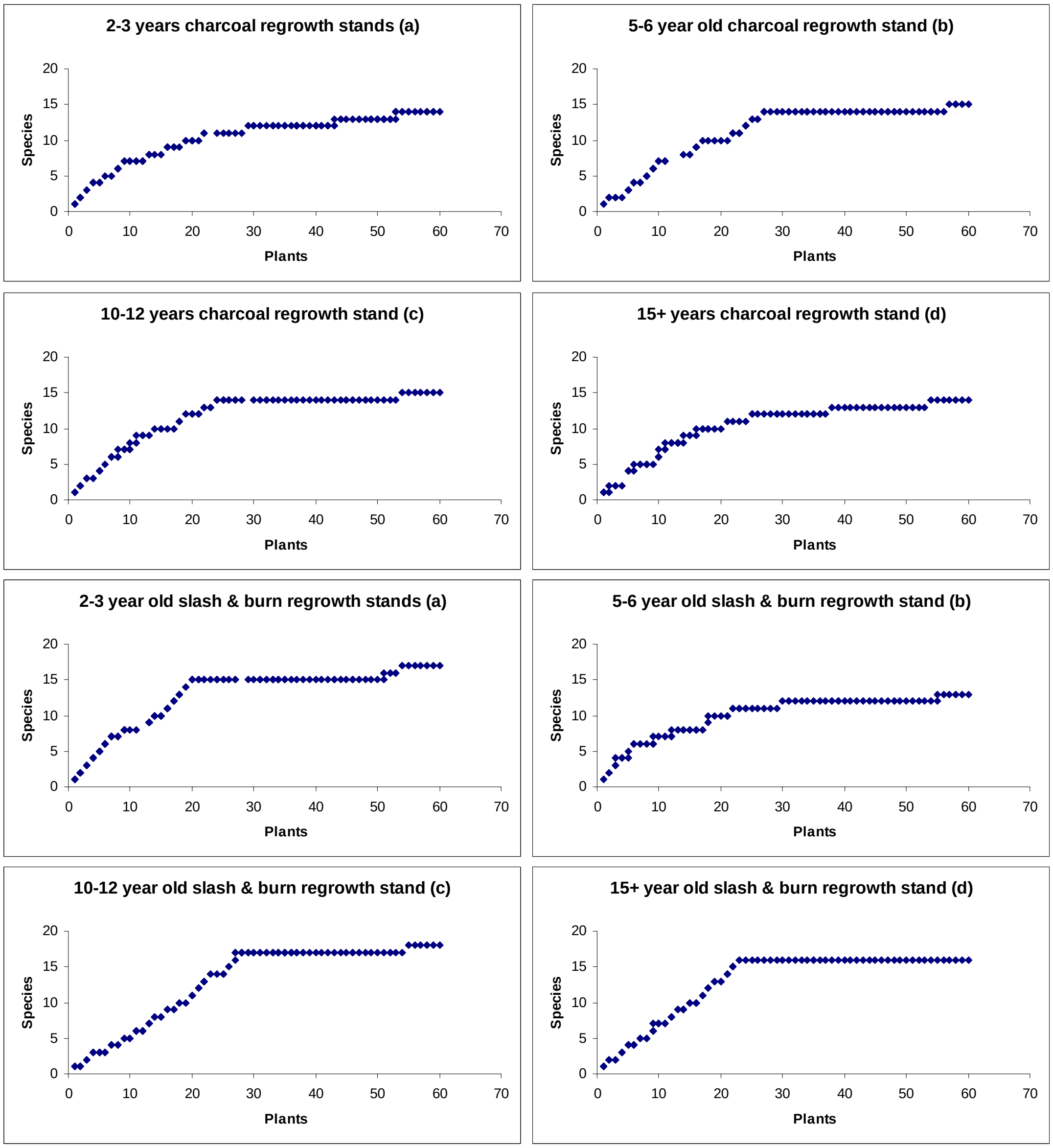

Figure 3.5 Species-plant curves for various age classes for slash & burn and charcoal regrowth stands

The number of plants and stems/ha required to adequately represent the vegetation composition in each stand under each disturbance category tend to vary from one disturbance category to another and also with age (Table 3.3). In the case of charcoal regrowth stands, the average number of plants ranges from 26.2±0.6 (for 5-6 year old stands) to 29.7±1.4 (2-3 year old stands) while in slash & burn stands, the number ranges from 22.0±1.5 (in 2-3 year old stands) to 31.0±3.4 (in 10-12 year old stands). The numbers of species that would be generated in plot sizes defined by these ranges of plant numbers are 13.0±1.3 (in 5-6 year old) to 14.0±1.7 (in 2-3 year old stands) for charcoal regrowth stands. In slash & burn regrowth stands, the number is from 13.0±0.8 (5-6 year old stands) to 14.0±1.3 (in 15+ and 2-3 year old stands).

Table 3.3 Minimum number of plants and minimum number of stems required to define the sample size with respective standard error in a plot

Stand age (years)	Disturbance category			
	Charcoal regrowth stands		Slash and burn regrowth stands	
	Number of plants	Number of species	Number of plants	Number of species
2-3	29.7±1.4	14.0±1.7	22.0±1.5	14.0±1.3
5-6	26.2±0.6	13.0±1.3	30.6±3.6	13.0±0.8
10-12	29.7±1.3	14.0±1.5	31.0±3.4	13.0±2.0
15+	26.9±1.1	13.0±1.6	22.3±4.8	14.0±1.3
Stand age (years)	Number of stems		Number of stems	
2-3	61.4± 7.1		70.0±9.0	
5-6	56.6± 4.6		52.1±5.8	
10-12	52.5±6.7		59.0±5.2	
15+	50.0± 3.7		57.3±5.4	

3.3.2 Mean radii and stocking (stems/ha) for each variable sample plot

The mean radii and stocking vary significantly between the youngest stands and the older stands both within and between disturbances (Table 3.4). In slash & burn regrowth stands, the highest significant difference ($P< 0.00001$) in radius is observed between the 2-3 and 15+ year old stands. There also exists a significant difference ($P< 0.03$) between 10-12 and 15+ year regrowth stands. Additionally, there is also a significant difference ($P< 0.0002$) in radius between 5-6 and 10-12 year old stands. In case of the charcoal regrowth stands, the significant difference in radius exists between 2-3 and 15+ year ($P< 0.007$) and 5-6 and 10-12 year old stands (($P< 0.009$). However, apart from the significant differences that exists between 5-6 and 10-12 year old slash & burn and charcoal regrowth stands, there exist no significant difference in radius between similar ages of different disturbances.

Table 3.4 Mean radius and stocking (stems/ha) for each stand type and age class category with respective standard error

Stand category	Stand age, years			
	2-3	5-6	10-12	15+
	Radius, m			
Charcoal regrowth stands	6.5 ±1.1 (4851± 1076.6)	12.5 ±2.0 (1213.9 ±287.3)	11.7 ±1.1 (1242.2±55.4)	11.2 ±1.4 (1306.6±456)
Slash & burn regrowth stands	5.9 ±1.0 (6685±1404.8)	17.8 ±1.9 (545.0±45.0)	13.9 ±1.7 (995.2±155.4)	13.1 ±2.2 (1121.5±268.9)

3.4 Discussion

3.4.1 Species-stems curves and minimum number of plants

The species-stem curves obtained in charcoal and slash & burn regrowth stands showed that as the number of stems increase the number of species also tend to increase up to a point when the curve begins to flatten (Figure 3.4). Similarly, the species-plant curves in both slash & burn and charcoal regrowth stands depict a similar curve pattern (Figure 3.5). This is because in a stand of any plant community, the individual plants exists in a certain number (density) distributed over an area. This explains why as the number(s) of plants and stems increase, the number of species increase up to a point when an increase in number of plants and stems results in decreasing rate of species increases within the same vegetation. This is the point at which species-stems and species-plants curves begin to flatten. This implies that there is little to be gained by increasing the number of stems/plants defining the plot size, if one wants to sample the number of species that may be used to describe the species composition of the plots. Table 3.3 shows the average number of plants and stems that would be used to capture the number of species per plot that would adequately describe its species composition. For example, an average of 29.7± 1.4 plants (or 61.4 ± 7.1 stems) for 2-3 year old charcoal regrowth stand would be used to define the size of the plot in which 14.0 ± 1.7 species would be captured to describe the species composition in the plot. The species numbers generated from this study are comparable to what Chidumayo (1987) reported on the study of mean species diversity in Miombo subtype near the current study area. Chidumayo (1987) reported the mean species number to range from 13.3 ± 1.3 in Coppice stand plot to 14.8 ± 0.5 in old regrowth stands of 0.1 ha. Unfortunately, Chidumayo (1987) does not indicate the respective ages of his sample plots or stands. But, even comparing the number of species in a 0.4 ha (see Chidumayo, 1987), the numbers generated from the current study would still be used to adequately describe the vegetation composition of each plot as most of the species are captured in the variable plots. However, the species number tends to vary with variation in the Miombo subtype (see Chidumayo, 1987) with the wetter Miombo having the highest species number per plot.

The study has also shown significant variation in radius required to define the sample size under each disturbance and age class category (Tables 3.4). This is because of variability in stand stocking and species composition over time (Strang, 1974; Stromgaard, 1986; Chidumayo, 1988). There is some variation between the age classes in the number of plants needed to adequately describe the community, but the numbers are relatively small. This means that 29.7±1.4 plants may be used in defining the plot size in charcoal regrowth stands while 30.6±3.6 plants may be used in slash and burn regrowth stands. However, since going for the lower limit of the range can result in missing some species, 31 and 34 plants (the upper limits) may be used in defining the variable sample sizes for charcoal and slash & burn regrowth stands, respectively. If one decides to use a uniform number of plants for both disturbances, 34 plants would be required to define the variable sample size of these charcoal and slash & burn regrowth stands.

3.4.2 Mean radii and stocking (stems/ha) for each variable sample plot

Table 3.4 shows the mean radius for each age and disturbance category that would be needed to generate information to adequately describe the species composition of each stand. The most significant difference in mean radius is between the youngest age category (about 6 m) and the three other age categories (about 11 to 14 m), in both charcoal and slash & burn sites (Table 3.4). The mean radius for the other age categories is more or less in the same order of magnitude, even between the two types of disturbances, except for the much higher radius in the 5-6 year category in slash & burn sites (about 18 m). These differences have direct implication for the use of fixed-area plots in sampling such stands. Firstly, the differences imply that no single radial distance could be used to adequately sample charcoal and slash & burn regrowth stands of all ages. For example, if one adopts the mean radial distance of about 12 m (or 0.045 ha) for 10-12 year old charcoal regrowth stands to define the plot throughout the different ages of both the charcoal and slash & burn regrowth stands, such a plot will give too many plants in the 2-3 year old stand (for both charcoal and slash & burn regrowth stands) with too few in the 5-6 year old slash & burn regrowth stands. Similarly, the use of common plot sizes such as 0.4 ha (Lees, 1962; Edmonds, 1964; Chidumayo, 1987) can result into measuring too many plants while the 20 m by 20 m plot (0.04 ha) (Lawton, 1978; Stromgaard, 1985, Araki, 1992) may result in too few plants in certain stands (e.g. 5-6 year old slash & burn regrowth stands). The differences in the required radial distances to sample different stand ages with minimum effort implies that there is need to adjust the sample sizes for a particular density of the vegetation under study and this may require additional labor (Cottam and Curtis, 1956) and time. Sampling of too many plants in other categories does not necessarily misrepresent the vegetation composition but may have direct cost implications in that more time may be spent in sampling those stands than what is necessary. However, sampling of too few plants may under represent the vegetation composition of the plots and therefore the stands.

Sub-sampling techniques were used in some studies (e.g. Shea *et al*., 1993; Geldenhuys, 2000) in which a smaller plot is established within the bigger plot. The use of smaller sub-sample plots may provide for an alternative technique to variable sampling in young regrowth stands (2-3 year old). This may imply that one could use smaller sub-sample plots (eg 0.01 ha) in measuring young stands (2-3 years) without measuring the bigger plots as there would be no need to measure the bigger plots, because there would be no big stems. In the oldest regrowth stands fixed-area plots could be used as for the mature stands. However, the problem with this technique is that a fixed plot of a specific size will capture either too many stems in younger regrowth stands but too few stems in the mature stands. The plot size may be comparable, but the information content will not be adequate. Capturing of most of species in a plot that would most adequately describe the vegetation may not be guaranteed.

3.5 Conclusions

From the foregoing discussion it can be concluded that sampling fixed-area plots are not suitable for comparing stands in different development stages with variable density and species composition, for several reasons: i) misrepresentation of vegetation composition in some stand categories; and ii) spending more time and effort than necessary in some stand ages. Fixed area plots are not flexible enough to provide for adequate and fair comparisons when sampling regrowth stands in different development stages. However, the variable sampling techniques, which use a fixed number of plants rather than a fixed plot size, is flexible enough as it does not require adjusting plot size from on stand/age category to another. Furthermore, the study has indicated that 31 and 34 plants would be used to define plot sizes for charcoal and slash & burn regrowth stands respectively. If we decide to use a single number to define the size of our variable plots, for all ages of the regrowth stands, 34 plants would adequately capture the vegetation composition. Such a number would provide for sampling of regrowth stands with minimum effort. It therefore can be concluded that variable sampling is more useful in sampling stands of variable stocking of composition. However, similar studies should be carried out in other woodland types in the region to ascertain the versatility of the method for wider application in future, and to compare this approach with sub-sampling with different sizes of sub-plots to capture different sizes of plants.

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4 DOES HUMAN DISTURBANCE HAVE A NEGATIVE IMPACT ON THE FLORISTIC COMPOSITION OF MIOMBO WOODLAND?

Abstract

Many researchers have generally contested the concept of succession in Southern African woodland ecosystems such as Miombo woodlands. As such, clearing of Miombo woodland either for slash & burn agriculture or charcoal production have been viewed to have negative implications on the Miombo woodland ecosystems. These forms of woodland utilization are condemned in favor of single tree selection timber harvesting. This paper argues in favor of slash & burn agriculture and charcoal production as being necessary disturbances in the management of Miombo woodland ecosystems. It addresses three important questions: What species characterizes each development stage of the Miombo woodland recovery after the cessation of the disturbance? Does the woodland floristic composition mimic typified Miombo woodland over time after disturbance cessation? What is the influence of environmental factors on species occurrence over surveyed areas? The study involved the selection of three different sites with vegetation in different ages occurring in close proximity to each other in Zambian Copperbelt Miombo woodland. The different ages were 2-3; 5-6; 10-12 and 15+ years from the time disturbance ceased. Additionally, the relatively undisturbed areas were selected to act as a control. The study revealed that the initial stages of woodland recovery are mainly composed of *Chipya* and *Uapaca* ecological species such as *Uapaca kirkiana, Anisophyllea boehmii*, *Parinari curatellifolia* and *Baphia bequeartii.* Additionally, the study revealed that the key species of Miombo woodland, *Isoberlinia angolensis, Julbernadia paniculata*, *Brachystegia floribunda, Brachystegia longifolia*, *Albizia antunesiana* and *Pterocarpus angolensis* also form an important component of the early stages of woodland development. These species have some survival mechanisms that make them less susceptible to fires in their early stages of development. For example, species like *Isoberlinia angolensis*, though not fire hardy, exhibit hypogeal germination which enhances its survival against fire. The study concluded that although slash & burn agriculture and charcoal production are viewed negatively, they may be necessary components in the management of the Miombo ecosystems if their associated rates of woodland clearing are controlled.

Key words: composition, Chipya ecological group, Miombo ecological group, *Uapaca* ecological group, species richness, turnover

4.1 Introduction

Woodland development after a disturbance may involve replacement of the earlier vegetation by a totally different vegetation or similar vegetation. However, this concept of succession has been contested by Walker (1981) in Southern African woodland, but a few studies (Strang, 1974; Brenan, 1978; Lawton, 1978; Stromgaard, 1986; Chidumayo, 1993a, b, 2004) provide data to test the concept in the region. Among these studies, the interest has focused more on later stages in changing of vegetation communities, frequently with emphasis on special ecological groups (Brenan 1978; Lawton, 1978) such as *Chipya*, *Uapaca* and *Marquesia*. In Zambia, Stromgaard (1986) showed the succession in slash & burn regrowth stands although the study did not consider development in terms of size classes for individual Miombo species to demonstrate species dominancy over time. Additionally, Chidumayo (1988, 1993a, b, 2004) studied the development of Miombo woodland over clearfelled areas but without emphasis on individual species development over time as well. In Zimbabwe, Strang (1974) reported the changes in overall stocking of slash & burn regrowth stands over time but did not show the changes in species composition. In general, although studies on succession of Miombo woodland have been conducted, the emphasis has not been much on the development of individual species over time in terms of their importance. Where such studies have been conducted (Boaler and Sciwale, 1966), there has been no deliberate attempt to compare the response of the woodland to the common human-induced disturbance factors namely single tree selection (timber) harvesting, slash & burn agriculture (shifting cultivation) and charcoal production, and to relate this to the natural disturbance-recovery processes that shape the adaptation of species. As such, the information on response of Miombo woodland to various disturbance factors is incoherent to provide a basis for effective understanding of the effects of these disturbances on recovery of Miombo woodland over time and therefore their management implications. The information from previous studies is inadequate to provide a thorough understanding of the variation in regeneration characteristics that may exist as a result of the differences in disturbance factors.

The study was designed to provide information on changes in the floristic species composition (species richness and diversity) in the regeneration and development stages of the Miombo woodland under varying human disturbance factors i.e. timber harvesting, slash & burn agriculture and charcoal production. It seeks to answer the following questions: (i) Which species dominate in particular development stages of the Miombo woodland under each disturbance regime? (ii) Do the current changes in woodland composition mimic the typical Miombo woodland based on available literature? (iii) Do environmental variables namely soil pH, soil depth, aspect, slope and altitude have an influence on the occurrence of characteristic species in both mature Miombo woodland stands and regrowth stands (after slash & burn and charcoal production) of the study sites.

4.2 Material and methods

4.2.1 Study area

The study area is located in Masaiti District, which is 90 km south of Ndola Town towards Kapiri- mposhi (Figure 4.1). It lies between 13^{o} 25' 00"S and 13^{o} 45' 00"S and 28^{o} 25' 00"E and 28^{o} 40' 00"E and occurs on Katanga rock system at an altitude of 1200 m.

The climate of the area, based on temperature and rainfall (Figure 4.2a, b), is characterized by three distinct seasons: hot dry season (September-November), hot wet season (December-April) and cool dry season (May-August). The temperatures vary from 18^{0}C in winter to about 30^{0}C in summer (Rao & Acharya, 1981). The lowest temperatures usually occur in June/July while the highest temperatures occur in October. The average annual rainfall is about 1200 mm (Rao & Acharya, 1981).

The soils of the study area are of eluvial origin occurring on basement quartzites, schists and granitic rocks (Chidumayo (1997). The soils are typically Oxisols and Ultisols which are acidic (pH 4-5), sand rich and highly leached with sandy-silty-clayey textural composition.

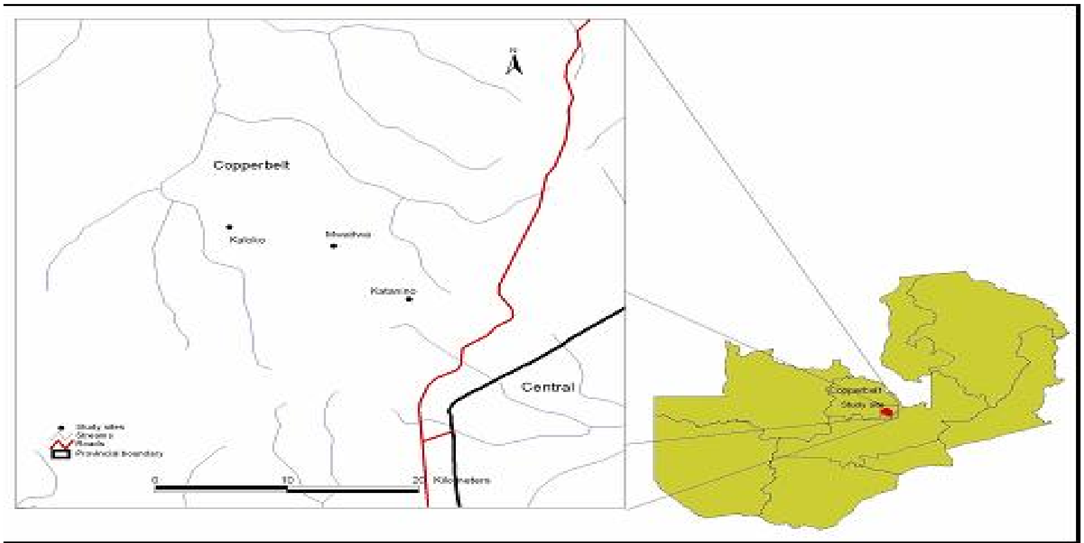

Figure 4.1 Map of Zambia showing the location of the study site in Masaiti District, Copperbelt Province.

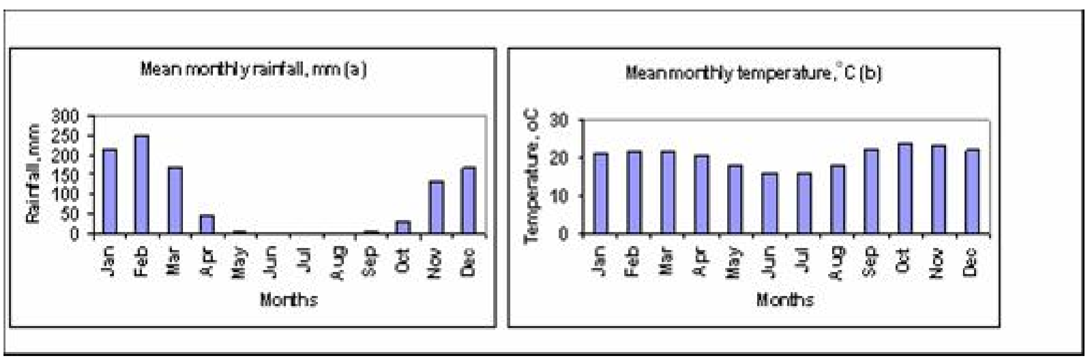

Figure 4.2 Mean monthly temperatures and rainfall for 2000-2006 for Copperbelt Province (Zambia Meteorological Dept. (unpublished)

The major vegetation of the study area is Miombo, a term used for *Brachystegia –Julbernadia-Isoberlinia* dominated woodland (Mansfield *et al*. 1976). It is a single tree-story woodland with a light, closed canopy (Fanshawe, 1971). The dominant canopy species of the study area are *Brachystegia spiciformis, Brachystegia floribunda, Julbernadia paniculata* and *Isoberlinia angolensis*. Canopy associates include *Pterocarpus angolensis, Pericopsis angolensis, Burkea africana, Swartzia madagascariensis, Albizia antunesiana* and *Parinari curatellifolia*. Common understory trees found in the area are *Anisophyllea boehmii, Diplorhynchus condylocarpon*, *Syzygium guineense* and *Uapaca spp*.

4.2.2 Methods

4.2.2.1 Sampling design and data collection

Five areas, each containing areas under disturbance categories of timber harvesting, slash & burn agriculture and charcoal production in the past in close proximity to each other, were selected. Selection of areas in close proximity to each other was done to ensure similarity in soils, landscape position, local climate and the surrounding vegetation. Only three of the five areas were randomly selected for the study, due to limited funds and time: *Kaloko, Mwaitwa* and *Katanino/Kashitu*.

In each study area, study sites with vegetation ages of 2-3; 5-6; 10-12 and 15+ years after cessation of land use activities were selected from within each disturbance category. The ages of the sites were estimated using records from the District Forest Office, *Kaloko* Trust and Traditional Councilors (*Ba Filolo*), and by interviewing the local farmers, and charcoal and timber producers. Additionally, relatively undisturbed woodland was selected in each study area to act as a control.

The site map for each of the selected sites of timber harvesting, slash & burn agriculture, charcoal production and undisturbed woodland was made from the corner coordinates observed with a global position system (GPS). On each site map, a grid system with latitudes and longitudes of 50 m by 50 m was superimposed to give the potential number of points from which a number of random sampling points was selected. Each intersecting point of the grid system capable of providing a plot, without overlapping into the neighboring area (i.e. points on the edge of the map with 50% area overlapping into the area outside the map), was considered a potential sample point. Six points were randomly selected from the potential sample points, in each age category of each disturbance category, based on the available time and funds. In each of the study areas a total of 24 points for slash & burn agriculture, 24 points for charcoal production, 18 points for timber harvesting and 6 points for mature undisturbed woodland, were sampled. This implies that a total of 72 points were sampled on each area except for *Katanino* which did not have charcoal regrowth stands of 15+ years old.

Although most of the sample plots in other Miombo woodland inventories have been systematically selected and located (Trapnell, 1959; Lees, 1962; Lawton, 1978; Chidumayo, 1987), the points in this study were randomly selected using a lottery method and then located using GPS in the field. Random selection of points avoids bias, and is cheaper, quicker and requires less skill once the points are entered into the GPS.

The literature shows the use of a variety of plot sizes but the common sample size used in miombo woodland inventories is 0.4 ha (Lees, 1962; Edmonds, 1964; Chidumayo, 1987). However, 20 m by 20 m (Lawton, 1978; Araki, 1992) and 40 m by 40 m (Scholes, 1990) plots have been used elsewhere in savanna woodland. Plot size, shape and inventory design are dependent on the type of information that the researcher wants to generate from the stand. Fewer inventories have used circular plots (e.g. Zimba, 1991, Geldenhuys & Murray, 1993; Geldenhuys & Pieterse, 1993, Geldenhuys & Venter, 2002). Geldenhuys (2004) used sampling units of 20 m radius in other Miombo inventories to generate data similar to the one for this study. The plot size of 20 m radius has been adopted in this study for sampling mature Miombo woodland i.e. timber harvesting areas and undisturbed woodland (control stands).

In assessing the regrowth stands (areas previously under charcoal production and slash & burn agriculture), variable sampling was used (Chapter 3), which is an adaptation of the closest individual method (Cottam & Curtis, 1956). The number of plants to define the size of the plot is determined by the species-stems/plants curve method (modification of species-area curve method by Huston, 1994 and Rosenzweig, 1995). It involves the use of a fixed number of plants rather than the fixed radius in determining the plot size. The method has several advantages when compared with the fixed-area plot method. It is faster, requires less equipment and fewer workers, and is much more flexible, in that there is no need to adjust the sample size for a particular density of the vegetation under study (Cottam & Curtis, 1956). The method gives comparable numbers, with differences in terms of numbers of species, and ratios of numbers of plants per species in the particular type of stand, but without having to measure many plants in one category of stand (younger stands) with too few in another category of stand (older stands). In this study, 34 plants for slash & burn and 31 plants for charcoal regrowth stands, were used as generated from the pilot study (Chapter 3). Trees were recorded by stem diameter at breast height (DBH), from 1 cm DBH and larger, and species name. The data for non-woody species were collected in sub-plots of 5 m radius around the sampling point. Data collection for the non-woody species involved the estimation of abundance of these species in terms of percentage cover of the sub-plot.

4.2.2.2 Data analysis

All the trees from 1 cm DBH and larger were used in the analysis. In addition, the data of the five dominant species in terms of importance value in each stand age category for each disturbance category and also the undisturbed woodland (control) were separated into three DBH categories and then a correspondence analysis was conducted. This was intended to indicate the size categories of species which drive the composition in each development stage. If, for example, the stem numbers for all sizes were lumped together, the larger numbers of smaller sizes could dominate and that may result in masking the differentiation of the development stages by size of stems of a species. For example, for a species like *Isoberlinia angolensis*, the three categories were Isa1 (stem 1.0-4.9 cm DBH); Isa2 (stems 5.0-9.9 cm DBH) and Isa3 (10+ cm DBH). The species names were abbreviated in a standardized manner (Table 4.1) in order to provide for enough space on the ordination diagram.

Multivariate ordination analysis of the most dominant species in undisturbed woodland stands and each stage of slash & burn and charcoal regrowth development was performed with the program CANOCO (version 4.0; ter Braak and Šmilauer, 1998) based on their three categories of size indicated earlier. The environmental variables observed were soil pH, slope, soil depth, altitude and aspect.

Table 4.1 Abbreviated species names with their corresponding full names

Abbreviated name	Full name
Anb	*Anisophyllea boehmii*
Bab	*Baphia bequaertii*
Brl	*Brachystegia longifolia*
Brs	*Brachystegia spiciformis*
Dic	*Diplorhynchus condylocarpon*
Ham	*Harungana madagascariensis*
Isa	*Isoberlinia angolensis*
Jup	*Julbernadia paniculata*
Moa	*Monotes africanus*
Ocp	*Ochna pulchra*
Pac	*Parinari curatellifolia*
Phl	*Phyllocosmus lemaireanus*
Psm	*Pseudolachnostylis maprouneifolia*
Uak	*Uapaca kirkiana*

The differences between different treatments were described in terms of species importance values, species richness, diversity indices and changes over time. Importance values were calculated as adopted from DWAF (2005):

For plants with dbh ≥ 5 cm

Importance value (IV) = (Relative frequency (RF) + Relative density (RD) + Relative basal area (RG))/3 where;

Relative frequency = $\frac{\text{[Number of plots in which species is present]*100}}{\text{Total number of plots recorded}}$

Relative density = $\frac{\text{[Number of stems recorded for the species]*100}}{\text{Number of stems recorded for all species}}$

Relative basal area = $\frac{\text{[Basal area of a species in a plot]*100}}{\text{Total basal area of all species in the plot}}$

For plants of 1 to 5 cm DBH

IV = (RF+RD)/2.

A biodiversity index (Shannon-Wiener index) was used to determine effects of different disturbance factors on biodiversity. Species diversity was calculated by the Shannon-Wiener index ($\hat{H}$) defined as:

$$\hat{H} = -\sum(n_i/N)*\log(n_i/N)$$

Where n_i is the number of individuals of plant species i, and N is the total number of individuals (Shannon & Wiener, 1963). Indices of similarity as adopted from Sorensen (1948) were determined between different stages of each disturbance category:

Index of similarity (S) = 2C $(A+B)^{-1}$

Where A= is the number of species in stage 1; B is the number of species in stage 2 and C is the number of species common to both stages. This was intended to show how the indices of similarity changes between the different stages of the stand development previously under the same disturbance category. The turnover rate between succession ages was determined by the turnover index (Schoener, 1983):

$$T_{rel} = \frac{(I_{abs} + E_{abs})\,100}{t\,(S_1+S_2)}$$

Where S_1 and S_2 are the number of species on the site at the beginning and end respectively, of a census interval, I_{abs} is the number of species at the end of the census interval absent at the beginning, E_{abs} is the number of species at the beginning of the census interval absent at the end, and t is the length of the census interval. The turnover index shows the percentage of species which have been involved in changes between stages (Stromgaard, 1986), either as new stages invading the abandoned cultivated and charcoal production areas or species lost.

4.3 Results

4.3.1 Development of different woodland regrowth stands in relation to the undisturbed woodland

Figure 4.3 demonstrates the recovery of Miombo woodland stands towards the undisturbed state (control) over years, after the cessation of the disturbance from single tree selection harvesting, slash & burn agriculture and charcoal production.

In Figure 4.3, axis 1 or dimension 1separates Shift and some Char sites to the left from Timb and Control sites to the right. However, the Char sites of 2-3 & 5-6 years, and the shift 2-3 year sites are separated from the rest along the axis 2 or dimension 2. Axis 1 represents the most variation followed by axis 2. Therefore, Char 5-6 year sites are still relatively similar to Timb and the Control sites. In general, Figure 4.3 shows that the stands previously under single tree selection harvesting are closer to the undisturbed Miombo (control) than regrowth stands arising from slash & burn agriculture and charcoal production. Additionally, the figure shows that, for charcoal regrowth stands initially (2-3 years old) the stands are closer to the control than the 5-6 year old stands. However, 10-12 years later, the stands begin to develop towards the control. At 15+ years, the charcoal regrowth stands are getting closer to the control. In the case of slash & burn regrowth stands, the 2-3 years is the farthest away from the control site, with other development stages reducing the distance between the control and their respective stands.

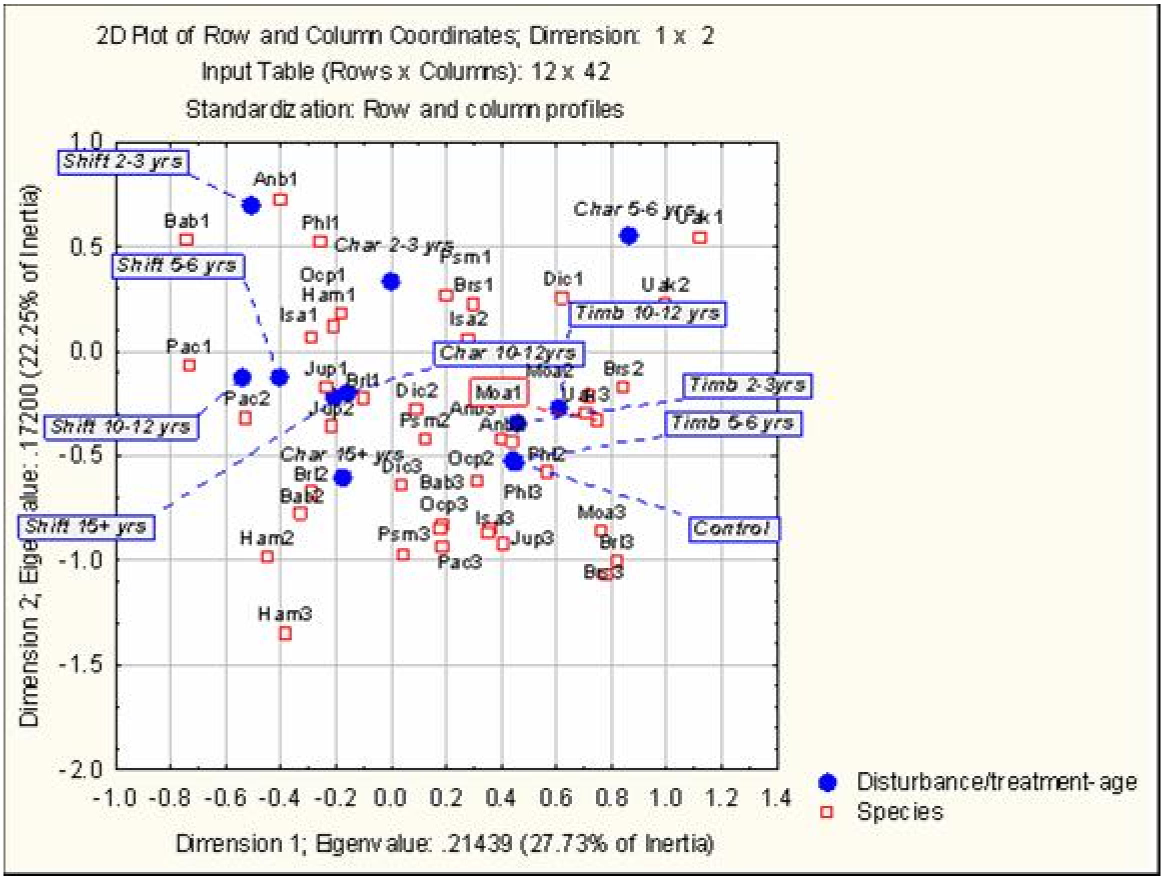

Figure 4.3 Ordination diagram showing the important species associated with each treatment and stages Note: Shift (slash & burn regrowth stand); Timb (timber harvesting stand); Char (charcoal regrowth stand); Control (undisturbed woodland stand)

Environmental variables did not have much influence on the distribution of the most characteristic species in all the sampled plots of either mature woodland stands or slash & burn and charcoal regrowth stands (Figure 4.4). However, the environmental factors influenced the distribution of the following species; *Baphia bequaertii3*, *Parinari curatellifolia*, *Harungana madagascariensis, Isoberlinia angolensis2* and *Pseudolachnostylis maprouneiflia2*.

