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Developing integrated silvicultural management systems for woodlands of northwestern Zimbabwe

By

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Declaration

I, Angella Chichinye 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

Angella Chichinye (candidate)

Abstract

Silvicultural management systems based on natural disturbance-recovery processes are fundamental so as to integrate multiple-use practices in the natural tree resources inorder to address local needs and global concerns. The study aimed at developing a new understanding of the *Baikiaea-Guibourtia-Pterocarpus* woodland recovery dynamics when exposed to different disturbances such as single tree selection, harvesting of poles and firewood and cultivation. Four specific objectives were studied to examine different parts of this overall study: Disturbance impacts on the composition and diversity of the *Baikiaea-Guibourtia-Pterocarpus* woodlands of North-western Zimbabwe; Ecological drivers of floristic and structural composition of *Baikiaea-Guibourtia-Pterocarpus* woodland communities; Disturbance impacts on regeneration of key ecological and/or economic species in the *Baikiaea-Guibourtia-Pterocarpus* woodlands; and Age and growth rate determination using growth rings of selected *Baikiaea-Guibourtia-Pterocarpus* species. Variation in floristic composition of recovering *Baikiaea-Guibourtia-Pterocarpus* woodlands was studied in different development stages (from early re-growth to mature woodland). TWINSPAN (TWo-way INdicator SPecies ANalysis) was used for classification of plots from different utilization systems and different development stages into communities. One-Way ANOVA in SPSS Version 21 was used to test for differences in species diversity for the different communities. Detrended Correspondence Analysis (DCA) in the CANOCO ordination programme was used to determine the extent of variation amongst the identified communities. Correspondence analysis in SPSS Version 21 Statistical Package was performed to analyse grain status for nine tree communities. Stem diameter class profiles were analysed in STATISTICA version 7 to determine the ratio of regeneration to mature trees of individual canopy tree species across tree communities**.** . The research revealed that even if the sites provide a potential for woodland of a specific type to develop, plant community formation is mainly influenced by existing utilization systems. The intense disturbance factors of clearing for crop cultivation and to a lesser extent harvesting for poles and firewood are necessary disturbances for the regeneration and growth of the *Baikiaea-Guibourtia-Pterocarpus* woodlands. The grain status (relative similarity between the composition of canopy species in the regeneration and in the canopy of the same stand) and stem diameter distributions in the different communities suggested that the species require some more intense disturbances, such as with cultivation and harvesting for poles and firewood, to promote regeneration and growth to higher size classes. The study also revealed that disturbances that cause the opening of canopy and more light penetration on the forest floor are required to facilitate sprouting and growth of suppressed shoots in these woodlands. The study concludes that clearing for cultivation and harvesting for poles and firewood are important components to which the woodland ecosystem is adapted and important for the recovery of the *Baikiaea-Guibourtia-Pterocarpus* woodlands. It is recommended that woodland utilization and management should integrate cultivation and harvesting for poles and firewood into forest management. Also, a comprehensive program is necessary to monitor the levels of cultivation and the impacts on woodland recovery. 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 to allow maximum sunlight for the regeneration stock.

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Lastly, I wish to thank the Almighty God for his mercy throughout the study period.

Dedication

This work is dedicated to my children. Let this be an inspiration to you.

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1 GENERAL INTRODUCTION

1.1 BACKGROUND TO THE STUDY

The most extensive vegetation systems in the Zambezian dry deciduous woodlands are the teak woodlands on the Kalahari sands (Piearce 1986; King *et al.* 2000 and Geldenhuys & Golding 2008). *Baikiaea-Guibourtia-Pterocarpus* woodlands, also called the Zambezi teak woodlands, are part of the Zambezian Regional Centre of Endemism (White 1983). They belong to the Zambezi dry deciduous forest and the undifferentiated Zambezi woodlands (White 1983; King *et al.* 2000). The *Baikiaea-Guibourtia-Pterocarpus* woodlands cover an extensive area of approximately 265 000 km^2 on the Kalahari sands of north-western Zimbabwe, north-eastern Botswana, north-eastern Namibia, south-western Zambia and south-eastern Angola (King *et al.* 2000; Timberlake *et al.* 2010). In Zimbabwe, they are confined to the north-western parts of the country, in Gwaai, Mbembesi, Ngamo, Gwampa, Mzola, Tsholotsho and Fuller forests. The woodlands grow slowly, and are adapted to infertile, deep Kalahari sands. Kalahari sands are deep sands that comprise deep unconsolidated Tertiary Sands of Aeolian origion (Nyamapfene 1991). The sands are strongly uniform physically and chemically. They comprise <10% of clay and silt, thus have a low water holding capacity.

Baikiaea plurijuga Harms (umkusi, Rhodesian teak) is the dominant tree species in these woodlands. It usually grows in association with *Pterocarpus angolensis* DC (umvagazi, mukwa) and/or *Guibourtia coleosperma* (Benth) J Leonard (umchibi) as the codominant species. Other species may include *Burkea africana* Hook, *Schinziophyton rautanenii* (Schinz) Radel-Sm, *Terminalia* species, mainly *T. sericea* Burch ex DC, *Combretum* species and *Commiphora* species. *B. plurijuga* is a medium sized to large tree 8 to 16m in height (Palgrave 2002). The species has a large, dense and spreading crown. The bark is smooth, pale in young stems and becomes vertically fissured, cracked and brown to grey in color in older stems (van Wyk 2001; Palgrave 2002). The species has leaves that are pinnately compound with four to five pairs of opposite leaflets. *B. plurijuga;* and produces large flowers, dark brown or golden brown buds. The pods are flattened and woody with a hook at the tip tapering to the base. The pods split explosively throwing seeds some distance. The wood is dark red brown in color and is even textured, hard, strong and durable (Palgrave 2002).

Guibourtia coleosperma is an evergreen tree with a wide spreading crown. It can grow up to a height of 6-20 m (van Wyk 2001; Palgrave 2002). The bark is smooth, cream to pinkish cream, often with dark brown patches to black flakes. In old large trees, the whole trunk sometimes appears dark blakish brown, rough and flaky. The leaves have sickle shaped pair of leaflets. The species produces small white star shaped flowers about 10 mm in diameter (Palgrave 2002). The fruit is small, almost circular up to 2 to 3cm long, flat but thickened pod which turns brown when mature. The seeds and arils are widely used as food in Botswana and Zambia. The wood is soft pinkish brown and is utilized commercially (van Wyk 2001; Palgrave 2002).

Pterocarpus angolensis is a medium sized to large tree up to 16m in height but can reach 20m. The species has a wide spreading flattened crown (van Wyk 2001). The bark is dark grey to brown, rough and fissured. The leaves have 5 to 9 pairs of sub opposite to alternate leaflets. The flowers are orange-yellow, pea shaped in large, branched sprays. When cut, it exudes a red, sticky and blood- like sap that leaves a permanent stain on clothes and therefore makes an effective dye (Palgrave 2002). The wood is fairly light but is the most favoured in the furniture making industry. It can also be used for producing sculptures of wild animals in the curio industry (van Wyk 2001).

Disturbance plays a major role in determining the structure and composition of the southern African deciduous woodlands composed of different tree species, with different strategies for regeneration, establishment and growth. The species respond differently to disturbances such as fire, herbivory and logging. The total species composition in the indigenous woodlands reflects the natural disturbance-recovery processes. The resource is usually utilized in ignorance of the natural disturbance-recovery processes and species adaptations to survive the natural processes. How do we develop sustainable forest management systems for deciduous woodlands in Southern Africa composed of a variety of tree species, with different strategies for regeneration, establishment and growth of these ecosystems? There are many arguments around sustainable forest management and climate change adaptation and mitigation. In essence, we need sustainable forest management and integrated multiple uses of the natural tree resources so as to address the local needs and global concerns. This prompts the need to come up with integrated silvicultural management systems based on the disturbance-recovery processes that can be used to improve population status of the key ecological and economical species of these systems. Disturbances such as fire, herbivory, deforestation among others continue unchecked; and yet very little is known about the disturbance-recovery processes in these woodlands, except that fires cause a lot of damage in the woodlands. The disturbance-recovery processes are said to be the key elements in developing silvicultural management systems that can help improve the management of the woodlands (Geldenhuys 2011). It has been noted that the world forests and woodlands have declined greatly in extent and health conditions, almost entirely as a result of anthropogenic disturbances and poor forest management strategies (White 1983; Ferguson1996; Geldenhuys 1997, 2003). Climate change is also said to worsen the situation especially by affecting forest productivity of juveniles and sub-adult trees (IPCC 2007; IUFRO-FORNESSA 2012). It has been noted that most of the African forests and woodlands are under severe pressure from harvesting of a diversity of products (Geldenhuys *et al.* 2011). Over the past years, people and timber industries have been using forests and woodlands for economic and social gains in an unsustainable way knowingly or unknowingly with no silvicultural management. This is done at the expense of the welfare of the present and future generations.

1.2 HISTORY OF RESOURCE USE/TENURE

Existing resource use categories in the study area include: gazetted forests where timber harvesting by concessions occurs, agricultural land consisting of mainly farm lands under cultivation, sport hunting, ecotourism and communal lands (Table 1.1). The Forestry Commission is a parastatal organization under the Ministry of Environment and Tourism that is responsible for the management of all forest resources in the country. The Forest Act of 1949 is used as the main legal instrument for the management of the woodlands. It is used in conjunction with other pieces of legislation such as the Parks and Wildlife Act of 1975, Communal Lands Act 1982, Communal Lands Forest Produce Act 1928 and the Rural District Councils Act (JAFTA & Forestry Commission 2001).

Different user groups obtain a variety of products from the woodlands, mainly through a permit system (Shumba 2001; Mudekwe 2006). Permits are obtained from the Forestry Commission (state owned) or Rural District Council (communally owned). The products include poles, thatch grass, fuel wood, grazing land, timber for small scale furniture industries and wood carving. Sometimes the products are harvested illegally (collecting products without a permit). The permit would usually state what is to be harvested, how much could be harvested and where the product should be harvested. Large populations of women are also dependent on these ecosystems for the collection of wild fruits, vegetables and relish that can be processed and sold to the urban markets for income generation.