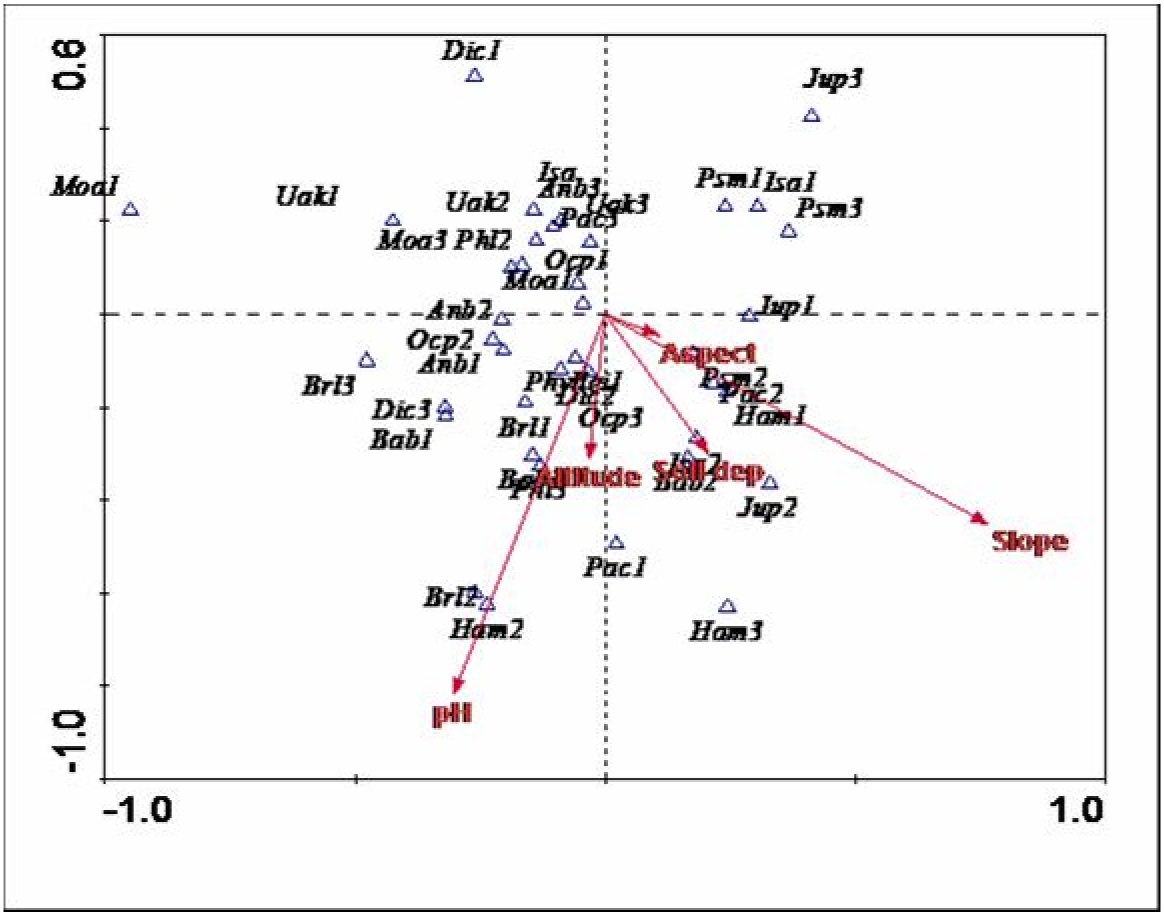

Figure 4.4 The influence of environmental variables on species occurrence in the study site

4.3.2 Species dominance over time in disturbed woodlands (regrowth stands and timber harvesting stands) in relation to the undisturbed miombo woodlands

The most important species in terms of IV in the relatively undisturbed Miombo woodland stands (control) were *Julbernadia paniculata* (43.6±2.4%), *Brachystegia longifolia* (42.0± 1.2%), *Brachystegia spiciformis* (33.7±2.4%), *Ochna pulchra* (32.0±2.4%) and *Isoberlinia angolensis* (29.9±2.4%) and *Monotes africanus* (29.5±2.3%) (Table 4.2). The dominance of these species is mostly from the size category of 10+ cm DBH (Figure 4.3).

A similar pattern is observed in stands which were previously under timber harvesting. Additionally, Figure 4.3 also shows that the timber harvested stands are closer to the control stands in terms of species dominance. However, the importance of species in regrowth stands tends to vary in relation to the control over time with the 2-3 year old slash & burn and 5-6 year charcoal regrowth stands being far away from the control (Figure 4.3). The details of species dominance and recovery over time are shown in the next sections.

Recovery after 2-3 years

Harungana madagascariensis (IV=59.4±2.4%) dominated slash & burn regrowth stands followed by *Ochna pulchra*, *Isoberlinia angolensis*, *Julbernadia paniculata*, *Baphia bequeartii* and *Brachystegia longifolia* (Table 4.2). Most of these species, except *Harungana madagascariensis* and *Baphia bequeartii*, also dominated the charcoal regrowth stands. Additionally, *Uapaca kirkiana*, a fruit species, was more important in the charcoal regrowth stands than in slash & burn regrowth stands. In some cases, *Uapaca kirkiana* almost existed as pure stands (Figure 4.5). Most stems of these species in this age category are in the 1 to 4.9 cm DBH category.

Figure 4.5 *Uapaca kirkiana* in a 2-3 year old charcoal re-growth stand, Kaloko area

The non woody component also varied from one disturbance category to another and also with stand age. In slash & burn regrowth stands, *Setaria pumila*, *Eragrotis aspera, Melinis repens* and *Rottboellia cochinchinensis* dominated the grass component while *Clematopsis scabiosifolia*, *Bidens pilosa* and *Dicoma angustifolia* dominated the herb component. In charcoal regrowth stands, *Eleusine indica*, *Panicum maximum*, *Melinis repens* and *Tristachya superba* (especially on former kiln areas) dominated the grass component, and *Centuarea praecox*, *Rhynchosia* spp and *Indigofera sutherlandioides* dominated the herbaceous component. In both the timber harvesting and undisturbed sites, *Eleusine indica*, *Hyparrhenia* spp., and *Tristachya superba* dominated the grass component and *Rhynchosia spp*. and *Indigofera* spp. dominated the herb component,

Table 4.2 Importance values (IV) for dominant species per disturbance and DBH class category and the undisturbed woodland

	2 to 3 year old stands			**5 to 6 year old stands**			**10-12 year old stands**			**15+ year old & undisturbed stands**		
Species*	**S & B**	**CP**	**TH**	**S & B**	**CP**	**TH**	**S & B**	**CP**	**TH**	**S & B**	**CP**	**UW**
	IV%	**IV%**	**IV%**	**IV%**	**IV%**	**IV%**	**IV%**	**IV%**	**IV%**	**IV%**	**IV%**	**IV%**
A. boehmii	**51.6±2.1**	16.8±3.0	15.5±1.2	7.2±2.0	**25.6±1.2**	26.9±1.2	2.2±2.0	**20.4**	25.3±1.4	19.5±2.2	17.6±2.0	21.3±2.1
B. longifolia	41.3±2.0	26.0±2.1	**43.7±2.0**	14.7±3.0	6.6±5.1	**51.6±3.0**	**31.0±2.2**	13.2±1.4	**49.3±2.3**	**24.5±2.1**	**30.1±2.1**	**42.0±1.2**
B. spiciformis	14.3±1.4	6.3±3.1	24.7±5.0	0	10.6±2.0	19.0±0.9	0	8.5±1.2	1.9±	8.9±1.1	7.3±2.0	**33.7±2.4**
D. condylocarpon	15.3±1.3	**37.7±2.4**	**35.0±**	**36.9±**	**32.1±**	30.2±	**20.9±2.3**	6.3±1.3	19.8±1.3	**38.9±1.5**	19.5±2.0	25.4±1.9
H. madagascariensis	**59.4±2.4**	16.2±2.4	0	0	0	0	2.4±1.4	6.8±5.0	0	6.2±2.2	0	0
I. angolensis	**47.9±3.2**	**56.3±3.1**	**45.0±2.4**	**39.5±2.1**	**36.9±2.0**	**41.8±1.4**	**24.0±1.4**	**29.3±1.2**	**40.6±2.4**	**40.8±2.1**	**41.1±2.2**	**30.0±2.4**
J. paniculata	44.8±1.2	**39.5±2.0**	**35±3.0**	**33.2±2.0**	20.1±1.6	**44.2±2.2**	**30.2±2.1**	**29.5±1.4**	**48.6±1.4**	**34.5±1.4**	**36.3±1.4**	**43.6±2.2**
M. africanus	0	15.7±2.1	13.6±2.1	0	17.1±2.0	31.0±3.0	6.6±1.4	**18.9±2.0**	0	4.1±0.5	3.2±1.4	**29.5±2.3**
O.pulchra	**51.2±3.1**	**44.1±2.2**	26.1±2.0	**17.5±1.9**	**30.4±1.4**	29.7±3.1	14.0±2.0	15.9±2.1	**30.0±2.0**	16.7±3.0	16.3±2.0	32.0±2.3
P.curatellifolia	14.5±3.0	21.5±3.1	18.2±3.0	**41.9±2.4**	22.9±2.0	26.4±3.0	**25.2±2.0**	16.0±2.4	17.8±2.1	17.8±1.4	18.3±2.2	25.8±2.1
P.lemaireanus	**52.1±3.0**	21.7±1.9	17.7±2.0	9.5±3.0	18.6±3.0	23.3±1.4	6.7±3.0	10.3±3.0	17.2±3.2	8.5±3.1	6.5±1.4	19.7±4.0
P. maprouneifolia	23.7±4.1	28.5±3.0	**28.0±3.0**	10.1±3.0	23.5±3.0	25.4±4.0	14.6±1.4	15.2±2.4	15.6±2.1	**24.1±1.4**	**25.3±3.2**	17.3±3.1
B.bequaertii	47.4±4.1	11.2±2.1	24.0±2.0	0	2.6±1.4	25.8±3.1	16.8±2.0	**24.4±4.1**	2.0±1.9	21.0±3.0	**23.2±2.0**	6.4±3.2
U. kirkiana	2.9±2.4	**38.8±5.0**	18.3±3.0	2.3±2.1	**47.9±2.1**	22.0±2.0	5.1±2.1	15.7±2.1	**30.4±2.4**	**24.1±1.4**	1.4±2.0	21.5±1.4

NB: *For complete botanical names, see Table 4.1; S & B (Slash and burn); CP (Charcoal production); TH (Timber harvesting) and UW (Undisturbed woodland); Values in bold indicate the five dominant species per disturbance and age categories.

Recovery after 5-6 years

Parinari curatellifolia (IV = 41.9±2.4%) dominated slash & burn regrowth stands followed by *Isoberlinia angolensis* and *Diplorhynchus condylocarpon* (Table 4.2). *Uapaca kirkiana* (47.9±2.2%) dominated the charcoal regrowth stands followed by *Isoberlinia angolensis* (36.9±2.3%) (Table 4.2). Other important species in charcoal regrowth stands were *Diplorhynchus condylocarpon*, *Ochna pulchra* and *Anisophyllea boehmii*. The timber species *Albizia antunesiana*, *Brachystegia floribunda* and *Pterocarpus angolensis* had higher importance values in both slash & burn and charcoal regrowth stands than in timber harvested stands (Appendix 4.1).

Setaria pumila and *Tristachya superba* dominated the grass component and *Vernonia* spp dominated the herbaceous component of slash & burn regrowth stands. *Eleusine indica*, *Digitaria ternata, Panicum maximum* and *Tristachya superba* dominated the grass component and *Rhyncosia* and *Indigofera* spp. dominated the herb component in the charcoal regrowth stands

Recovery after 10-12 years

The most important species in slash & burn regrowth stands were *Brachystegia longifolia* (31.0±2.2%), *Julbernadia paniculata* (30.2±2.2%), *Albizia antunesiana* (25.0±2.4%) and *Isoberlinia angolensis* (24.1±1.4%) (Appendix 4.1; Table 4.3). However, *Julbernadia paniculata* (29.5±2.4%), *Isoberlinia angolensis (*29.3±1.3%), *Baphia bequaertii* (24.4±4.1%) and *Albizia antunesiana* (20.4±2.1%) were the most important species in charcoal regrowth stands. These species were mostly of size category 5.0-9.9 cm DBH class. The most important species in timber harvested and undisturbed woodland stands were *Isoberlinia angolensis*, *Brachystegia longifolia* and *Julbernadia paniculata* (Table 4.2, Appendix 4.1). These were of 10+ cm DBH class category. The importance values for timber harvested species were higher in both slash & burn and charcoal regrowth stands than in timber harvested and undisturbed woodland stands (Appendix 4.1).

The characteristic grass and herbaceous components were *Tristachya superba*, *Eleusine indica* and *Hyparrhenia spp*. while the herbaceous components were *Rhynchosia* spp. and *Indigofera* spp in both regrowth stands. These were also characteristic species for the timber harvested stands

Recovery after 15+ years and mature woodland

Isoberlinia angolensis, *Brachystegia longifolia* and *Julbernadia paniculata* were the most important species in both slash & burn and charcoal regrowth stands (Table 4.2; Appendix 4.1). Similarly, these species were also the most important in both the timber harvested and undisturbed woodland stands. Comparatively, the timber species had higher importance values in regrowth stands (charcoal, slash & burn) than the mature woodland stands (Appendix 4.1).

The characteristic grass species of this recovery stage were *Tristachya superba*, *Eleusine indica* and *Hyparrhenia* spp and the important herbs were *Rhynchosia* spp and *Indigofera* spp. These are the common grass species of the mature Miombo woodland.

4.3.3 Species richness and turnover rates

Table 4.3 shows the number of species occurring in stands previously under different disturbance categories. It also shows that charcoal regrowth stands tend to yield the highest number (74) of species compared to either undisturbed woodland stands (50) or timber harvested stands (64) or slash & burn stands (69). The table also shows that species richness tends to vary with age of a particular stand. For example, the species richness for both slash & burn and charcoal regrowth stands varied from one age category to another. The species richness for slash & burn and charcoal regrowth stands was at its maximum at 10-12 years and 2-3 years respectively, since disturbance cessation. However, the woody component was at its lowest at 5-6 years since disturbance cessation in slash & burn regrowth stands (Table 4.3). Similarly, the herbaceous component was at its maximum at 15 years for the slash & burn regrowth stands. The species richness for timber harvesting was almost stable throughout and comparatively, the species richness was almost the same with that of the undisturbed Miombo woodland stands.

The significant differences in species occurrence between stands under different disturbances were observed with the highest significance ($P < 0.0005$) occurring between the undisturbed woodland and the 5-6 year old slash & burn regrowth stands.

Table 4.3 Species richness of each treatment category by age and in undisturbed Miombo woodland stands

Disturbance category	Total number of species (= woody + herbaceous*) per age category				Total number of species recorded per treatment
	2-3 yrs	5-6 yrs	10-12 yrs	15+ yrs	
Undisturbed woodland	50± 0.9 (43 + 7)				50
Timber harvesting	53 ± 0.6(45 + 8)	56± 0.5(46 + 10)	56± 0.6(46 + 10)	-	64
Slash & burn agriculture	58± 0.6(48 + 10)	45± 1.7(35 + 10)	60± 1.2 (48 + 12)	59± 0.3 (46 + 13)	69
Charcoal production	57± 1.2 (49 + 8)	50± 1.5(48 + 6)	63 ± 1.8(54 + 9)	47± 0.6 (40+ 7)	74

Note: * the herbaceous component includes herb and grass species.

The species diversity, Shannon-Wiener diversity, indices of similarity between disturbance categories or treatments and also the turnover rates are shown in Table 4.4. The turnover (T) between developmental stages show the most drastic changes in species composition of the regrowth between 2-3 and 5-6 years in both slash & burn agriculture (T = 13.8%) and charcoal regrowth (T = 9.7%) respectively. Thereafter, the turnover is gradually lower in both disturbance categories respectively, between 5-6 and 10-12 (T = 5.6% and 4.1%) and between 10-12 and 15+ years (T = 2.8% and 2.8%).

Table 4.4 Mean diversity and similarity indices per treatment category (disturbance category and the undisturbed miombo woodland) over time

Treatment (disturbance category and undisturbed miombo woodland)												
Timber harvesting				Slash & burn agriculture				Charcoal production				Undisturbed woodland
	Age (years) and Shannon-Wiener indices											
	2-3	5-6	10-12	2-3	5-6	10-12	15+	2-3	5-6	10-12	15+	
	3.1	3.1	3.0	3.6	3.3	3.3	3.1	3.3	2.9	3.1	2.9	2.9
	Similarity indices and turnover for species composition between successive stages of each disturbance category											
Age (years)	2-3	5-6	10-12	2-3	5-6	10-12	15+	2-3	5-6	10-12	15+	
	2-3	0.76	0.76		0.58(13.8%)	0.71(3.2%)	0.71(1.8%)		0.71(9.7%)	0.76(2.3%)	0.66(2.2%)	
	5-6		0.75			0.67(5.6%)	0.67(1.6%)			0.74(4.1%)	0.62(2.8%)	
	10-12						0.79(2.8%)				0.76(2.7%)	

Note: Number in brackets denotes turnover.

4.4 Discussion

4.4.1 Environmental factors

The study areas were selected to represent relatively uniform conditions to facilitate the comparison of the vegetation recovery after cessation of the three major human disturbances. The influence of recorded environmental factors on the occurrence of species varied among species, with most of the species showing that the environmental factors did not have much influence on their occurrence in the studied stands. This probably is because the study areas are relatively flat with minimal differences in altitude. Similar observations of low variation in soil pH and soil depth between stands were made. The soils in the study area were both shallow and acidic, ranging from pH 4.7 to pH 5.5, which is the survival range for most of the Miombo woodland species (Chidumayo, 1997). However, environmental factors have been reported to exert an influence on the occurrence of species in Tanzanian Miombo woodland (Kikula, 1979; Luoga *et al*., 2002) and South African savanna (Shackleton *et al*., 1994). These studies reported the influence of local environmental gradients on species composition over an area.

4.4.2 Species dominance over time

The study has shown that stands previously under timber harvesting are closer to the undisturbed woodland stands (control) in terms of the characteristic Miombo species composition than to stands arising from either slash & burn agriculture or charcoal production (Figure 4.3). The closeness of timber harvested stands to the undisturbed woodland stands shows that single tree selection timber harvesting does not result in the alteration of the characteristic species composition of Miombo woodland stands. As such, single tree selection harvesting as a disturbance does not alter the Miombo functional environment or if it does, then the resulting impact is too minor to elicit a response of the Miombo ecosystem as a whole. Similar observations were made by Schwartz and Caro (2003) in a study of a Tanzanian Miombo woodland where single tree selection did not have an effect on either species richness or woodland stocking.

The study has also revealed that the composition of regrowth stands in relation to the undisturbed woodland is age and disturbance factor dependent (Figure 4.3). For example, in terms of the Miombo woodland characteristic species composition, the 2-3 year old charcoal regrowth will be closer to the undisturbed woodland than the 2-3 year slash & burn regrowth stands. The reason for this could be that the regeneration of the woodland after clearing for charcoal production would consist of stumps/root suckers/shoots and recruitment from old stunted seedlings present in the grass layer at the time of clearing (see Chidumayo and Frost, 1996; Luoga *et al*. 2004). Figure 4.3 indicates that most of the species in 2-3 year old regrowth stands are those in 1.0-4.9 cm DBH category and therefore confirms the observation of Chidumayo and Frost (1996). However, although Chidumayo and Frost (1996) made a general statement about the regeneration of Miombo woodland from stumps/roots and recruitments present at the time of forest clearing, this observation may not necessarily apply to the development of slash & burn regrowth stands. Firstly, this is because weeding during cultivation results in removal of woodland plants as they are perceived to be weeds by cultivators. Secondly, cultivation may also result in dying of some plants due to injuries they sustain during the cultivation period (Strang, 1974). As such, the establishment of plants in regrowth stands may be considered to be dependent on the interactions between the environment and the regeneration mode. For example, the early stages of slash & burn regrowth stands were dominated by young plants of *Ochna pulchra, Baphia bequeartii*, *Parinari curatellifolia* and *Diplorhynchus condylocarpon* which belong to the *Chipya* ecological group (Lawton, 1978; Figure 4.3, Appendix 4.1).This group is composed of species which grow in habitats where dry season fires are intense (Lawton, 1978). This is because the early stages of the woodland recovery for stands previously under slash & burn agriculture are associated with high incidences of fire (Boaler and Sciwale, 1966). However, other species namely *Isoberlinia angolensis, Julbernadia paniculata*, *Brachystegia floribunda, Brachystegia longifolia*, *Albizia antunesiana* and *Pterocarpus angolensis* also formed an important component of the early stages of woodland development. Other species like *Isoberlinia angolensis*, though not fire hardy, exhibit hypogeal germination which enhances their survival against fire (Frost, 1985). Similarly, the early stages of charcoal regrowth stands were associated with *Chipya* and *Uapaca* ecological species namely *Uapaca kirkiana*, *Diplorhynchus condylocarpon*, *Ochna pulchra* and *Anisophyllea boehmii* (see Lawton, 1978). The *Uapaca* group is capable of surviving fires of medium intensity (Lawton, 1978). However, *Uapaca kirkiana* does not seem to favour the slash & burn sites as compared to charcoal regrowth stands. *Uapaca kirkiana*, like many other *Uapaca* ecological group species, is unable to survive intense fires which the *Chipya* ecological group is capable of surviving. Clayton (1962) made similar observations in Savanna woodland of Nigeria in which the early stages of woodland recovery was dominated by fire resistant species. He observed the association of *Isoberlinia doka* with *Uapaca togoensis* (fire resistant) in the early stages of central and western African woodland recovery. Similarly, Stromgaard (1986) observed that the initial stages of the Miombo woodland recovery after slash & burn agriculture was a mixture of fire-resistant woody species and shade intolerant colonizing species. Additionally, Boaler and Sciwale (1966) and Strang (1974) also observed the development of key Miombo woodland species together with fire hardy species in Tanzanian and Zimbabwean woodlands, respectively. Therefore, although Chidumayo (2004) suggested that the regeneration of the key Miombo species in regrowth stands was not facilitated by *Chipya* ecological species, the dominance of *Chipya* and *Uapaca* ecological species in the early stages of the studied stands is strong evidence to suggest that such species are precursors of Miombo woodland canopy species and therefore confirms the findings of the earlier researchers elsewhere (Boaler and Sciwale, 1966; Strang, 1974)**.** However, the members of the *Chipya* and *Uapaca* ecological species can only grow well under light canopies (Lawton, 1978). This explains why even though the members of the Miombo group (e.g. *Brachystegia* spp., *Julbernadia* spp.) regenerate under the protection of either the *Uapaca* or *Chipya* ecological species, later get eliminated when the canopy of the former gets dense (Kikula, 1986). This implies that the co-existence of the Miombo ecological species with either *Chipya* or *Uapaca* groups is not obvious. The *Miombo* ecological group refers to species like *Isoberlinia angolensis*, *Julbernadia* spp. and *Brachystegia* species. These species do not grow under *Chipya* conditions or rather intense fires while the *Uapaca* ecological group is composed of *Uapaca* species like *Uapaca kirkiana, Uapaca nitida*. The *Uapaca* group is capable of surviving fires of medium intensity. The *Chipya* group consists of species like *Pterocarpus angolensis*, *Diplorhynchus condylocarpon* which grow and survive under intense dry season fires.

The study has also shown that the initial stages of either slash & burn or charcoal regrowth stand development (after 2-3 and 5-6 years) are mostly dominated by low diameter classes (1 to 4.9 cm DBH and 5.0 to 9.9 cm DBH). However, as years proceed, the most important species become predominantly of the 10+ cm DBH class (Figure 4.3).This is an indication of the rate of increase in diameters of the characteristic species over time. According to Chidumayo (1988) and Strang (1974), this increase is enhanced by reduction in stocking of the regrowth stands over time. Chidumayo (1997) and Savory (1963) attributed the reduction in stocking to the fact that most of the young plants are generally susceptible to fire, water stress, insectivory, herbivory and drought. These factors result in natural mortality of the young plants with time. The dominance in terms of basal area increase also comes with the start of canopy closure and therefore reduces the prevalence of the *Uapaca* ecological group (Kikula, 1986).

4.4.3 Species richness and turnover over time

The study recorded higher numbers of species in all age class categories of slash & burn and charcoal regrowth stands (except for 5-6 year old regrowth stands of Shift or Char opr both?) than in mature woodland stands (timber harvested and undisturbed) (Table 4.2). This suggests that opening up of Miombo woodland tends to enhance species richness of the area. According to Lees (1962), many Miombo woodland species require high light intensities to regenerate and grow. Additionally, reduced competition for nutrients and moisture and also reduced allelopathy also enhance regeneration and growth of woodland plants. Rapid development of Miombo regrowth in abandoned cleared plots in certain parts of the Miombo ecoregion namely: Tanzania (Boaler and Sciwale, 1966); Zambia (Chidumayo, 1988; Chidumayo, 2004) and Zimbabwe Strang (1974) may support the significance of light intensities, reduced competition for moisture and nutrients in promoting regeneration. Unfortunately, single tree selection harvesting does not result in the opening up of the canopy. As such, this kind of forest utilization does not enhance species richness. This is because the growth and abundance of Miombo woodland understory vegetation beneath the intact forest canopy, like many other vegetation types (Bassaz and Wayne, 1994) are strongly limited by heavy shade and root competition for moisture with overstory species. Increased light, soil moisture and nutrient availability and creation of microsites for colonization associated with canopy disturbance promote succession dependent on the intensity of disturbance (Reader and Bricker, 1995).

The study also revealed high turnover rates between 2-3 and 5-6 year old stands for both slash & burn and charcoal regrowth stands (Table 4.4). This marks a trend in the recovery process of the woodland which was previously under slash & burn or charcoal production. It indicates the start of a new phase where competition is reduced (Stromgaard, 1986), from either cultivated plants in case of slash & burn regrowth stands or other woody species in case of charcoal regrowth stands. Similar observation on high turnover in the early phase of Miombo woodland recovery previously under slash & burn agriculture was made by Stromgaard (1986) in northern Zambia. The high turnover between 2-3 and 5-6 years may be attributed to the fact that seeds of most Miombo woodland species tend to germinate within a short period of time after dispersal (Ernst, 1988; Chidumayo, 1993a). Therefore, most of the seeds held in the soil tend to germinate within this phase. Secondly, this phase is also associated with high incidences of fire (Boaler and Sciwale, 1966; Stromgaard, 1986) which results in reduction in species composition due to the dying of fire tender species (Lawton, 1978) from fire. In the case of grass, only species of *Melinis repens*, *Setaria pumila*, *Eragrotis aspera* and *Tristachya superba* seem to survive this phase well in slash & burn re-growth stands. The ability of these grass species to persist as the characteristic of this phase under each disturbance may be attributed to the fact that they have the ability to multiply vegetatively (Vernon, 1983). The dominant grass species in charcoal regrowth stands, namely *Eleusine indica*, *Digitaria ternata*, *Panicum maximum* and *Tristachya superba,* are also characteristic of the mature woodland stands. This may be explained by the fact that charcoal production does not cause excessive disturbance of the soil and therefore, of the existing species. i.e. charcoal production practices cause microsites of high disturbance (burnt spots) with most of the cleared area with partial disturbance.

4.5 Conclusion

The study has shown that the study areas varied little in environmental variables and that these did not necessarily impact on the occurrence of species over the studied areas. The development of Miombo woodland after a disturbance is dependent on the disturbance and the interaction between the regeneration modes of the species and the conditions of the disturbed environment. For example, the development of slash & burn and charcoal regrowth stands is a mixture of fire hardy species and other Miombo woodland species in the early stages when the incidences of fire occurrence are high. With time, the dominance of fire hardy species reduces while the key Miombo species increases in dominance and abundance. The Miombo woodland as an ecosystem is able to recover once it is disturbed because some of its species such as *Anisophyllea boehmii*, *Uapaca kirkiana,* etc. act as precursors for the key species during harsh environments when the key species may not easily survive. Secondly, some of the key species are morphologically suitable to survive a harsh environment during their early stages. In terms of single tree selection timber harvesting, this kind of disturbance does not result in any major impact on the Miombo woodland ecosystem as a whole and therefore does not change species composition and richness.

However, the study has not dealt with the influences of the different slash & burn practices on the response of Miombo woodland once the area is abandoned to regrow. The results on the influence of environmental variables just demonstrate the response of these species in less variable environments. There is a need therefore, to extend this study to include impacts of different forms of slash & burn agriculture on Miombo woodland recovery. The study should also be conducted in variable environments so as to ascertain the influences of different environmental variables on species occurrence. Lastly, there is a need to carry out long term studies to determine how the Miombo woodland would respond after it has been under either slash & burn agriculture or charcoal production on second rotation basis. These recommendations are intended to enhance the reliability of these findings.

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Appendix 4.1 Importance values and the associated relative frequency (RF %), relative density (RD %) and relative basal area (RG %) of woody species in slash & burn, charcoal re-growth stands and timber harvested and undisturbed woodland. Legend: S& B=Slash & burn; CP=charcoal production; TH=Timber harvested and UW=Undisturbed woodland.

	2 to 3 years abandoned sites												5 to 6 years abndoned sites												10 to 12 years abandoned sites												15 + years abandoned sites											
	S & B				CP				TH				S & B				CP				TH				S & B				CP				TH				S & B				CP				UW			
Species	R. F%	R. D%	R. G%	IV	R. F.%	R. D%	R. G%	IV	R. F%	R. D%	R. G%	IV	R. F%	R. D%	R. G%	IV	R. F%	R. D%	R. G%	IV	R. F%	R. D%	R. G%	IV	R. F%	R. D%	R. G%	IV	R. F%	R. D%	R. G%	IV	R. F%	R. D%	R. G%	IV	R. F%	R. D%	R. G%	ort. Value	R. F%	R. D%	R. G%	IV	R. F%	R. D%	R. G%	IV
Acacia polyacantha	0	0	0	0	0	0	0	0	0	0		0	46.67	2.88	1.86	17.1±4.6	17.65	0.69	1.39	6.6±3.9	0	0	0	0	6.25	0.13	0.75	2.4±4.2	0	0	0	0	0	0	0	0	0	0	0	0	8.33	0.38	0.64	3.1±2.3	0	0	0	0
Acac sieberana	0	0	0	0	0	0	0	0	0	0	0	0	33.33	0.55	0.52	11.5±4.8	0	0	0	0	0	0	0	0	18.75	1.28	0.99	7.0±4.4	0	0	0	0	0	0	0	0	11.76	0.97	1.95	4.9±4.4	0	0	0	0	0	0	0	0
Afzelia quanzensis	5.56	1.01	0	3.3±4.6	52.94	2.69	0	27.8±2.7	5.56	0.25	0.5	2.1±4.3	6.67	0.27	0.22	2.4±4.3	5.88	0.14	0.14	2.1±2.8	0	0	0	0	6.25	0.26	0.34	2.3±2.9	5.88	0.14	0.04	2.0±4.4	0	0	0	0	11.76	1.57	0.19	4.5±4.4	0	0	0	0	0	0	0	0
Albizia adianthifolia	0	0	0	0	0	0	0	0	5.56	0.08	0.01	1.9±2.1	0	0	0	0	0	0	0	0	0	0	0	0	12.5	0.89	0.96	4.8±4.4	0	0	0	0	5.56	0.08	0.15	1.9±2.1	11.76	0.61	1.81	4.7±4.1	0	0	0	0	11.11	0.25	0.02	3.8±4.3
Albizia antunesiana	11.11	0.25	0	5.7±4.6	5.88	0.38	0	3.1±4.3	27.8	0.58	1.16	9.9±4.5	80	5.48	3.13	29.5±4.4	52.29	2.92	2.08	19.1±4.6	5.56	0.08	0.08	1.9±4.0	56.25	7.54	11.11	25.0±4.0	52.9	3.04	5.19	20.3±4.0	20.38	33.3	1.12	11.8±4.4	58.82	3.4	7.31	23.2±4.6	58.33	2.44	5.14	22.0±3.0	55.56	1.48	1.24	19.4±4.0
Albizia versicolor	0	0	0	0	0	0	0	0	11.11	0.17	0.19	3.8±3.9	46.67	1.37	0.6	16.2±4.5	23.52	1.25	0.83	8.5±4.6	11.11	0.41	0.24	3.9±4.4	25	0.89	0.92	8.9±4.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anisophyllea boehmii	88.89	14.25	0	51.6±2.1	29.41	4.09	0	16.8±3.0	44.44	1.75	0.4	15.5±1.2	20	1.23	0.44	7.2±2.0	70.59	3.06	3.08	25.6±1.0	77.8	2.44	0.46	26.9±1.0	6.25	0.13	0.21	2.2±2.0	58.8	1.66	2.13	20.4±4.3	72.2	2.96	0.74	25.3±1.4	52.94	3.4	2.19	19.5±2.2	50	2.25	0.6	17.6±2.0	61.11	1.97	0.67	21.3±2.1
Annona senegalensis	0	0	0	0	0	0	0	0	5.56	0.08	0.01	1.9±3.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bauhinia thonningii	0	0	0	0	0	0	0	0	0	0	0	0	13.3	0.55	1.59	5.2±5.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.88	0.12	0.04	2.0±2.5	0	0	0	0	0	0	0	0
Baphia bequaertii	88.89	5.82	0	47.4±4.1	17.65	4.73	0	11.2±2.0	66.67	1.75	3.48	24.0±2.0	0	0	0	0	5.88	1.39	0.42	2.6±1.4	66.67	7.07	3.7	25.8±3.0	43.75	4.85	1.87	16.8±2.0	58.8	9.13	5.21	24.4±4.1	5.56	0.32	0.33	2.0±1.9	52.94	5.34	4.98	21.0±3.0	58.33	6.94	4.17	23.2±2.1	16.67	1.81	0.74	6.4±3.2
Boscia angustifolia	0	0	0	0	0	0	0	0	16.67	0.25	0.58	5.8±6.0	0	0	0	0	0	0	0	0	16.67	0.41	0.28	5.8±4.1	0	0	0	0	0	0	0	0	22.2	1.12	0.78	8.0±4.1	5.88	0.24	0.44	2.2±2.3	0	0	0	0	16.67	0.41	0.93	6.0±3.7
Brachystegia boehmii	5.56	0.25	0	2.9±1.5	5.88	0.13	0	3.0±1.5	5.56	0.08	0.06	1.9±1.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.88	9.13	0.03	2.0±1.6	16.67	0.4	0.54	5.9±1.4	11.76	0.61	0.98	4.3±1.4	0	0	0	0	11.11	0.57	1.19	4.3±1.4
Brachystegia floribunda	55.56	1.6	0	28.6±4.5	17.65	0.64	0	9.2±4.0	27.77	1.08	1.79	10.2±4.6	60	4.38	7.9	24.1±4.4	29.41	2.08	4.19	11.9±4.4	11.11	0.32	0.67	4.0±4.4	56.25	2.17	1.95	20.1±4.0	35.29	1.52	1.81	12.9±4.2	44.4	1.12	1.57	15.7	35.29	1.82	1.18	12.8±4.6	83.33	4.69	9.72	32.6±3.0	33.33	0.99	1.8	12.0±4.4
Brachystegia longifolia	77.78	4.89	0	41.3±2.0	47.06	4.99	0	26.0±2.1	88.89	17.6	25.14	43.7±2.0	40	2.74	1.21	14.7±3.0	17.65	1.25	1.03	6.6±5.1	100	22.75	31.9	51.6±3.0	75	8.56	9.52	31.0±2.2	35.39	0.97	3.44	13.2±1.4	100	23.24	24.77	49.3±2.3	64.71	4.85	3.8	24.5±2.1	66.67	11.63	12.04	30.1±2.1	88.89	15.6	21.44	42.0±1.2
Brachystegia spiciformis	27.78	0.84	0	14.3±1.4	11.77	0.77	0	6.3±3.1	61.11	5.09	7.77	24.7±5.0	0	0	0	0	29.41	1.67	0.64	10.6±2.0	50	3.33	3.71	19.0±0.9	0	0	0	0	23.53	0.69	1.14	8.5±1.2	5.56	0.08	0.08	1.9±4.5	23.53	1.58	1.68	8.9±1.1	8.33	0.75	1.78	7.3±2.0	77.78	9.11	14.28	33.7±2.4
Brachystegia utilis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	41.18	1.66	1.56	14.8±4.3	38.89	3.53	4.7	15.7±4.4	0	0	0	0	0	0	0	0	0	0	0	0
Bridelia macrantha	22.22	1.18	0	11.7±4.5	5.88	0.38	0	3.1±2.8	11.11	0.25	0.12	3.8±3.9	33.33	0.68	0.36	11.5±3.4	0	0	0	0	5.56	0.08	0.02	1.9±2.1	18.75	0.51	0.48	6.6±4.3	5.88	0.14	0.09	2.0±2.8	0	0	0	0	29.4	0.97	0.72	10.4±4.1	8.33	1.31	0.31	3.3±3.5	0	0	0	0
Burkea africana	0	0	0	0	5.88	0.13	0	3.0±4.8	22.22	0.67	0.45	7.8±4.2	20	0.96	0.69	7.2±4.5	0	0	0	0	5.56	0.16	1.08	2.3±4.6	0	0	0	0	0	0	0	0	0	0	0	0	11.76	0.24	0.2	4.1±4.5	0	0	0	0	5.56	0.08	0.01	1.9±2.4
Byrssocarpus orientalis	5.56	0.08	0	2.8±4.4	17.65	0.51	0	9.1±4.5	11.11	0.25	0.12	3.8±4.1	0	0	0	0	0	0	0	0	16.67	0.32	0.13	5.7±4.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.56	0.16	0.11	1.9±2.1
Canthium crassum	0	0	0	0	29.41	1.15	0	15.3±4.5	27.77	0.67	0.45	9.5±4.7	0	0	0	0	11.76	0.56	0.13	4.2±4.6	55.56	1.62	0.37	19.2±4.4	0	0	0	0	5.88	0.14	0.08	2.0±4.4	38.89	0.96	0.13	13.3±4.6	17.65	0.36	0.2	6.1±4.5	0	0	0	0	44.4	0.82	0.16	15.1±
Cassia abbreviata	5.56	0.25	0	2.9±4.3	5.88	0.13	0	3.0±4.5	5.56	0.17	0.17	2.0±4.5	0	0	0	0	5.88	0.14	0.13	2.1±4.4	0	0	0	0	0	0	0	0	5.88	0.14	0.08	2.0±3.1	0	0	0	0	0	0	0	0	0	0	0	0	5.56	0.08	0.1	1.9±3.9
Cassia singueana	16.67	0.59	0	8.6±4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.25	0.13	0.22	2.2±4.5	11.76	0.28	0.18	4.1±4.6	0	0	0	0	0	0	0	0	8.33	0.38	0.18	3.0±2.7	0	0	0	0
Combretum molle	5.56	0.25	0	2.9±4.0	11.77	0.26	0	6.0±4.3	33.33	1.17	0.75	11.4±4.4	13.33	0.27	0.84	4.8±4.6	5.88	0.14	0.13	2.1±4.3	11.11	0.24	0.04	3.8±4.3	12.5	0.26	0.08	4.3±4.5	5.88	0.14	0.09	2.0±4.4	44.44	0.96	0.94	15.4±4.5	0	0	0	0	5.88	0.38	0.18	2.2±2.7	22.22	1.23	0.49	8.0±4.3
Combretum zeyheri	0	0	0	0	0	0	0	0	11.11	1.33	0.57	4.3±4.6	0	0	0	0	0	0	0	0	0	0	0	0	37.5	2.43	2.35	14.1±4.6	5.88	0.14	0.19	2.1±4.6	0	0	0	0	0	0	0	0	5.88	0.38	0.18	2.2±2.7	0	0	0	0
Dalbergia nitidula	22.22	1.01	0	3.3±4.5	35.29	2.05	0	18.7±4.5	33.33	0.75	0.76	11.6±4.2	0	0	0	0	5.88	0.14	0.62	2.2±4.6	5.56	0.32	0.27	2.1±4.4	0	0	0	0	11.76	0.28	0.28	4.1±4.3	27.78	1.76	1.41	10.3±4.5	0	0	0	0	0	0	0	0	27.78	1.56	0.72	10.0±4.5
Dalbergiella nyasae	0	0	0	0	11.77	1.02	0	6.4±4.6	5.56	0.08	0.02	1.9±4.5	20	1.23	0.55	7.3±4.6	0	0	0	0	5.56	0.08	0.01	1.9±3.7	0	0	0	0	0	0	0	0	5.56	0.16	0.07	1.9±4.5	0	0	0	0	8.33	0.19	0.04	2.9±3.1	0	0	0	0
Dichrostachys cinerea	22.22	1.26	0	11.7±3.5	23.53	0.64	0	12.1±4.6	22.22	0.83	0.14	7.7±4.1	0	0	0	0	17.65	1.11	1.16	6.6±4.5	11.11	0.32	0.18	3.9±4.4	12.5	0.77	0.69	4.7±4.5	17.65	1.66	0.96	6.8±4.3	0	0	0	0	11.76	1.58	1.23	4.9±4.6	33.33	3.75	1.9	13.0±3.2	0	0	0	0
Diospyros batocana	11.11	0.59	0	5.9±4.6	0	0	0	0	11.11	0.58	0.06	3.9±4.3	0	0	0	0	0	0	0	0	5.56	0.16	0.13	2.0±3.8	12.5	0.26	0.56	4.4±4.6	0	0	0	0	5.56	0.08	0.12	1.9±4.5	17.64	0.49	0.29	6.1±4.5	8.33	0.56	0.23	3.0±2.7	0	0	0	0
Diospyros kirkii	16.67	0.51	0	8.6±4.4	5.88	0.13	0	3.0±4.6	16.67	0.58	0.39	5.9±4.7	0	0	0	0	17.65	0.56	0.96	6.4±4.4	5.56	0.32	0.06	2.0±4.6	12.5	0.38	0.25	4.4±4.5	11.76	0.28	0.16	4.1±3.9	11.11	0.32	0.38	3.9±4.3	17.64	0.49	0.29	6.1±4.6	0	0	0	0	11.11	0.16	0.02	3.8±4.4
Diplorhynchus condylocarpon	27.78	2.87	0	15.3±1.3	58.82	6.65	0	37.7±2.5	94.44	7.76	2.76	35.0±4.3	93.33	9.86	7.49	36.9±4.6	76.47	8.47	11.33	32.1±4.5	77.78	5.44	7.51	30.2±4.2	50	6.77	5.92	20.9±4.4	17.65	0.83	0.46	6.3±4.3	55.56	2.8	1.15	19.8±4.6	82.35	16.87	17.45	38.9±3.9	50	4.5	3.96	19.5±3.1	72.22	3.03	0.81	25.4±4.6
Dombeya rotundifolia	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0.41	0.2	0.3±4.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8.33	0.19	0.19	2.9±3.1	0	0	0	0
Ekerbegia capensis	16.67	1.43	0	9.1±4.5	0	0	0	0	0	0	0	0	0	0	0	0	5.88	0.14	1.42	2.5±4.4	0	0	0	0	25	0.51	0.35	8.6±4.5	11.76	0.41	0.15	4.1±4.5	0	0	0	0	23.53	0.73	0.46	8.2±4.6	11.11	0.37	0.05	3.8±2.7	0	0	0	0
Erythrina abyssinica	5.56	0.51	0	3.0±4.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Erythrophleum africanum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17.65	3.87	6.57	9.4±4.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Faurea saligna	11.11	0.76	0	5.9±4.3	23.53	2.05	0	12.8±4.3	22.22	0.75	0.24	7.7±4.3	0	0	0	0	0	0	0	0	33.33	0.65	0.35	11.4±4.4	6.25	0.13	0.79	2.4±4.6	0	0	0	0	27.78	0.88	0.4	9.7±4.5	0	0	0	0	0.33	0.38	0.31	3.0±3.1	44.44	1.64	0.4	15.5±4.2
Faurea speciosa	0	0	0	0	0	0	0	0	11.11	0.17	0.03	3.8±4.2	0	0	0	0	5.88	0.14	0.17	2.1±4.5	5.56	0.08	0.02	1.9±4.5	18.75	1.53	1.95	7.4±4.0	5.88	0.14	0.02	2.0±4.5	0	0	0	0	0	0	0	0	0	0	0	0	16.67	0.25	0.08	5.7±3.6
Ficus natalensis	0	0	0	0	0	0	0	0	5.56	0.08	0.06	1.9±4.0	0	0	0	0	5.88	0.14	0.38	2.1±4.5	0	0	0	0	0	0	0	0	5.88	0.14	0.25	2.1±4.3	11.11	0.16	0.54	3.9±4.3	0	0	0	0	0	0	0	0	11.11	0.16	0.05	3.8±4.6
Flacourtia indica	5.56	0.34	0	3.0±4.1	5.88	0.26	0	3.1±3.6	22.22	0.33	0.06	7.5±4.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.88	0.28	0.14	2.1±4.2	0	0	0	0	5.88	0.12	0.02	2.0±2.4	8.33	0.19	0.07	2.9±2.7	0	0	0	0
Garcinia huillensis	5.56	0.08	0	2.8±4.4	0	0	0	0	5.56	0.17	0.02	1.9±2.3	0	0	0	0	5.88	0.27	0.16	2.1±4.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.56	0.16	0.05	1.9±2.3
Harungana madagascariensis	55.56	3.88	0	29.7±4.6	29.41	2.94	0	16.2±2.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.25	0.38	0.49	2.4±1.4	17.65	0.41	2.41	6.8±5.0	0	0	0	0	17.64	0.73	0.2	6.2±0.9	0	0	0	0	0	0	0	0
Hymenocardia acida	16.67	0.67	0	8.7±4.3	0	0	0	0	0	0	0	0	0	0	0	0	5.88	0.14	0.13	2.1±4.4	0	0	0	0	6.25	0.26	0.26	2.3±4.6	29.41	1.38	0.81	10.5±4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 4.1 continues