Settlements and agricultural lands are found along Gwayi and Bembesi river valleys due to availability of water supplies, occurrence of fertile soils and better grazing land. Woodlands growing on the Kalahari sands are the main source of timber, thatching grass, and firewood, poles for fencing of farmlands and houses and grazing area for livestock (Shumba 2001; Mudekwe 2006). Exploitation of timber in the woodlands began in the 1890s to supply mines and railways with railway sleepers (Shumba 2001). However this operation became so extensive that regulation became necessary, leading to the birth of the Forest Act in 1949 and demarcation of some forest reserves as gazetted forests in 1954. Timber harvesting in the woodlands is based on a 60-year cutting cycle. The first cutting cycle was from 1910 to 1970. Currently the woodlands are in their second cutting cycle, i.e. from 1971 to 2030. Timber harvesting was and still is selective and is concentrated on three commercial species: *B. plurijuga*, *G. coleosperma* and *P. angolensis.* Various timber harvesting concessionaires have operated in the woodlands mainly taking these three species. Timber concessions are contractual agreements with the Forestry Commission if operating in the gazetted forests; with the commercial farmer with supervision from the Forestry Commission if operating in the private farm or with the Rural District Council with supervision from the Forestry Commission if the operation is in a communal or resettlement area (Mudekwe 2006). A legal framework of licensing for periods not exceeding ten years regulates the concession system (Mudekwe & Mushaka 2004).

When the indigenous woodlands were gazetted, some of the original inhabitants were left in situ as tenants who also provided labour for the Forestry Commission. However, the population of the forest tenants has drastically increased as people continue to settle inside the forest areas (Shumba 2001). The illegal settlement of the people in the gazetted forests has resulted in uncontrolled and unplanned cultivation of land; rampant soil erosion caused by overgrazing, clearing forest for construction and agricultural purposes; and poaching of forest products such as timber and wildlife (Shumba 2001). The fields are abandoned after years of cultivation when they are old and can no longer produce sufficient yield.

Table 1.1: Land use vs. land tenure in the deciduous *Baikiaea-Guibourtia-Pterocarpus* woodlands in Zimbabwe

Land use	Land tenure (ownership)*		
	State	Private	Communal
Timber concessions	xxx	x	xx
Pole harvesting		xx	xxx
Fuel wood harvesting	xx	xx	xxx
Cropping	xx	xxx	xxx
Non-wood forest products	xx	xxx	xxx
Hunting	xxx		
Ecotourism	xxx		
Protection	xxx		

*** X = Present; XX = Common; XXX = Dominant**

1.3 MOTIVATION AND PHILOSOPHICAL ARGUMENT

The indigenous woodland ecosystems are managed as one super organism with the assumption that all species have the same requirements and therefore respond similarly to disturbances. The current management systems ignore the ecological requirements of key species in the woodlands. (Walker 1985; Frost *et al.* 1986 and Scoones 1990) emphasized the importance of considering the possible responses to disturbance of ecosystems as a whole, as well as the individual species within them. Knowledge of the requirements of key species is of paramount importance in ensuring proper management of the species/ecosystems and continued existence of the species for future generations. Also, sustainable resource management of a specific forest requires that its biodiversity (species composition and stand structure) and ecological processes be maintained to ensure sustained resource use (Geldenhuys 2009). The silvicultural management practices that are applied in the woodlands are not aligned with the ecological requirements of the key species (Geldenhuys 2010). It is not known whether the current harvesting rates match the regeneration rates and potential of the key species. Over the years there has been a reduction in stocking densities of *P. angolensis* and *G. coleosperma*. A different species *B. plurijuga* with a different market has been seen to be taking over in these woodlands. This was a result of the change in silvicultural practices that resulted in control of fires in the woodlands (Geldenhuys 2009). Control of fires resulted in the reduction of stocking densities of *P. angolensis* (a fire tolerant species) and an increase in stocking densities of the fire sensitive *B. plurijuga*. The decision could have been implemented without a clear understanding of the role of fire on the growth and regeneration of some of the key species in these woodlands.

Many ecologists and environmentalists have concluded that disturbances are bad and should by all means be avoided. However it is important to note that this study is not advocating for rampant destruction of the woodland ecosystems. A change in perception and attitude on woodland management should be encouraged, from that disturbances are bad towards considering that they are important components of woodland management to rejuvenate the regeneration and growth of the *Baikaiea-Guibourtia-Pterocarpus* woodland ecosystems. Many authors (Mather 1992; Bradley & Dewees 1993; Mather & Needle 2000; Gambiza 2001and Dube 2005) have condemned disturbances, especially deforestation, as it leads to massive loss of biodiversity. These observations and conclusions have led to the formulation of a variety of policies and acts that protect woodland and forest ecosystems from interference by local communities. In Zimbabwe, the woodlands were declared gazetted in 1954 as a result of massive deforestation that occurred during the construction of the Bulawayo-Victoria Falls railway line in the early 1900s. Single tree harvesting is now practiced during harvesting operations. Many ecologists and foresters perceive single tree harvesting as the best harvesting system as it leads to minimal negative impacts on forests and woodlands. Several authors (Nduwamungu & Malumbu 1997; Grundy & Cruz 2001; Luoga *et al.* 2002 and Mudekwe 2006) reported on the negative impacts of single tree harvesting of the Miombo woodlands. They argued that single tree harvesting allows very little to no regeneration of the canopy species, under the canopy of the standing trees. The timber species do not regenerate well under the canopy because they require high light intensity to develop and grow (Lees 1962). However, it should be noted that increased light intensity does not only promote growth of regeneration in the canopy gaps, but that of grasses and thickets as well. The growth of grasses in the canopy gaps would result in increased fuel load and hence increase the fire hazard. Fire is one of the disturbances that have been blamed for the destruction of woodland ecosystems (Piearce 1986). The studies revealed that the commonly harvested species exhibited unstable population structures. Boaler (1966); Werren *et al.* (1995); Graz (1996) and Syampungani (2009), have reported that *P. angolensis* performs well in previously cleared areas.

A number of reports and papers presented at conferences, in proceedings (Victoria Falls 1992 (Piearce & Gumbo 1993; Piearce 1993, Zambia) and from research (Piearce 1986; Gambiza 2001; JAFTA & Forestry Commission 2001; Mufandaedza 2002 & Dube 2005) have expressed the need for interventions to save the *Baikaiea-Guibourtia-Pterocarpus* woodlands as a result of reduction in extent and stocking densities of key species in these woodlands. The few studies that have been carried out in the woodlands did not focus on individual species development and change over time. Additionally, the studies did not compare the impacts of different types of utilization (timber harvesting, harvesting for poles, firewood and cultivation) over time to provide for the integration of these utilization aspects into *Baikaiea-Guibourtia-Pterocarpus* woodland management programmes. There is no management framework/system/guideline that has been developed to improve the regeneration, recruitment and growth of these woodlands despite the concerns that have been raised.

Therefore, the important questions that need to be answered in relation to woodland/forest management are as follows: what kinds of resource use management strategies are good for the *Baikiaea-Guibourtia-Pterocarpus* woodlands? Does selective tree harvesting of timber species suppress regeneration of the canopy tree species under the remaining canopy? Does clear felling for cultivation and/or harvesting for poles and firewood enhance regeneration?

1.4 OBJECTIVES OF THE STUDY

The overall objective of the study was to develop generalised and integrated silvicultural management systems for the sustainable management of the *Baikiaea-Guibourtia-Pterocarpus* woodlands based on the ecological processes of disturbance-recovery. The envisaged silvicultural systems should improve the regeneration and growth of the ecologically and economically important species in the woodlands, and maintain the plant diversity and productivity of these woodlands. This would ensure the continued existence of the woodlands and hence the continued supply of resources (timber, poles, thatch grass, fodder, and fruits) to all sectors dependent on the woodlands.

1.4.1 Specific objectives and related questions

Five specific objectives were formulated, each with related questions

Specific objective 1

To assess and compare the variation in the floristic composition of the woodlands over different ages since cessation of resource use activities in the *Baikiaea-Guibourtia-Pterocarpus* woodlands.

Research questions

- How do woodland communities under different disturbance regimes differ in terms of their floristic composition over time?
- How does the growing stock of the woodland vary between tree communities in different disturbance regimes and stand development stages?

Specific objective 2

To assess the ecological drivers of the floristic and structural composition of plant communities and their key ecological and economic species in the woodlands.

Research questions

- What are the ecological drivers of floristic composition of plant communities in the *Baikiaea-Guibourtia-Pterocarpus* woodlands
- What is the scale of the ecological processes in woodland communities based on grain analysis and the population status of key ecological and economic canopy species in different development stages compared to mature woodland?
- What are the regeneration requirements or constraints in determining resource status for the major ecological and economic species?

- What environmental variables drive species composition and stand development potential?

Specific objective 3

To assess the seedling and vegetative regeneration strategies of key economic and/or ecological species under different disturbance regimes.

Research questions

- What are the key regeneration strategies (seed or vegetative regrowth) of the major economic and/or ecological species?
- What are the differences in stem density and height of seedlings/saplings by regeneration strategies (reseeding versus sprouting (coppice) for the key economic and/or ecological species?
- How does stump diameter (small or large) influence the number and height growth of coppices produced for each of the economic and/or ecological species?

Specific objective 4

To determine the age and growth of key economic and/or ecological species in the *Baikiaea-Guibourtia-Pterocarpus* woodlands using annual growth rings.

Research questions

- How reliable are growth rings or stem diameter in age determination of tree species and what fluctuations in growth rate occur over time in the development of trees of different species across the different stand development stages?
- What is the relationship between stem diameter, age of the study sites (period from last disturbance cessation) and the number of growth rings of the economically and/or ecologically important species in the woodlands?

Specific objective 5

To develop silvicultural management strategies and systems for the sustainable and integrated multiple use management of the *Baikiaea-Guibourtia-Pterocarpus* woodlands.