2 to 3 years abandoned sites

	S & B				CP				TH			
Species	R. F%	R. D%	R. G%	IV	R. F.%	R. D%	R. G%	IV	R. F%	R. D%	R. G%	IV
Hexalobus monopetalus	0	0	0	0	0	0	0	0	5.56	0.08	0.01	1.9±2.3
Isoberlinia angolensis	88.89	7	0	47.9±3.2	94.12	18.41	0	56.3±3.1	94.44	15.68	24.96	45.0±2.0
Julbernadia paniculata	83.33	6.16	0	44.8±1.2	70.59	8.44	0	39.5±3.1	83.33	7.17	14.39	35.0±3.0
Unknown 1	0	0	0	0	0	0	0	0	0	0	0	0
Lannea discolor	16.67	0.51	0	17.2±4.5	11.76	0.26	0	6.0±4.2	44.44	1.08	1.01	15.5±7.5
Lannea stuhlmannii	0	0	0	0	0	0	0	0	0	0	0	0
Magnistipula butayei	5.56	0.252	0	2.9±4.1	11.76	0.38	0	6.1±4.6	0	0	0	0
Mapronea africana	0	0	0	0	0	0	0	0	0	0	0	0
Maranthes floribunda	0	0	0	0	0	0	0	0	0	0	0	0
Monotes africanus	0	0	0	0	29.41	1.92	0	15.7±2.1	38.89	1.25	0.56	13.6±2.0
Monotes katangensis	0	0	0	0	0	0	0	0	0	0	0	0
Unknown 2	0	0	0	0	5.88	0.13	0	3	0	0	0	0
Ochna pulchra	94.44	7.93	0	51.2±3.0	82.35	5.88	0	44.1±2.2	72.22	5.09	0.98	26.1±2.0
Olax obttusifolia	0	0	0	0	11.76	0.89	0	6.3±4.5	16.67	0.5	0.13	5.8
Ozoroa reticulata	22.22	1.43	0	11.8±4.7	11.76	0.26	0	6.0±4.5	0	0	0	0
Parinari curatellifolia	27.78	1.27	0	14.5±2.1	41.18	1.79	0	21.5±3.1	50	2.17	2.28	18.2±3.0
Pericopsis angolensis	22.22	1.43	0	11.8±4.5	11.76	0.38	0	6.1±4.3	55.55	2	1.86	19.8±4.6
Phyllocosmus lemaireanus	94.44	9.78	0	52.1±3.0	41.18	2.17	0	21.7±1.9	50	2.34	0.68	17.7±2.0
Phyllocosmus mueranus	11.11	0.17	0	5.6±4.6	5.88	0.13	0	3.0±4.5	0	0	0	0
Protea angolensis	0	0	0	0	5.88	0.13	0	3.0±4.6	0	0	0	0
Pseulochnostylis maprouneifolia	44.44	2.87	0	23.7±4.1	35.29	1.66	0	28.5±3.0	77.78	3.84	2.45	28.0±3.0
Psorospermum febrigum	0	0	0	0	0	0	0	0	0	0	0	0
Pterocarpus angolensis	5.56	0.927	0	3.2±4.6	41.18	3.45	0	22.3±3.9	44.44	0.92	0.49	15.3±3.3
Rothmannia englerana	77.78	6.75	0	42.3±4.5	29.41	1.79	0	15.6±4.6	5.56	0.08	0.07	1.9±4.4
Rhus longipes	0	0	0	0	5.88	0.13	0	3.0±3.1	0	0	0	0
Securidaca longepedunculata	27.78	1.1	0	14.4±4.6	0	0	0	0	5.56	0.08	0.01	1.9±4.6
Steganoteania araliacea	5.56	0.93	0	3.2±4.4	0	0	0	0	0	0	0	0
Strychnos cocculoides	5.56	0.93	0	3.2±4.6	0	0	0	0	16.67	0.33	0.06	5.7±5.4
Strychnos innocua	5.56	0.25	0	2.9±4.6	41.18	2.05	0	21.6±4.5	27.77	0.5	0.16	9.5±4.6
Strychnos pungens	0	0	0	0	0	0	0	0	0	0	0	0
Strychnos spinosa	44.44	2.36	0	23.4±4.4	11.76	0.03	0	5.9±4.6	0	0	0	0
Swartzia madagascariensis	33.33	0.76	0	17.0±3.4	29.41	1.28	0	15.4±4.3	50	1.08	0.55	17.2±4.2
Syzygium guieense	33.33	1.52	0	17.4±4.6	23.53	1.28	0	12.4±4.5	16.67	0.58	0.19	5.8±4.6
Terminalia mollis	0	0	0	0	5.88	1.28	0	3.6±4.0	16.67	0.25	0.18	5.7±4.3
Uapaca benguelensis	16.67	0.76	0	8.7±4.4	17.65	2.43	0	3.6±4.5	0	0	0	0
Uapaca kirkiana	5.56	0.17	0	2.9±2.4	70.59	7.03	0	38.8±5.0	50	4.25	0.74	18.3±3.0
Uapaca nitida	0	0	0	0	0	0	0	0	0	0	0	0
Uapaca sansibarica	0	0	0	0	5.88	0.26	0	3.1±4.4	0	0	0	0
Vitex fischeri	33.33	1.6	0	17.5±2.4	0	0	0	0	0	0	0	0
Vitex doniana	0	0	0	0	11.76	0.38	0	6.1±4.2	5.56	0.08	0.01	1.9±2.0
Zanha africana	0	0	0	0	0	0	0	0	0	0	0	0
Ziziphus abyssinica	0	0	0	0	0	0	0	0	11.11	0.33	0.08	3.8±4.1
Ximenia americana	0	0	0	0	0	0	0	0	16.67	0.25	0.1	5.7±4.1

5 to 6 years abndoned sites

	S & B				CP				TH			
Species	R. F%	R. D%	R. G%	IV	R. F%	R. D%	R. G%	IV	R. F%	R. D%	R. G%	IV
Hexalobus monopetalus	20	0.41	0.19	6.9±4.3	0	0	0	0	11.11	0.16	0.08	3.8±4.2
Isoberlinia angolensis	93.33	13.15	11.93	39.5±2.1	76.47	22.92	11.28	36.9±2.0	100	10.97	14.3	41.8±1.4
Julbernadia paniculata	73.33	7.81	18.35	33.2±2.0	52.94	3.61	3.71	20.1±1.6	100	12.35	20.25	44.2±2.2
Unknown 1	0	0	0	0	5.88	0.14	0.07	2.0±4.5	0	0	0	0
Lannea discolor	6.67	0.41	0.78	2.6±4.6	23.53	0.69	0.56	8.3±3.9	33.33	0.65	0.45	11.5±4.3
Lannea stuhlmannii	0	0	0	0	0	0	0	0	0	0	0	0
Magnistipula butayei	0	0	0	0	5.88	0.28	0.1	2.1±4.6	0	0	0	0
Mapronea africana	0	0	0	0	17.65	0.97	1.84	6.8±3.7	11.11	0.24	0.03	3.8±3.9
Maranthes floribunda	0	0	0	0	0	0	0	0	0	0	0	0
Monotes africanus	0	0	0	0	47.06	1.81	2.27	17.1±2.0	88.89	2.52	1.65	31.0±3.0
Monotes katangensis	0	0	0	0	0	0	0	0	0	0	0	0
Unknown 2	0	0	0	0	0	0	0	0	0	0	0	0
Ochna pulchra	46.67	4.25	1.68	17.5±2.0	82.35	5.28	3.5	30.4±1.4	83.33	4.87	1.01	29.7±3.0
Olax obttusifolia	0	0	0	0	0	0	0	0	27.78	0.57	0.1	9.5±4.0
Ozoroa reticulata	53.33	10	16.89	29.7±4.4	23.53	1.38	1.96	9.0±3.8	0	0	0	0
Parinari curatellifolia	100	15.89	9.85	41.9±2.4	58.82	2.64	7.14	22.9±2.0	72.22	3.49	3.36	26.4±3.0
Pericopsis angolensis	13.33	0.27	0.46	4.7±4.6	0	0	0	0	50	1.54	1.15	17.6±4.6
Phyllocosmus lemaireanus	26.67	1.51	0.34	9.5±3.0	52.94	1.53	1.26	18.6±3.0	66.67	2.6	0.55	23.3±1.4
Phyllocosmus mueranus	0	0	0	0	0	0	0	0	0	0	0	0
Protea angolensis	0	0	0	0	0	0	0	0	0	0	0	0
Pseulochnostylis maprouneifolia	26.67	1.51	2.17	10.1±3.0	64.71	3.61	2.13	23.5±3.0	72.22	2.84	1.09	25.4±4.0
Psorospermum febrigum	0	0	0	0	0	0	0	0	0	0	0	0
Pterocarpus angolensis	66.67	7.26	4.87	26.3±4.6	11.76	1.67	0.4	4.6±4.6	33.33	1.62	0.07	11.7±4.6
Rothmannia englerana	0	0	0	0	0	0	0	0	0	0	0	0
Rhus longipes	0	0	0	0	0	0	0	0	0	0	0	0
Securidaca longepedunculata	20	0.41	0.17	6.9±4.5	0	0	0	0	0	0	0	0
Steganoteania araliacea	0	0	0	0	5.88	0.14	0.04	2.0±4.6	5.56	0.16	0.13	2.0±2.7
Strychnos cocculoides	0	0	0	0	0	0	0	0	5.56	0.08	0.04	2.0±2.8
Strychnos innocua	20	0.41	1.27	7.2±4.4	5.88	0.14	0.05	2.0±4.6	22.22	0.57	0.23	8.0±4.5
Strychnos pungens	0	0	0	0	0	0	0	0	0	0	0	0
Strychnos spinosa	0	0	0	0	0	0	0	0	0	0	0	0
Swartzia madagascariensis	20	0.96	0.82	7.3±4.5	47.06	2.36	2.63	17.4±4.3	38.89	1.87	0.82	13.9±4.6
Syzygium guieense	20	0.68	0.59	7.1±4.6	17.75	1.81	1.81	7.1±4.3	11.11	0.57	0.1	3.9±4.3
Terminalia mollis	20	0.82	0.57	7.1±4.6	5.88	0.14	0.09	2.0±4.6	0	0	0	0
Uapaca benguelensis	0	0	0	0	5.8	0.28	0.25	2.1±4.2	5.56	0.16	0.02	1.9±2.3
Uapaca kirkiana	6.67	0.27	0.09	2.3±2.0	100	19.58	23.96	47.9±2.0	61.11	3.41	1.32	22.0±2.0
Uapaca nitida	13.33	0.68	0.5	4.8±4.4	29.41	0.83	1.86	10.7±4.6	27.78	0.41	0.17	9.5±3.8
Uapaca sansibarica	0	0	0	0	35.29	1.39	0.5	12.4±4.5	11.11	0.24	0.08	3.8±3.9
Vitex fischeri	40	0.82	0.5	13.8±5.2	0	0	0	0	0	0	0	0
Vitex doniana	0	0	0	0	5.88	0.14	0.08	2.0±4.2	0	0	0	0
Zanha africana	0	0	0	0	0	0	0	0	11.11	0.32	0.21	3.9±4.0
Ziziphus abyssinica	0	0	0	0	0	0	0	0	0	0	0	0
Ximenia americana	0	0	0	0	0	0	0	0	11.11	0.48	0.03	3.9±4.2

10 to 12 years abandoned sites

	S & B				CP				TH			
Species	R. F%	R. D%	R. G%	IV	R. F%	R. D%	R. G%	IV	R. F%	R. D%	R. G%	IV
Hexalobus monopetalus	12.5	0.38	0.45	4.4±2.3	0	0	0	0	33.33	1.44	0.21	11.7±4.4
Isoberlinia angolensis	56.25	7.54	8.39	24.1±1.4	64.71	9.41	13.89	29.3±1.2	94.44	11.62	15.81	40.6±2.4
Julbernadia paniculata	75	7.2	8.26	30.2±2.1	64.71	12.03	11.76	29.5±1.4	100	15.63	30.24	48.6±1.4
Unknown 1	0	0	0	0	0	0	0	0	0	0	0	0
Lannea discolor	43.75	1.66	1.48	15.6±4.6	76.47	4.15	3.08	27.9±4.6	38.89	0.72	0.71	13.4±4.7
Lannea stuhlmannii	0	0	0	0	5.88	0.28	0.08	2.1±4.2	11.11	0.16	0.1	3.8±4.0
Magnistipula butayei	0	0	0	0	0	0	0	0	0	0	0	0
Mapronea africana	0	0	0	0	35.29	1.8	2.71	13.3±4.4	0	0	0	0
Maranthes floribunda	0	0	0	0	0	0	0	0	0	0	0	0
Monotes africanus	18.75	0.51	0.47	6.6±1.4	52.94	2.21	1.47	18.9±2.0	0	0	0	0
Monotes katangensis	0	0	0	0	11.76	0.96	0.68	4.5±4.5	0	0	0	0
Unknown 2	0	0	0	0	0	0	0	0	0	0	0	0
Ochna pulchra	37.5	2.3	2.27	14.0±2.0	41.18	4.52	1.94	15.9±2.1	83.3	5.77	1.05	30.0±2.0
Olax obttusifolia	6.25	0.26	0.21	2.2±4.4	5.88	0.14	0.12	2.1±4.4	11.11	0.24	0.05	3.8±4.2
Ozoroa reticulata	50	1.92	2.1	18.0±3.4	29.41	1.51	1.09	10.7±4.4	5.56	0.08	0.01	1.9±2.3
Parinari curatellifolia	62.5	8.05	5.05	25.2±2.0	41.18	3.56	3.32	16.0±2.4	50	1.36	1.88	17.8±2.0
Pericopsis angolensis	43.75	2.55	2.85	16.4±4.6	64.71	3.7	3.98	24.1±4.6	77.78	2.32	2.29	27.5±4.5
Phyllocosmus lemaireanus	18.75	0.77	0.54	6.7±3.0	29.41	1.1	0.49	10.3±3.0	50	1.36	0.27	17.2±3.2
Phyllocosmus mueranus	0	0	0	0	0	0	0	0	0	0	0	0
Protea angolensis	6.25	0.13	0.12	2.2±2.0	11.76	0.55	0.22	4.2±4.6	0	0	0	0
Pseulochnostylis maprouneifolia	37.5	1.79	4.38	14.6±1.2	41.18	1.92	2.51	15.2±2.2	44.4	1.6	0.85	15.6±2.1
Psorospermum febrigum	0	0	0	0	0	0	0	0	11.11	0.24	0.13	3.8±4.5
Pterocarpus angolensis	12.5	1.79	2.54	5.6±4.6	41.18	4.38	4.93	16.8±4.5	16.67	0.24	0.36	5.8±4.6
Rothmannia englerana	6.25	0.13	0.03	2.1±4.4	5.88	0.14	0.14	2.1±4.5	5.56	0.24	0.02	1.9±4.4
Rhus longipes	0	0	0	0	0	0	0	0	0	0	0	0
Securidaca longepedunculata	37.5	4.85	4.51	15.6±3.3	23.53	1.37	0.57	8.5±4.5	5.56	0.08	0.01	1.9±4.6
Steganoteania araliacea	0	0	0	0	11.76	0.28	0.16	4.1±4.3	0	0	0	0
Strychnos cocculoides	0	0	0	0	0	0	0	0	0	0	0	0
Strychnos innocua	12.5	0.38	0.69	4.5±4.6	11.76	0.41	0.28	4.2±4.6	50	2.24	0.53	17.6±4.6
Strychnos pungens	0	0	0	0	11.76	0.28	0.07	4.0±4.6	0	0	0	0
Strychnos spinosa	6.25	0.13	0.08	2.2±4.4	35.29	1.51	0.55	12.5±4.6	5.56	0.02	0.01	1.9±2.3
Swartzia madagascariensis	50	4.21	3.84	19.8±	41.18	2.05	1.94	15.1±4.3	61.11	1.92	0.7	21.2±4.5
Syzygium guieense	43.75	5.75	2.86	17.5±4.0	88.24	7.81	4.33	33.5±4.3	5.56	0.08	0.07	2.1±4.6
Terminalia mollis	31.25	1.79	1.44	11.5±3.5	0	0	0	0	0	0	0	0
Uapaca benguelensis	18.75	0.89	1.05	6.9±4.0	11.76	0.28	0.17	4.1±4.4	5.56	0.16	0.02	1.91
Uapaca kirkiana	12.5	1.4	1.46	5.1±2.0	41.18	3.15	2.82	15.7±2.0	83.3	5.61	2.17	30.4±2.4
Uapaca nitida	18.75	0.26	0.27	6.4±4.5	11.76	0.82	0.45	4.3±4.6	5.56	0.08	0.04	1.9±4.6
Uapaca sansibarica	6.25	0.51	1.29	2.7±4.4	11.76	0.28	0.71	4.3±4.6	38.89	0.72	0.53	13.4±4.3
Vitex fischeri	0	0	0	0	0	0	0	0	0	0	0	0
Vitex doniana	18.75	0.38	0.28	6.5±5.0	0	0	0	0	0	0	0	0
Zanha africana	6.25	0.26	0.08	2.2±4.4	0	0	0	0	16.67	0.4	0.04	5.7±3.2
Ziziphus abyssinica	0	0	0	0	0	0	0	0	11.11	0.24	0.05	3.8±4.5
Ximenia americana	0	0	0	0	0	0	0	0	0	0	0	0

15 + years abandoned sites

	S & B				CP				UW			
Species	R. F%	R. D%	R. G%	ort. Value	R. F%	R. D%	R. G%	IV	R. F%	R. D%	R. G%	IV
Hexalobus monopetalus	0	0	0	0	0	0	0	0	38.89	1.07	0.18	13.4±4.3
Isoberlinia angolensis	94.12	12.5	15.62	40.8±2.1	90.91	13.32	18.95	41.1±2.2	66.67	9.2	13.82	30.0±2.4
Julbernadia paniculata	88.24	8.86	6.41	34.5±1.4	81.82	11.44	15.61	36.3±1.4	88.89	14.78	27.13	43.6±2.2
Unknown 1	0	0	0	0	0	0	0	0	0	0	0	0
Lannea discolor	58.82	3.15	2.48	21.5±4.1	63.34	3	2	22.9±3.1	27.78	0.57	0.27	9.5±4.6
Lannea stuhlmannii	0	0	0	0	0	0	0	0	0	0	0	0
Magnistipula butayei	0	0	0	0	0	0	0	0	0	0	0	0
Mapronea africana	0	0	0	0	0	0	0	0	0	0	0	0
Maranthes floribunda	0	0	0	0	0	0	0	0	0	0	0	0
Monotes africanus	11.76	0.24	0.23	4.1±0.5	9.09	0.38	0.1	3.2±1.4	66.67	3.28	18.62	29.5±2.3
Monotes katangensis	0	0	0	0	0	0	0	0	0	0	0	0
Unknown 2	0	0	0	0	0	0	0	0	0	0	0	0
Ochna pulchra	47.06	1.94	1.18	16.7±3.0	45.45	2.44	0.93	16.3±2.0	88.89	6.16	1.11	32.0±2.3
Olax obttusifolia	5.88	0.12	0.13	2.0±4.4	0	0	0	0	5.56	0.16	0.04	1.9±2.4
Ozoroa reticulata	47.06	2.12	3.66	17.6±4.6	36.36	0.75	0.11	12.4±3.1	0	0	0	0
Parinari curatellifolia	47.06	4	2.34	17.8±1.4	45.45	5.07	4.51	18.3±2.2	72.22	2.87	2.33	25.8±2.1
Pericopsis angolensis	52.94	4.25	4.47	20.6±4.5	18.18	1.31	0.7	6.7±3.1	50	1.89	2.06	18.0±4.3
Phyllocosmus lemaireanus	23.53	1.46	0.55	8.5±3.1	18.18	0.93	0.5	6.5±1.4	55.56	3.04	0.58	19.7±4.0
Phyllocosmus mueranus	0	0	0	0	0	0	0	0	0	0	0	0
Protea angolensis	11.76	0.49	0.24	4.2±3.9	0	0	0	0	0	0	0	0
Pseulochnostylis maprouneifolia	67.71	2.79	1.67	24.1±1.4	63.64	5.82	6.28	25.3±3.2	50	1.56	0.41	17.3±3.1
Psorospermum febrigum	0	0	0	0	0	0	0	0	11.11	0.16	1.47	4.3±3.8
Pterocarpus angolensis	23.53	1.7	0.52	8.6±4.1	0	0	0	0	44.44	1.72	0.03	15.4±4.1
Rothmannia englerana	5.88	0.12	0.13	2.0±2.2	0	0	0	0	0	0	0	0
Rhus longipes	0	0	0	0	0	0	0	0	0	0	0	0
Securidaca longepedunculata	5.88	0.12	0.13	2.0±4.6	0	0	0	0	0	0	0	0
Steganoteania araliacea	0	0	0	0	0	0	0	0	0	0	0	0
Strychnos cocculoides	0	0	0	0	18.18	0.38	0.07	6.2±3.1	5.56	0.16	0.02	1.9±2.6
Strychnos innocua	0	0	0	0	36.36	1.88	0.87	13.0±3.2	38.89	1.56	0.27	13.6±4.6
Strychnos pungens	0	0	0	0	0	0	0	0	0	0	0	0
Strychnos spinosa	29.41	1.58	1.19	12.7±4.4	18.18	1.88	1.03	7.0±3.1	5.56	0.08	0.01	1.9±2.3
Swartzia madagascariensis	41.18	3.4	2.36	15.7±4.6	63.64	4.32	3.54	23.8±3.1	33.33	1.64	0.51	11.8±4.4
Syzygium guieense	47.06	2.31	1.99	17.1±4.6	36.37	1.13	0.3	1.3±2.0	11.11	0.33	0.08	3.8±4.1
Terminalia mollis	11.76	0.73	0.12	4.2±4.6	0	0	0	0	5.56	0.08	0.06	1.9±4.6
Uapaca benguelensis	5.88	0.12	0.01	2.0±4.3	0	0	0	0	5.56	0.08	0.51	2.1±4.5
Uapaca kirkiana	64.71	3.64	4	24.1±1.4	36.36	3	1.66	1.4±1.3	55.56	6.96	1.96	21.5±1.4
Uapaca nitida	0	0	0	0	0	0	0	0	0	0	0	0
Uapaca sansibarica	5.88	0.12	0.04	2.0±4.4	0	0	0	0	5.56	0.08	0.01	1.9±2.3
Vitex fischeri	5.88	0.24	0.12	2.1±2.4	18.18	0.75	0.29	6.4±3.2	0	0	0	0
Vitex doniana	0	0	0	0	5.88	0.26	0.2	2.1±2.3	0	0	0	0
Zanha africana	5.88	0.12	0.1	2.0±4.2	5.88	0.27	0.24	2.1±2.4	0	0	0	0
Ziziphus abyssinica	0	0	0	0	5.88	0.7	6.36	4.3±2.8	0	0	0	0
Ximenia americana	0	0	0	0	0	0	0	0	0	0	0	0

5 REGENERATION AND RECRUITMENT POTENTIALS OF KEY SPECIES OF MIOMBO WOODLAND AFTER DISTURBANCE

Abstract

Miombo woodland utilization can be either through charcoal production or slash & burn agriculture or single tree selection for timber harvesting. Slash & burn agriculture and charcoal production have commonly been viewed as forest degradation with negative impacts compared to single tree selection harvesting. This paper argues in favor of charcoal production and slash & burn agriculture as necessary components of the Miombo woodland ecosystems and that many Miombo woodland species have become adapted to such kinds of disturbance. Additionally, the paper argues against the sustainability of single tree selection at population level. To achieve this, three areas previously under charcoal production, slash & burn agriculture and single tree selection timber harvesting occurring in close proximity to each other were selected for study. These areas were of known age. The study reveals that most species in charcoal and slash & burn regrowth stands show gradual development from one size class to another with this development being significantly ($P < 0.0005$) influenced by species rather than the disturbance category. This is because the key Miombo species are light demanding and requires maximum exposure to sunlight. By contrast, species in single tree harvested stands exhibited static size class profiles with no individuals in certain classes. The study concludes that whilst single tree selection appeared to show that the forest is intact at the stand level, it is actually not a sustainable management option for individual species at population level.

Key words: regeneration, size class profile, bell-shape, Inverse J curve, static size class

5.1 Introduction

Forest canopies have a substantial influence on the understory environment; buffering temperature changes, reducing light intensity, changing the spectral quality of solar radiation and intercepting a significant proportion of precipitation (Aussenac 2000). It therefore influences the regeneration and recruitment of individual forest species. This is why Walker (1985), Frost *et al.* (1986) and Scoones (1990) emphasise the importance of considering the possible responses to disturbance of ecosystems as a whole, as well as the individual species within them. Forest exploitation either for charcoal production, slash & burn agriculture or timber harvesting is a form of disturbance on the forest/woodland ecosystem.

There have been very few studies conducted in the region on the response of individual forest species to disturbances such as charcoal production, slash & burn (shifting cultivation) and timber harvesting. Most of the studies in the region (Trapnell, 1959; Geldenhuys, 1977, 1993, 1996; Desmet *et al.,* 1996; Grundy & Cruz, 2001) concentrated on the effect of individual disturbance factors on the forest species without comparing effects of different disturbances over time. However, Neke (2002) studied the effects of resource utilisation, primarily fuelwood harvesting and livestock browsing, on woody population dynamics in a South African Savanna woodland. Vesey-FitzGerald (1973) studied the recruitment and replacement potentials of selected species in the Arusha National Park in Tanzania. In Zambia, most of the researchers (Stromgaard 1986; Chidumayo, 1989, 2004) discussed succession of Miombo woodlands in general, especially after cutting, with or without cultivation and after destruction by fire (Trapnell 1959; Lawton 1978) without emphasis on the regeneration and recruitment potentials of individual species after a disturbance. Yet such information is essential to understanding woodland stability and resilience, with direct implications both for species persistence and for people's livelihood. However, Shackleton (2000) studied the influence of stump size and height on coppicing effectiveness of individual species in the Bushbuck Ridge area, South Africa. Most of the studies on the Miombo woodlands (Chidumayo, 1989, 1990, 1991, 1992, 1993, 2004) dealt with the response of Miombo woodlands based on a single disturbance. Although such studies have added value to the already existing body of knowledge on the Miombo response to disturbance, it is important to compare the impact of different disturbances/treatments on the Miombo woodland so as to classify the impact based on the response of the Miombo woodland either as a whole or at population level.

The aim of this research was to investigate the regeneration and recruitment potentials of key Miombo woodland species in areas that have been under charcoal production, slash & burn agriculture and timber harvesting over periods of 2 to over 15 years. The research was designed to answer the following questions: i) What are the diameter and height class distributions of the key species of Miombo woodland under different disturbance regimes and age since the disturbance ceased? ii) What are the modes of regeneration under each disturbance regime?

5.2 Material and methods

5.2.1 Study area

The study area is located approximately 90 km south of Ndola Town towards Kapiri- mposhi (Figure 5.1) in Masaiti District which lies between 13^{o} 25' 00" S and 13^{o} 45' 00"S and 28^{o} 25' 00" E and 28^{o} 40' 00" E.

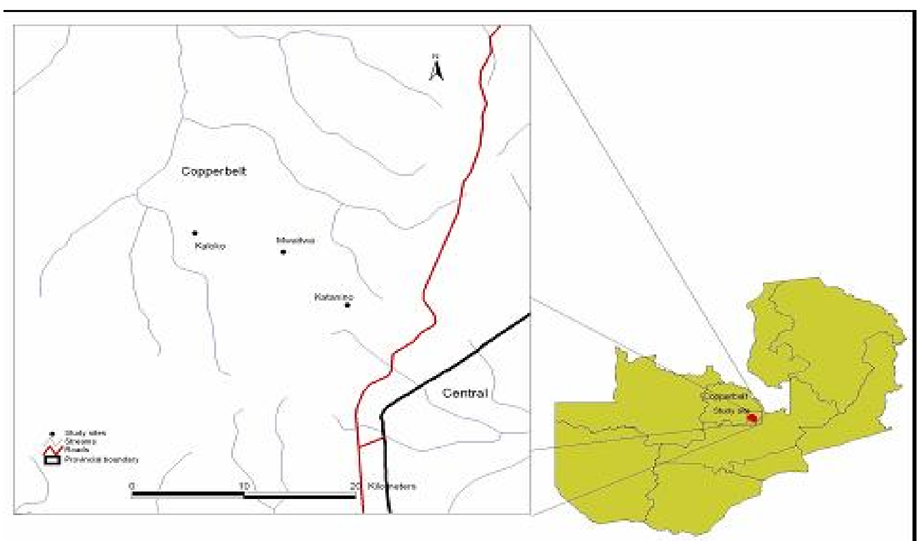

Figure 5.1 Map of Zambia showing study area in Masaiti District, Copperbelt Province

It occurs on the Katanga rock system at an altitude of 1200 m. The soils of the study site are of eluvial origin occurring on basement quartzites, schists and granitic rocks. Such soils are Oxisols and Ultisols which are acidic (pH 4-5), sand rich and highly leached with sandy-silty-clayey textural composition (Chidumayo 1997).

The climate of the area is characterized by an alternation of dry and wet seasons. Based on temperature and rainfall (Figure 5.2), three distinct seasons are recognized in the area: hot dry season (September-November), hot wet season (December-April) and cool dry season (May-August). The temperatures vary from 18^{0}C in winter to about 30^{0}C in summer (Rao & Acharya, 1981). The lowest temperatures usually occur in June/July while the highest temperatures occur in October. The average annual rainfall is about 1200 mm.

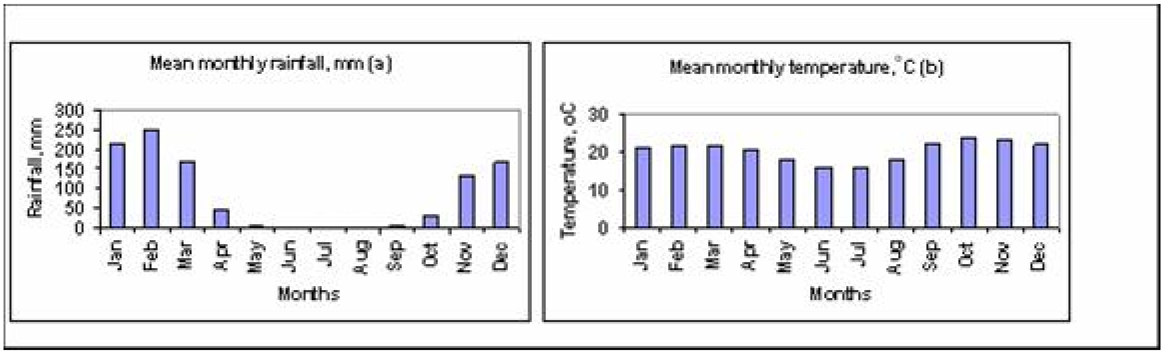

Figure 5.2 Monthly temperatures and rainfall for 2000-2006 for Copperbelt Province (Zambia Meteorological Dept. (unpublished)

The major vegetation of the study area is Miombo. Miombo is a *Kinyamwezi* term for *Brachystegia boehmii* (Mansfield *et al*. 1976) but has been accepted to refer to the woodland types dominated by *Brachystegia* spp., *Julbernadia* spp. and *Isoberlinia angolensis*. It is a single tree-story woodland with a light, closed canopy, dominated by Papilionacae and Caesalpiniodae, especially of the genera *Brachystegia, Isoberlinia* and *Julbernadia.* The dominant canopy species of the study area are *Brachystegia spiciformis, Brachystegia floribunda, Julbernadia paniculata* and *Isoberlinia angolensis* with *Pterocarpus angolensis, Pericopsis angolensis, Burkea africana, Swarzia madagascariensis, Albizia antunesiana and Parinari curatellifolia* being the canopy associates. *Anisophyllea boehmii, Diplorhynchus condylocarpon*, *Syzygium guineense* and *Uapaca spp* are the common understory trees in the study area.