1.5 CONCEPTUAL FRAMEWORK

There is need for sustainable forest management through the maintenance of ecological processes, biodiversity and productivity of the woodlands. Prudent management of the natural woodland therefore requires information on:

i. Variation in the floristic and structural composition of these woodlands.

ii. Interaction of disturbance-recovery processes with the biophysical environment and how this drives the composition of the woodlands and ecological status of the key species.

iii. Regeneration strategies (vegetative or seedling) and survival strategies of each major ecological and economic species.

iv. Ecological status of key ecological and economic species within the vegetation development stages.

The conceptual framework for this study within the *Baikiaea-Guibourtia-Pterocarpus* woodlands under the disturbance factors is presented in Figure 1.1.

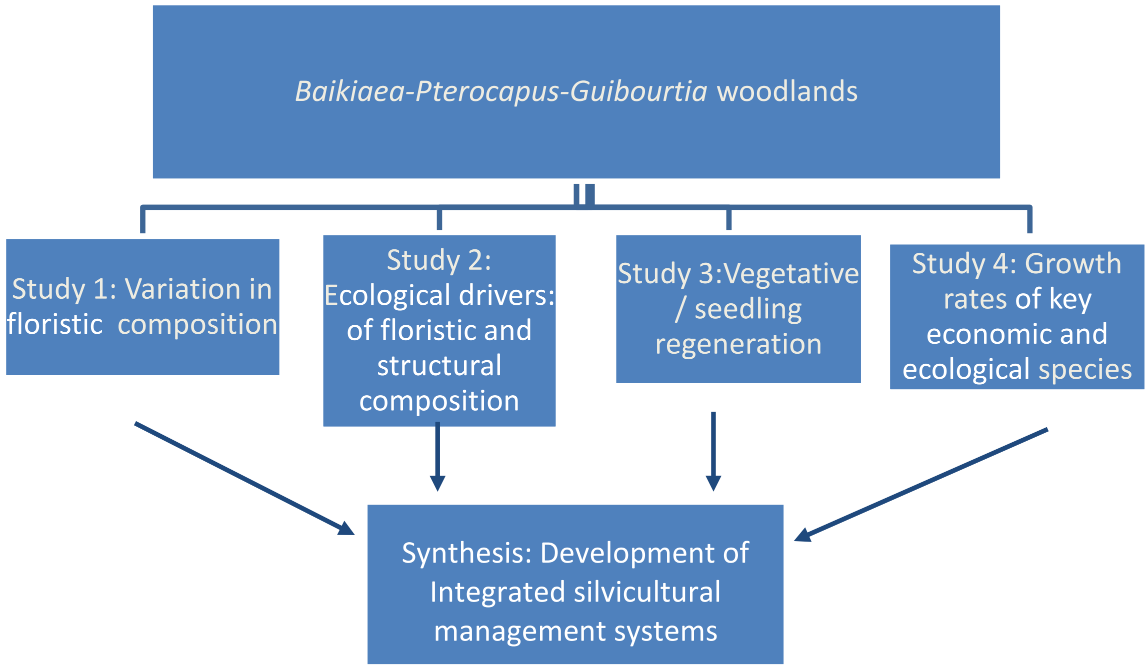

Figure 1.1: Conceptual framework for the study in four disturbance regimes to develop generalized and integrated silvicultural management systems for the *Baikiaea-Guibourtia-Pterocarpus* woodlands.

Different utilization practices in natural woodlands impact on the recovery potential of the woodlands. In order to develop integrated silvicultural management systems, it is important for resource users to understand the functioning of the woodlands as a system, i.e. what are the major ecological drivers and how the species have adapted to respond to these drivers to regenerate and grow. Human disturbances through resource use should therefore imitate natural disturbances so as to ensure sustainable resource use and management.

1.6 THESIS STRUCTURE

The thesis is divided into six chapters.

- Chapter 1 describes the background to the study, research concept and objectives of the study. Chapters 2 to 5 deals with specific components of the study to address stated objectives:

- Chapter 2: Disturbance impacts on the composition and diversity of the *Baikiaea-Guibourtia-Pterocarpus* woodlands of North-western Zimbabwe.
- Chapter 3: Ecological drivers of floristic and structural composition of the *Baikiaea-Guibourtia-Pterocarpus* woodlands.
- Chapter 4: Disturbance impacts on regeneration of key ecological and/or economic species in the *Baikiaea-Guibourtia-Pterocarpus* woodlands of North-western Zimbabwe.
- Chapter 5: Analysis of growth rings to determine age and mean radial growth of selected *Baikiaea-Guibourtia-Pterocarpus* species.
- Chapter 6 synthesizes the information from chapters 2 to 5 to develop a silvicultural management system for the *Baikiaea-Guibortia-Pterocarpus* woodlands.

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2 DISTURBANCE IMPACTS ON THE COMPOSITION AND DIVERSITY OF THE *BAIKIAEA-GUIBOURTIA PTEROCARPUS* WOODLANDS OF NORTH-WESTERN ZIMBABWE

Abstract

Variation in floristic composition of recovering *Baikiaea-Guibourtia-Pterocarpus* woodlands was studied in different development stages (from early regrowth to mature woodland) under different utilization systems (protected areas, timber harvesting, pole and firewood collection, and abandoned crop fields), in Gwaai and Tsholotsho areas in north-western Zimbabwe. A total of 150 nested concentric circular plots were sampled in four different development stages based on the different disturbance factors. Diameter at Breast Height (DBH) and tree height were recorded by species for all stems of trees with DBH $\geq$15 cm and 5.0 – 14.9cm trees were measured in a 30 m radius concentric plot (0.283 ha) and 11.3 m radius concentric plot (0.04 ha) respectively. Stems <5 cm DBH were counted by species in an inner sub-plot of 5.65 m (0.01 ha) radius. Tree data (stems $\geq$5 cm DBH) and regeneration data (stems <5 cm DBH) by stem counts per species per plot, were used separately to run TWINSPAN (TWo-way INdicator SPecies ANalysis) classifications of species assemblages. Importance values were calculated for all tree species per community. Shannon Weiner diversity indices were calculated for each community and tested for differences using the One-Way ANOVA in SPSS Version 21. Detrended Correspondence Analysis (DCA) in the CANOCO ordination programme was used to determine the extent of variation amongst the identified communities. The classification identified 12 tree communities and 13 regeneration communities, when plots from different disturbance factors were clustered together. *Baikiaea plurijuga* was the most important tree in all tree communities, except where *Combretum collinum* Frescen, *Combretum apiculatum* Sond, *Commiphora mossambicensis* (Oliv) Engl and *Pterocarpus angolensis* were dominant. *P. angolensis* showed low importance in most communities, except for communities from undisturbed sites (mostly mature trees) and abandoned fields (mostly young trees). *B. plurijuga* was most important in most regeneration communities, except in communities dominated by *Baphia massaiensis* Taub, *C. collinum*, *C. apiculatum* and *P. angolensis.* Species diversity differed significantly ($p<0.05$) amongst tree communities. The DCA ordination showed little variation amongst the communities. The cumulative contribution of environmental factors explaining variation in species composition was 22.6% for tree communities and 26.1% for regeneration communities, suggesting that disturbance is the main driver of changes in species composition among other factors.

Keywords: Disturbance, woodland, species diversity, regeneration

2.1 INTRODUCTION

The majority of people in Africa live in rural areas and relies directly on natural resources for their survival. This emphasizes the need for sustainable use of natural resources, a topical issue in many countries (Chidumayo 1993; Piearce & Gumbo 1993; JAFTA & Forestry Commission 2001; Mufandaedza 2002 and Mapaure & Ndeinoma 2011). Poor resource use management strategies (White 1983; Ferguson 1996; Geldenhuys 1997, 2003; Mapaure & Ndeinoma 2011) combined with pressures from increasing population densities (Mapaure & Ndeinoma 2011), have led to the decline of many African forest and woodland ecosystems. Southern Africa is endowed with woody vegetation ecosystems, such as Miombo, Undifferentiated and Mopane woodlands, semi-arid shrublands and the southern dry forests (White 1983), that sustain millions of people in rural societies. In Southern Africa, the *Baikiaea-Guibourtia-Pterocarpus* woodlands, within the Undifferentiated woodlands of White (1983), cover an extensive area of approximately 265 000 km² on the Kalahari sands of north-western Zimbabwe, north-eastern Botswana, north-eastern Namibia, south-western Zambia and south-eastern Angola (King *et al.* 2000; Timberlake *et al.* 2010). In Zimbabwe, they are confined to the north-western parts of the country, in Gwaai, Mbembesi, Ngamo, Gwampa, Mzola, Tsholotsho and Fuller forests (Childes & Walker 1987; JAFTA & Forestry Commission 2001).

Gondo & Mkwanda (1991) noted a decline in Zimbabwean gazetted woodlands, mainly due to clearing for agriculture, harvesting wood for fuel and construction, infrastructure development and overstocking of domestic animals. In particular, the *Baikiaea-Guibourtia-Pterocarpus* woodlands are subjected to a number of natural and human disturbances, such as fire, drought, herbivory (especially by elephants, buffalo, antelope), logging for timber, poles and fuel wood harvesting, other non-timber and non-wood forest products, and clearing for crop cultivation (Mutsiwegota & Mudekwe 1998). Piearce & Gumbo 1993 blamed the observed decline of the *Baikiaea-Guibourtia-Pterocarpus* woodlands to anthropogenic disturbances and emphasized that extinction of the woodlands is imminent if intensive exploitation and devastating fires continued unchecked. Mufandaedza (2002) stated that the management of these woodlands is difficult because of the presence of settlers within the woodlands whose practices are against forest demarcation (setting aside woodland areas for conservation and timber production) and protection. Different user groups harvest a variety of products from the woodlands, mainly through a permit system. Permits are issued by the Forestry Commission (state owned land) or Rural District Councils (communally-owned land). The products include poles, fuel wood, thatch grass, grazing, timber used by rural communities for small scale furniture industries, and wood carving. Sometimes the products are harvested illegally.