5.2.2 Methodology

Five areas which have been under timber harvesting, slash & burn agriculture and charcoal production occurring in close proximity to each other were selected to ensure the soil, geology, landscape position, local climate and the surrounding vegetation were similar. From the five areas, only three areas were randomly selected for the study, namely *Kaloko, Mwaitwa and Katanino/Kashitu*. This was done because of the limited funds and time for the study. Within each study area, four study sites of different age within each of the land use categories were selected. The ages of the sites were estimated using records from the District Forest Office, Kaloko Trust and Traditional Councilors (*Ba Filolo*), and by interviewing the local farmers, and charcoal and timber producers.

The ages of the sites were 2-3; 5-6; 10-12 and 15+ years for the areas previously under charcoal production and slash & burn agriculture, while for timber harvested areas the oldest sites were only 10-12 years old after disturbance cessation. This is because the preliminary investigation showed no major difference between areas that were under timber harvesting and the relatively undisturbed Miombo woodland. Additionally, relatively undisturbed woodland within each study area was selected to act as a control.

Site maps for the selected sites under timber harvesting, slash & burn agriculture, charcoal production and relatively undisturbed Miombo woodland were prepared, using the corner coordinates obtained with a Global Position System (GPS). On each site map, a grid system with latitudes and longitudes of 50 m by 50 m was superimposed to give the potential number of points from which random sampling points were selected. A total of 72 plots were sampled in each study area, i.e. calculated as (Two disturbance categories, i.e. charcoal production and slash & burn agriculture) * Four age class categories * Six plots per age class) + (one timber harvesting disturbance * Three age class categories * Six plots per age class) + 6 plots from undisturbed woodland. However, Katanino/Kashitu did not have 15+ year old charcoal regrowth stand.

Most of the sample plots in Miombo woodland inventories have been systematically selected and located (Trapnell 1959; Lees 1962; Lawton 1978; Chidumayo 1987). However, in this study, the plots were randomly selected from a systematic grid of points using the lottery method, and then located in the field using a GPS. Random selection of points avoids bias. The grid reference of each plot was entered into the GPS and this made it relatively easy, cheap, and quick to locate the points in the field.

Different researchers have used different plot sizes in their Miombo woodland inventories namely 0.4 ha (Lees, 1962; Edmonds, 1964), 20 m by 20 m (0.04 ha) (Lawton, 1978; Stromgaard, 1985; Araki, 1992) and 40 m by 40 m (0.16 ha) (Scholes, 1990). However, the use of circular plots (e.g. Zimba, 1991) has not been a common practice among the Miombo woodland researchers. The variation in plot sizes in the previous studies is because the plot size and inventory design are dependent on the type of information that the researcher wants to generate from the stand. For example, Geldenhuys (2004) used sampling units of 20 m radius in other Miombo inventories to generate data similar to that collected in this study. Hence this approach was adopted in this study for the mature Miombo woodland sites. Mature woodland refers to the woodland that had been under timber harvesting and the relatively undisturbed woodland (the control).

In assessing the regrowth stands (areas previously under charcoal production and slash & burn agriculture), variable sampling was used (Chapter 3), which is an adaptation of the closest individual method (Cottam & Curtis, 1956). The number of plants to define the size of the plot is determined by the species-stems/plants curve method (modification of species-area curve method by Huston, 1994 and Rosenzweig, 1995). It involves the use of a fixed number of plants rather than the fixed radius in determining the plot size. The method has several advantages when compared with the fixed-area plot method. It is faster, requires less equipment and fewer workers, and is much more flexible, in that there is no need to adjust the sample size for a particular density of the vegetation under study (Cottam & Curtis, 1956). The method gives comparable numbers, with differences in terms of numbers of species, and ratios of numbers of plants per species in the particular type of stand, but without having to measure many plants in one category of stand (younger stands) with too few in another category of stand (older stands). In this study, 34 plants for slash & burn and 31 plants for charcoal regrowth stands, were used as generated from the pilot study (Chapter 3).

A number of vegetation parameters were observed and recorded at each sample point, namely species, height (m) of any key species more than 1 mm in collar diameter (for those plants less than 5 cm in dbh) and diameter (cm) at breast height (for those 5 cm in dbh and larger). Additionally, the modes of regeneration under each disturbance category were determined by excavating around plants of selected species in young charcoal and slash & burn regrowth stands (2-3 years and 5-6 years old stands). In mature woodlands, the soil around young plants was excavated. This helped in determining whether the mode of regeneration of such a plant was either by a seedling from seed, root suckering or coppicing. A subplot of 5 m radius was established at the centre of the main plot. In each of the subplot, excavation of the soil to some depth around each plant of the key species was conducted in order to be able to determine the mode of regeneration for each plant.

5.3 Data analysis

Some key species were selected for study to determine the response of Miombo woodland species to harvesting, namely *Brachystegia longifolia, Brachystegia floribunda, Brachystegia spiciformis, Pterocarpus angolensis, Julbernadia paniculata, Albizia antunesiana, Pericopsis angolensis, Pseudolachnostylis maprouneifolia, Parinari curatellifolia* and *Isoberlinia angolensis.*

Different authors have defined and analyzed regeneration and recruitment capabilities of forest species in various ways. For example, Ben-Shahar (1996) in northern Botswana analyzed it based on different height classes: new seedlings (< 0.25 m in height), seedlings (0.25-1 m), shrubs (1-3 m in height) and trees (> 4.0 m in height). Vesey-FitzGerald (1973) used the following height classes: regeneration (≤ 1.0 m), recruitment (1.0-5 m) and replacement (5-10 m). However, other authors used size-class distributions (diameter class distributions) to explain the dynamics of various ecosystems when exposed to a disturbance (Midgley *et al*. 1990; Everard *et al*. 1995; Geldenhuys 1996; van Wyk *et al*. 1996; Grundy and Cruz 2001). In this study, both height and diameter distributions were used to explain the regeneration and the population dynamics of the selected species under different disturbance factors over time.

The height and diameter data were used to show the size class profiles of each species under each disturbance category. The analysis involved making comparisons of the stand and population level differences between undisturbed stands, timber harvesting stands, slash & burn and charcoal regrowth stands. Additionally, in each of the two comparisons the two sets of data, namely stems less than 5 cm DBH (over different heights) and stems with DBH above 5 cm (over different diameter classes), were dealt with separately. This provided an in-depth understanding of differences between the different disturbance regimes of the different treatments. Stand and population size class profiles were generated using Microsoft Excel 2003.

Correspondence analysis was conducted on the mode of regeneration data to determine if variation existed in regeneration modes among individual species under different disturbance categories.

5.4 Results

5.4.1 Dynamics at stand level

Figure 5.3 shows the stem size distribution for stems of less than 5 cm DBH of woodlands which were previously under timber harvesting, slash & burn agriculture, charcoal production and the relatively undisturbed woodland. Although the graphs are from stands with varying ages since the disturbance occurred, all of them, including the one from the undisturbed woodland stands, show examples of the inverse *J*-shaped size class structure**.** All the disturbance categories and also the undisturbed woodlands show a gradual decrease in stem frequency from <1 m height class to 2.0 m height to 4.9 cm DBH class.

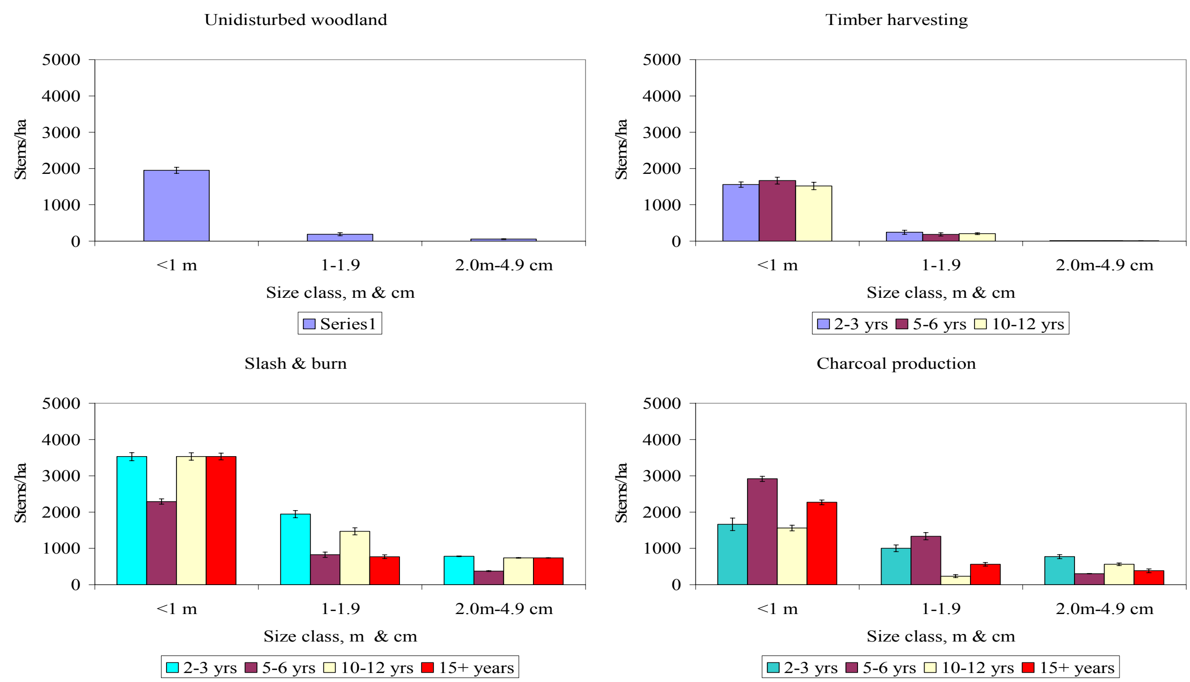

Figure 5.3 Stem size distribution of woody stems <5 cm DBH in woodland stands previously under different disturbances and the relatively undisturbed stand

However, the stands which were previously under slash & burn and charcoal production have a higher stocking in terms of stem density compared to the undisturbed and the single tree selection harvesting (timber harvested) stands.

Similarly, the comparison of size class structure of stems above 5 cm DBH revealed some similarities between timber harvested and the undisturbed woodland stands (Figure 5.4).

For the stands previously under cultivation, all the age classes show examples of the inverse *J*-shaped size class structure (Figure 5.4). They show the diameter distribution pattern in which the lower size classes have higher diameter frequencies than the higher classes. This pattern is also exhibited by charcoal regrowth stands up to the age of 10-12 yrs (Figure 5.4). However, the charcoal regrowth stands of 15+ years show a somewhat different size class structure, i.e. a fluctuation in stem frequency from the 7.5-9.9 cm class to the 10-12.4 cm, followed by an increase in stem frequency from 10 to 17.4 cm and a drop thereafter which gives rise to the fluctuation in size class profile. The stems above 12 cm DBH show bell-shaped size class structure. Similarly, the pattern exhibited by timber harvested and undisturbed woodland shows different structures in the larger size classes when compared to the smaller classes. For example, in both timber harvested and undisturbed woodland stands their size class profiles show humps between 7.5 cm to 14.9 cm, **i.e**. the bell-shaped size class profile.

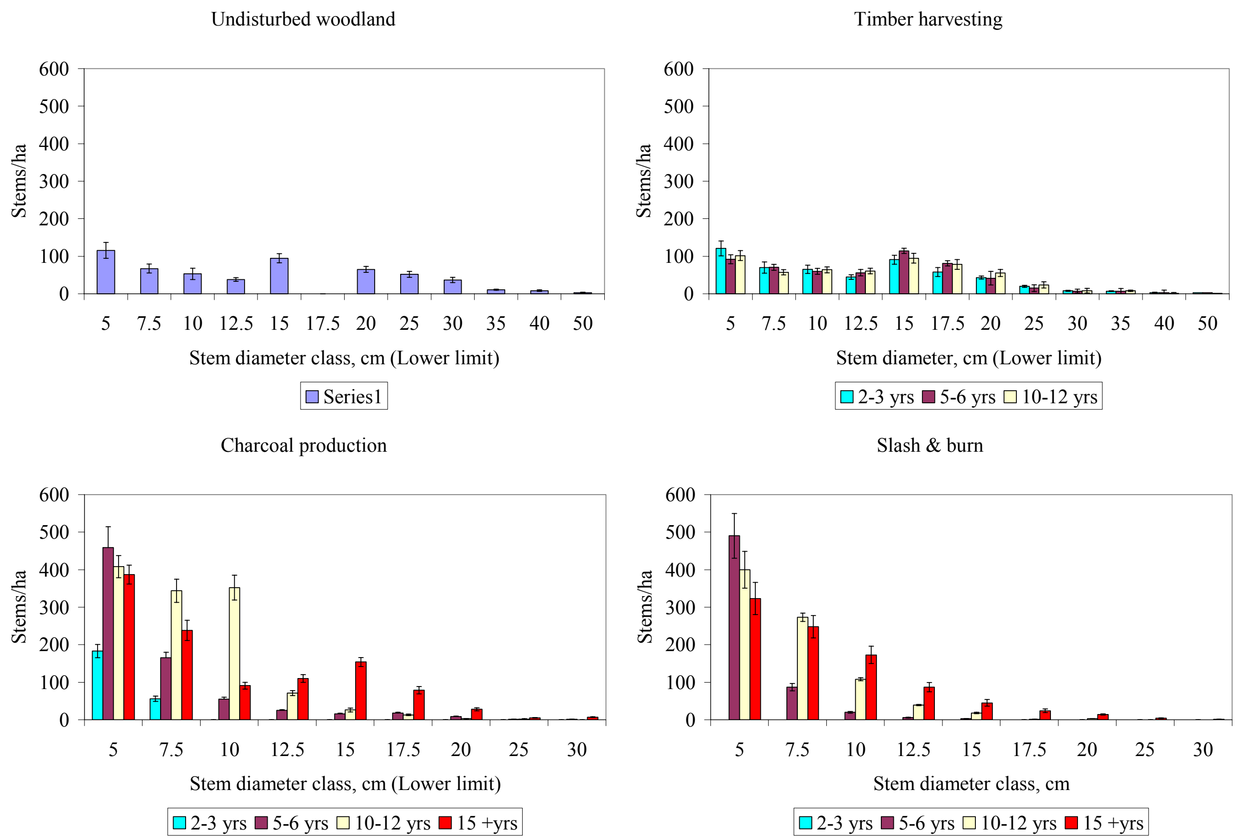

Figure 5.4 Stem diameter distribution of stems ≥ 5cm DBH in stands previously under different disturbances and the relatively undisturbed woodland stands.

5.4.2 Dynamics at population level of selected species under different disturbance regimes

The comparison of the size class structure (height and diameter) of individual species for stems which are less than 5 cm DBH across age and disturbance categories allowed for grouping of species based on their size class profiles. Figure 5.5 compare the differences within and between one selected species, but the diagrams for the other selected species are shown in Appendix 5.1. *Isoberlinia angolensis*, *Albizia antunesiana*, *Brachystegia floribunda*, *Brachystegia longifolia, Julbernadia paniculata,* and *Pericopsis angolensis* showed an inverse *J*-shaped structure under timber harvesting, slash & burn agriculture and charcoal production and the undisturbed woodland stands. Within this group other species such as *Brachystegia floribunda*, *Brachystegia spiciformis* and *Julbernadia paniculata* do not have stems in the 2.0 m height to 4.9 cm diameter class for timber harvested stands while *Isoberlinia angolensis* in timber harvested stands shows a fluctuation in the 1.0-1.9 m height class.

Parinari curatellifolia exhibited a static size class profile in both the charcoal regrowth and timber harvested stands. However, it has an inverse *J*-shaped structure, especially in the early stages of stand development in the stands previously under cultivation (Appendix 5.1). *Pseudolachnostylis maprouneifolia* exhibited a static size class profile in all the disturbance categories. Both species have a higher stocking in both charcoal and slash & burn regrowth stands.

Pterocarpus angolensis depicted a static size class structure in charcoal regrowth stands while in timber harvested stands it depicted a variable size profile (Appendix 5.1). In cultivation regrowth stands, the species had very few stems but also lacked stems in the <1 m height class.

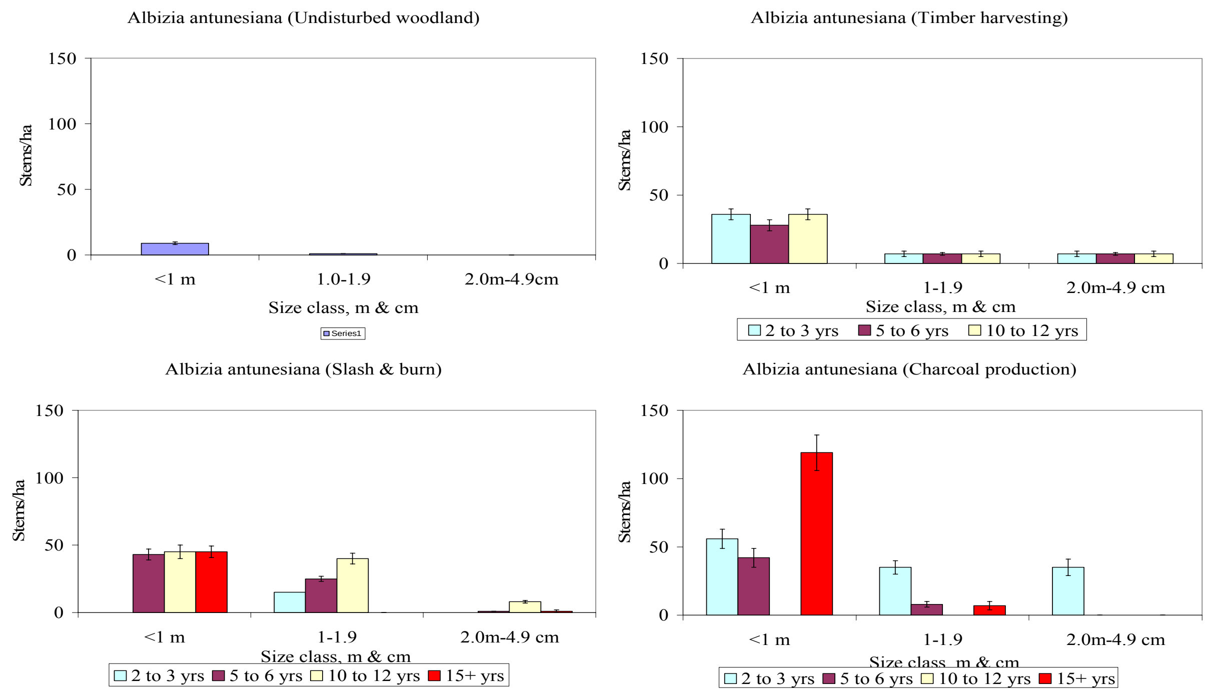

Figure 5.5 Stem size distribution (stems less than 5 cm DBH) of *Albizia antunesiana* in stands previously under different disturbance categories

The comparison of stem diameter distribution for stems above 5 cm DBH across different disturbance categories shows different size class profiles for the studied species (Figure 5.6 for one selected species; Appendix 5.2 for all the selected species). The timber species exhibited very low to no stems in certain size classes, namely *Albizia antunesiana*, *Brachystegia floribunda* (5.0-7.4 cm to 12.5-14.9 cm) and *Pterocarpus angolensis* (7.5-9.9 cm; 12.5-14.9 cm DBH) and classes higher than 20-22.4 cm DBH) in timber harvested stands while these species had bell-shaped curves in undisturbed woodland stands. Additionally, these species do not have stems in classes higher than 32.5 cm in stands which were under selection harvesting. In slash & burn and charcoal regrowth stands, the stand age significantly ($P < 0.031$) influenced the size structural profile of individual species. For example, *Brachystegia longifolia, Albizia antunesiana, Isoberlinia angolensis, Brachystegia floribunda* and *Julbernadia paniculata* exhibited inverse *J*-shaped curves in 5-6 years old stands while in 15+ year old stands, especially the charcoal regrowth stands, they depicted bell-shaped curves (Figure 5.4; Appendix 5.1). These species (except *Brachystegia spiciformis*) exhibited inverse *J*-shaped curves in slash and burn regrowth stands.

Brachystegia longifolia, *Brachystegia spiciformis, Isoberlinia angolensis, Parinari curatellifolia* and *Julbernadia paniculata* depicted the bell-shaped structure in the single tree selection harvested stands (Figure 5.6; Appendix 5.2). However, in both cultivation and charcoal regrowth stands these species exhibited the inverse *J*-shaped size class profile (Figure 5.6; Appendix 5.2). Comparatively, these species have a higher stocking in charcoal and slash & burn stands than in the mature woodland

Comparison of the development of stem sizes from one diameter class to another over years was significantly (P< 0.0005) influenced by species rather than the disturbance category. *Julbernadia paniculata*, *Brachystegia floribunda*, *Brachystegia longifolia*, *Isoberlinia angolensis*, *Albizia antunesiana* and *Brachystegia spiciformis* entered the higher classes faster than other species, namely *Pseudolachnostylis maprouneifolia*, *Parinari curatellifolia*, *Pericopsis angolensis* and *Pterocarpus angolensis* in slash & burn and charcoal regrowth stands.

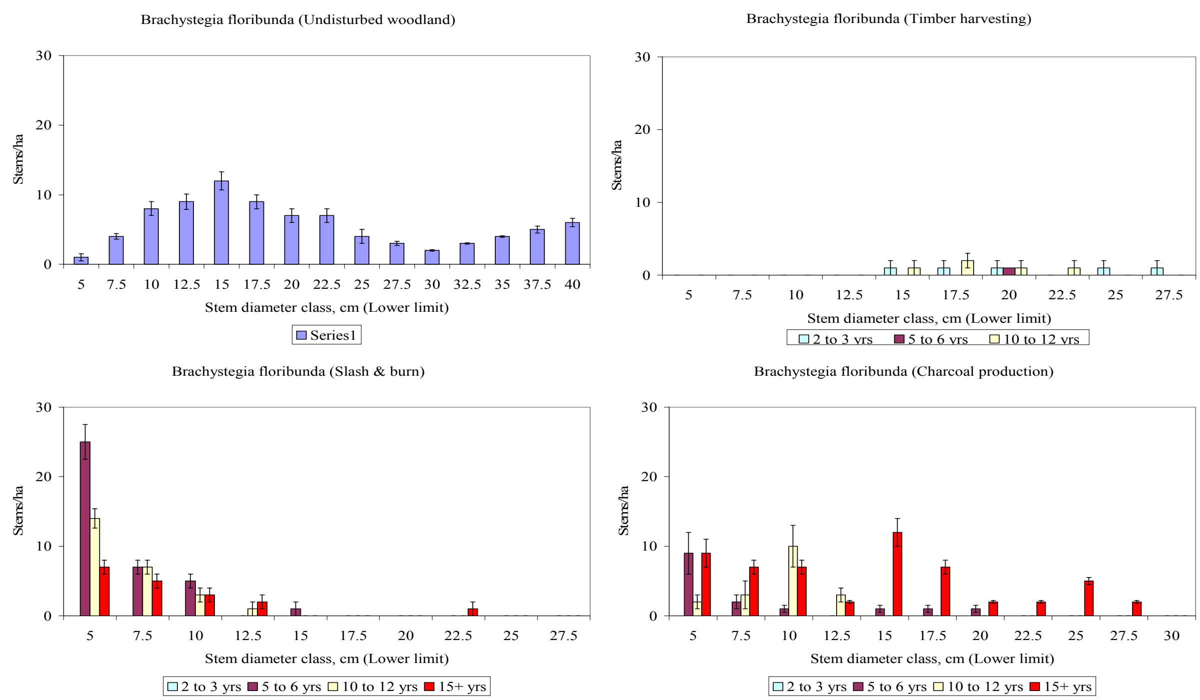

Figure 5.6 Stem diameter distribution of selected individual species in stands previously under different disturbance categories and undisturbed woodland stands (above 5 cm DBH)

5.4.3 Mode of regeneration under different disturbance categories

Miombo woodland species in the study area regenerate either through seed, coppicing or root suckering. A correspondence analysis carried out revealed some variation in modes of regeneration under different disturbance categories for species (Figure 5.7). The ordination diagram (Figure 5.7) shows the mode of regeneration for each of selected species under different disturbances. In the ordination space, the closer the species is to the mode of regeneration under each disturbance the more often it is regenerated by that particular mode of regeneration.

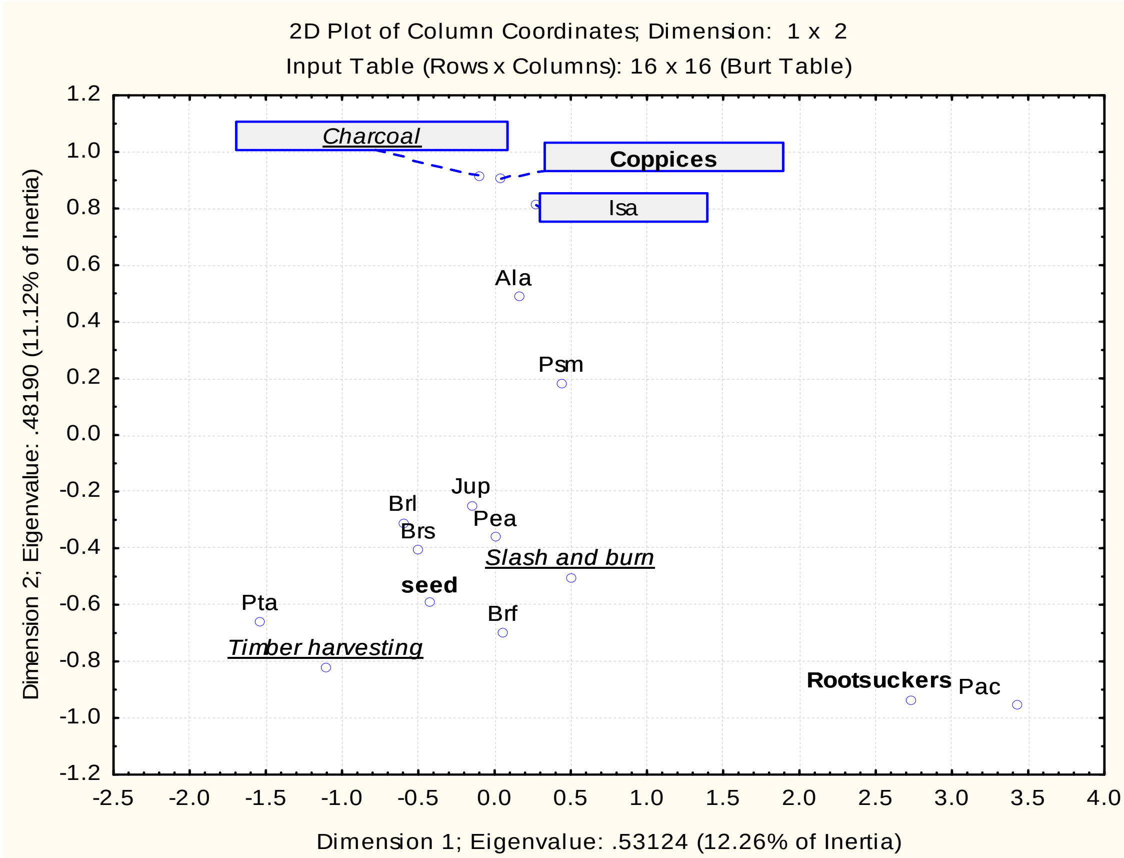

Figure 5.7 Ordination diagram showing mode of regeneration of the selected species under different disturbance categories.

Figure 5.8 shows the mode of regeneration each species is mostly associated with under each disturbance category. In timber and previously cultivated stands, *Parinari curatellifolia* mostly develop from root suckers (Figure 5.8a) while *Albizia antunesiana(Ala)*, *Brachystegia floribunda(Brf)*, *Brachystegia longifolia(Brl)*, *Brachystegia spiciformis(Brs)*, *Isoberlinia angolensis(Isa)*, *Julbernadia paniculata(Jup), Pericopsis angolensis(Pea)*, *Pseudolachnostylis maprouneifolia(Psm)* and *Pterocarpus angolensis(Pta)* mostly develop from seed (Figure 5.8b). Coppicing is mostly common in *Albizia antunesiana*, *Brachystegia floribunda*, *Isoberlinia angolensis*, *Julbernadia paniculata* and *Pseudolachnostylis maprouneifolia* (Figure 5.8c). Other species, such as *Brachystegia longifolia*, *Brachystegia spiciformis*, *Parinari curatellifolia*, *Pericopsis angolensis* and *Pterocarpus angolensis* regenerated mostly from seed (Figure 5.8d).

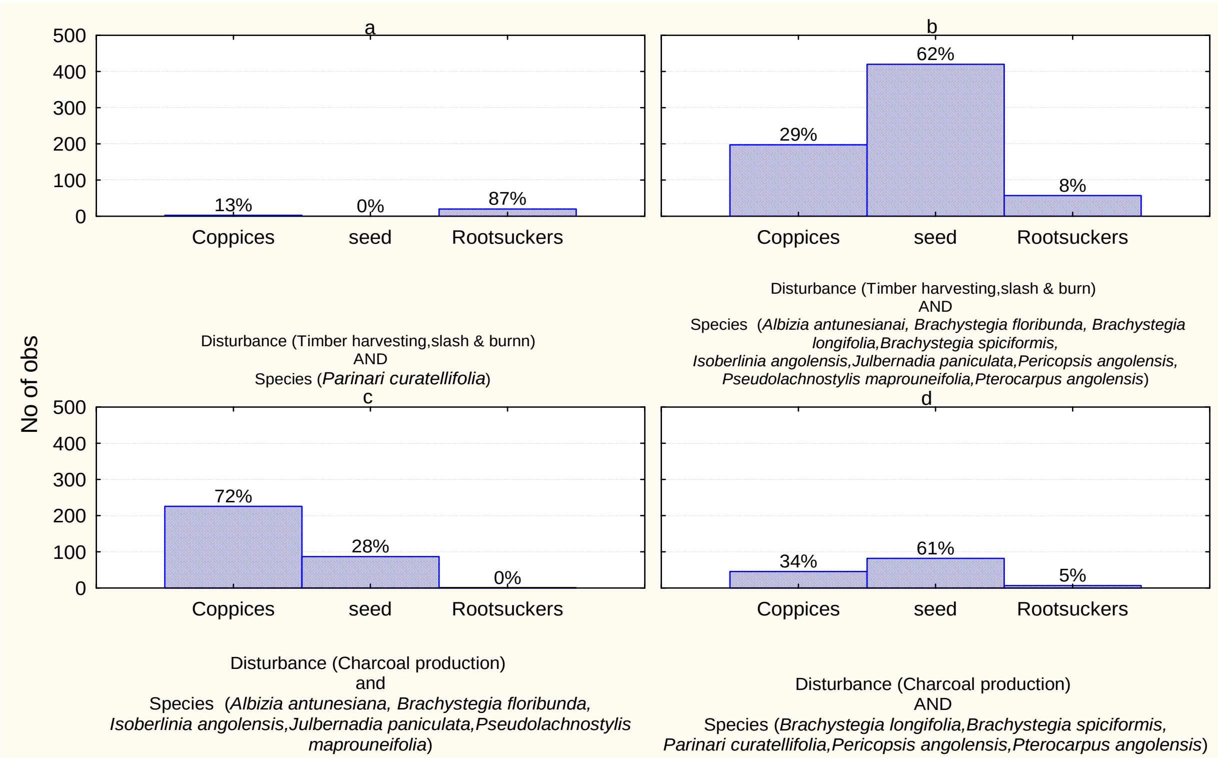

Figure 5.8 Percentage distribution of regeneration modes under different disturbance categories

5.5 Discussion

5.5.1 Dynamics at stand level

The characteristic inverse *J*-shape curve in stems sizes <5cm DBH implies a higher abundance of individuals in smaller size classes than in larger classes (Zagt & Werger, 1998), i.e. continued regeneration or the accumulation of stems because they cannot grow larger through some kind of constraint. It is indicative of the population of species that are tolerant of the conditions prevailing in a stand e.g. shade-tolerance in evergreen forest and fire-tolerance in the woodlands (Geldenhuys, 1993). Therefore, the inverse *J*-shape size class profile exhibited by plants from <1 m height class to the 2.0 m height to 4.9 cm diameter (Figure 4.3) is indicative of the extent to which various Miombo species can tolerate the conditions prevailing in the woodland since germination in both regrowth and mature woodland stands. This could be competition from light, grazing pressure, or fires. However, the bell-shaped size class profile of exhibited by the mature woodland stands (undisturbed and timber harvested) (Figure 4.4) depicts the characteristic population which experience sporadic or irregular seedling establishment (see Peter, 2005). The actual levels of regeneration may be sufficient to maintain the woodland, but its infrequency of occurrence cause noted peaks as the new seedlings grow into larger size classes. According to Peter (2005), such a size class structure is common among species that depend on canopy gaps for regeneration. This is explained by the fact that the dominant Miombo species require high light intensities to develop (see Lees, 1962) and therefore require large gaps. According to Ackerley (1996) and van Wyk *et al*. (1996) opening of the canopy stimulates germination of the soil seed reserves as the temperature and light intensity increase. Exposure of stumps to sunlight enhances their coppicing effectiveness for most woodland species that develop vegetatively (Reader and Bricker, 1995). Most Miombo woodland species are capable of developing vegetatively (Luoga *et al.* 2004). They generally have both extensive vertical and horizontal root systems which facilitate rapid recuperation after cutting (Malimbwi *et al*., 1994; Mistry, 2000).

The slash & burn regrowth stands exhibited inverse *J* shaped curve in all the age class categories while in the charcoal regrowth stand, this profile was exhibited up to an age category of 10-12 years only. The higher number of smaller stems than larger stems explains why the inverse *J* shaped curve is observed in these stands. However, charcoal regrowth stands exhibited a bell-shaped size class profile in 15 year old stands. This may be attributed to the fact that as the regrowth stands become older, some stems of the same age tend to grow faster than other stems, and if no more stems recruit into the stand, the bell shaped curve develop. It may be assumed that the slash & burn regrowth stands will with time develop bell shaped curves. The difference in rate of bell-shaped curve formation between slash & burn and charcoal regrowth may be because most of the trees in charcoal regrowth stands develop from coppices while those in slash & burn regrowth stands develop from seedlings (Figure 5.8b). The coppices develop from the already established root stocks. As such most of the biomass is allocated to stem development. However, most of the biomass for the trees that develop from seedlings is allocated to root growth in their seedling phase (Chidumayo, 1991, 1992) and plants that develop from seedlings may be slower in stem size development. Additionally, stems with diameter of ≤3.2 cm are normally left behind when trees are being cut for charcoal production (Chidumayo, 1990). With reduced competition after clearing these stems tend to grow faster and therefore contribute to stem frequencies in higher diameter classes than in slash & burn stands

However, as some authors have pointed out (Goff & West, 1975; O'Hara & Milner, 1994), there are anticipated difficulties and complications in the use of inverse *J* structure profile as a tool for the management of uneven-aged forests/woodlands like Miombo woodlands. This is because the model assumes equal mortality among species over size classes in the forest, which is biologically unrealistic as individual species respond to disturbances differently. Additionally, the disturbances to which the individual forest species are exposed differ as is the case with Miombo woodland of the study site where disturbance took the form of single tree selection harvesting of timber species namely *Pterocarpus angolensis*, *Albizia antunesiana*, *Afzelia quanzensis* and *Brachystegia floribunda*. It is therefore, important to understand the implications of such a model by looking at how individual species behave when exposed to single tree selection harvesting, charcoal production and slash & burn agriculture.

5.5.2 Dynamics at population level

With the <5 cm DBH level comparison, the inverse *J*-shaped size structure observed in *Isoberlinia angolensis, Albizia antunesiana, Brachystegia floribunda, Brachystegia longifolia, Julbernadia paniculata* and *Pericopsis angolensis* (Figure 5.5; Appendix 5.1) is indicative of the presence of young seedlings of these species under canopy in mature woodland stands. A higher abundance of individuals in smaller classes than the larger classes and almost constant reduction in the number of trees from one class to the next leading to an inverse *J*-shaped size class distribution is regarded as an indicator of adequate regeneration and population maintenance (Zagt & Weger, 1998) of these species from the <1 m height to the 2.0 m height to 4.9 cm diameter. Ideally, this is the type of structure that a forest manager should strive to maintain in order to have adequate regeneration and population development of these species. However, as these species are shade intolerant, if they are not adequately exposed to sunlight, they remain stunted, and thus prolonging the period during which they are susceptible to fires, water stress, insectivory and herbivory (see Savory, 1963; Huston, 1994; Chidumayo, 1997). As long as they remain under canopy cover, these saplings may either die or remain suppressed in stunted form (Werren *et al*. 1995) due to either insufficient sunlight or competition for nutrients and moisture or allelopathy. Chidumayo (1993) observed that exposure to sunlight significantly enhances coppice effectiveness of most of the Miombo woodland species. Other species like *Pseudolachnostylis maprouneifolia* and *Parinari curatellifolia* which mostly develop through root suckering (Appendix 5.1) have higher stems in previously cultivated stands than in stands which were either under single tree selection harvesting or charcoal production. Similarly, Strang (1974) observed unusually dense stands of root suckers in stands which were open shrub savanna prior to cultivation. This may be attributed to the fact that damages and cuts to roots made during land clearing and weeding enhance root suckering.

At ≥5 cm DBH level, the comparison revealed various size class profiles of species as depicted from respective graphs (Figure 5.6; Appendix 5.2). For example, *Brachystegia longifolia, Brachystegia spiciformis*, *Isoberlinia angolensis*, *Parinari curatellifolia* and *Julbernadia paniculata* exhibited bell-shaped curves in timber harvested and undisturbed woodland stands while species which were harvested for timber showed a static size class profile. In some cases, it was usual to find no stems per hectare for most of the upper diameter classes for species which were being selectively harvested for timber (such as *Albizia antunesiana*).

The bell-shaped curves exhibited by the species indicated above are similar to the curves exhibited by *Ocotea bullata* (a partially shade intolerant species) in the evergreen forest of South Africa (DWAF, 2005). This suggests that these species are shade intolerant and require large gaps to allow for maximum exposure to sunlight for their establishment and development. Additionally, the periodic fires which occur in Miombo woodland tend affect regeneration from time to time (Trapnell, 1959). *Pterocarpus angolensis* may considered to belong to the group of species which are light demanding species although it exhibited *J* shaped size class profile in a fire adapted Namibian vegetation (see Geldenhuys, 1977). Two reasons may be advanced for considering *Pterocarpus angolensis* to belong to this group. Firstly, casual observations are indicative of the fact that the species performs well in cleared areas (Figure 5.9). Secondly, various studies attest to the fact that *Pterocarpus angolensis* is shade intolerant and associate the good performance of this species in cleared areas to exposure to maximum light (Boaler, 1966; von Breitenbach, 1973; Werren *et al*. 1995; Graz, 1996). However, it is not only exposure to light that make these species do well in opened up areas arising from charcoal production and slash & burn activities but also reduced competition for moisture and nutrients contribute to the good performance of these species. Opening up of forest land may also result in reduced effects of allelopath arising from interaction between species.

Figure 5.9 *Pterocarpus angolensis* dominating the cleared area of Miombo woodland at Kaloko

The study has also shown the impact of species preference and single tree selection harvesting on the overall population structure of the preferred species. *Albizia antunesiana, Brachystegia floribunda* and *Pterocarpus angolensis*, the species mostly preferred for timber, have been negatively impacted to an extent that the occurrence of stems in higher diameter classes is so low that their exploitation may not be economic (Figure 5.6, Appendix 5.2). Similar observations were made in the study of the utilization of the woodlands close to Maseyu village, Tanzania (see Nduwamungu & Malimbwi, 1997) in which the low levels of mature *Pterocarpus angolensis* were observed due to past harvesting of the species for window frames and doors (Luoga *et al*., 2002). Schwartz *et al*. (2002) refer to such a situation as an economic extinction of the species. The economic extinction allows the species to persist at low densities which make their exploitation costly. This economic extinction of shade intolerant species if not checked, can result in non availability of merchantable stems of species being exploited, although the species has ample regeneration. Many other studies in the Miombo ecoregion have shown the impact of species preference and utilization on the overall population structure: Malawi (Makungwa & Kayambazinthu, 1999), Mozambique (Grundy & Cruz, 2001), Zimbabwe (Mudekwe, 2006) and Tanzania (Hall & Rodgers, 1986). These studies have revealed that the commonly harvested species namely *Pterocarpus angolensis, Erythrophleum africanum, Brachystegia boehmii* and *Afzelia quanzensis* exhibited unstable population structures with reduction in absolute densities, species richness and also missing size classes. Shackleton *et al.,* (2005) also reported low densities of mature stems for *Diospyros mespiliformis, Philenoptera violacea* and *Ziziphus mucronata* in the South African semiarid lowveld where such species were being bark harvested for medicinal purposes. The unstable population size class profile tends to decrease the likelihood of conspecific replacement and increases the risk of collapse of the natural successional pathway (Hall & Rodgers, 1986; McKenzie, 1988). The collapse of the natural successional pathway a is a disaster at population level as this has the ability to result in total collapse of the population if such a situation persists for a long time as there would be no replacement of individual plants as they die. Shackleton *et al.,* (2005) indicated that there is actually a growing evidence and concern that levels of extraction are unsustainable for many species areas in the South African lowveld. Furthermore, Shackleton *et al.,* (2005) emphasized that the major concern for designing sustainable harvesting levels is lack of research and guidelines on possible harvestable levels and growth rates of the species being harvested.

5.5.3 Differences between the behaviour of species during woodland recovery

In both disturbance regimes (slash & burn and charcoal burning), the differences in the rate of growth among species became apparent as years proceed. *Julbernadia paniculata*, *Brachystegia floribunda*, *Brachystegia longifolia*, *Isoberlinia angolensis* and *Albizia antunesiana* appear to be the fastest growing species at every stage of the woodland recovery under either of the two disturbances. However, the rate of growth of these species differs from one disturbance category to another. Stems of the same species grow faster in the abandoned charcoal regrowth stands than in the slash & burn regrowth stands. One causal factor that may contribute to this is that the areas that were previously under agriculture tended to have higher fuel levels of grass and other herb layers that pile up. The quantities of grass are much higher in areas previously under agriculture (Boaler & Sciwale, 1966) than in areas that were previously under charcoal production. As such, the areas previously under agriculture will have higher incidences of fire thus affecting the development of the species since most of them are fire hardy species (see Trapnell, 1959; see also 5.5.1).

The availability and development of *Julbernadia paniculata*, *Brachystegia floribunda*, *Brachystegia longifolia*, *Isoberlinia angolensis* and *Albizia antunesiana* throughout the Miombo woodland recovery process confirms the observation by Fanshawe (1971) that Miombo woodland regrows virtually unchanged following clearing Miombo regrows unchanged because its regeneration consists of stumps/root suckers and recruitment from old stunted seedlings present in the grass layer at the time of clearing (Chidumayo & Frost, 1996). However, the current observation is contrary to Boaler and Sciwale (1966)'s observation that the canopy dominant trees of the mature Miombo are not conspicuous in the earlier stages of the regrowth because at this time they grow more slowly than the pioneer species. However, the rates of growth vary among species. Some species such as *Brachystegia spiciformis*, and *Julbernadia globiflora* are extremely slow in growth (see Chidumayo, 1992) while other species e.g. *Isoberlinia angolensis, Brachystegia longifolia, Albizia antunesiana* have been observed to be faster in growth as they have higher frequencies in higher size classes compared to other species. Slow shoot growth has been attributed to recurrent annual shoot die-back (Chidumayo, 1991).

5.6 Conclusion

The absence of stems in most of the diameter classes for species which were under single tree harvesting should be a reason for concern and has management implications. This is because this has the ability to decrease the likelihood of conspecific replacement and to increase the risk of collapse of the natural successional pathway if regeneration is not perpetuated and enhanced. Single tree selection harvesting may therefore be a disaster for individual species populations. There is a need to manage the harvesting of these species to perpetuate and enhance regeneration. But if the Miombo woodland has to be managed sustainably, the following questions have to be taken into consideration: i) What is good for Miombo woodland? ii) Is it selective tree harvesting of timber species that visually looks good but allows very little to no regeneration of the canopy tree species under the remaining canopy? ii) Or is it slash & burn agriculture and charcoal production that visually look bad but results in maximum light intensities, reduced competition for moisture and nutrients, etc on stumps/root suckers and recruitments. This study has certainly shown the dangers of single tree selection at population level. Additionally, the study has also shown that the key Miombo woodland species usually have ample regeneration under the tree canopy that tends to be enhanced on exposure to maximum light intensities (see also Geldenhuys, 2005) and reduced competition for moisture and nutrients. Therefore, if their population levels are to be managed sustainably, there is need to open up the woodland as they are being harvested so that the regeneration can be enhanced. In general, the study has shown that charcoal production and slash & burn agriculture are necessary components to which the individual key Miombo species have become adapted. However, there is also need to determine the influence of the size of the cleared plot size on the regeneration of these species and subsequently recovery of the woodland. There is also need to determine the influence of cultivation period and also the type of cultivation on the regeneration of these species.

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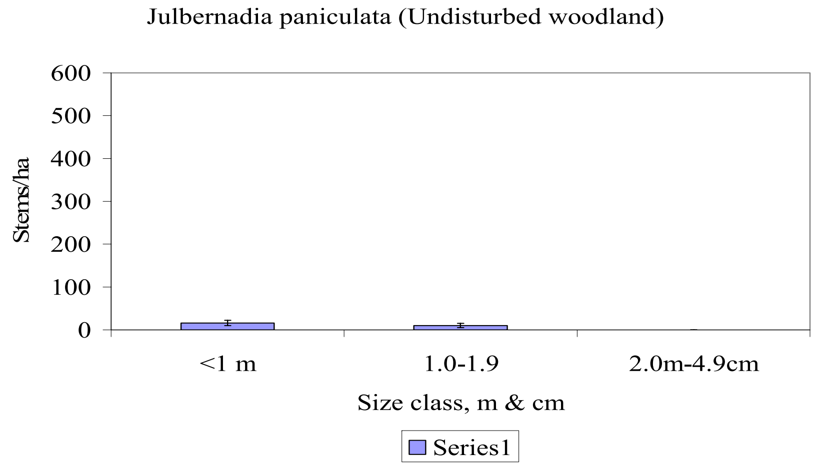
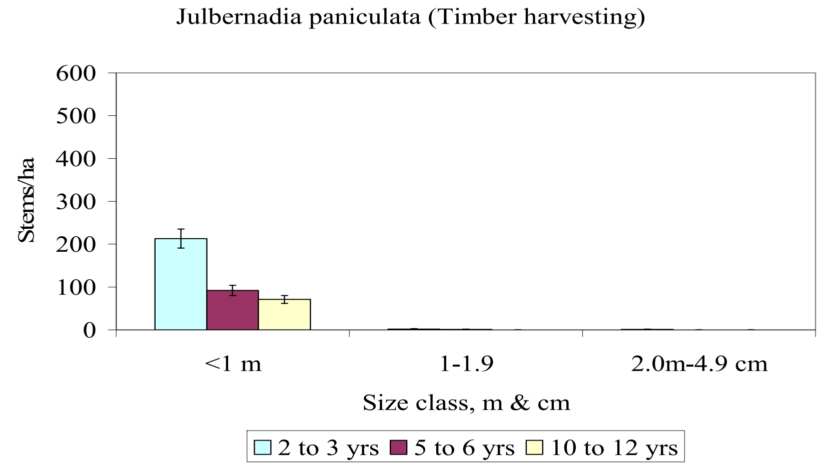
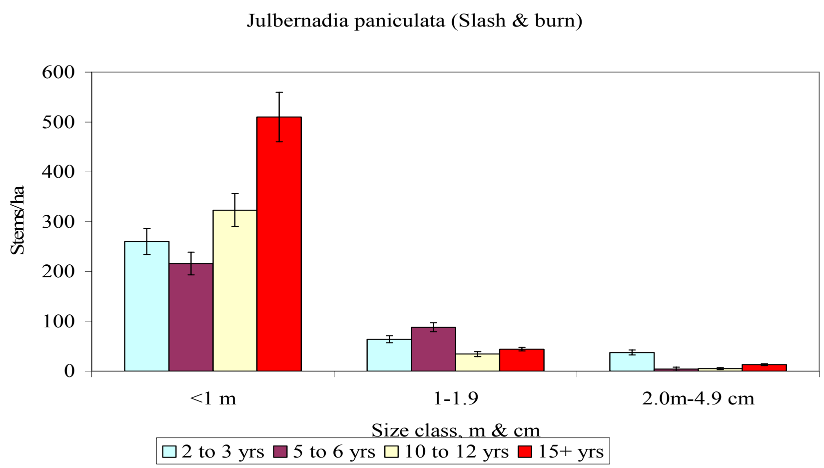
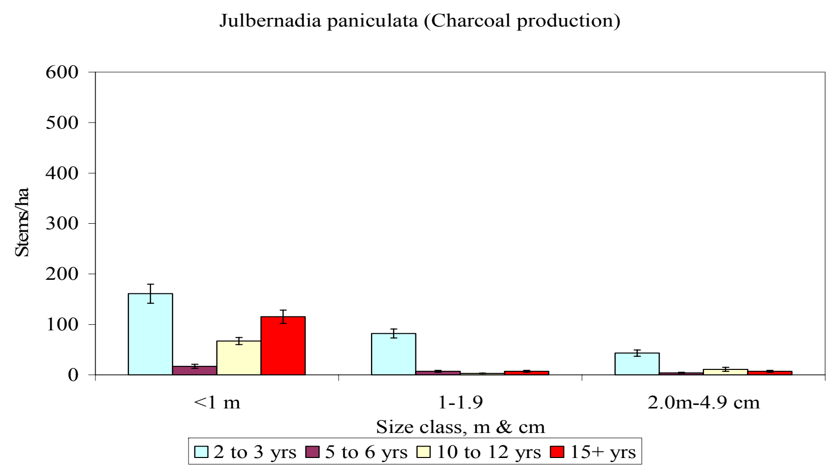
Appendix 5.1 Stem size distribution of selected individual species in stands previously under different disturbance categories and undisturbed woodland stands (<5 cm DBH) (the Y-axis scale of all diagrams within a species is kept the same, but may differ between species).









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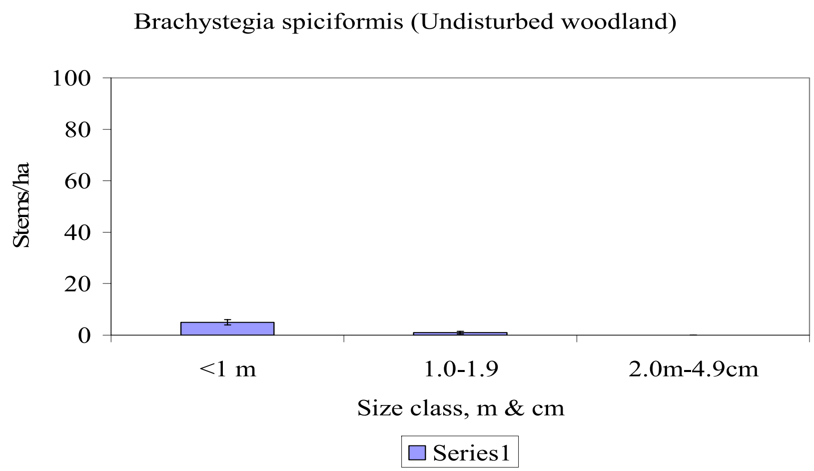

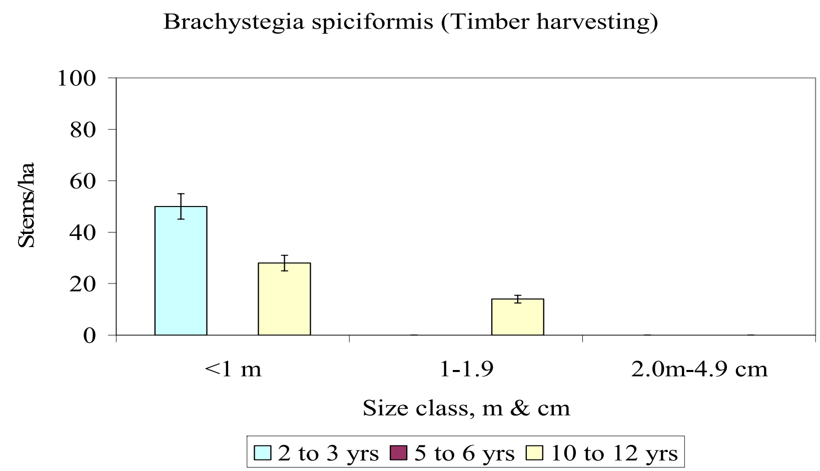

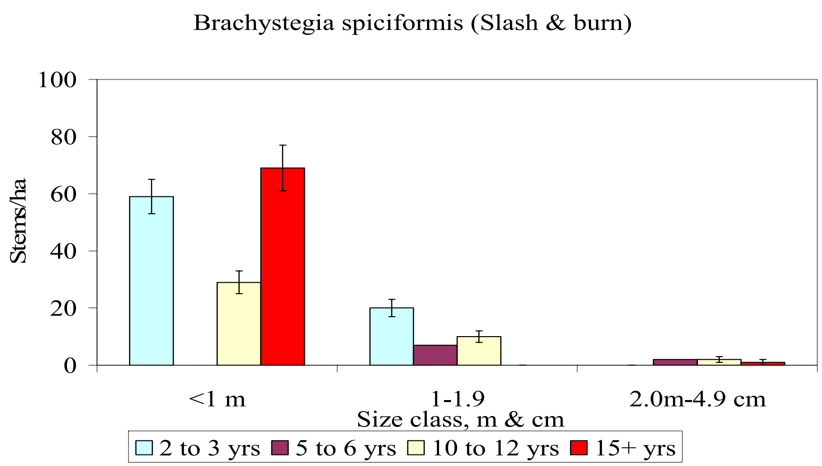

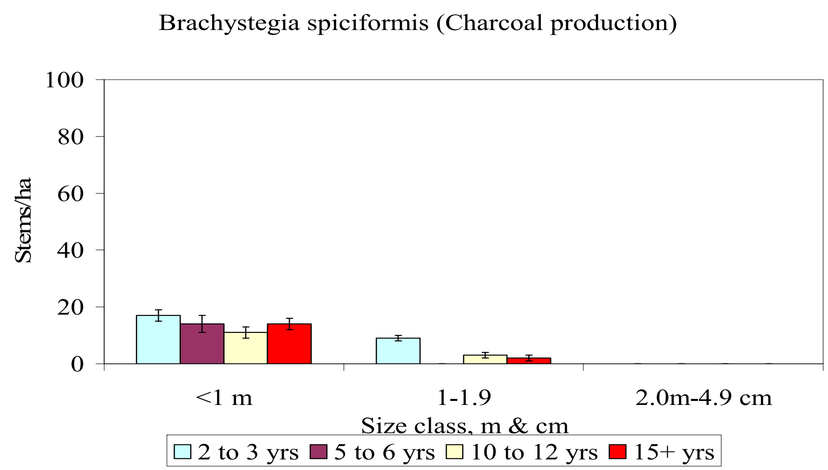

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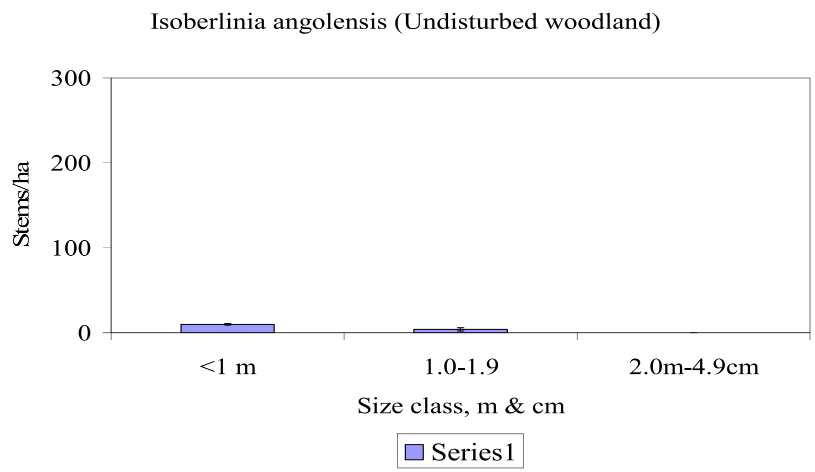

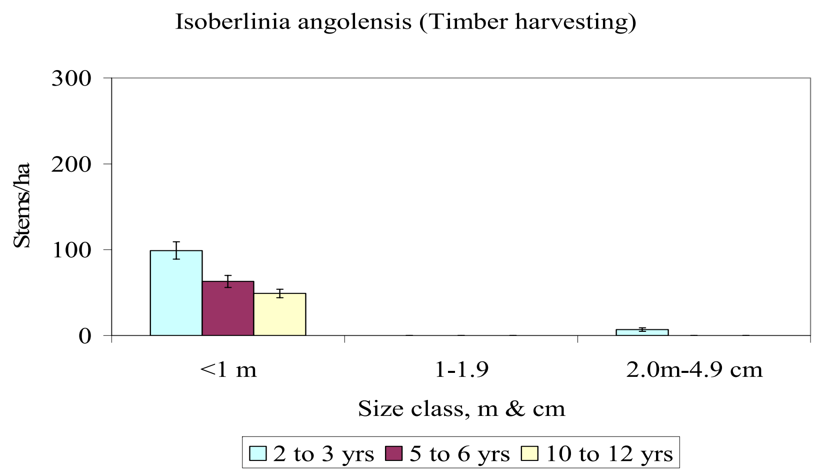

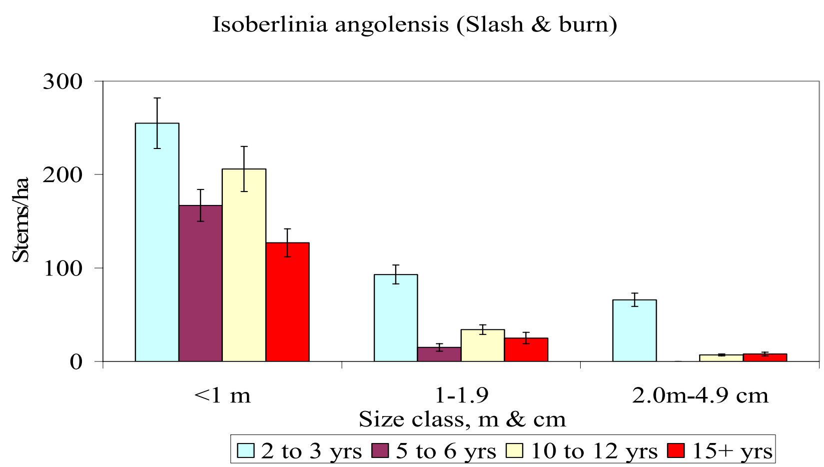

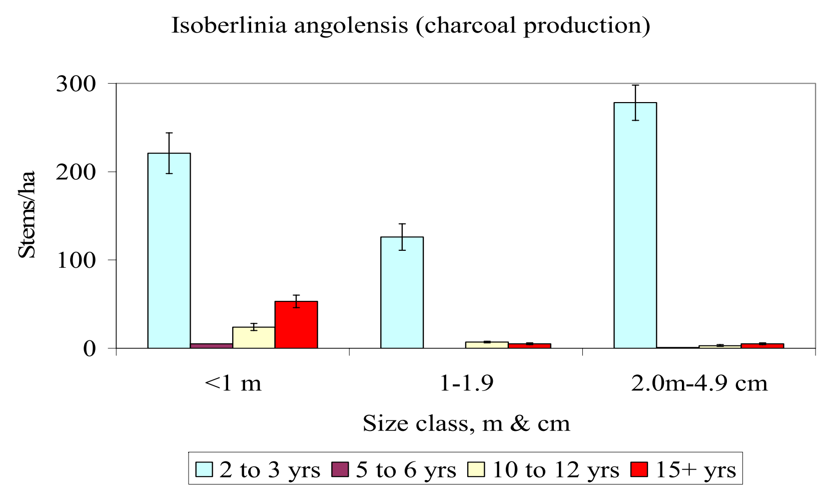

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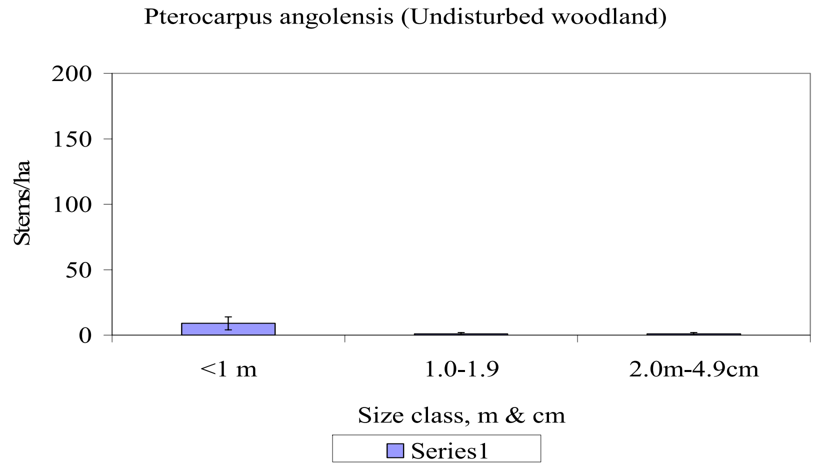

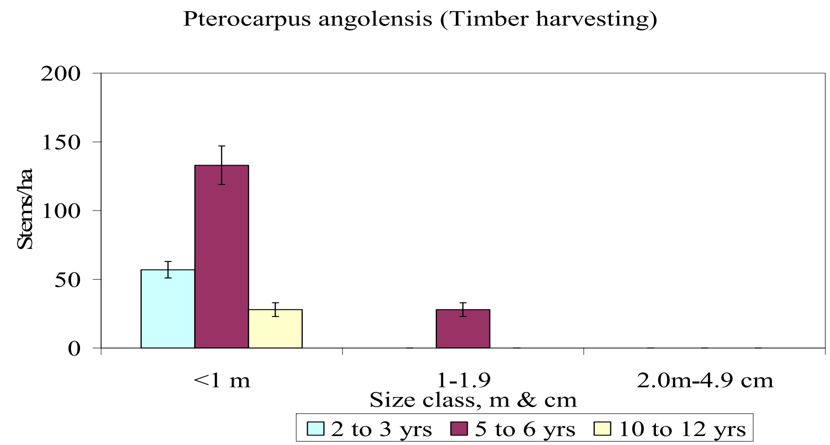

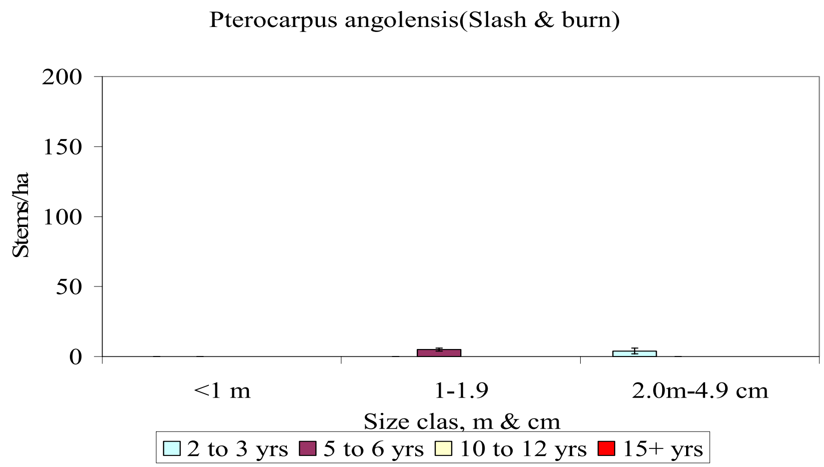

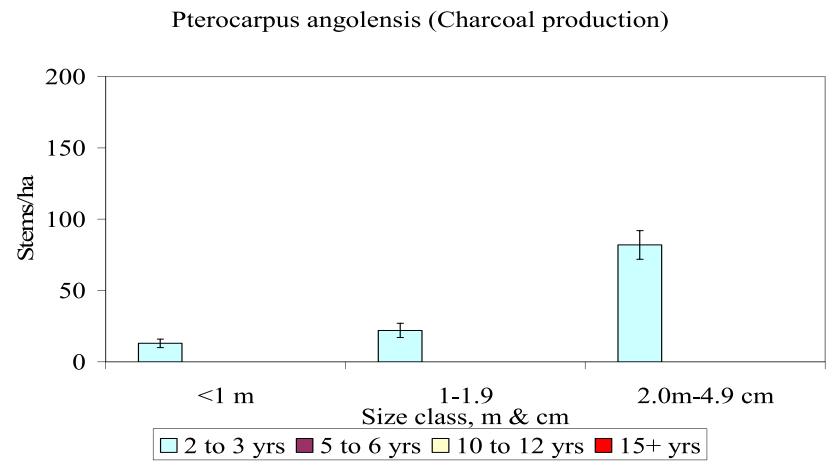

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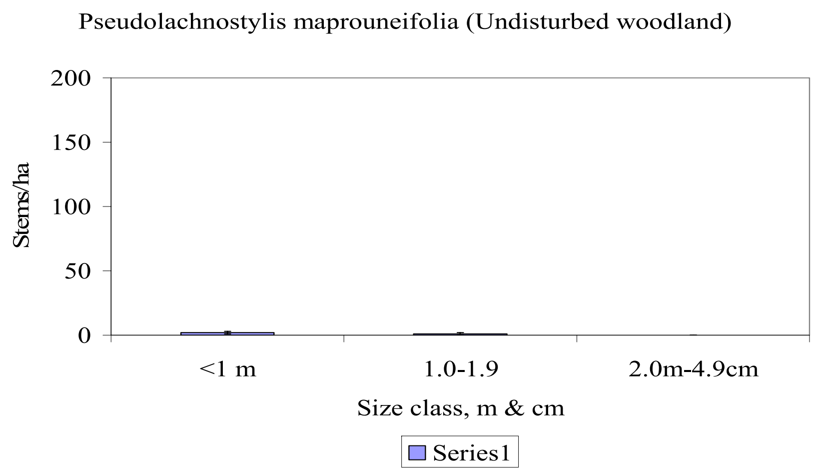

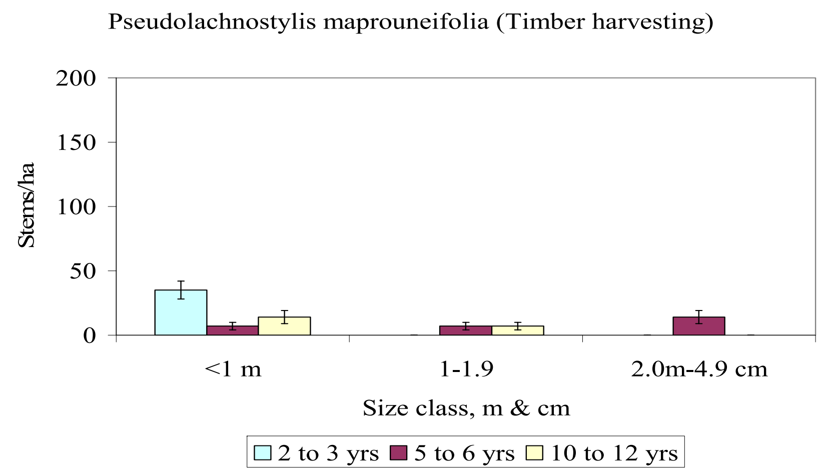

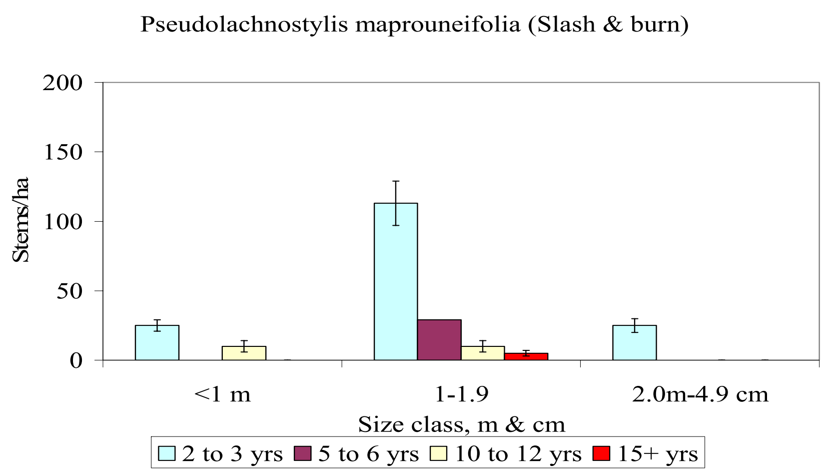

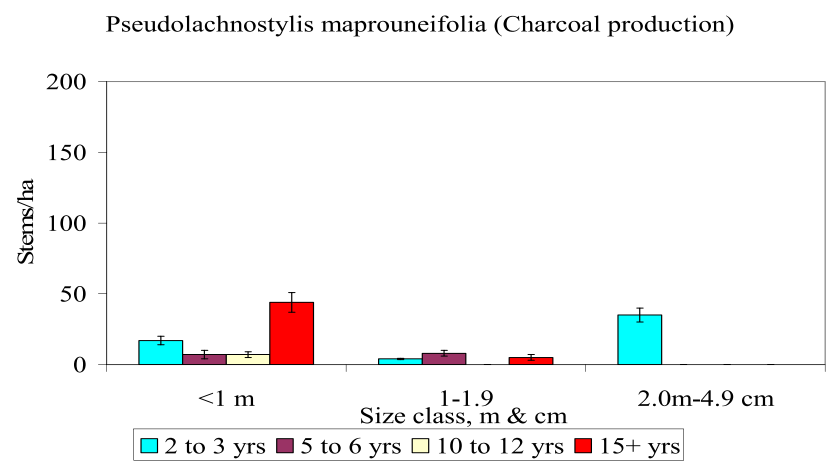

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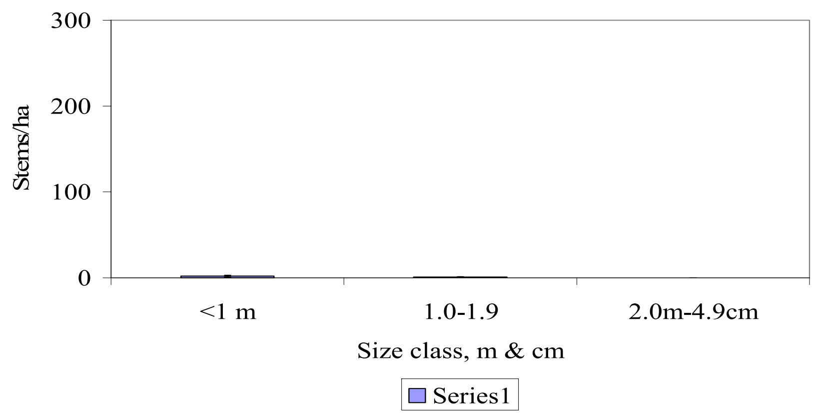
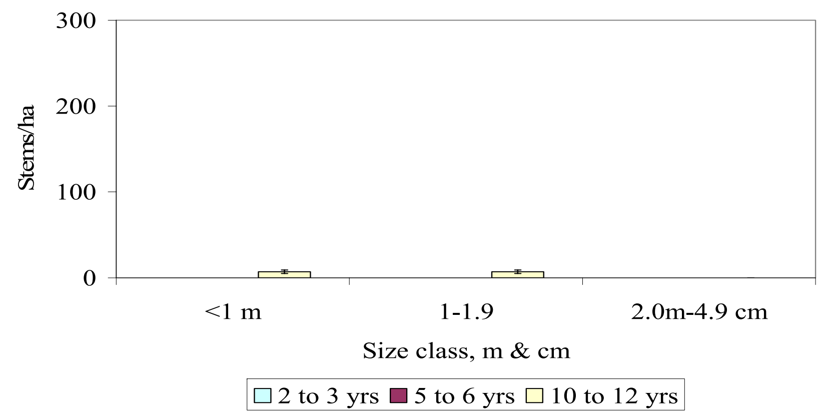
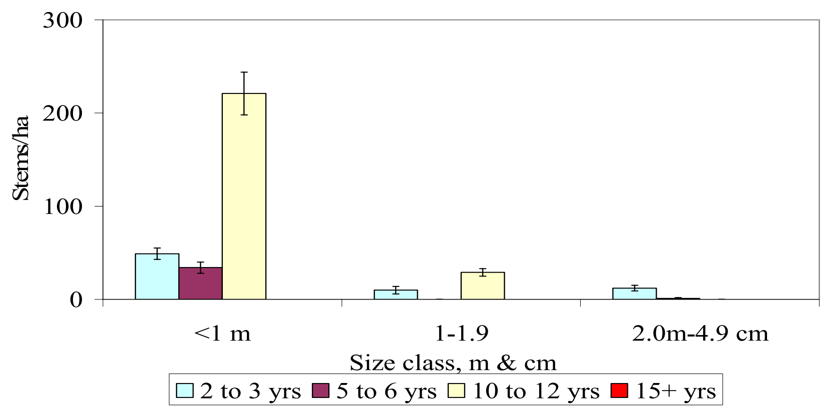
Parinari curatellifolia (Undisturbed woodland)



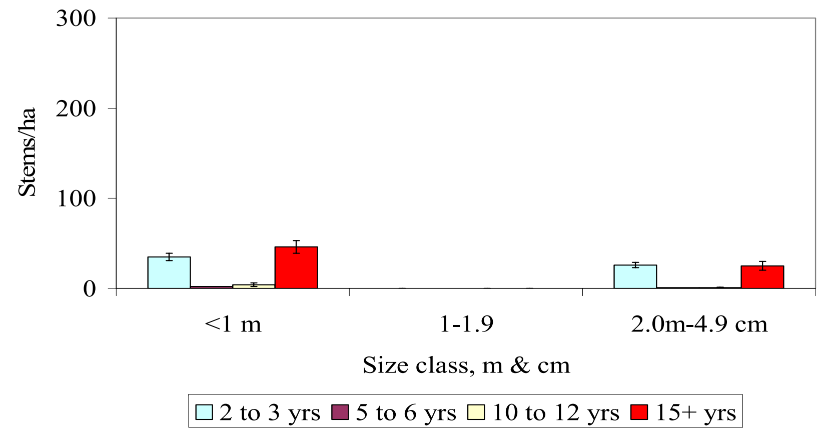
Parinari curatellifolia (Timber harvesting)



Parinari curatellifolia (Slash & burn)



Parinari curatellifolia (Charcoal production)