No harvesting operations (for commercial or subsistence purposes) are allowed in the protected areas. Timber harvesting by concession companies is conducted in the gazetted forests and also in communal areas. Timber is harvested in a single-tree selection system that is based on variable diameter limits for different species. For example, cutting diameter limits are 31 cm DBH (stem diameter at breast height that is 1.3 m above ground level) for *P. angolensis* and 25 cm for any other species. Trees with straight stems of good form are usually selected for harvesting, whereas deformed, damaged or diseased trees are left behind. Trees are usually cut with chain saws 15 cm above the ground. The selective cutting of individual trees leads to the creation of relatively small, open canopy gaps.

In Tsholotsho communal areas (refer to figure 2.1), tree harvesting is allowed through an open-access regime for domestic and commercial use. Trees of different sizes are cut, using axes at different heights for various purposes (fuel wood, construction, fences, and curios.) (Matose 2002). Large canopy gaps are usually created if groups of trees are removed (personal observation). Forest settlers, living inside the forest reserves, grow maize, sorghum and other crops on their fields. After the harvesting season, the crop residues from maize are collected and fed to cattle during the dry season. Some farmers leave the debris on the field floor so as to add nutrients to the soil while others burn the debris. The agricultural fields are usually abandoned after many years (40 years or less) of cultivation. Fields are abandoned when they are old and are not producing much yield (Mutsiwegota & Mudekwe 1998). Trees of different species grow on abandoned fields from seed or sprouting from cut or damaged stems or rootstocks (personal observation).

Disturbances have played a major role in determining the structure and composition of ecosystems (Sousa 1984). Geldenhuys (2011) stated that the interaction between the regime (frequency, intensity, season and area of impact) of a particular disturbance and the habitat within which a suite of species live, determines how the species adapt to survive in that particular environment. This contributes to the vegetation and biodiversity patterns in ecosystems within similar landscapes. Thus, the main type of disturbance becomes the driver of the system, and changes the potential of a site based on habitat features into reality of current patterns. The deciduous woodlands are generally driven by tolerance to fire in the dry season, but adaptation to grazing/browsing is an important secondary driver in most woodland ecosystems (Geldenhuys 2011). The species of all vegetation types therefore generally represent adaptations to different disturbance regimes and also form part of different recovery stages of the vegetation.

Childes & Walker (1987), in a study of the woody vegetation on Kalahari sand deposits in Hwange National Park, suggested that depth of sand and soil moisture regime determined overall vegetation structure, with well developed, mature *B. plurijuga* woodlands on deep sands, and scrub *Terminalia sericea* and mixed woodland on soils with a higher clay content or compact layer. They found the central groups of stands of mixed woodlands and scrub, were less easy to interpret, possibly because of previous logging disturbance, that regeneration of *B. plurijuga* may be inadequate, that elephants had only a minor effect on change in the woodlands, and that fire is a dominant feature in the scrub area and interacts with frost. Syampungani (2009) and Syampungani *et al*. (2010, 2016) compared Miombo woodland recovery in Zambia for over 15years in stands in close proximity to each other (to control for site differences, after cessation of disturbances from land use practices such as charcoal production, slash & burn agriculture and timber harvesting, within protected areas). Recovery of regeneration, plant diversity and productivity was best in charcoal production sites and slash and burn agriculture than in stands of single tree timber harvesting and protected areas, primarily because most of the species are light demanding and require maximum exposure to sunlight to grow fast.

Five woodland stand development stages, from cessation of disturbance to mature woodland, have been identified as basis for selective stem thinning and branch pruning in Miombo Woodlands (Geldenhuys 2014). The stages in this development process are primarily based on stem density and stand height. Stage 0 represents the early regrowth after clearing or crop cultivation. Stage 1 is the early regrowth with short multi-stem plants (<2 m height), and it develops through Stages 2 and 3, with growth focused on fewer stems associated with self-thinning of the initial many young pole-sized stems, towards mature trees with more umbrella-shaped crowns (Stage 4). Silvicultural actions (thinning and pruning in stages 1 to 3, and clear-felling in stage 4) and potential use of removed stems and branches vary with stand development stage. Such identification and definition of stand development stages had not been done for *Baikiaea-Guibourtia-Pterocarpus* Woodlands.

We therefore need to understand how different resource use practices, including protection, affect the species composition (diversity), structure, regeneration and growth of the *Baikiaea-Guibourtia-Pterocarpus* woodland ecosystems, to develop better management strategies. The findings from such studies would contribute to the body of knowledge on woodland recovery and management under different disturbance factors, to ensure availability of the woodlands to future generations. Prudent management of the natural woodland therefore requires information on variation in the floristic and structural composition of these woodlands.

The main objective of this study was to explore the floristic variation of four stand development stages under different disturbance regimes (timber harvesting, pole and firewood collection, and crop fields under recovery) when compared with protected areas. The following research questions guided the data collection and analyses:

(i) How does species composition and species diversity vary across stand development stages within the different disturbance regimes?

(ii) What underlying factors influence species composition differently than disturbances caused by utilization systems?

2.2 MATERIALS AND METHODS

2.2.1 Description of study area

The study was conducted in the Gwaai and Tsholotsho indigenous *Baikiaea-Guibourtia-Pterocarpus* woodlands of north-western Zimbabwe (Figure 2.1). Gwaai woodlands (19º16^{1}20 S and 27º56^{1}36E) and Tsholotsho (19º46^{1}00 S and 27º 45^1 00 E) (JAFTA & Forestry Commission 2001) are both located in the Matabeleland North Province at an altitude ranging between 1010 and 1055 m. Kalahari sands (uniform, both physically and chemically) cover the bulk of the study area. They belong to the regosol group in the amorphic soil order (Nyamapfene 1991, as cited by Gambiza 2001). The underlying geology is of sedimentary rocks overlying Karoo basalt and sedimentary deposits (JAFTA & Forestry Commission 2001). Mean monthly temperature ranges from 15°C (June to September) and 25°C (October to December) (Nyamapfene 1991;

JAFTA & Forestry Commission 2001). A short and erratic wet season usually characterised by dry spells and sporadic droughts is reported for this area (Nemarundwe & Mbedzi 1999).

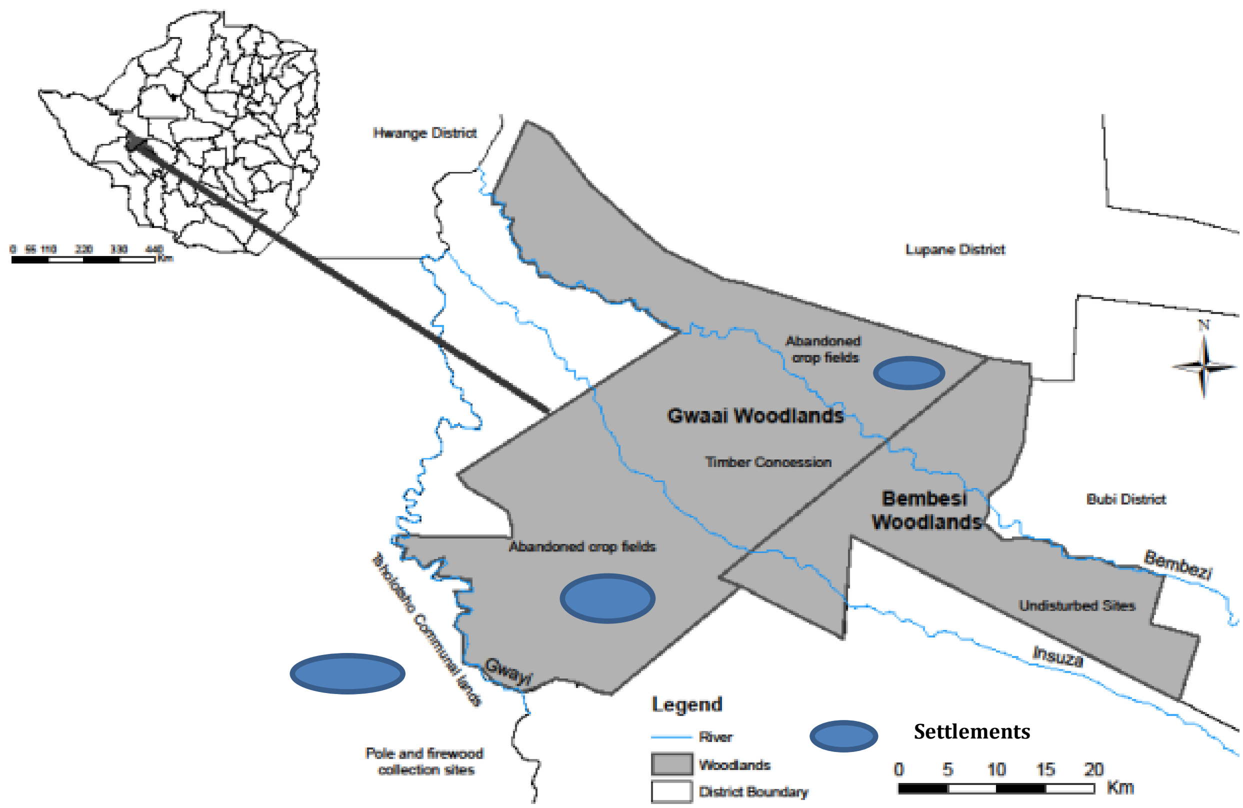

Figure 2.1: Location of *Baikiaea-Guibourtia-Pterocarpus* woodlands of north western Zimbabwe. The blue ovals indicate where settlements are found in the study area.