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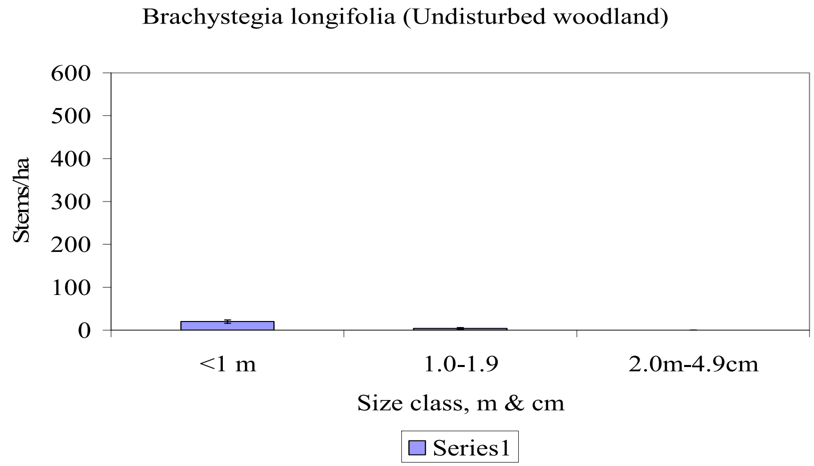

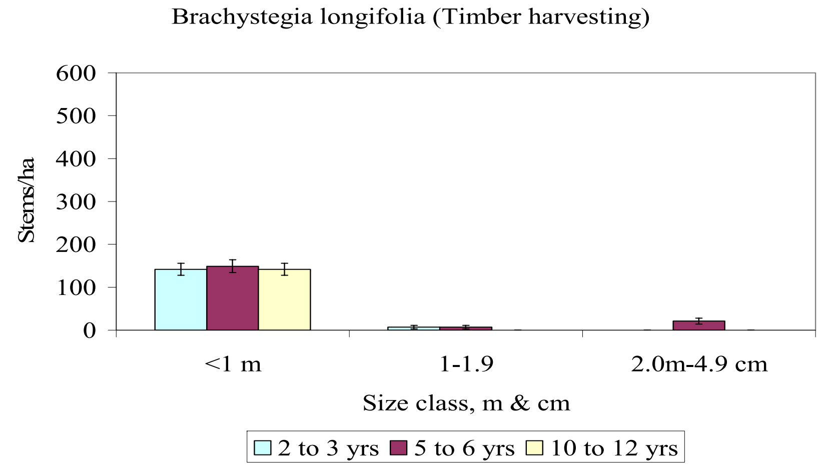

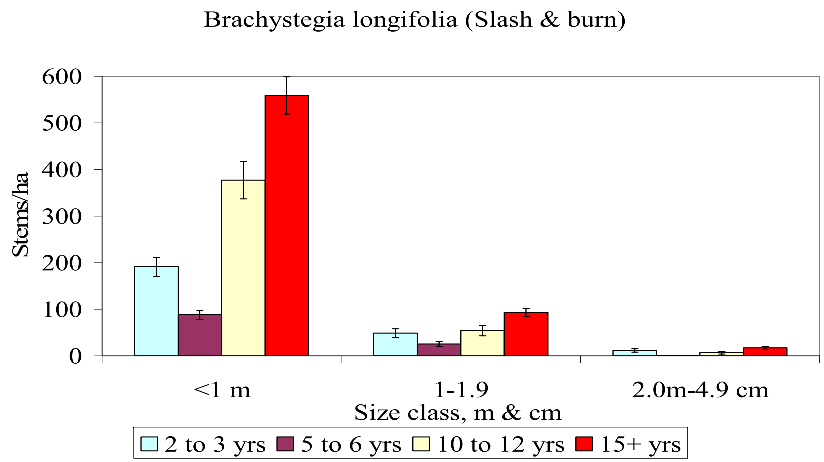

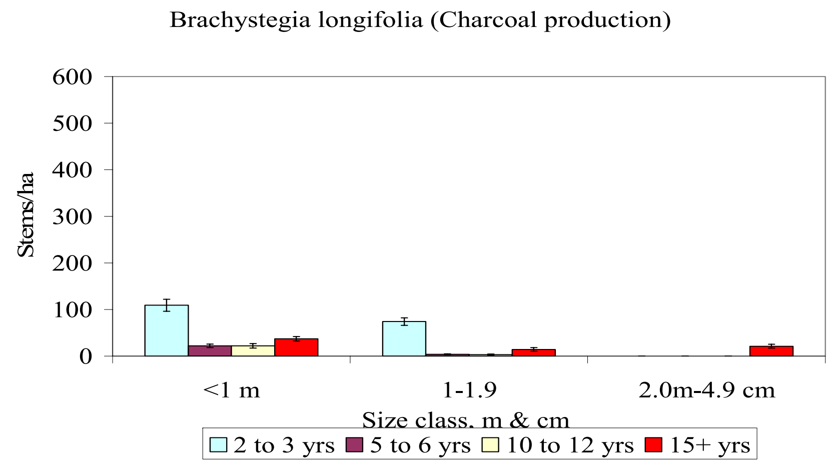

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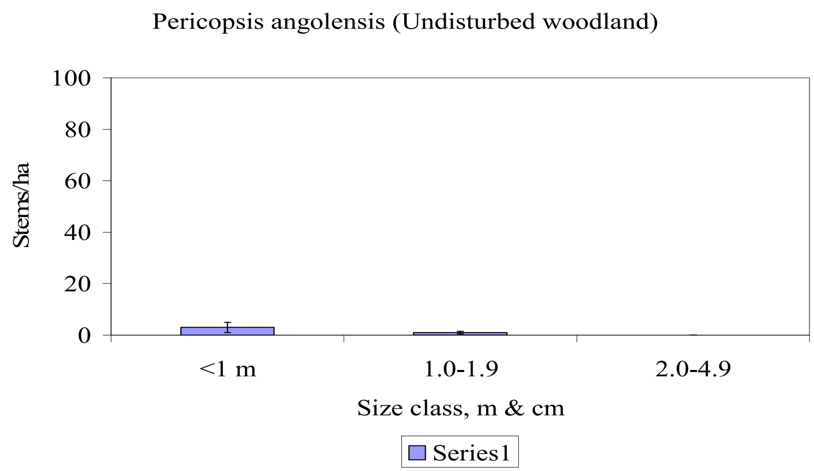
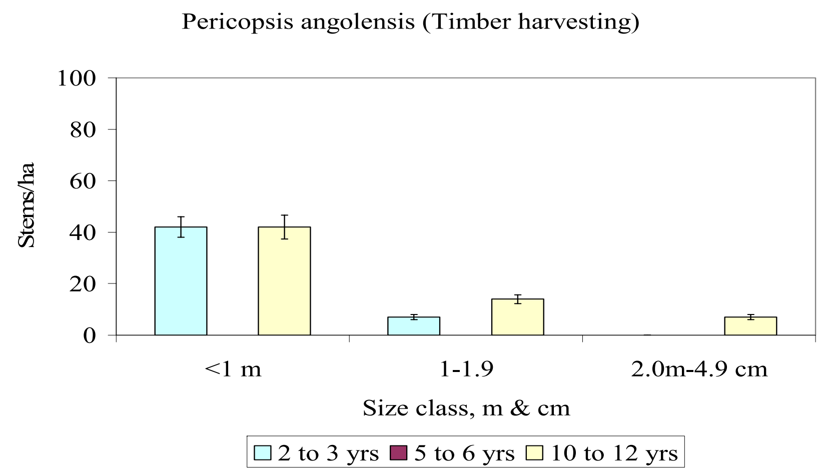
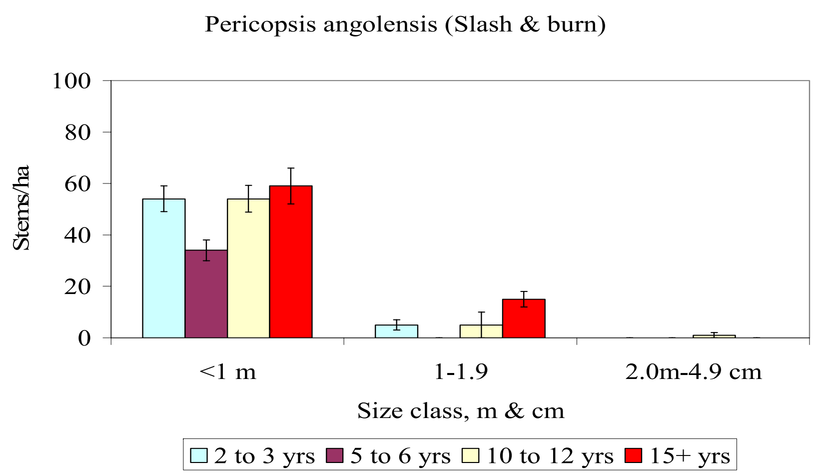
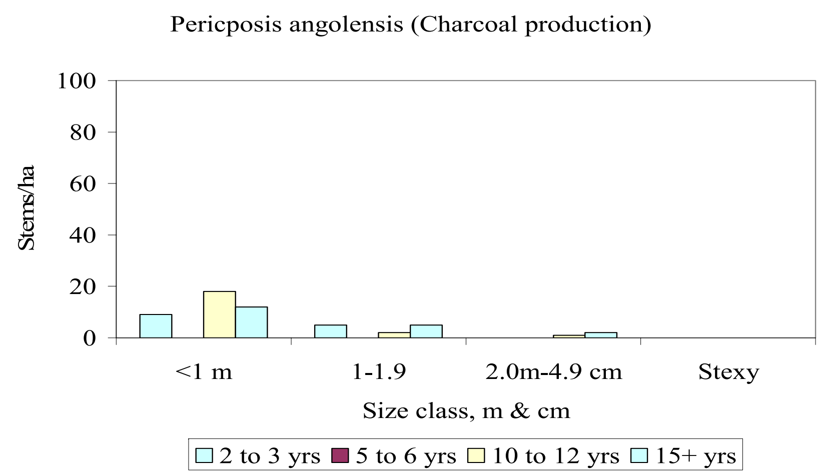
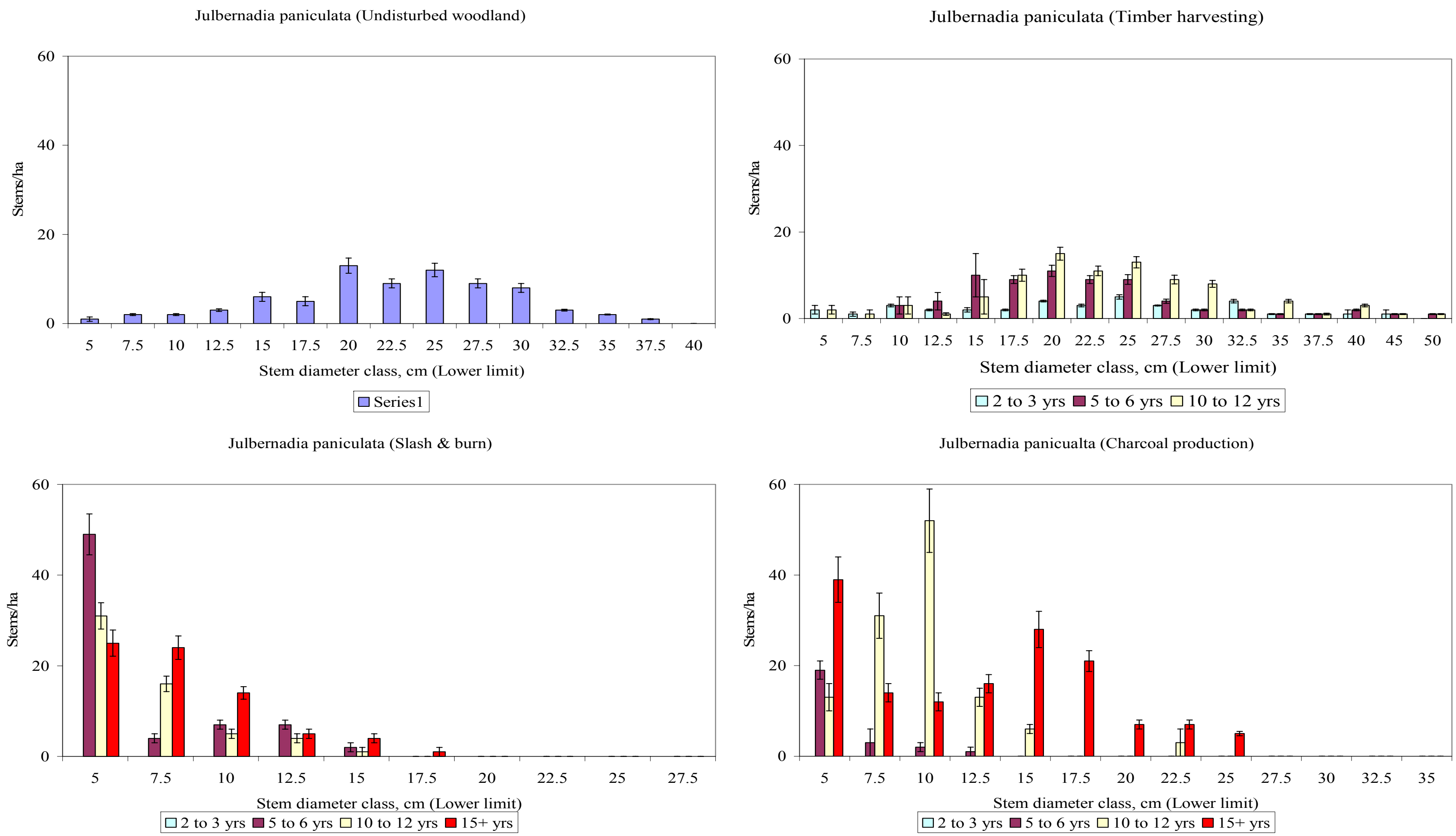








Appendix 5.2 Stem diameter distribution of the selected species in stands previously under different disturbance categories and undisturbed woodland stands (stems ≥5 cm DBH) (the Y-axis scale of all diagrams within a species is kept the same, but may differ between species)



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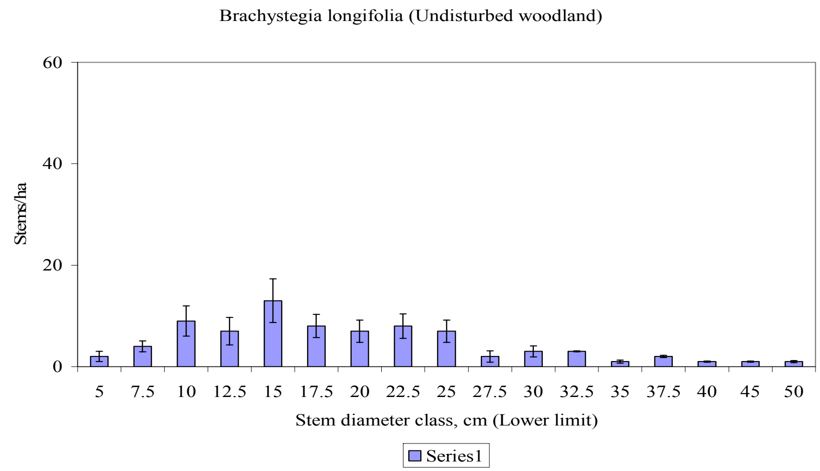

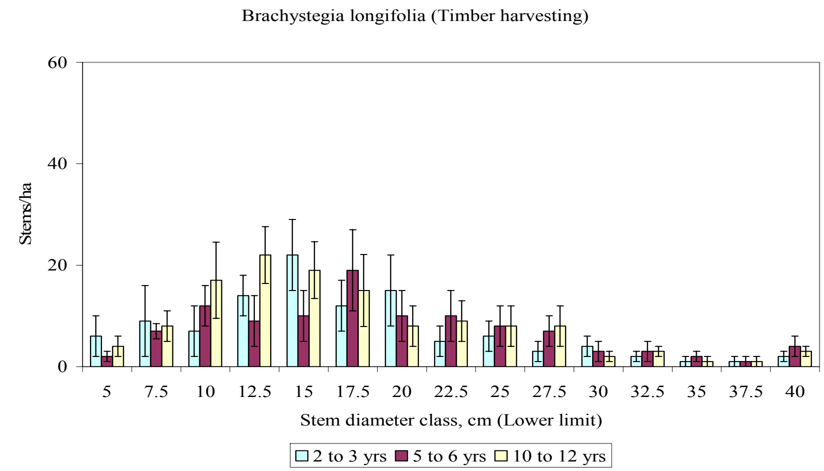

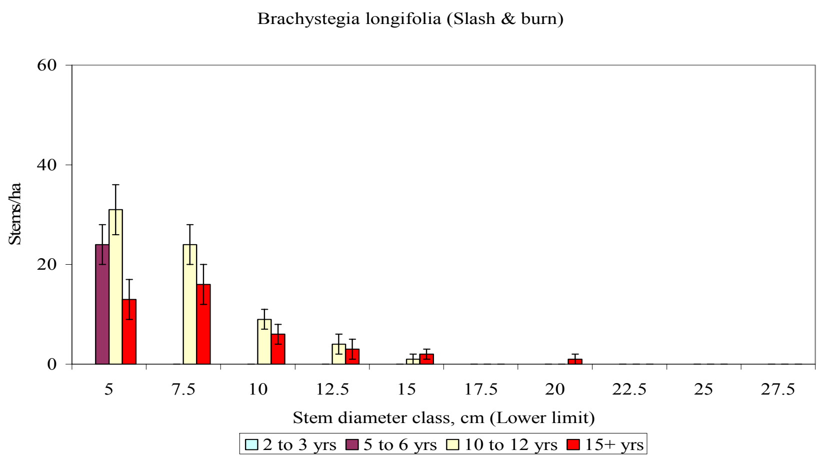

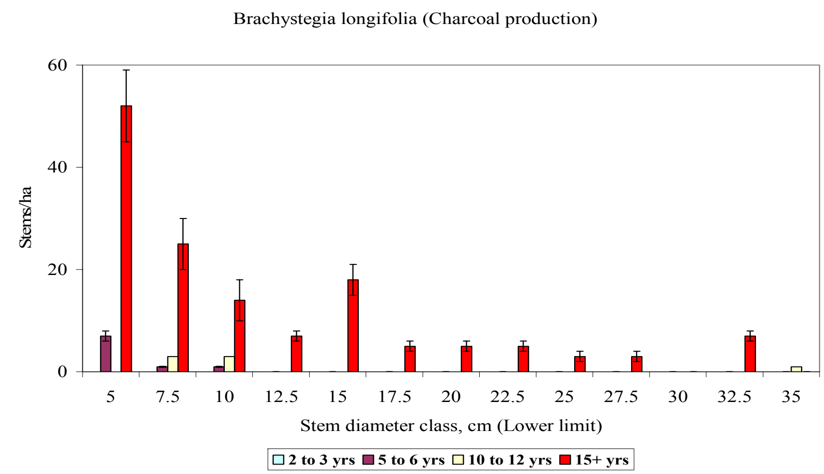

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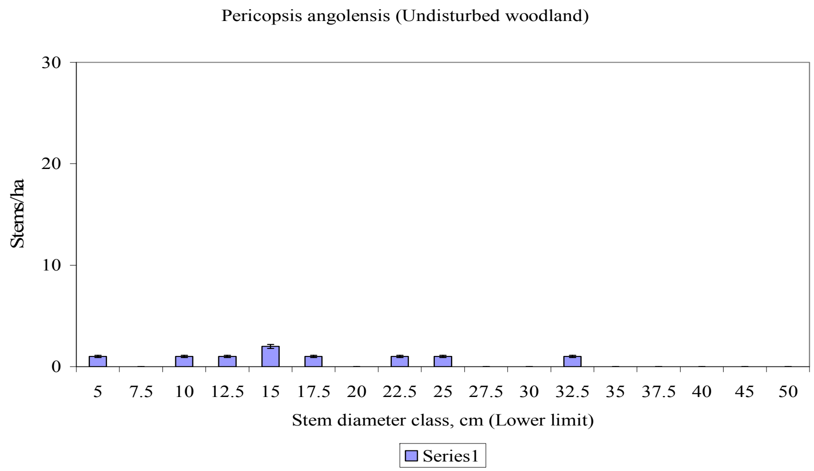

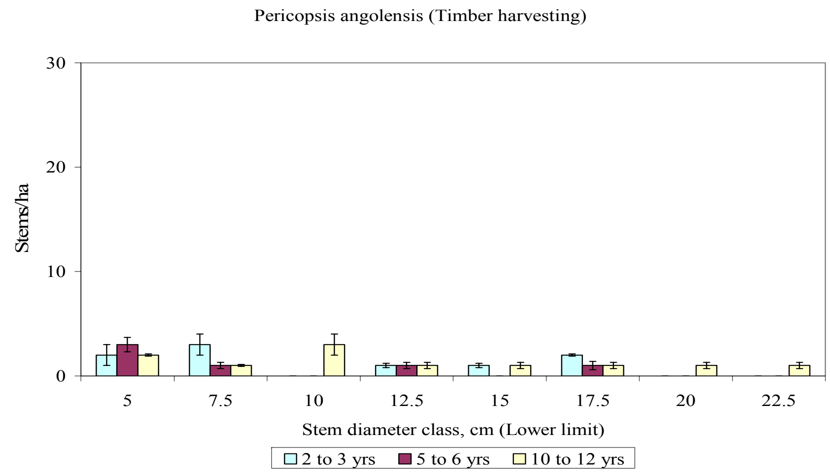

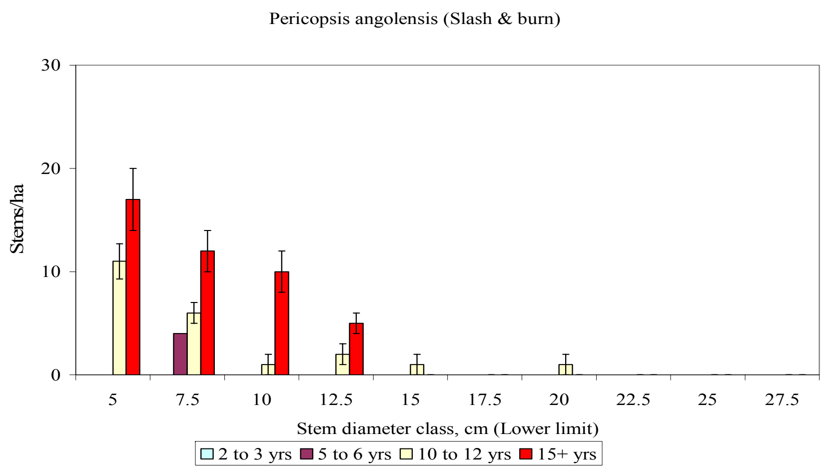

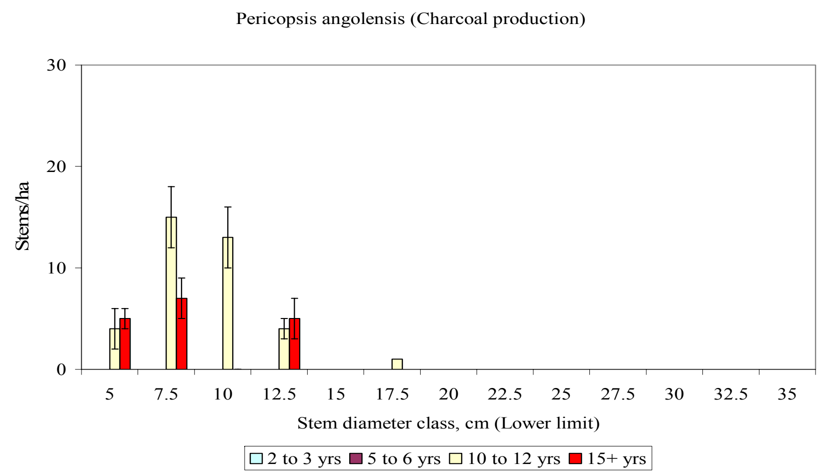

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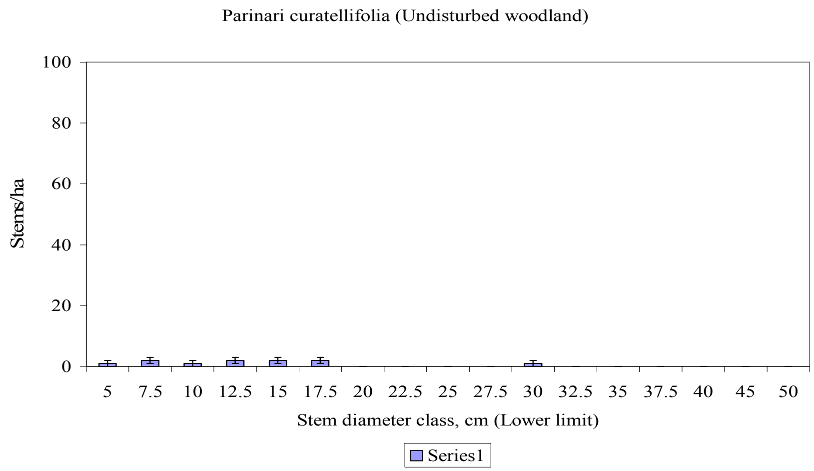

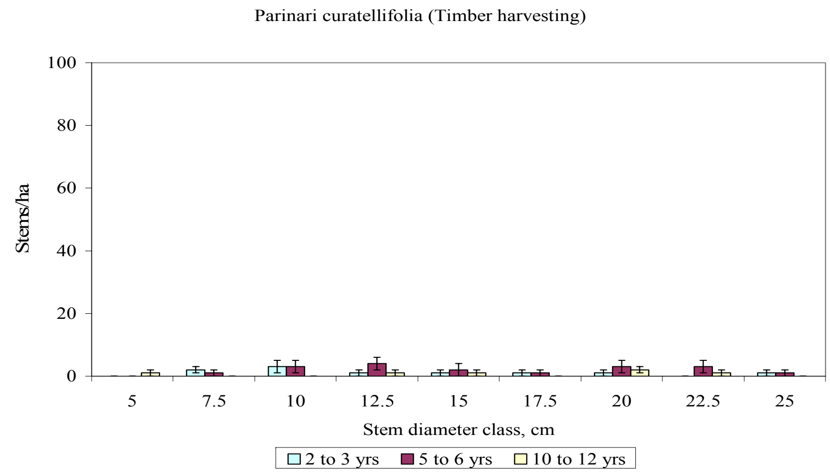

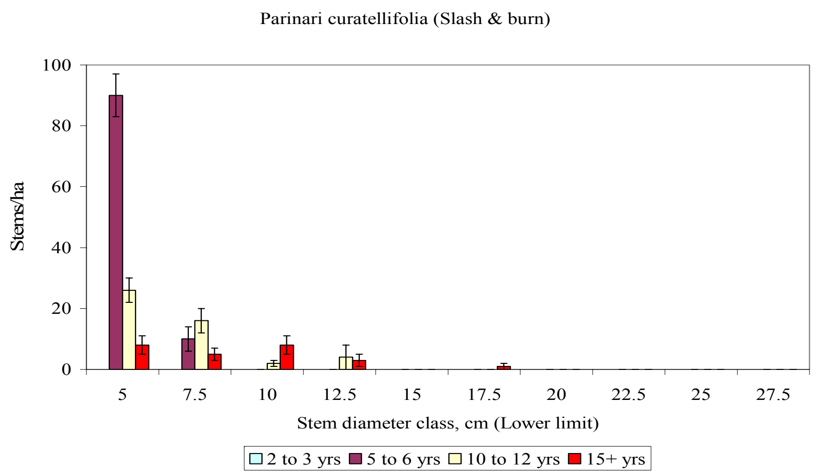

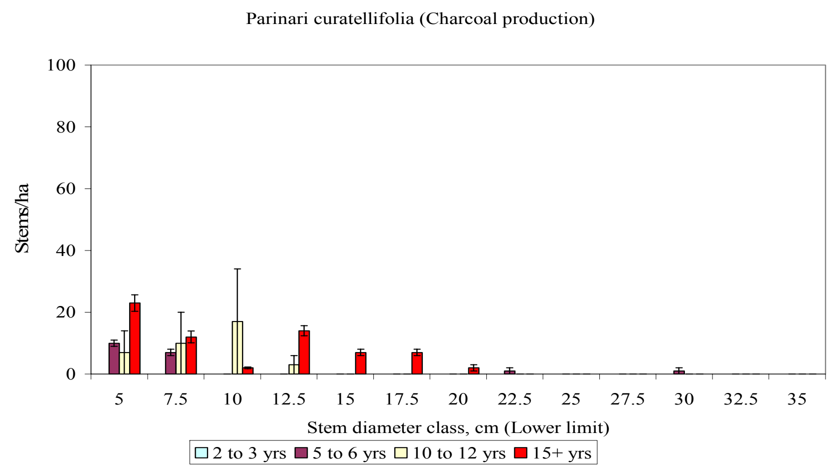

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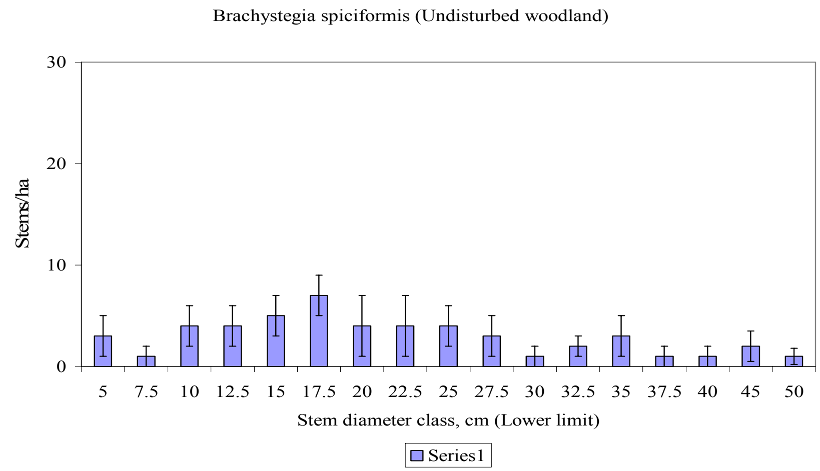

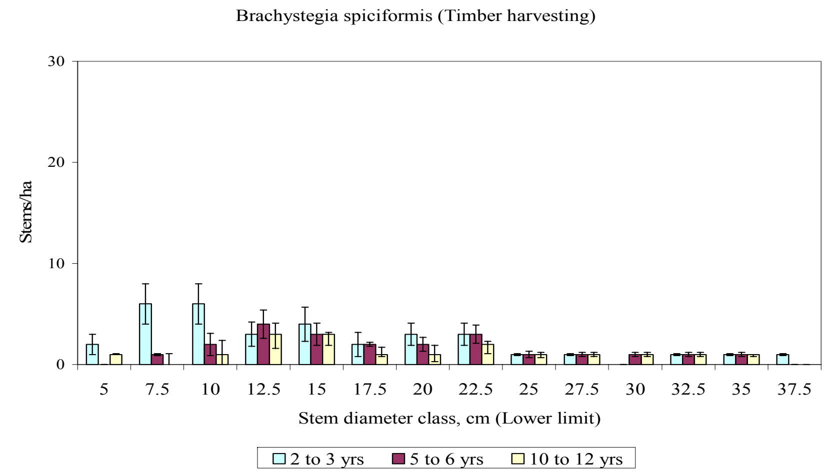

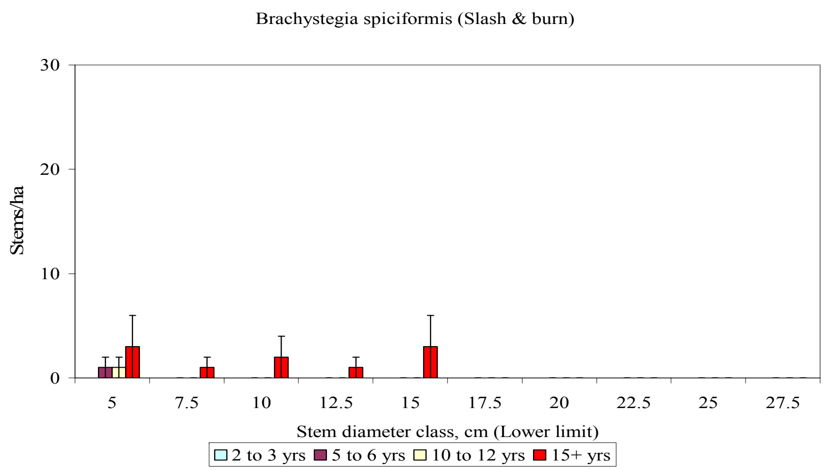

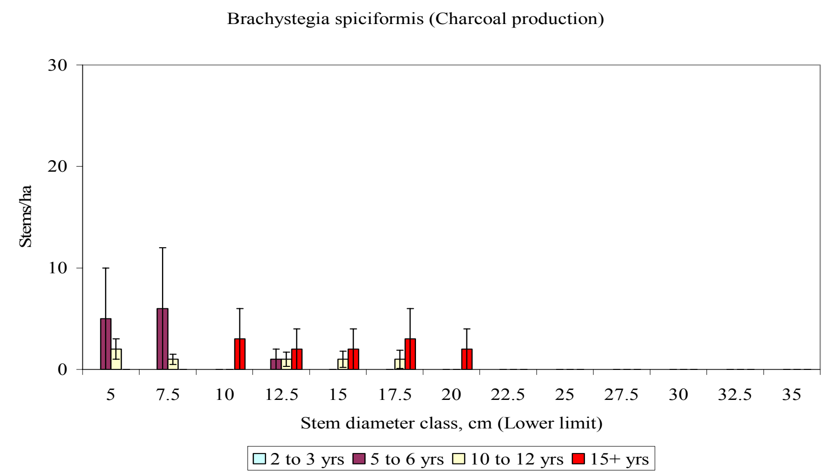

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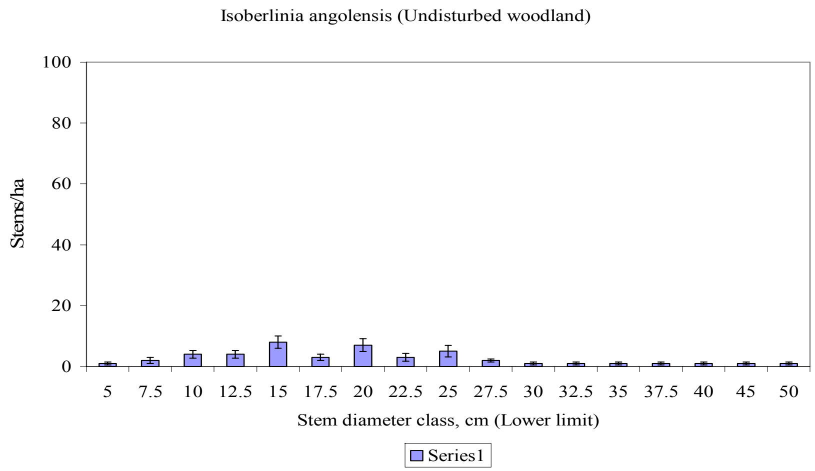

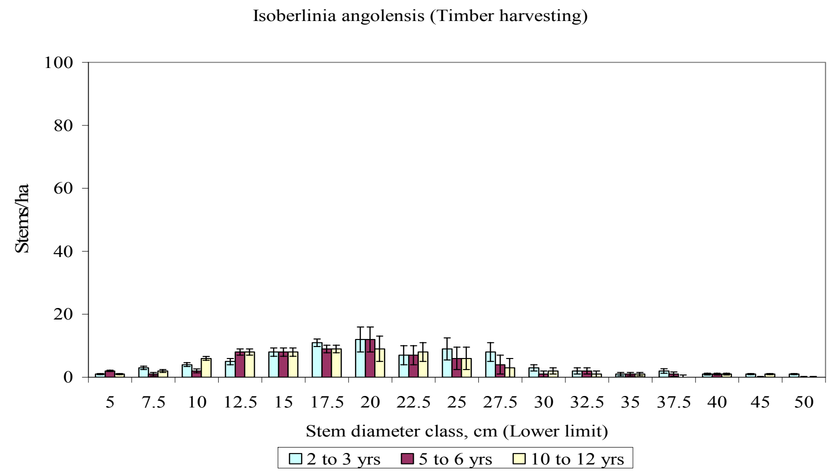

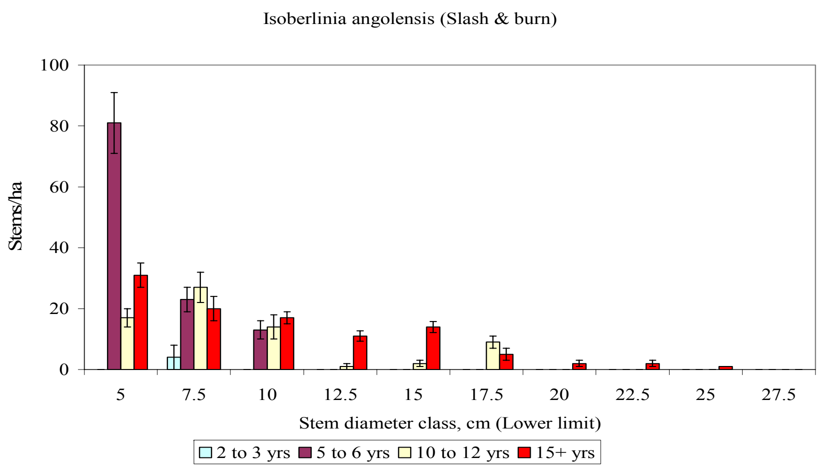

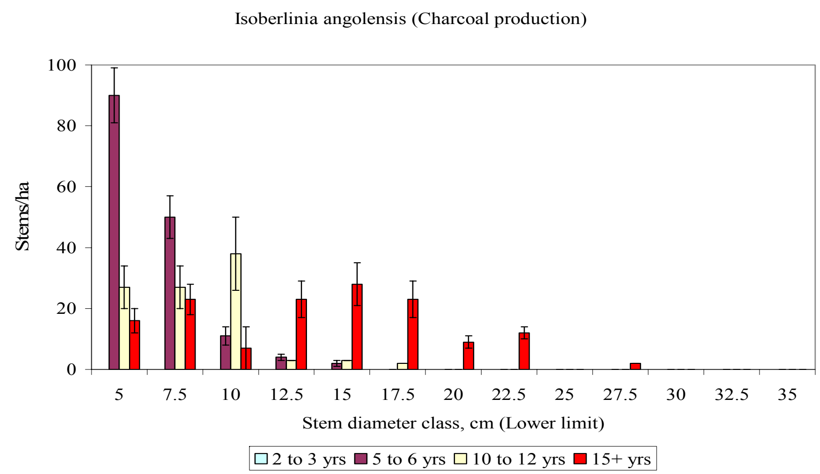

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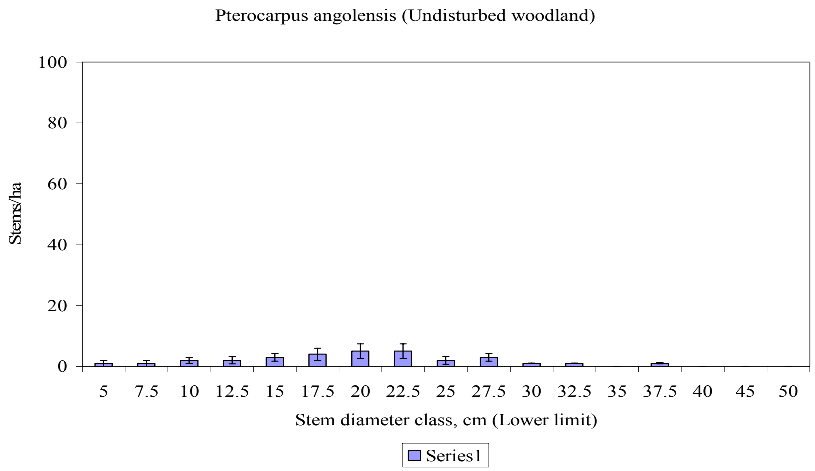