The area is characterised by six main vegetation types (JAFTA & Forestry Commission 2001): *Baikiaea-Guibourtia-Pterocarpus* woodland mainly occurs as closed to open woodland on the Kalahari sands. *Brachystegia* woodland mainly occurs along the upper Bembesi river (shallower soils and contains more silt). *Colophospermum mopane* (Kirk ex Benth.) J Leonard woodland is characterized by either stunted or multi-stemmed *C. mopane* trees. The woodland is mainly found along rivers or river valleys on alluvial soils that are poorly drained and highly erodible (JAFTA & Forestry Commission 2001). Vleis (a grassy or marshy wetland, mostly covered by water during the rainy season) are dominated by a single layer of grasses. Trees may be absent, or occur isolated along vlei fringes (JAFTA & Forestry Commission 2001). *P. angolensis* (in association with *B. africana*) belts occur as localised stands inside the *Baikiaea-Guibourtia-Pterocarpus* woodlands. *G. coleosperma* woodland is mainly characterised by the dominance of *G. coleosperma* and scattered *B. plurijuga* trees.

2.2.2. Methodology

2.2.2.1 Data collection

Four resource use types were identified: protected area (PA – no utilization of the woodlands is allowed), single-tree timber harvesting in concession areas (CA), pole and firewood collection (PFC), and abandoned crop fields under recovery (AF). Protected area, concession area and abandoned field sites were located in Gwaai woodlands and Pole and firewood collection sites were in Tsholotsho communal woodland areas. Four stand development stages were identified in each disturbance regime, based on the age and height of the vegetation. Stand age was based on the time since cessation of disturbance of the vegetation. The information on age was obtained from Forestry Commission, Rural District Council and local communities records. The development stages were pre-determined using height as the main criterion. Stage 1 height was <2 m; Stage 2 height was 2.1-5 m; Stage 3 height was 5.1-8 m; and Stage 4 height was >8 m.

In each area selected for sampling (disturbance factor x stand development stage; with four mature stands in protected areas), five points each were sampled along two parallel 500 m long transects, with inter plot distance of 100 m along transects.

Four tree size categories were defined for sampling: Seedling, <1 m height; Sapling, 1 m height to <1 cm DBH; Pole, 1-5 cm DBH; and Tree, ≥5 cm DBH.

Three nested circular plots, around the same center point, were used to sample trees by size categories: a main plot of 30 m radius (0.283 ha) to record trees ≥15 cm DBH by species, DBH and height; an intermediate plot of 11.3 m radius (0.04 ha) to record trees 5.0-14.9 cm DBH by species, DBH and height; and an inner plot of 5.65 m radius (0.01 ha) to count stems of seedlings, saplings and poles by species. A caliper was used for measuring DBH and a clinometer was used for measuring tree height. Information was collected on relevant environmental variables for each plot to relate floristic and structural composition of a stand with causal factors: altitude and aspect, using a GPS; slope, using qualitative scoring (1 = flat terrain; 2 = gently sloping) and soil depth, using a soil auger. Other variables such as soil properties (soil texture, soil nutrients, soil pH) and wood properties were not assessed in this study. These could also be potential sources of variation in plant community formation. In general, the sampled sites were all in similar parts of the landscape.

2.2.2.2 Data analysis

Classification: The TWINSPAN (TWo-way INdicator SPecies ANalysis) programme package of Hill (1979) was used to classify the tree (stems ≥5 cm DBH) and regeneration (stems <5 cm DBH) using the number of stems of a species in each plot. *B. plurijuga* was subdivided into three surrogate species (subsets of stems of the same species representing different diameter classes), based on stem diameter: *B. plurijuga* class 1 = 5-10 cm DBH, *B. plurijuga* class 2 = 10.1-30 cm DBH and *B. plurijuga* class 3 = >30 cm DBH. This was done to differentiate plots containing *B. plurijuga* with a high number of stems <5 cm DBH from plots with a low number of stems >30 cm DBH. This meant that *B. plurijuga* could be represented by three surrogate *B. plurijuga* species in a nested plot. The number of species therefore increased from 46 to 48. Within the analysis, TWINSPAN created pseudospecies, for each species in the dataset, based on the abundance of a species in a plot, and in this analysis the cut levels for the different pseudospecies were: 0, 3, 5, 15 and 25. The cut level defines the value that must be exceeded for a pseudospecies to be present: pseudospecies 1 = 1-3 stems/plot; pseudospecies 2 = 4-5 stems/plot; pseudospecies 3 = 6 to 15 stems/plot; pseudospecies 4 = 16-25 stems/plot; pseudospecies 5 = >25 stems/ plot.

Importance values of each species in each community identified in the classification (step one) were calculated using the following formulas:

For plants with DBH ≥5 cm: Importance Value (IV) = (Relative Frequency (RF) + Relative Density (RD) + Relative Basal Area (RBA))/3, where

> **Relative Frequency** = <u>(Number of plots in which a species is present) x 100 / </u>Total number of plots recorded, in particular community

> **Relative Density** = <u>(Number of stems recorded for the species) x 100 / </u>Total number of stems recorded for all species, in particular community

Relative Basal Area = (Basal area of a species in a plot) x 100 / Total basal area of all species in all the plots, in the particular community.

For plants <5 cm stem DBH: Importance Value (IV) = (Relative Frequency (RF) + Relative Density (RD))/2, where

Relative Frequency = (Number of plots in which a species is present) x 100 / Total number of plots recorded, in particular community

Relative Density = (Number of stems recorded for the species) x 100 / Total number of stems recorded for all species, in particular community

Shannon Weiner diversity index was calculated for each community using the formulae:

$$\hat{H} = -\sum p_i \times \log p_i$$

Where p_i = proportion of each species

A One-Way Analysis of Variance (ANOVA) in SPSS Version 21 was then performed to test for differences in species diversity across different communities identified from the classification. *Post hoc* analysis for sub communities with significant differences in species diversity was carried out using Tukey's Honestly Significant Difference (HSD).

Ordination: The Detrended Correspondence Analysis (DCA) (CANOCO programme package of Ter Braak (1988) ordination (indirect gradient analysis) was used to show the spatial distribution of plots of the identified tree and regeneration communities in ordination space. No direct gradient analysis was done with the environmental variables collected in the field because they showed little variation across the study sites.

2.3 RESULTS

A total of 150 nested circular plots were sampled, with 40 plots each in abandoned crop fields, in pole and firewood collection sites and in the protected areas (which only had stage 4 or mature stands), with 30 plots in the concession areas. The concession area had no stage 1 stands because there is no clear felling that would allow plants of almost the same height and age to develop, instead selective harvesting is done resulting in small canopy gaps). 146 sampled plots, recorded in the different disturbance regimes and stand development stages, were used in the TWINSPAN classification analyses. Four plots were excluded from the initial 150 plots; they did not aggregate with any community during the initial TWINSPAN analysis. A total of 47 species, representing 36 genera from 18 families, were recorded (Appendix 2.1). The tree data included 46 species, and regeneration data included 31 species. The species aggregated in different associations, as shown in the TWINSPAN classification output tables for tree communities (Appendix 2.2) and regeneration communities (Appendix 2.3).

2.3.1 Species associations in tree stands

2.3.1.1 Classification of tree communities

Three tree communities were identified, with subdivisions into sub-communities, to level 5 for community 2 (Figure 2.2), based on the TWINSPAN output table (Appendix 2.2). The eigenvalues and indicator species at each level of division are shown. Branch 1 of the first division leads to communities 1 and 2 (*Combretum* and *Baikiaea plurijuga* communities respectively), consisting of all undisturbed site plots and most plots from advanced stages (stages 3 and 4) from different disturbance regimes. The indicator species for this branch are *B. plurijuga* 3 and 2 (stems ≥10 cm DBH). Branch 2 (*B. plurijuga* 1) consists of plots from mostly the least developed stages 1 and 2 of different disturbance factors with indicator species *B. plurijuga* 1 (stems <10 cm DBH). Both branches have communities with indicator species seemingly not related to the main groupings with *B. plurijuga*, *G. coleosperma* and *P. angolensis*. The indicator species for *Combretum* community are *Combretum collinum* and *C. apiculatum*, for *Baikiaea plurijuga* 2 & 3 community are *B. plurijuga* 2 & 3 (a mature woodland) and *G. coleosperma*, and for *Baikiaea plurijuga* 1 community is *B. plurijuga* 1 (community of early regrowth stages) (Appendix 2.2). The identified communities are named using both the number following the branching sequence and also using the first 2 or 3 dominant species adopted from Munishi *et al.* (2007, 2011). The community names are shown in Table 2.1.

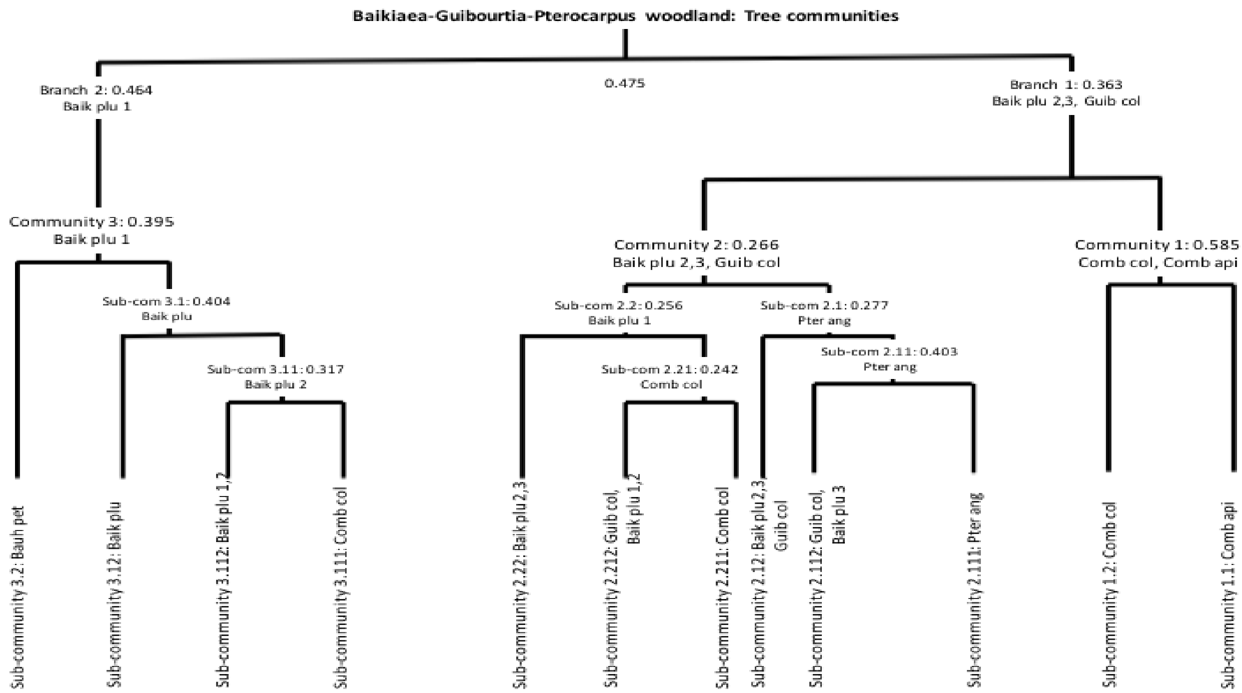

Figure 2.2: Schematic relationships between communities and sub-communities of tree stands in *Baikiaea-Guibourtia-Pterocarpus* woodlands based on TWINSPAN output table (Appendix 2.2). The eigenvalues at each subdivision and indicator species for the sub-communities are shown. See Appendix 2.1 for complete species names.

The relationship of the 12 identified tree communities and sub-communities with the disturbance regime x development stage combinations show that plots from the advanced development stages of different disturbance regimes more likely aggregate with plots from undisturbed sites to form communities (Table 2.2). For example, 60 to 100%; 20 to 44% and 10 to 80% of plots from concession areas, pole and firewood sites and abandoned crop fields respectively aggregated with plots from undisturbed sites.

Table 2.1 Tree plant communities and species associations in *Baikiaea-Guibourtia-Pterocarpus* woodland in northwestern Zimbabwe.

Community		Most dominant species	Importance values (%)
1.1	*Combretum apiculatum* *Dichrostachys cineria* (L) Wight and Am sub community	*Combretum apiculatum* *Dichrostachys cineria* *Kirkia acuminata* Oliv	42.7 11.2 9.8
1.2	*Combretum collinum* *Combretum apiculatum* sub community	*Combretum collinum* *Combretum apiculatum* *Baikiaea plurijuga 1* *Terminalia sericea*	46.9 12.7 6.4 6.3
2.111	*Pterocarous angolensis* *Guiboutia coleosperma* sub community	*Pterocarous angolensis* *Guiboutia coleosperma* *Combretum molle* R. Br ex G Don	54.9 10.3 7.1
2.112	*Baikiaea plurijuga 3* *Guibourtia coleosperma* *Pterocarpus angolensis* sub community	*Baiakiaea plurijuga 3* *Guibourtia coleosperma* *Pterocarpus angolensis*	35.9 29.0 12.7
2.12	*Baikiaea plurijuga 3* *Guibourtia coleosperma* *Baikiaea plurijuga 2* sub community	*Baiakiaea plurijuga 3* *Guibourtia coleosperma* *Baiakiaea plurijuga 2*	25.1 16.9 9.6
2.211	*Guibourtia coleosperma* *Baikiaea plurijuga 2* *Combretum collinum* sub community	*Guibourtia coleosperma* *Baikiaea plurijuga 2* *Combretum collinum*	19.0 17.4 15.1
2.212	*Baikiaea plurijuga 2* *Baikiaea plurijuga 3* *Guibourtia coleosperma* sub community	*Baikiaea plurijuga 2* *Baikiaea plurijuga 3* *Guibourtia coleosperma*	31.9 13.5 13.3
2.22	*Baikiaea plurijuga 3* *Baikiaea plurijuga 2* sub community	*Baikiaea plurijuga 3* *Baikiaea plurijuga 2*	44.5 21.6
3.111	*Baikiaea plurijuga 1* *Baikiaea plurijuga 2* *Combretum collinum* sub community	*Baikiaea plurijuga 1* *Baikiaea plurijuga 2* *Combretum collinum*	22.2 22.1 18.8
3.112	*Baikiaea plurijuga 2* *Baikiaea plurijuga 1* sub community	*Baikiaea plurijuga 2* *Baikiaea plurijuga 1*	45.5 24.4
3.12	*Baikiaea plurijuga 1* sub community	*Baikiaea plurijuga 1*	77.7
3.2	*Baikiaea plurijuga 1* *Bauhinia petersiana* Bolle sub community	*Baikiaea plurijuga 1* *Bauhinia petersiana* *Vangueria infausta* Burch	45.7 20.3 9.5

Table 2.2: Distribution of plots in each tree community across different disturbance regime X stand development stage for trees ≥5 cm DBH

Disturbance regime x Stage combinations	Number of plots by Tree Communities												Total plots
	1.1	1.2	2.111	2.112	2.12	2.211	2.212	2.22	3.111	3.112	3.12	3.2	
Protected area	-	-	-	8	22	3	3	4	-	-	-	-	40
Concession area stage 4	-		-	-	-	-	2	8	-	-	-	-	10
Pole-firewood stage 4	2	2	-	-	-	-	-	4	-	-	1	-	9
Abandoned field stage 4	-	5	-	-	1	2	1	-	1	-	-	-	10
Concession area stage 3	-		-	-	-	-	7	-	1	2	-	-	10
Pole-firewood stage 3	3	2	1	-	-	-	3	-	-	-	-	-	9
Abandoned field stage 3	-	-	1	-	3	2	2	1	-	1	-	-	10
Concession area stage 2	-	2	-	-	1	3	2	-	2	-	-	-	10
Pole-firewood stage 2	-	3	-	-	-	-	1	1	-	2	3	-	10
Abandoned field stage 2	-	2	-	-	-	1	-	-	-	-	6	1	10
Pole-firewood stage 1	-	-	-	-	-	-	-	-	-	-	5	3	8
Abandoned field stage 1	-	-	1	-	-	-	-	-	-	-	9	-	10
Total plots	5	16	3	8	27	11	21	18	4	5	24	4	146

2.3.1.2 Relationship between tree communities in ordination space

The DCA ordination (indirect gradient analysis) shows the spatial distribution of tree communities, sub-communities and their plots in ordination space (Figure 2.3). The respective eigenvalues were 0.607 for axis 1 and 0.442 for axis 2, explaining respectively 8.4% and 5.9% of the variation, indicating a random distribution of species in the communities. The total variation explained by the first four axes was 22.6% (Table 2.3). The display showed *Combretum* and *Baikaea plurijuga* 2&3 communities on the positive side of axis are clearly separated from *Baikiaea plurijuga* 1 community, on the negative side of axis 1. *Baikiaea plurijuga* 1 community is also clearly separated from *Baikiaea plurijuga* 2&3 community along axis 2. *Combretum* species community showed much scatter of the plots, with sub-communities clearly separated along axis 1. *Baikiaea plurijuga* 2&3 community plots are scattered along both axes, with *Pterocarous angolensis-Guibourtia coleosperma* (2.111) and *Baikiaea plurijuga 3-Guibourtia* *coleosperma-Pterocarpus-angolensis* (2.112) sub-communities separated along axis 1, also separated from the other sub-communities in relatively further apart clusters along axis 2. The plots of *Baikiaea plurijuga* 1 community are closely grouped, along axis 1, with a few outlier plots along axis 2, and with a separation between *Baikiaea plurijuga* 1&2 and *Baikiaea plurijuga 1-Bauhinia petersiana* (3.2) sub-communities.

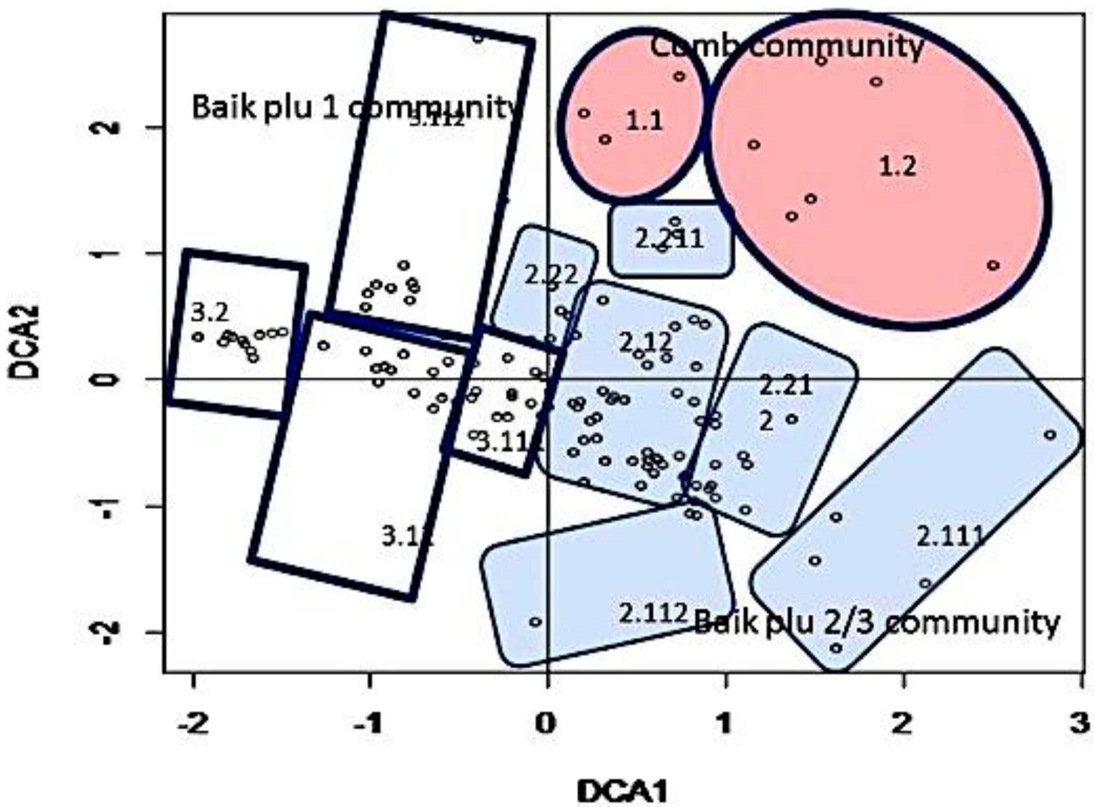

Figure 2.3: DCA ordination diagram of plots for the different tree communities and sub-communities. The community names and sub-community codes are indicated within the different colored blocks. See Appendix 2.1 for complete species names.