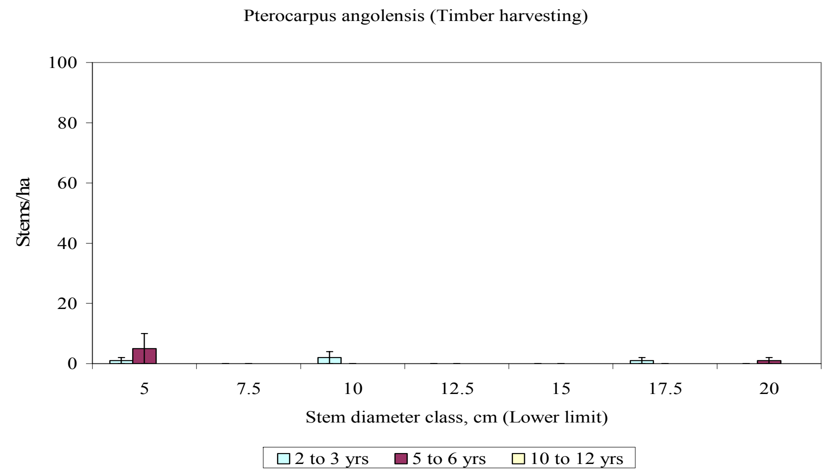

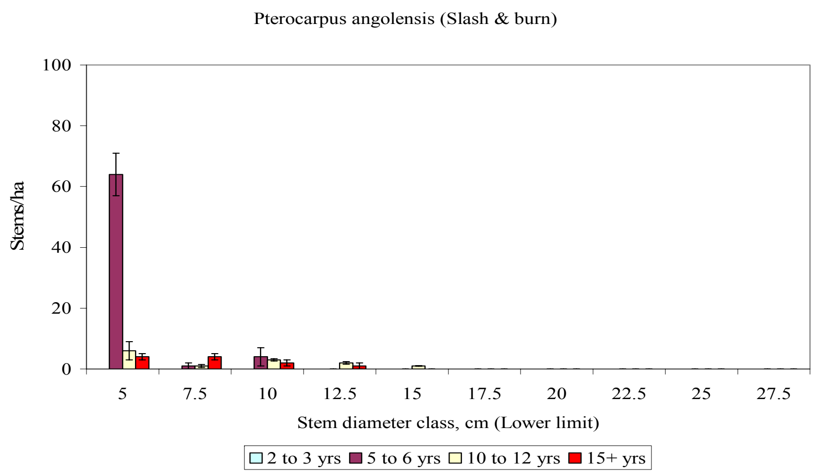

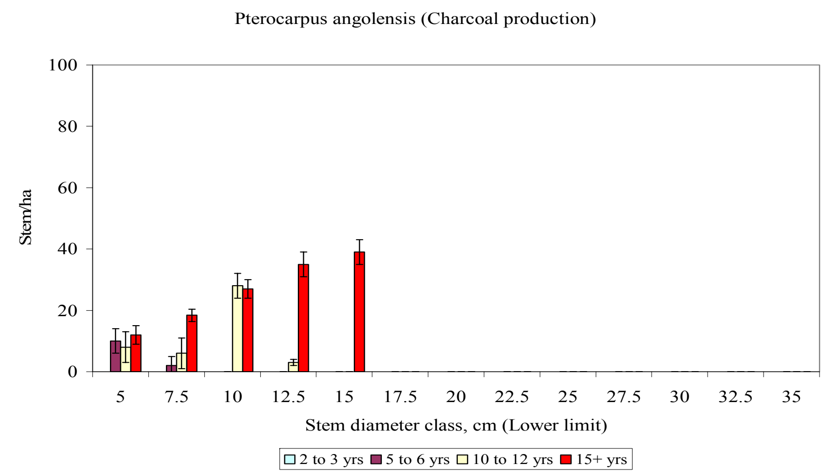

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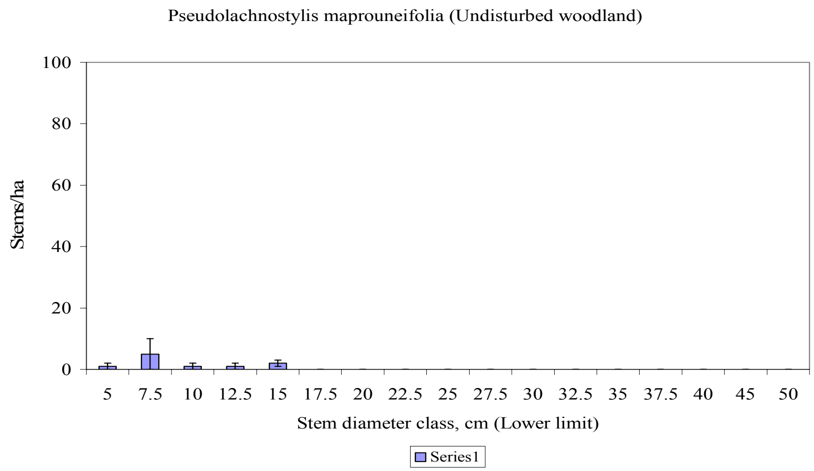

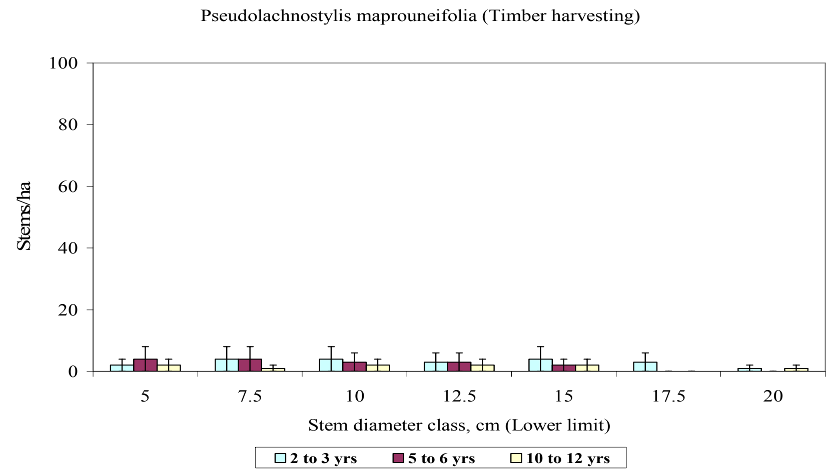

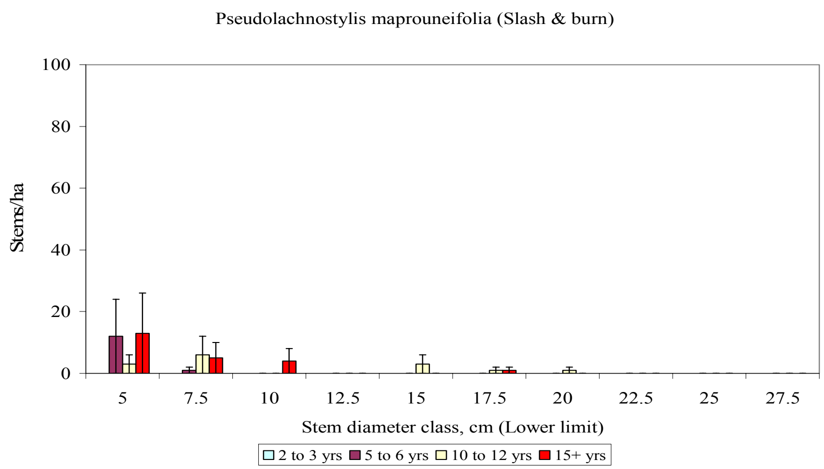

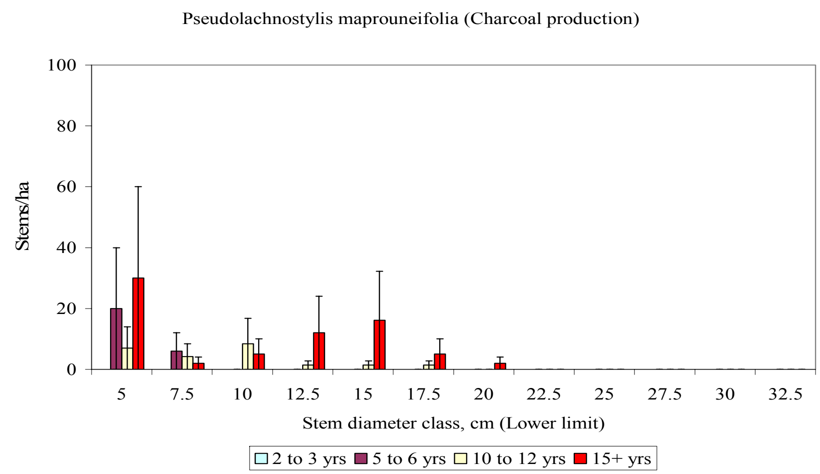

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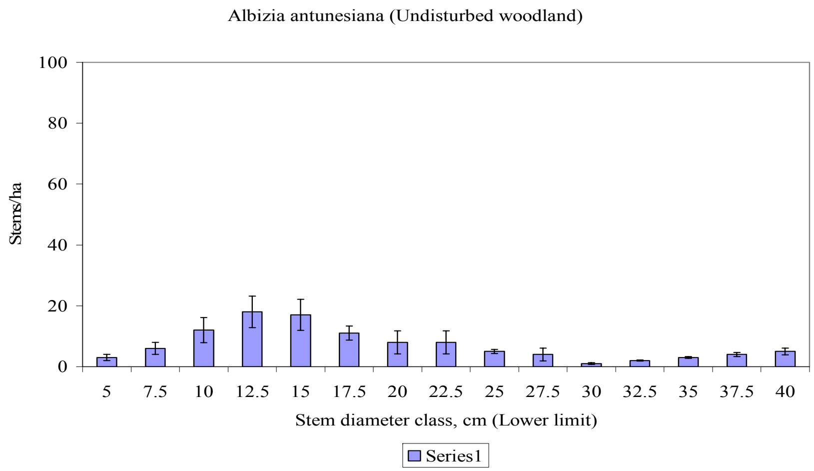

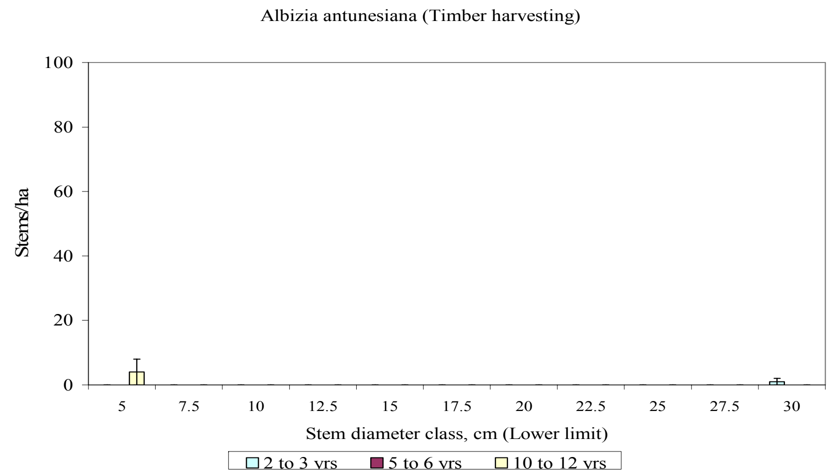

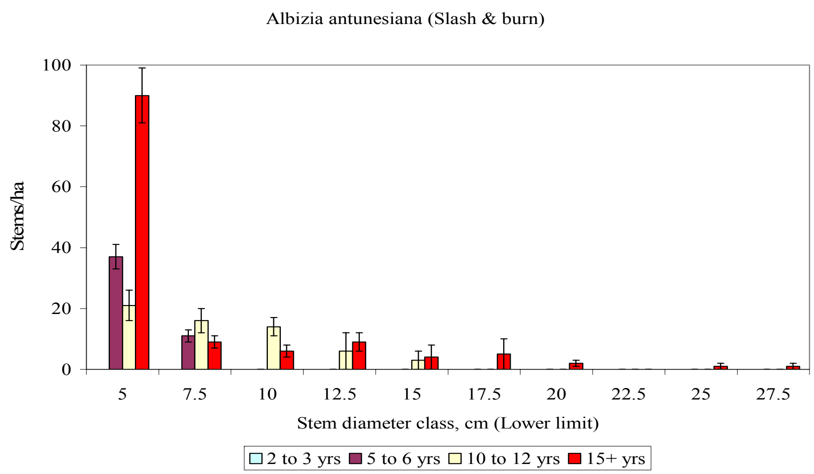

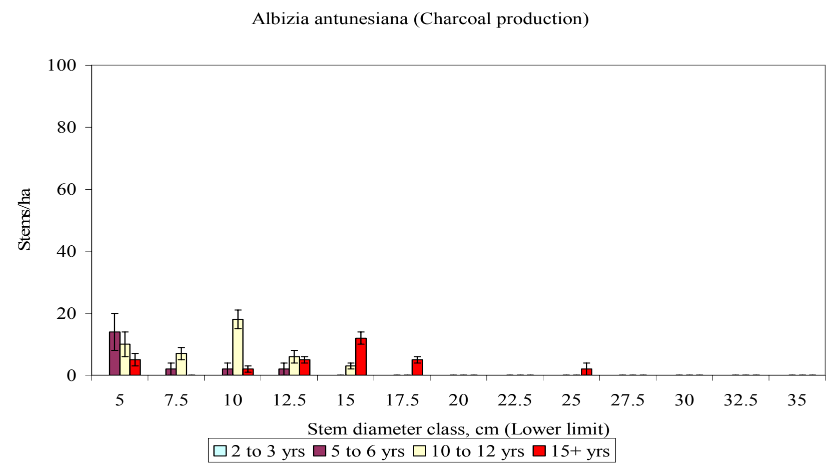

6 AGE AND GROWTH RATE DETERMINATION USING GROWTH RINGS OF SELECTED MIOMBO WOODLAND SPECIES

Abstract

The field of dendrochronology has not been widely applied in tropical species because scientists generally perceive that such species rarely produce distinct growth rings. However, evidence shows that even the tropics experiences distinct seasonality in precipitation and temperatures. The absence of this knowledge has made it difficult for forest managers to come up with effective cutting rotations and sound management prescriptions. This study was undertaken in order to determine if the key Miombo species produce distinct growth rings and to determine the relationship between the number of growth rings and age of the tree and stem diameter. The results showed a high correlation between number of growth rings and stand age for both charcoal regrowth ($P< 0.001$, $r=0.9246$) and slash & burn ($P< 0.001$, $r=0.9019$) regrowth stands. Additionally, the study has revealed high mean annual ring width values ranging from 4.4 to 5.6 mm in both charcoal and slash & burn regrowth stands. The pattern of ring development per year and the mean annual ring width values provide a basis for the use of ring counts in determining the age of Miombo regrowth stands and predicting the merchantable age for key Miombo woodland species. The results can therefore be used in planning the cutting cycles in Miombo woodlands. However, the phenomenon of missing growth rings suggests that the influence of environment in the use of growth rings in age determination need to be considered in areas that experience droughts. This requires an understanding of the relationship between growth ring counts and drought frequencies over an area.

Keywords: Growth rates, growth rings, slope, diameter at breast height and cutting rotations

6.1 Introduction

Can growth rings of trees in Miombo woodlands in the tropics be used to determine their age and hence growth rates? Many people would say that is not possible because scientists generally perceive that tropical species rarely produce anatomically distinct growth rings each year (see Celander, 1983; Lilly, 1977) as the tropics do not show a strong seasonality in temperature and day length. However, some tree stems especially in regrowth stands, do show relatively distinct rings. Dendrochronology or tree-dating has been widely applied to climatic, ecological and forestry problems in the temperate latitudes where strong seasonality in temperature and day length induce dormancy and annual growth ring formation in many trees (Stahle *et al*.1999). Tree-dating has been applied in few studies namely *Podocarpus falcatus* (McNaughton and Tyson, 1979) and *Pterocarpus angolensis* (van Daalen *et al*. 1992) in Southern African species.

The absence of clearly identifiable annual growth rings in tropical species to determine the age and growth rate of trees, when compared with clear rings in many temperate tree species, has made it difficult for forest managers to effectively determine cutting rotations and sound management of these forests. This also applies to Miombo woodland species (Grundy, 1995; Geldenhuys, 2005). However, the distinct seasonality of precipitation in many tropical climates does induce annual rhythms in the physiology of many tropical species, which may result in the production of annual growth rings (Borchert, 1991). Additionally, annual growth rings have, in the past, been used by forest managers in determining the age of Miombo woodland in Zambia (Fanshawe, 1956) and recently, research has shown that some tropical and sub-tropical species are capable of producing growth rings which correlate with age (Fahn *et al*. 1981; Jacoby, 1989; Gourlay and Barnes, 1994; Grundy, 1995; Stahle *et al*.1999; Geldenhuys, 2005). The studies of Grundy (1995) and Stahle *et al*. (1999) were specific to Miombo woodland. Each of these studies had some limitations. Grundy's observation was based on a four-year study period on stems of unknown management history. Stahle *et al*. (1999) observed evidence of phenology, ring anatomy, cross dating and the correlation between the growth rings in *Pterocarpus angolensis* and seasonal climatic data. They left out evidence of the relationship between the number of growth rings and the age of the study site and the relationship between the growth rings and the diameter of these species. Whilst their findings are promising, it must be recognized that they need to be supplemented with studies of other key species of Miombo in order to add to the existing body of knowledge on use of growth rings in determining growth rates and the age of the Miombo woodland.

Most investigations of growth rate using growth rings have been based on either coring (Stahle *et al*. 1999), or whole discs (Gourlay, 1995), or a combination of the two, or by damaging the cambium (Grundy, 1995) and then cutting the cross section of the stems to allow for counting of the growth rings. However, the Gourlay (1995) and Grundy (1995) studies were based on observations at heights of 1.3 m or 1.4 m from the ground, respectively. Each method has some complications, for example increment core sampling in species with dense wood is difficult. Gourlay (1995) noted that it is not unusual for the tempered steel borer to break due to excessive torque, or the operator may miss or fail to reach the pith. Additionally, a seedling may take time to reach the height (1.3m/1.4 m) at which the samples were taken and hence could result in missing some growth rings. However, Chidumayo (1988) used diameter increment data collected over a long period of time to determine the influence of early burning and complete protection on the growth rate of some Miombo species. Apart from being limited to the influence of fires, Chidumayo (1988) based his observation 1.3 m from the ground. Additionally, the study did not involve any study of growth rings.

In this study, the research objectives were: i) To determine the relationship between the number of growth rings in selected key Miombo species and the age of the chosen sites. ii) To determine the relationship between growth rings and the diameter of the chosen species. iii) To determine the reliability of growth rings in age determination. The key questions were: i) What are the largest diameters for each selected species in each disturbance and age categories? ii) What is the number of growth rings in each stem diameter? iii) What number of growth rings does each species show in each age category?

6.2 Study area and methods

6.2.1 Study area.

Two different sites in *Masaiti* District 13^{o} 25' 00"S to 13^{o} 45' 00"S, and 28^{o} 25' 00"E to 28^{o} 40' 00"E) were selected for the study: *Mwaitwa* and *Kaloko-Luansobe* (Figure 6.1). The sites were selected because they were of known management history that made it easier to relate the number of growth rings with age and therefore determine the growth rates of species.

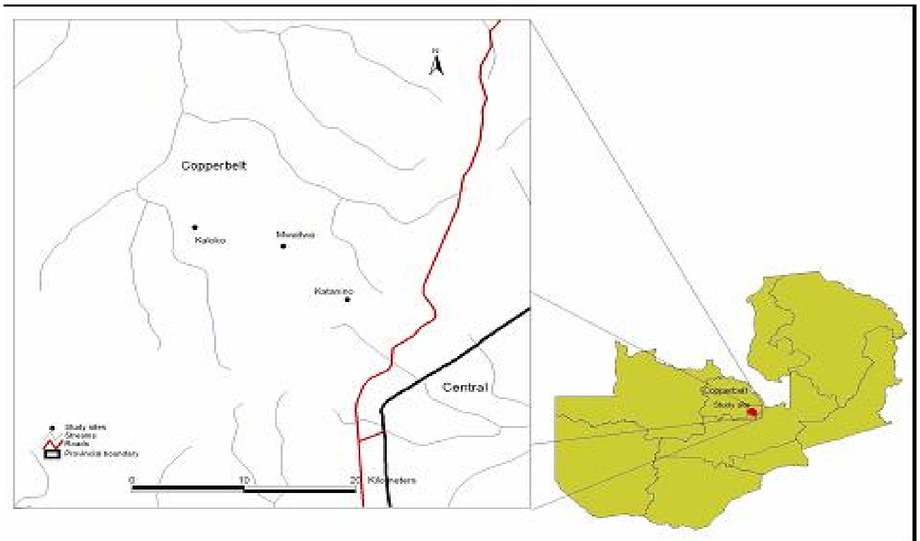

Figure 6.1 Map of Zambia showing study area in Masaiti District, Copperbelt Province

The climate of the area is characterized by an alternation of dry and wet seasons. Based on temperature and rainfall, three distinct seasons are recognized in the area: hot dry season (August-October); hot wet season (November-April); and cool dry season (May-July) (Figure 6.2). The average annual rainfall is 1200 mm (Rao & Acharya, 1981).

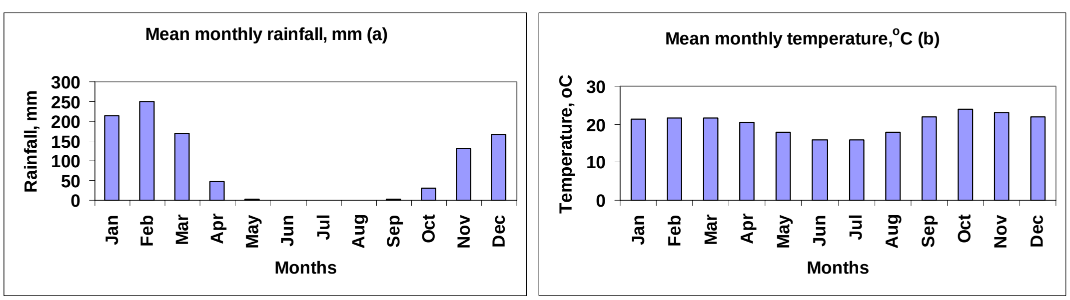

Figure 6.2 Monthly temperatures and rainfall for 2000-2006 for Copperbelt Province (Zambia Meteorological Dept. (unpublished)

The temperatures vary from 18^{0}C in winter to about 30^{0}C in summer (Rao & Acharya, 1981). The lowest temperatures usually occur in June/July while the highest temperatures occur in October.

6.2.2 Methodology

6.2.2.1 Sampling design

The data were collected in areas of known age after previously being under slash & burn agriculture or charcoal production, and also from natural mature forests. Within the different stand categories selected for study for chapter 4 and 5, the approximate ages of individual stands with well known ages were used for this study. In each land use category, sites were selected with the following ages: 7, 8, 10, 16, 17, and 20 years since disturbance cessation. In each site, six plots were randomly selected. The Global Positioning System was used to locate plots in the field. Within each stand, the stems with the largest diameters of the key species were selected for study (Figure 6.3). The assumption was that the largest stems of a species were the oldest in each stand and therefore would be more reliable in determining the relationship between stand age and number of growth rings. The three selected key species, *Brachystegia floribunda*, *Isoberlinia angolensis* and *Julbernadia paniculata,* were abundant in both the former charcoal production and slash & burn agricultural sites.

Figure 6.3 *Isoberlinia angolensis* multiple stems in a ten year abandoned slash & burn regrowth stand

The selected stems were located by measuring distances from the tree to the centre of the plot and the following recorded for each stem: diameter at breast height (DBH) and diameter at the point where the disc was cut.

6.2.2.2 Collection of stem sections

In this study an attempt was made to minimize the errors mentioned in Section 6.1 arising from collecting the stem sections from Miombo woodland for dating. Firstly, the stems selected for study were cut at 10 to 20 cm height from the ground level or stump, in case of a shoot, in order to capture the maximum number of growth rings. Secondly, the discs were cut using a sharp silky saw that made the final surface smooth with clear ring boundaries. From each stem, one disc was cut for study.

A number of cut sections for each species were selected for study. Table 6.1 shows the number of sections which were selected for each species under each disturbance and age category.

Table 6.1 Number of stem sections selected for each species under each disturbance category.

Species	Cultivation (years)			Charcoal production (years)			Mature forest (years)	
	7-8	10	15+	7-8	10	15+	7-8	10
Julbernadia paniculata	20	21	21	20	20	20	20	20
Brachystegia floribunda	20	20	20	20	20	20	20	20
Isoberlinia angolensis	20	20	20	21	21	20	20	20

Each disc had three points marked at known distances from each other before taking the photograph using a Canon PowerShot A620 digital camera. These points were used to scale the software during data analysis.

6.2.2.3 Data analysis

Image *J* 1.37 version (see National Institutes of Health, 2007) software was used in counting rings and also in determining the ring widths of the key species. Thereafter, the Bonferroni test using STATISTICA statistical package version 6.0 (StaSoft, inc., 2003) was used to determine the relationship that exist in growth rates within species under different disturbances, and also between different species under similar disturbances.

6.3 Results

6.3.1 Growth rings and stand age

The growth ring boundaries were reasonably distinct in all three species from both the charcoal and slash & burn regrowth stands (Figure 6.4a & b) although the less clear growth rings were observed in older stands (Figure 6.4c). Less clear rings were typical of the discs from mature woodlands (Figure 6.4d). Additionally, the plotted profiles of all the studied species clearly showed distinct growth rings.

The number of growth rings showed a strong positive linear relationship with stand age in both slash & burn ($r = 0.9019$; $P<0.01$; slope of curve = 0.97; $n = 182$) and charcoal ($r = 0.9246$; $P<0.01$; slope of curve = 1.01; $n = 182$) regrowth stands (Figure 6.5). However, the discs from mature woodland of the same diameter as those from the regrowth stands did not show any distinct growth rings (Figure 6.4 d).

The slope of 0.97 for the slash & burn regrowth stand curve indicates one missing growth ring in every stand age, while the slope of 1.01 for the charcoal regrowth stand curve shows the occurrence of one additional growth ring per every stand age.

(a) *Julbernadia paniculata* (b) *Brachystegia floribunda*

(10 year old charcoal regrowth stand) 10 year old slash & burn regrowth stand)

(c)*Brachystegia floribunda* (d) *Brachystegia floribunda*

(16 year old slash & burn regrowth stand) (Mature woodland stand)

Figure 6.4 Discs of *Julbernadia paniculata* (a) and *Brachystegia floribunda* (b, c, d) in charcoal regrowth stands slash & burn regrowth and mature woodland stands respectively.

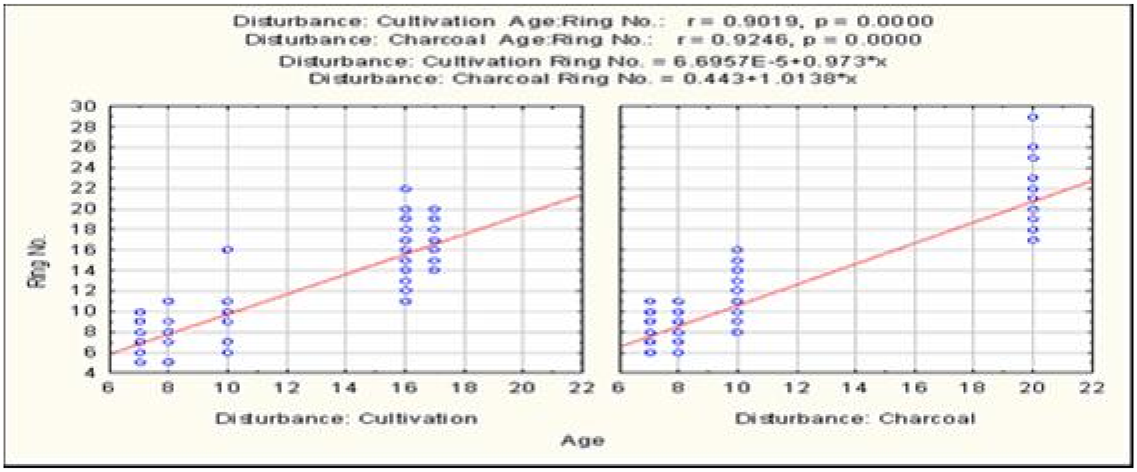

Figure 6.5 The positive linear relationship between stand age and the number of growth rings in regrowth stands after different years after abandoning slash & burn agriculture (cultivation) and clearing for charcoal production.

6.3.2 Growth rings and dbh

All the species studied showed strong correlation between the number of growth rings and the dbh of a tree, in both slash and burn ($r = 0.8806$; $P<0.01$; slope of curve = 0.83; $n = 182$) and charcoal ($r = 0.9068$; $P<0.01$; slope of curve = 1.21; $n = 182$) regrowth stands (Figure 6.6). The slope of 0.83 for the slash & burn regrowth stand curve indicates a growth ring in every 1-2 cm change in dbh. The slope of 1.21 for the charcoal regrowth stand curve indicates a growth ring in every 1 cm change in dbh. This shows that trees in the slash & burn sites grow faster than trees in the charcoal production sites.

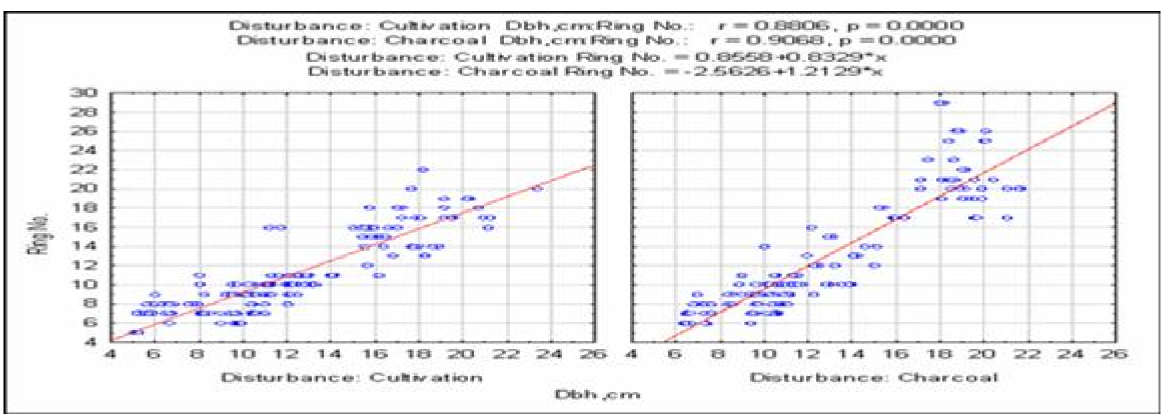

Figure 6.6 The relationship between DBH and number of growth rings in stems in regrowth stands after different years after abandoning slash & burn agriculture (cultivation) and clearing for charcoal production

6.3.3 Growth rate in charcoal and slash & burn regrowth stands.

Table 6.1 shows the mean annual ring widths observed in individual key species in charcoal and slash & burn regrowth stands. Mean annual width was significantly different between species within the same disturbance category (P<0.005) with stand age. *Isoberlinia angolensis*, with the mean ring width of 5.60 mm in charcoal regrowth stands and 5.40 mm in slash & burn regrowth stands, exhibited the highest growth rate amongst the key species. Generally, the ring width tends to increase from the youngest stands to the stands of ten years in age in all three species (Table 6.1). Thereafter, the ring width tends to reduce. However, there is no significant difference in mean ring width within the same species under different disturbance factors.

Table 6.2 Growth rates of key Miombo species under different disturbances

Species	Mean annual ring width, mm							
	Stand category and age							
	Slash & burn regrowth stands/age (yrs)				Charcoal regrowth stands/age (yrs)			
	7-8	10	15+	Mean	7-8	10	15+	Mean
Brachystegia floribunda	4.8± 0.3	5.8± 0.2	4.7±0.2	**5.1± 0.6**	3.8± 0.3	4.9±0.3	4.6± 0.1	**4.4± 0.6**
Isoberlinia angolensis	5.7± 0.4	5.8± 0.1	4.6± 0.6	**5.4± 0.7**	5.6± 0.3	6.6±0.4	4.6±0.2	**5.6± 0.9**
Julbernadia paniculata	5.0± 0.2	5.0± 0.2	4.2± 0.2	**4.7± 0.5**	3.6± 0.2	4.8±0.2	4.7± 0.2	**4.4± 0.7**

6.4 Discussion

6.4.1 Growth rings, stand age and DBH

All three selected species for this study showed that the number of growth rings can be used as a good estimate of stand age in both charcoal and slash & burn regrowth stands. However, the slope of the positive linear regressions suggests that in slash and burn regrowth stands there is about one missing growth ring every stand age (slope of 0.97) and that in charcoal regrowth stands there is an additional one ring per every stand age (slope of 1.01). This shows that a tree of 20 years age will have about 19 rings in a slash & burn regrowth stand and 21 rings in a charcoal regrowth stand. In charcoal regrowth stands, an additional growth ring may be attributed to the fact that young plants are left behind during clearing for charcoal production. Additionally, some stumps tend to sprout as clearing for charcoal proceeds and consequently develop into trees. Missing or locally absent growth rings are frequently due to very dry years or droughts (Stokes & Smiley, 1968). However, the absence of one ring in slash & burn regrowth stands every year can not be attributed to the occurrence of drought as the charcoal regrowth stands in the same area did not show the same patterns**.** Additionally, the rainfall data (1261 ± 55 mm) (Zambia Meteorological data, unpublished) indicated that the study area received within the normal range of rainfall for the period included in the study (see Rao & Acharya, 1981). Therefore, the missing ring suggested by the slope in slash and burn regrowth stands may be attributed to constant removal of seedlings or sprouts observed during the cultivation period as they are considered as weeds. Additionally, delayed stem development due to shoot die-back resulting from frequent fires as slash and burn sites normally have higher incidences of fires (see Boaler & Sciwale 1966) may also contribute to discrepancies between stand age and the number of growth rings. The discrepancy may also be attributed to delayed germination as most plants in slash & burn regrowth stands developed from seed (chapter 5).

The high correlation between growth rings and stand age may be attributed to the fact that the Copperbelt Province experiences strong seasonality in both temperature and rainfall (see Rao and Acharya, 1981; Tyson, 1986) which according to Stahle *et al*. (1999) results in annual ring formations. Additionally, these species are deciduous during the annual dry season and their phenology is tightly synchronized with the seasonality of temperature and precipitation (see Rao and Acharya, 1981; Storrs, 1995). According to Borchert (1991), the seasonality in flowering, leaf flush and leaf fall strongly suggests that radial growth is also restricted to the summer wet season. Additionally, Geldenhuys (2005) suggested that the strong and consistent diameter growth of free growing stems in re-growth stands contributes to the clear and wide rings. The linear relationship between growth rings and tree age have been reported in other Miombo ecoregion species, namely *Brachystegia spiciformis* in Zimbabwe (Grundy, 1995), *Pterocarpus angolensis* in Tanzania (Boaler, 1963) and *Acacia tortilis* in Kenya (Wyant and Reid, 1992).

The study has also revealed a highly significant relationship between diameter at breast height and the number of growth rings, in both charcoal and slash & burn regrowth stands for all species (Figure 6.6). This implies that the bigger the DBH the higher the number of growth rings. This also implies that larger stems selected in the study have given reliable data for use in estimating the age of the Miombo woodland stands.

6.4.2 Growth rate

The mean annual ring width observed between different species under different disturbances revealed that there is a significant difference in mean annual ring width between these species. However, the mean annual ring widths of similar species under different disturbances did not differ significantly although the modes of regeneration differed between charcoal and slash & burn regrowth stands (chapter 5). The results seem to suggest that the mode of regeneration does not result in significant differences in growth rate of individual species. Although the mode of regeneration may be important in influencing the growth rate of plants, there is a general consensus that, in arid regions, it is rainfall that is the dominant factor in determining growth rate (Fahn *et al*., 1963; Glock 1941) between different areas of different rainfall regimes.