Table 2.3: Percentage variance explained for tree communities

Axes	1	2	3	4	Total inertia
Eigenvalues	0.607	0.422	0.378	0.218	7.205
Lengths of gradient (m)	4.795	4.813	6.663	3.401	

Cumulative % variance explained	8.4	14.3	19.5	22.6	

2.3.1.3 Importance of tree species across tree communities

The species with the highest importance value in *Combretum apiculatum-Dichrostachys cineria* (1.1) *sub* community are *Combretum apiculatum* and *Dichrostachys cineria*, and in *Combretum collinum-Combretum apiculatum* (1.2) sub community are *C. collinum* and *C. apiculatum*. These communities were dominated by stages 2 and 3 of different disturbances factors, and had no plots from undisturbed sites. *B. plurijuga* 2&3, *G. coleosperma* had high importance values in most sub communities of *Baikiaea plurijuga* 2&3 and *Baikiaea plurijuga* 1. These sub communities were dominated by plots from undisturbed sites and stages 3 and 4 from different disturbance regimes. *B. plurijuga* 1 had high importance values in all sub communities of *Baikiaea plurijuga* 1sub community which consisted of plots from abandoned fields' and pole and firewood collection sites' stages 1 and 2. *P. angolensis* had a high importance value in *Pterocarpus angolensis-Guiboutia coleosperma* (2.111) sub community that mainly comprise of plots from pole and firewood collection sites and abandoned crop fields' stages 1 and 3.

2.3.2 Species associations in tree regeneration

2.3.2.1 Classification of tree regeneration communities

Four regeneration communities were identified, with subdivision into sub-communities, to level 6 for *Baikiaea plurijuga* community (Figure 2.4), based on the TWINSPAN output table (Appendix 2.3). The eigenvalues at each level of division and indicator species for sub-communities are shown. Branch 1 of the first division leads to *Baikiaea plurijuga* and *Baphia massaensis* communities, consisting of 30% undisturbed site plots and most plots from different land use systems. The indicator species for Branch 1 is *B. plurijuga*. Branch 2 leads to *Combretum* and *Pterocarpus angolensis* communities, consisting of 63% undisturbed site plots and a few from other utilization systems. The indicator species are *Combretum* species and *P. angolensis* (stems <10 cm DBH) respectively. The indicator species for *Baikiaea plurijuga* community is *B. plurjuga*, for *Baphia massaiensis* community is *Baphia massaiensis*, for *Combretum* community are *C. collinum* and *C. molle* (it has no plots from protected areas), and for *P. angolensis* community is *P. angolensis* (it has only 7.5% of plots from undisturbed sites)

(Appendix 2.3). Note that *B. plurijuga* regenerated well in communities that had few plots from undisturbed sites and an aggregation of plots from different disturbance regimes, while *P. angolensis* regenerated well in *P. angolensis* community that had a few plots from undisturbed sites and abandoned crop fields stages 4 (Appendix 2.3). *G. coleosperma* showed poor regeneration in all the identified communities.

Table 2.4: Importance values (%) for species with stems ≥5 cm DBH (with IV values ≥5% in at least one community - highlighted), in the different tree communities in the *Baikiaea-Guibourtia-Pterocarpus* woodlands in north-western Zimbabwe

Community Species*	1.1	1.2	2.111	2.112	2.12	2.211	2.212	2.22	3.111	3.112	3.12	3.2
Comb api	42.7	12.7	-	-	6.7	1.5	-	0.5	-	-	-	-
Comb mol	7.9	4.4	7.1	-	1.6	3.4	2.4	2.0	-	2.1	3.2	-
Comm mos	4.3	4.7	-	-	1.4	4.6	0.4	3.8	9.4	1.6	2.0	
Dich cin	11.2	-	4.6	-	-	-	-	-	-	-	-	-
Kirk acu	9.8	-	-	-	0.7	1.4	-	1.2	-	-	-	-
Schl bir	9.2	1.2	-	-	-	-	-	-	-	-	1.9	-
Schi rau	5.5	-	5.5	4.6	0.4	4.6	1.2	-	5.0	6.4	3.0	-
Zizi muc	6.2	0.9	-	2.8	-	-	1.0	1.9	-	-	-	-
Comb col	-	46.9	-	1.6	5.9	15.1	4.0	3.5	18.8	6.5	-	-
Eryt afr	-	1.6	5.7	1.4	0.5	-	1.4	0.5	-	-	0.9	-
Term ser	-	6.3	5.5	-	0.5	4.9	0.3	0.7	-	7.2	-	-
Baik plu 1	-	6.4	-	1.0	8.3	9.0	11.4	8.3	22.2	24.4	77.7	45.7
Baik plu 2	-	3.5	-	2.7	9.6	17.4	31.9	21.6	22.1	45.5	-	-
Baik plu 3	-	2.6	-	35.9	25.4	13.9	13.5	44.5	10.4	-	-	-
Guib col	-	-	10.3	29.0	16.9	19.0	13.3	1.1	2.4	-	-	-
Pelt afr	-	-	6.4	-	-	-	0.4	-	-	-	-	-
Pter ang	-	-	54.9	12.7	6.1	1.5	4.3	2.3	-	2.1	-	-
Ochn pul	-	-	-	1.4	0.5	1.4	-	0.5	-	-	1.4	8.2
Pseu map	-	1.7	-	4.1	0.7	-	5.7	0.5	-	-	-	-
Bauh pet	-		-	-	0.8	-	1.3	1.2	5.0	-	1.2	20.3
Vang inf	-	-	-	-	-	-	-	-	-	-	0.9	9.5

* See Appendix 2.1 for complete names

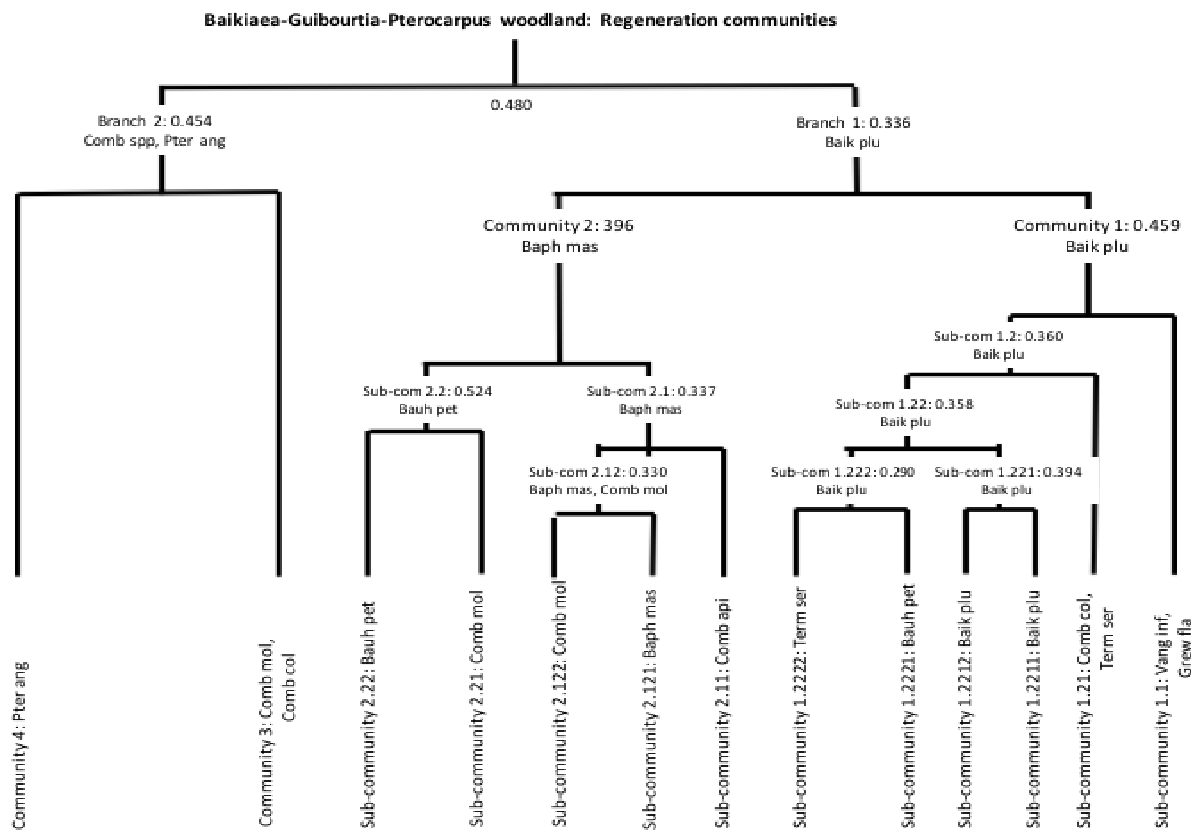

Figure 2.4: Schematic relationship between communities and sub-communities of tree regeneration in *Baikiaea-Guibourtia-Pterocarpus* woodlands based on TWINSPAN output table (Appendix 2.3). The Eigenvalues at each subdivision and indicator species for the sub-communities are shown.

The relationship of the 13 identified regeneration communities and sub-communities with the disturbance regime x development stage showed that plots from advanced development stages of different disturbance factors more likely aggregate with plots from undisturbed sites to form communities (Table 2.6). For example, 60 to 80%; 33 to 88% and 20 to 100% of plots from concession areas, pole and firewood collection sites and abandoned crop fields respectively aggregated with plots from undisturbed sites (Table 2.6).