Comparatively, the mean annual ring width values observed in the study (Table 6.1) are relatively higher than the range of values reported by Chidumayo (1988) in his study of the influence of fire on Miombo species growth. Chidumyo (1988) reported annual growth rate values ranging from 3.6 mm to 4.8 mm. Additonally, the current mean annual ring width values are higher than the growth rate values observed in *Pterocarpus angolensis* in South Africa. For example, Shackleton (2002) reported the mean annual diameter of 4.5 mm (mean ring width value of 2.3 mm) and Groome *et al*. (1957) reported the mean annual diameter increment ranging from 0.3-2.8 mm per year (mean ring width range of 0.15-1.4mm). Von Maltitz and Rathogwa (1999) reported the growth of 3.5 mm. In Zimbabwe, Grundy (1995) reported the mean growth of 0.27 cm^{-1} $year^{-1}$ for all trees in an area protected from fire and human disturbance. The higher growth rate values in the current study when compared to the previous studies may be attributed to the fact that the current study dealt with the younger stands while the previous works dealt with mature woodland stands. Relative growth rates tend to decline with age of trees. This nonetheless suggests that trees in open areas grow much faster than in mature stands. This confirms Geldenhuys (2005)'s observation in Mozambican Miombo woodlands.

6.5 Conclusion

The identification of annual growth rings in *Julbernadia paniculata*, *Brachystegia floribunda* and *Isoberlinia angolensis* has important implications for forest ecology and management of Miombo woodlands. Even with the problem of a missing growth ring in slash & burn regrowth stands, the study still suggests that the ring counts could still be used in determining the age of Miombo regrowth stands as the ecosystems has a strongly seasonal, unimodal rainfall pattern. Additionally, the growth rates information generated from the study will help in size predictions of the key Miombo species in that the study has provided a means of collecting growth rate data which is relatively easy. The current data may be supplemented with other growth rate data for trees of known age or measuring larger trees over time. The growth rate data have shown that trees that grow on open areas (outside mature woodland) will be much faster in growth than tree seedlings that have to start under the canopy of the mature woodland. Trees in slash & burn regrowth stands will therefore reach merchantable sizes (35-40 cm dbh) (see Chigwerewe, 1996; Geldenhuys, 1996) faster than those in mature woodlands.

However, care must be taken in the use of rings and growth rate data in areas that experience drought or dry years as some studies elsewhere (e.g. Stokes & Smiley, 1968) have shown that droughts result in missing growth rings. Such information would be very useful when used together with the climatic data and also an understanding of the disturbance factor that land was exposed to in order to relate the missing growth rings with drought frequencies and the disturbance factor. Lastly, since the study was carried out in wet Miombo woodlands, it would be important to carry out a similar study in dry Miombo woodlands in order to increase the validity and applicability of this information. Additionally, since the models were derived from species of the same family, future studies should include other species so as to enhance the understanding of the Miombo woodland ecosystem

6.6 References

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7 LINKING DISTURBANCES TO SUSTAINABLE MANAGEMENT OF THE COPPERBELT MIOMBO WOODLAND ECOSYSTEMS OF ZAMBIA

Abstract

Deforestation, not only of the Zambian Copperbelt woodland but many forests all over the world, is an emotional topic of the popular environmental debate today. Many people concerned about the environment have been persuaded by graphic images of either burning forests or the sight of the complex ancient forests being felled by commercial loggers, or slash & burn agriculturalists or charcoal producers who seem to care little for the losses to global heritage, biodiversity and impact on the global climate. This mindset created by this paradigm links loss to forests with degradation of the environment. The mindset has led to the formulation of a variety of policies that seek to protect forests and their ecosystems from the local communities who utilize the forests for charcoal production and slash & burn agriculture in preference for single tree selection harvesting. However, recent research has shown the regrowth of a wide range of species over areas previously deforested. Perhaps what is important is to try and classify the impact of these forms of forest utilization at both population and stand level. This chapter summarizes and synthesizes information from various studies undertaken to determine the regeneration and recovery potential of Miombo woodland under different disturbance factors. It characterizes the Miombo woodland response to these disturbances based on the size class profiles exhibited at both population and stand levels. It also compares these with the undisturbed woodland. The results indicate that single tree selection timber harvesting as a disturbance at stand level is a *non event* while at population level, this disturbance may be a *disaster*. Additionally, the results also reveal that Miombo woodland is dominated by mostly light-demanding species. Such species require large gaps for regeneration establishment and development. As such, the dominant species perform better in open areas than under closed canopy. The study concludes that these species are better adapted to the kind of disturbance-recovery processes associated with charcoal production and slash & burn agriculture although these disturbances may be viewed as a *disaster* to the Miombo woodland structure at community level over the short term but *incorporated* disturbances at the population level. The study recommends the need for integrating these forms of forest utilization on a controlled basis into the forest management programs so as to reduce undesired destruction of the woodlands while maintaining the essential disturbance-recovery processes that drives Miombo woodland diversity.

7.1 Introduction

Deforestation, not only of the Zambian Copperbelt woodlands but of many forests all over the world, is an emotional topic of the popular environmental debate today. This is because many people concerned about the environment have been persuaded by the graphic images of either burning forest, or the sight of the complex ancient forests being felled in minutes by commercial loggers, or slash & burn agriculturalists and charcoal producers who seem to care little for losses to global heritage, biodiversity and impact on global climate (Forsyth, 2003). Many authors (Richards, 1952; Myers, 1984; Mather, 1992; UNCED, 1992; Bradley and Dewees, 1993; GRZ, 1998; Mather and Needle, 2000; Brown, 2001) have outright condemned deforestation and associated it with massive loss of fauna, flora and some high productive forest ecosystems. Such commentaries assume a direct relation between area of forest lost and the species lost (Forsyth, 2003). The mindset created by this paradigm links the loss of forests with degradation of the environment. This mindset has led to the formulation of a variety of policies that seek to protect forests and their ecosystems against interference from the local communities for charcoal production and slash & burn agriculture. Such policies have condemned these two practices as forms of forest utilization in preference for single tree selection harvesting which is perceived to result in minimal negative impact on forests and woodlands. However, later research has shown, by contrast, that this direct relationship between the area of forest lost and species lost overestimates the reality on the ground (Wu and Loucks, 1995) and many species tend to survive in the remaining clumps of forests. Many studies in other parts of the world (Fairhead and Leach, 1998; Schmidt-Vogt, 1998; Sillitoe, 1998; Fox *et al.,* 2000) have shown the occurrence of a wide range of species over areas previously deforested. Perhaps what is most important is to try and classify the disturbances based on their associated impacts at both stand and population levels for a particular woodland. This approach may help to understand the implication of each disturbance and also how such a disturbance may be incorporated into sustainable forest management. According to Hansen and Walker (1985), a disturbance can either be a *non-event or incorporated or a disaster or catastrophe* relative to the scale at which it occurs, such as individual, population, community and landscape. A specific disturbance is a non-event if it does not alter the functional environment of an entity or may do so with a frequency too minor to elicit a response. It is an incorporated disturbance if it elicits dynamics of a scale to which the entity is adapted and thus necessary to maintain the entity in its present states. It is a disaster or catastrophe if it forces the entity into a new state.

The study attempted to develop a new understanding of the regeneration and recovery potential of Miombo woodland and the selected key Miombo woodland species when exposed to timber harvesting (single tree selection), slash & burn agriculture and charcoal production. These disturbances vary in intensity and in effects on the systems. Timber harvesting involves the removal of some trees, some opening of the canopy, and some soil disturbance. Slash & burn agriculture removes most or all of the trees, burns the tree debris over the site, and cultivates the soil to various degrees which may continue intermittently over several years. Charcoal production removes most of the canopy and includes some soil turnover and fire in specific localities. These practices bring into context the classification of the land use disturbances in Miombo woodland based on their impacts at both population (species) and stand (ecosystem) level. This chapter assesses how the results from the individual studies (Chapters 2 to 6) answered the research questions posed to achieve the specific and overall objectives posed for the study. It reviews and synthesizes the information on the regeneration characteristics and characteristic development stages of Miombo woodland that has been under single tree selection, slash & burn agriculture and charcoal production. In conclusion, the new understanding of regeneration and recovery potentials is assessed with a view to effectively integrate these disturbances into sustainable forest management.

7.2 Evaluation of methodological issues developed for the study

Five specific studies were conducted to examine different parts of this overall study: Miombo woodland utilization, management and conflict resolution among stakeholders (Chapter 2); the use of species-stem curves in sampling the development of Miombo woodland species in charcoal and slash & burn regrowth stands over time (Chapter 3); the impact of human disturbance on the floristic composition of Miombo woodland (Chapter 4); regeneration and recruitment potentials of key species of Miombo woodland species after disturbance and recovery of the woodland and species population structure (Chapter 5); and age and growth rate determination using selected Miombo woodland species (Chapter 6).

Different methods were developed for each specific study. In the case of Chapter 2, semi-structured and key informant interviews were selected to generate the data. In order to minimize discrepancies rising from such errors as fear, ignorance, hope of benefits by the respondents, etc. (see Chamber, 1983). In this regard, the research assistants who assisted in data collection were familiar with the communities and also well known within the local communities. Additionally, group meetings were conducted during which community members were divided into user groups to discuss issues relating to woodland utilization and management.

Assessment of Miombo woodland dynamics under different land-use practices was important to provide for the new understanding of the regeneration and recovery potentials of the Miombo woodlands (Chapters 4 and 5). As indicated earlier, each of these land use practices has different impacts on, and therefore triggers different responses, of the Miombo woodland ecosystem as a whole. This requires a comparison of the responses of different species to these different land uses. The post-utilization stands and their recovery stages over time are highly variable in both plant stocking and species composition (see Strang, 1974; Stromgaard, 1985). Timber harvesting does not involve clearing of the woodland and the stem density does not change from pre-harvested stands. Slash & burn agriculture and charcoal production result in clearing of current woodland stands and the recovery of these stands results in dense regrowth of small stems which gradually grow taller with reduction of stem density through natural thinning, and increase in stem diameters. Young regrowth stands tend to have many stems while the older more advanced stands have fewer stems (Chapter 5). Therefore, the traditional methods of fixed plot sizes, such as 0.4 ha (Lees, 1962), 20 by 20 m (Lawton, 1978) and 40 m by 40 m (Schole, 1990), are not suitable for this kind of survey. They may be too large and time consuming and therefore impracticable for the young, dense regrowth stands (Mark and Esler, 1970). The use of species-stem curves for determining the species response to different land uses proved to be very useful (Chapter 3).The use of this technique avoids measuring too many plants in one plant age category with too few in other age categories. It also avoids a need to adjust the sample size from one stand to another and from one age class to another. This is because the technique involves the use of fixed number of plants derived from species-stem curves in collecting data for comparison purposes. Variable sampling has significant implications for sampling regrowth stands in terms of time and number of species captured of the regrowth stands. However, the versatility of this technique has not been ascertained in other woodland types. Secondly, its versatility and suitability even in Miombo regrowth stands, of varying slash & burn practices has not been tested. In case of charcoal regrowth stands, the technique has not been ascertained in either a second rotation or more. Therefore, although the method is promising, it still needs to be ascertained in relation to different types of slash & burn practices and duration of cultivation and cultivated crops.

The fast growth of Miombo woodland species in regrowth stands of known area provides a means to determine growth rates of trees. In order to provide information necessary for determining cutting rotations in the Copperbelt Miombo woodlands, the growth rings and growth rates of selected dominant Miombo woodland species were determined (Chapter 6). The method provided for important improvements on past approaches by cutting the selected stem discs at 10 to 20 cm from the ground level or stump in case of a shoot so as to capture maximum number of growth rings (see Chapter 6).

7.3 Resource use issues and perceptions on the recovery of Miombo woodland

The resources of Miombo woodlands are central to livelihood systems of millions of rural and urban people (Campbell *et al*., 1991; Chapter 2). It provides products for the towns and cities of the region, the most important of which is fuel (Campbell *et al*., 1996) and firewood and ash for slash & burn agriculture for the rural population. Of all the uses to which Miombo woodlands are important to different user groups, the most controversial uses are charcoal production and slash & burn agriculture. For example, Katsvanga *et al*. (2008) reported that charcoal production along roads on the Copperbelt Province, Zambia, has had a negative impact on the woody vegetation. Furthermore, GRZ (1998) and Chidumayo (1987) also attributed the degradation of both forest reserves and open areas of the Copperbelt region (Chapter 1, Table 1.1) to charcoal production due to increased demand for both industrial and household wood fuel in urban centers.

Deforestation arising from slash & burn agriculture has been reported to be high in Zambia (Chapter 1, Tables 1.1 & 1.2). Reports of deforestation arising from either charcoal production and slash & burn agriculture have been made in some other parts of the Miombo Ecoregion. In Tanzania, Ahlback (1988) estimated diminution of forest cover due to charcoal production to range from 300 000 - 400 000 ha year^{-1}. Additionally, Monela *et al*., (1993) also associated charcoal production in Tanzania woodlands to a wide range of impacts namely soil erosion and other environmental effects like biodiversity loss. In Mozambique, Mlay *et al*., (2003) associated charcoal production and slash & burn agriculture to loss of both forest cover and biodiversity. Charcoal production and slash & burn agriculture are blamed as the principal causes of deforestation and its associated negative environmental impacts in tropical Africa (see Myers, 1989; Jepma, 1995; GRZ, 1998). This perception may be attributed to inadequate information on the recovery of the woodland once these disturbances cease. Some of the available information seems to suggest that woodland recovery for the southern African woodland is not possible (Walker, 1981; Stromgaard, 1986). Additionally, some of the available information on the growth rate of Miombo woodland seedling shoots (Lees, 1962; Chidumayo, 1992) suggests very low growth rates and therefore may support the perception that charcoal production or slash & burn agriculture does not result in woodland recovery once these are terminated over an area.

7.4 Overview of the studies on Miombo woodland response to different land use impacts

Many researchers (Grundy, 1990; Tuite and Gardiner, 1990; Dewees, 1994; Mbwambo, 2000; Luoga *et al*., 2002) acknowledge the importance of Miombo woodlands in supplying products essential for the well-being of its inhabitants. Miombo woodlands are important for charcoal production, building materials (timber and pole production) and slash & burn agriculture. Each of these has an impact on the Miombo woodland ecosystems.

7.4.1 Single tree selection harvesting

Single tree selection harvesting either for timber or poles or for carving has been perceived to have no serious negative impact on the woodland ecosystem as a whole. Schwartz and Caro (2003) in their study of Tanzanian Miombo woodland which was previously under single tree harvesting support this perception in that their findings did not show any significant change in terms of species richness and stocking as a result of timber harvesting. However, the negative impact of single tree selection harvesting has been widely reported in many parts of Tanzania (Hall and Rodgers, 1986; Nduwamungu and Malimbwi, 1997; Mbwambo, 2000; Luoga *et al*., 2002). Both Nduwamungu and Malimbwi (1997) and Luoga *et al*. (2002) observed very low levels of mature *Pterocarpus angolensis* due to past harvesting of species for window frames and doors. According to Schwartz *et al*. (2002), such a situation is referred to as an economic extinction of the species. The economic extinction allows such species to persist at low densities which make their exploitation costly. The impact of single tree selection harvesting on species richness has also been reported in other parts of the Miombo ecoregion: Malawi (Konstant, 1999; Makungwa and Kayambazinthu, 1999); Mozambique (Grundy and Cruz, 2001) and Zimbabwe (Grundy *et al*., 1993, Mudekwe, 2006). These studies have revealed that the commonly harvested species for either timber or pole production namely *Pterocarpus angolensis, Erythrophleum africanum, Brachystegia boehmii, Brachystegia spiciformis, Brachystegia bussei, Brachystegia utilis, Pericopsis angolensis, Khaya anthotheca* and *Afzelia quanzensis* have been reported to exhibit unstable population structures with reduction in absolute densities and also species richness. Similarly, *Brachystegia floribunda, Pterocarpus angolensis and Albizia antunesiana* have been reported to exhibit unstable population structures and low densities in mature Miombo woodland stands in which these species were under single tree harvesting (Chapter 4, Figure 4.6, Appendix 3.2**).**

7.4.2 Charcoal production and slash & burn agriculture

The response of Miombo woodland to clearing for either charcoal production or slash & burn agriculture is reflected on the development of regrowth stands once these disturbance factors are terminated over an area. Several studies in many parts of the Miombo ecoregion namely Tanzania (Boaler and Sciwale, 1966); Zimbabwe (Strang, 1974) have shown the development of Miombo regrowth stands once the disturbance ceases. Strang (1974), in his study of the highveld system after land clearing, observed *Brachystegia spiciformis* and *Julbernadia globiflora* remaining the characteristic and dominant species throughout the developmental stages of Miombo succession. Boaler and Sciwale (1966) and Graz (1996) observed the occurrence and good performance of *Pterocarpus angolensis* in areas previously under slash & burn agriculture**.** In Zambia, the development of regrowth stands have been reported in various studies (Chidumayo, 1988, 1993a, b, 2004) although these studies did not deal with individual species development over time after the disturbance ceases**.** Additionally, these studies did not make any comparison of responses of the woodland when exposed to different disturbances. Fanshawe (1971) also noted that Miombo woodland regrows virtually unchanged in a Zambian Miombo following clearing. Stromgaard (1986) reported that although the initial stages of the regrowth stand development of a previously cultivated area is a composition of fire resistant and some key Miombo species, the development of Miombo regrowth does not revert back to the original Miombo.

7.5 Miombo vegetation recovery after human disturbance

7.5.1 Species and diversity over time

The occurrence and diversity of species tend to differ from one disturbance type to another and also with stand age within the same disturbance type. Charcoal production tends to yield the highest number of species, followed by either slash & burn agriculture, then single tree selection harvesting, with undisturbed Miombo woodland having the lowest number of species (Chapter 4, Table 4.2). This suggests that opening up of Miombo woodland enhances species richness of the area. According to Lees (1962), many Miombo woodland species require high light intensities to regenerate and establish. Additionally, under canopy, the growth and abundance of understory vegetation of Miombo like in many other vegetation types (Bassaz and Wayne, 1994) are strongly limited by heavy shade and root competition for moisture with canopy species. Increased light, soil moisture and nutrient availability and creation of microsites for colonization associated with canopy disturbance promote succession dependent on the intensity of disturbance (Reader and Bricker, 1995). Rapid development of Miombo regrowth in abandoned cleared plots in certain parts of the Miombo ecoregion, such as in Tanzania (Boaler and Sciwale, 1966); Zambia (Chidumayo, 1988; Chidumayo, 2004) and Zimbabwe (Strang, 1974) also supports the significance of light intensities and reduced competition for nutrients and water in promoting regeneration. Among the new species gained in stands of 2-3 year old regrowth once slash & burn agriculture or charcoal production are terminated over an area are those of ubiquitous and chipya ecological groups (see Kikula, 1986) such as *Dalbergiella nyasae*, *Garcinia huillensis*, *Hexalobus monopetalus*, *Ozoroa reticulata* (Appendix 4.1). All these species are typical of the Miombo sub-canopy and understory (Fanshawe, 1971; Storrs, 1995). Some of the species were typical of only one disturbance type. For example *Protea* spp, *Rhus longipes, Bridelia macrantha* and *Burkea africana* were typical of the charcoal regrowth stands. However, a number of species are lost during the development of regrowth stands arising from charcoal production or slash & burn. Charcoal production suffers the greatest loss of species over time (Table 4.3).This probably because it starts with a higher number of species and therefore, to get back to the typical mature Miombo woodland species level, more species have to be lost. Among the species gained through charcoal production are a mixture of *Mateshi, Chipya* and *Ubiquitous* ecological group species like *Bridelia* *macrantha*, *Diospyros spp., Cassia singueana*, *Afzelia quanzensis*, etc while some, among which are the *Uapaca* ecological group, are lost over time (Chapter 4; Appendix 4.1). The entrance of a mixture of species of different ecological groups in the early stages may suggest a variation in environmental conditions such as fire intensities within the same disturbance type. Some *Uapaca* spp. reduce in abundance due to natural mortality as the canopy of the regrowth stands begin to close (Kikula, 1986). Members of the *Chipya* and *Uapaca* ecological groups can only grow well under light canopies (Lawton, 1978). This explains why even though the members of the Miombo group regenerate under the protection of the *Uapaca* and *Chipya* groups, these groups get eliminated later when the canopy of the Miombo group gets dense (Kikula, 1986). Clayton (1962) made a similar observation on the reduction in prevalence of *Uapaca togoensis* as regrowth stands advance in the Savanna woodland of Nigeria.

7.5.2 Mechanisms and management of Miombo woodland recovery

The mechanism of regeneration for individual Miombo species is mostly dependent on the disturbance mechanism (Chapter 5, Figure 5.8). For example, in timber and slash & burn stands, *Parinari curatellifolia* mostly develop by root suckering (Figure 5.8a) while *Albizia antunesiana*, *Brachystegia floribunda*, *Brachystegia longifolia*, *Brachystegia spiciformis*, *Isoberlinia angolensis*, *Julbernadia paniculata*, *Pericopsis angolensis*, *Pseudolachnostylis maprouneifolia* and *Pterocarpus angolensis* from seed (Figure 5.8b). This observation offers a potential approach for managing individual forest crops based on their mode of regeneration. For example, if one has to enhance establishment and development of *Parinari curatellifolia*, there would be need to disturb the root system of this species to produce root suckers. However, the management of *Albizia antunesiana, Brachystegia floribunda, Brachystegia longifolia, Brachystegia spiciformis, Isoberlinia angolensis, Julbernadia paniculata, Pericopsis angolensis, Pseudolachnostylis maprouneifolia* and *Pterocarpus angol*ensis in timber and slash & burn stands requires silvicultural management approach that would enhance seedling establishment and growth. Chapter 5 (Figure 5.5, Appendix 5.1) has shown that opening up of the woodland stands for slash & burn agriculture enhances the establishment and growth of seedlings of these species. As long as they remain under canopy cover, they may either die or remain suppressed in a stunted form (Werren *et al*., 1995). This is because these species are shade intolerant and therefore, if they are not exposed to sunlight for a long time they remain stunted thus prolonging the period during which they are susceptible to fires, water stress, insectivory and herbivory (Savory, 1963; Chidumayo, 1997). Most of the photosynthetic products during seedling development are allocated to root growth while shoot growth may be further hampered by recurrent annual die-back caused by drought or fires (Chidumayo, 1989, 1991, 1992). Therefore, management of young regrowth stands arising from slash & burn agriculture should adapt management strategies that protect seedlings against either fire or drought. Weeding around seedlings results in reduced fire hazards especially at a tender age. Furthermore, the reduction in stocking may reduce the water stress. However, in charcoal regrowth stands, coppicing is common in *Albizia antunesiana, Brachystegia floribunda, Isoberlinia angolensis, Julbernadia paniculata* and *Pseudolachnostylis maprouneifolia*. This implies that if such species are to be managed in charcoal regrowth stands the emphasis should be placed on coppice enhancement and development. Stumps of almost all Miombo tree species produce coppices once cut (Banda, 1988). Management of coppices for the above species should begin with the protection of a stump against fires and herbivory may increase their survival rate. Secondly, increased stump heights during felling for charcoal can also enhance the survival of stumps and coppicing. Grundy (1990) observed a reduction in coppices in lower stumps (<5 cm) compared to higher stumps (>1.3 m) for *Brachystegia spiciformis.* Additionally, adhering to optimum diameter classes within which particular species have high coppicing effectively can enhance coppicing of such species. Handavu (2008) observed that *Brachystegia longifolia*, *Brachystegia spiciformis* and *Isoberlinia angolensis* tend to have high coppicing ability in the diameter range of 15 to 36 cm DBH. Other factors that may be considered to enhance coppice effectiveness include plant age, stump height and surface area (See Grundy, 1995; Shackleton, 2001; Luoga *et al.,* 2002). Lastly, thinning should also be done to reduce competition for nutrients between the often many shoots that develop from one stump (Banda, 1988; Chidumayo, 1989).

7.5.3 Structural changes over time under different disturbance categories

The size class profile exhibited by individual stands and species populations previously under a particular disturbance allows for the characterization of such a disturbance. This is because the stand or population structural profile explains the resultant influence of a particular disturbance at either the stand or population levels (Peter, 2005). For example , the bell-shaped size class profile which is typical of both the undisturbed Miombo woodland and timber harvested stands (Chapter 5, Figure 5.5) shows that Miombo woodland as an ecosystem is composed of populations which experience sporadic or irregular seedling establishment and requires large gaps to become established (DWAF, 2005; Peter, 2005). It is a result of fluctuations in stem stocking between diameter classes close to each other. The fluctuations in stocking between diameter classes may be attributed to infrequency of regeneration from time to time which results in notable peaks or 'valleys' in diameter classes. The infrequency of regeneration may be attributed to the effect of periodic fires that Miombo woodland is exposed to (Trapnell, 1959). However, the similarity in size class profiles between the undisturbed and timber harvested stands implies that single tree selection as a disturbance on Miombo woodlands is a *non-event* as it does not alter the functional environment of the Miombo woodland or if it does then its impact is too minor to elicit a response of the Miombo ecosystem as a whole (Figure 5.4).

The inverse *J*-shaped structural profile exhibited by both slash & burn and charcoal regrowth stands up to about 10-12 years (in case of charcoal regrowth stands) (Chapter 5; Figure 5.3 & 5.4) shows that these stands have adequate regeneration. In short, the opening up of the woodland through slash & burn and charcoal production enhances regeneration which is present in the form of root suckers and recruitment of old stunted seedlings existing under the forest canopy (Chidumayo and Frost, 1996). However, the 15 + year old charcoal regrowth stands show the bell-shaped stem diameter profile. Casual observation indicates that the canopy begins to close in 15 + year old charcoal regrowth stands. Charcoal regrowth stands begin to close faster than the slash & burn regrowth stands because stems with diameter less than 3.2 cm are left behind during charcoal production (Chidumayo, 1990). These tend to grow faster due to reduced competition for nutrients and sunlight. The development of a bell-shaped stem diameter distribution in slash & burn and charcoal regrowth stands may be attributed to the initial even-aged stand at high density. As the regrowth stand develops over time, some of the even-aged stems tend to grow faster than others. There is not much recruitment of young stems and hence the bell shaped curve develops. The difference in structural profile formation between the charcoal and slash & burn regrowth stands is mainly because most of the charcoal regrowth stands develop from coppices while those in slash & burn develop from seedlings (Figure 5.8b). The coppices develop from already established root stocks. As such most of the biomass is allocated to stem development. However, most of the biomass for the trees which develop from seedlings is allocated to root growth in their seedling phase (Chidumayo, 1991) and therefore, plants which develop from seedlings may be slower in stem size development. Additionally, stems with diameters below 3.2 cm are normally left behind when trees are being cut for charcoal production (Chidumayo, 1990). With reduced competition after clearing , these stems tend to grow faster and therefore contribute to high stem frequencies in higher diameter classes than in slash & burn regrowth stands.

At the individual population level, *Brachystegia floribunda*, *Pterocarpus angolensis* and *Albizia antunesiana* exhibit a static size class profile and low densities in mature Miombo woodland stands from which these species are under single tree harvesting (Chapter 5; Figure 5.6, Appendix 5.2). These species exhibit the inverse *J*–shaped size class profile up to 10-12 years (in case of charcoal regrowth stands) while in slash & burn regrowth stands this structural profile is observed up to 15+ years. Seedling establishment and development for these species under canopy are limited even though there could be ample regeneration (Chapter 5, Figure 5.5). Miombo timber species do not regenerate well under canopy because they require high light intensities to develop and grow (Lees, 1962). Additionally, reduced competition for nutrients and moisture also enhances the establishment and development of such species. Therefore, it can be concluded that opening up of the Miombo woodland canopy, which also results in reduction in competition for nutrients and water, stimulates and enhances seedling development. This explains why saplings of dominant Miombo species occur in larger numbers in either slash & burn regrowth stands or charcoal regrowth stands as compared to either undisturbed woodland or timber harvested stands (Chapter 5, Figure 5.5, Appendix 5.1). Additionally, the key Miombo woodland species tend to be present throughout the different age class categories for each disturbance during woodland recovery contrary to the perception of non recovery of Miombo (Walker, 1981) or non existence of dominant Miombo species in the early stages of regrowth stand development (Boaler and Sciwale, 1966). This suggests that Miombo woodland species are adapted to the kind of disturbances associated with either slash & burn agriculture or charcoal production. Therefore, the Miombo woodland ecosystem is capable of incorporating the disturbances arising from either slash & burn agriculture or charcoal production.

The static size-class profile exhibited by species which were under single tree selection harvesting shows the negative impact of species preference and single tree selection harvesting on the overall population of such species. The results confirm various observations made by other researchers in other parts of the Miombo ecoregion: Tanzania (Hall and Rodgers, 1986; Nduwamungu and Malimbwi, 1997; Mbwambo, 2000; Luoga *et al*., 2002); Malawi (Konstant, 1999; Makungwa and Kayambazinthu, 1999); Mozambique (Grundy and Cruz, 2001) and Zimbabwe (Grundy *et al*., 1993). Very low levels of species which were under single tree selection were observed in these studies. According to Schwartz *et al.,* (2002) such a situation is referred to as an economic extinction. This allows the species to persist at low densities which make their exploitation costly. This economic extinction of shade intolerant species if not checked, can result in limited availability of species being harvested, although such species could have ample regeneration. Additionally, this has the potential to result in decrease of the likelihood of conspecific replacement and increasing the risk of collapse of the natural successional pathway (McKenzie, 1988). The study therefore, concludes that even though many authors (Richards, 1952; Myers, 1984, 1989; Mather, 1992; UNCED, 1992; Bradley and Dewees, 1993; Jepma, 1995; GRZ, 1998; Mather and Needle, 2000; Brown, 2001) have outright condemned deforestation and associated it with massive loss of fauna, flora and some high productive forest ecosystems, single tree selection harvesting has a negative effect on species richness and population status of harvested stands. It can therefore be concluded that single tree selection harvesting may be a disaster at population level although it is non event at stand (community) level as this does not enhance regeneration of the species that are being harvested.

7.5.4 Growth rates of selected Miombo woodland species

The growth rates of Miombo woodland seedlings and shoots have been said to be very low (Lees, 1962; Chidumayo, 1992). Additionally, some Miombo woodland species that occur in other woodland types have been reported to have very low growth rates. For example, Groome *et al*., (1957) and Shackleton (2002) have reported mean annual diameter increment of 4.5 mm and 0.3 -2.8 mm respectively, in their studies of *Pterocarpus angolensis* of South African savannas. This information may support the perception that Miombo woodland may not recover from clearing for either charcoal production or slash & burn agriculture. However, the current study (Chapter 6, Table 6.1) reported the mean annual ring width ranging from 4.4 to 5.6 mm in *Julbernadia paniculata, Brachystegia floribunda* and *Isoberlinia angolensis* in both slash & burn and charcoal regrowth stands. In terms of diameter increment, this translates to be ranging from 0.9 to 1.1 cm per year. According to Geldenhuys (2005), a mean diameter increment of 1 cm indicates very productive Miombo regrowth. The higher mean annual width values in the current study than those observed by Chidumayo (1988) in his long term studies of diameter increment of Miombo canopy species confirms Geldenhuys (2005)'s observation in the productivity of Miombo woodland. It can therefore be concluded that the trees which develop from either slash & burn agriculture or charcoal regrowth stands are more productive than those that develop under the canopy of mature woodlands. It may be concluded that trees in regrowth stands will reach merchantable sizes faster than those in mature woodlands. The current data may be supplemented with other growth rate data for trees of known age or measuring larger trees over time to plan cutting rotation in Miombo woodlands.

7.6 Integrating different disturbance factors into sustainable management of Miombo woodland

The realization of the importance of Miombo woodlands to the livelihood security of rural people (Chapter 2) is a key to integrating livelihood needs and environmental security. The national planning sectors in Zambia have not adequately integrated timber harvesting by concessionaires, land use practices of rural communities, Miombo woodland conservation and environmental security in general. Rural economics is mainly based on the premises of charcoal production, slash & burn agriculture and to some extent timber production. These activities are on the increase and the result has been accelerated deforestation from slash & burn agriculture and charcoal production. Currently, the deforestation rate in Zambia is estimated to range from 250, 000 to 300, 000 hectares per annum (MENR, 2002). Slash & burn agriculture and charcoal production activities have increased in Zambia like in many other parts of the Miombo ecoregion. Kaimowitz (2003) attributes the increase to the fact that the economy of the Miombo ecoregion is growing slowly with the per capita income growth rate of as low as 0.1 % between 1990 and 1999. It is a reality that the stand structure of mature Miombo woodland is changed due to either slash & burn agriculture or charcoal production over large areas, and the rate at which this takes place, is too fast and uncontrolled. However, this study has shown that both charcoal production and slash & burn agriculture may be incorporated disturbances as clearing of up to 3.5± 0.4 ha and 1.9 ± 0.9 ha for slash & burn agriculture and charcoal production, respectively can still support woodland recovery (Chapter 2). But when the large tracts of woodland are cleared for slash & burn agriculture and charcoal production, these tend to be a disaster for the Miombo woodland. Hence sustainable management of Miombo woodland and its ecosystems should incorporate controlled slash & burn agriculture and charcoal production with single tree selection timber harvesting to provide adequate regeneration of harvested species.

7.6.1 Zonation of forest resource area into management classes

The integration of single tree selection harvesting, slash & burn agriculture and charcoal production in Miombo woodland should involve zoning the forest resource area into management classes. This is because different resource use management systems have to be applied to each of the woodland/forest types (Geldenhuys, 2005). The zonation requires that Miombo vegetation units are mapped into management classes of timber, poles, charcoal, fruits and protection, and should consider the requirements of adjacent rural farmer and village needs.

Timber and pole production

Both slash & burn and charcoal production result in enhanced seedling/recruitment establishment of timber species on termination of the disturbance impacts over an area (Chapters 4 and 5). Therefore, slash & burn agriculture and charcoal regrowth stands may be managed for selected trees of timber species to grow into good-sized trees. Geldenhuys (2005) showed that a number of timber species regenerate well and grow fast in the regrowth stands after abandoning the slash & burn agriculture in Mozambique. Management should involve appropriate silviculture for improved quality of potential logs from young trees in those stands through pruning. Additionally, thinning should also be carried out to enhance the growth of the intended crop (see also Geldenhuys, 2005). During thinning, the thinned out stems can be used as poles for construction purposes. Other silvicultural operations as indicated earlier (section 7.5.2) should also be carried out to enhance the survival of the intended crop. In turn the timber concessionaires can be buying logs from the local farmers who tend young trees on their abandoned farms. This could provide for an additional source of income to the local communities and may change the rate of clearing of the woodland.

Fruit production

Chapter 4 has revealed that *Uapaca kirkiana* and *Anisophyllea boehmii* are among the dominant species in the early stages (2- 6 years) of woodland recovery from charcoal production. These are important fruit species. The use of Miombo woodland as a source of wild fruits by the local communities is an important aspect throughout the ecoregion, namely Zaire (now Democratic Republic of Congo); Tanzania (Mbwambo, 2000) and Malawi (Akinnifesi *et al*., 2006). The use of fruits for income generation has been reported both in Zambia (Chidumayo and Siwela, 1988) and also in other parts of the ecoregion (Campbell, 1987; Olsen *et al*., 1999). This is one of the strategies to meet specific cash needs, as a contingency in case of crop failure (Brigham *et al.,* 1996). Therefore, the integration of fruit production into forest management can enhance financial security among local community members, and also sustainable forest management.

The charcoal regrowth stands can be managed to yield *Uapaca kirkiana* and *Anisophyllea boehmii.* Stand management could involve the control of the dominance of the Miombo ecological species like *Isoberlinia angolensis, Julbernadia paniculata,* etc so that the stand canopy does not close. This is because these species do not grow well under canopy cover.

7.7 Conclusions and recommendations

Firstly, the study has characterized the Miombo woodland in general as being the woodland type that exhibits the bell-shaped size class profile for stems ≥5 cm in dbh. Secondly, the study has also shown that Miombo woodland has ample regeneration (≤5 cm dbh). The bell-shaped size class profile exhibited by the mature Miombo woodland stands (timber harvested and undisturbed woodland stands) is an indication of the forest stands which are dominated by species whose regeneration and recruitment require large canopy gaps to get established and develop. The similarity in size class profiles between timber-harvested and undisturbed woodland stands show that single tree selection harvesting as disturbance on the woodland stands is a *non-event.* However, at population level, single tree selection may be considered to be a *disaste*r as it does not encourage or enhance the establishment of regeneration and recruitment under canopy. This is because the timber species, like many other Miombo canopy species, are light demanding and require maximum exposure to light to develop into poles and trees. Additionally, opening uip of the canopy also may result in reduced competition for nutrients, water and sunlight and therefore enhances regeneration of species. Furthermore, the study concludes that the characteristics of the species of Miombo indicate that they are adapted to recover more effectively and productively from charcoal production and slash & burn agriculture. The precursor species and other species facilitate the recovery of Miombo woodland over time. The study is cognizant of the fact that the drivers of deforestation, such as unemployment and poverty, are prominent in the region. Therefore, as long as causes of deforestation are not incorporated into forest management programs, deforestation will continue and may be difficult to arrest. The study concludes that Miombo woodland management should incorporate and integrate charcoal production and slash & burn agriculture as they are necessary components of the Miombo woodland to which the system is adapted. This should involve working out rotational cycles based on the growth rates of the Miombo woodland species. The study also recommends that there is an opportunity for managing the Miombo woodland for fruit production by manipulating species composition of the charcoal regrowth stands in the early stages of woodland recovery.

The study also realizes its limitations and recommends the need to carry out further research in the following areas to determine

- if the size of the cleared area for either charcoal production and slash & burn agriculture has an influence on the response/recovery of the woodland ecosystem;

- the growth rates of other Miombo woodland species (both either other canopy species and understory species) to enhance the understanding of the system.

7.8 References

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