Table 2.5: Regeneration plant communities in a *Baikiaea-Guibourtia-Pterocarpus* woodland in northwestern Zimbabwe

Community		Most dominant species	Importance values (%)
1.1	*Vangueria infausta* *Grewia flavescens* Juss *Baikiaea plurijuga* sub community	*Vangueria infausta* *Grewia flavescens* *Baikiaea plurijuga*	32.1 22.3 20.7
1.21	*Baikiaea plurijuga* *Terminalia sericea* *Grewia monticola* Sond sub community	*Baikiaea plurijuga* *Terminalia sericea* *Grewia monticola* *Ochna pulchra* Hook	18.4 12.5 11.5 11.0
1.2211	*Baikiaea plurijuga* *Vangueria infausta* sub community	*Baikiaea plurijuga* *Vangueria infausta* *Onchna pulchra*	44.3 17.3 14.2
1.2212	*Baikiaea plurijuga* sub community	*Baikiaea plurijuga*	71.2
1.2221	*Baphia massaiensis* *Combretum apiculatum* sub community	*Baphia massaiensis* *Combretum apiculatum* *Ochna pulchra* *Grewia flavescens*	28.8 24.4 13.8 13.1
1.2222	*Baikiaea plurijuga* *Commiphora mossambicensis* *Bauhinia petersiana* sub community	*Baikiaea plurijuga* *Commiphora mossambicensis* *Bauhinia petersiana*	35.2 18.8 18.1
2.11	*Baikiaea plurijuga* *Pseudolachnostylis maprouneifolia* Pax *Terminalia sericea* sub community	*Baikiaea plurijuga* *Pseudolachnostylis maprouneifolia* *Terminalia sericea*	34.2 13.6 13.6
2.121	*Baphia massaiensis* *Baikiaea plurijuga* sub community	*Baphia massaensis* *Baikiaea plurijuga*	27.4 21.5
2.122	*Baikiaea plurijuga* *Baphia massaiensis* *Bauhinia petersiana* sub community	*Baikiaea plurijuga* *Baphia massaiensis* *Bauhinia petersiana*	25.6 19.0 12.1
2.21	*Baphia massaiensis* *Combretum collinum* *Baikiaea plurijuga* sub community	*Baphia massaiensis* *Combretum collinum* *Baikiaea plurijuga*	21.2 13.8 12.8
2.22	*Bauhinia petersiana* *Baphia massaiensis* sub community	*Bauhinia petersiana* *Baphia massaiensis* *Baikiaea plurijuga*	35.2 21.4 14.1
3.2	*Combretum collinum* *Combretum molle* sub community	*Combretum collinum* *Combretum molle* *Combretum apiculatum*	20.0 19.9 11.8
4.0	*Pterocarpus angolensis* *Combretum apiculatum* sub community	*Pterocarpus angolensis* *Combretum apiculatum*	22.7 12.9

2.3.2.2 Relationship between regeneration communities in ordination space

The DCA ordination shows the spatial distribution of regeneration communities, sub-communities and their plots in ordination space (Figure 2.5). The respective eigenvalues were 0.631 for axis 1 and 0.410 for axis 2, explaining respectively 9.9% and 6.5% of the variation, and the total variation explained by the first four axes is 26.1% (Table 2.5). The display shows a gradient of plots in a relatively central band along axis 1, with *B. plurijuga* and *B. massaiensis* communities overlapping from the center to the left, and *Combretum* and *P. angolensis* communities at the positive end, but separate from each other. *B. plurijuga* communities (lower part) and 2 (upper part) are separated along axis 2. The sub-communities within *B. plurijuga* and *B. massaiensis* communities are seemingly well-separated along both axes 1 and 2.

Table 2.6: Distribution of plots in each regeneration community from different disturbance regimes X stages for stems <5 cm DBH

Disturbance regime	Tree regeneration communities													Total
	1.1	1.21	1.2211	1.2212	1.2221	1.2222	2.11	2.121	2.122	2.21	2.22	3.0	4.0	
Protected area	-	-	-	6	3	3	5	7	6	4	3		3	40
Concession area 4	-	1	1	2	3	2			1	-	-	-	-	10
Pole-firewood 4	-	1	-	3	1	1	1	2		-	-	-	-	9
Abandoned field 4	-	1	1	1	-	-	-	-	-	-	-	4	3	10
Concession area 3	1	-	-	1	5	1		-	2	-	-	-	-	10
Pole-firewood 3	2	1	3	2	-	-	-	-	-	1	-	-	-	9
Abandoned field 3	-	1	1		-		-		-	-	-	6	2	10
Concession area 2	-	3	1	2	-	2		1	-	1	-	-	-	10
Pole-firewood 2	2	1	1	2	-	-	-	-	-	2	-	2	-	10
Abandoned field 2	-	-	-	-	-	1	1	3		2	3		-	10
Pole-firewood 1	-	-	4	4	-	-	-	-	-	-	-	-	-	8
Abandoned field 1	-	-	-	10	-	-	-	-	-	-	-	-	-	10
Total	5	9	12	33	12	10	7	13	9	10	6	12	8	146

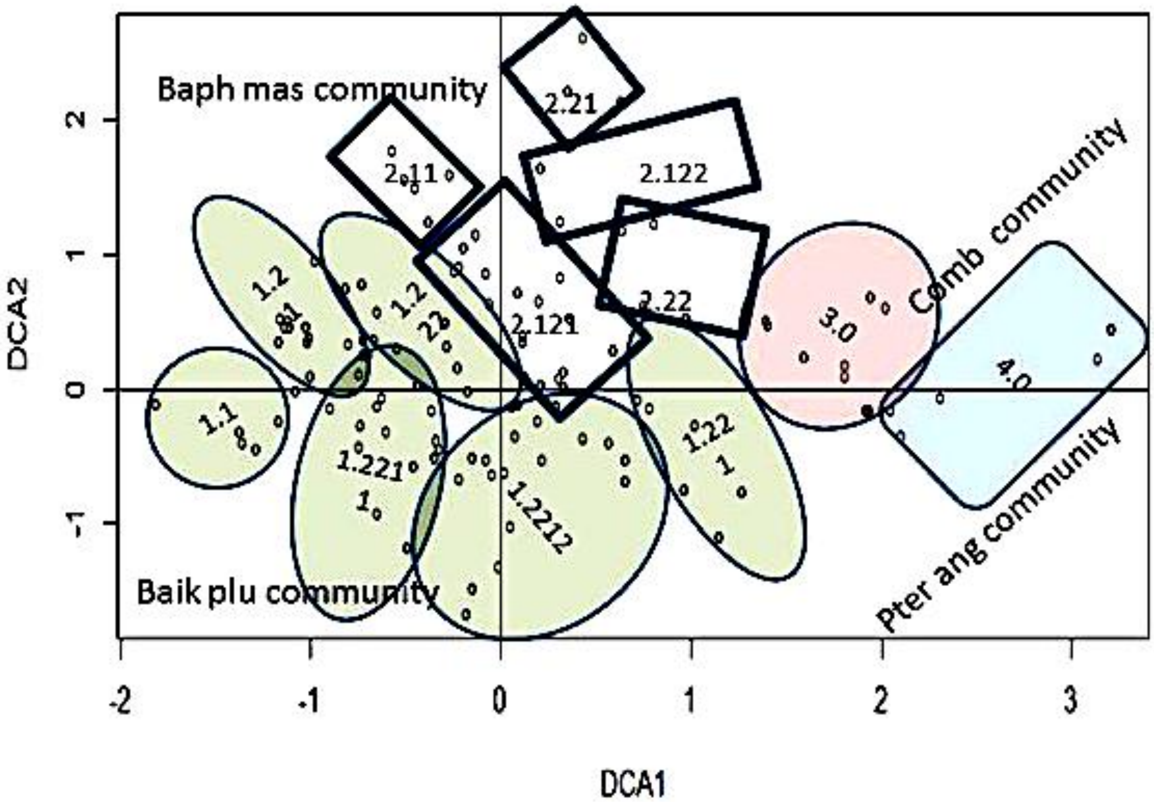

Figure 2.5: DCA ordination diagram of plots for the different regeneration communities and sub-communities. The community names and sub-community codes are indicated within the different colored blocks.

Table 2.7: Percentage variance explained for regeneration communities

Axes	1	2	3	4	Total inertia
Eigenvalues	0.631	0.410	0.351	0.269	6.358
Lengths of gradient	5.014	4.389	4.033	2.968	
Cumulative % variance explained	9.9	16.4	21.9	26.1	

2.3.2.3 Importance of tree species across tree regeneration communities

The species with the highest importance value in *Vangueria infausta-Grewia flavescens-Baikiaea plurijuga* (1.1) sub community are *V. infausta, G. flavescens* and *B. plurijuga*, and in *Baikiaea plurijuga-Terminalia sericea-Grewia monticola* (1.21) sub community are *B. plurijuga* and *T. sericea* (Table 2.8). Note that *B. plurijuga* had high importance values in most sub-communities of community 1 and 2 (a mixture of plots from all utilization systems and undisturbed sites), except *Baphia massaiensis-Combretum apiculatum (*1.221) and *Baphia massaiensis-Baikiaea plurijuga* (2.121) and *Bauhinia petersiana - Baphia massaiensis* (2.22) sub communities. *C. collinum* and *C. molle* had high importance values in *Combtretum* community. This community had no plots from the undisturbed sites but abandoned fields stages 2, 3 and 4. *P. angolensis* and *C. apiculatum* had high importance values in community 4, a mixture of plots from undisturbed sites and stages 3 and 4 of abandoned fields.

Table 2.8: Importance values (%) for species in the regeneration (stems <5 cm DBH) (with IV values ≥5% in at least one community - highlighted), in the different regeneration communities in the *Baikiaea-Guibourtia-Pterocarpus* woodlands in north-western Zimbabwe.

Communities Species*	1.1	1.21	1.22 11	1.22 12	1.22 21	1.22 22	2.11	2.12 1	2.12 2	2.21	2.22	3	4
Acac ata	-	8.8	1.9	-	-	-	-	6.9	2.9	4.3	-	5.4	-
Baik plu	20.7	18.4	44.3	71.2	-	35.2	34.2	21.5	25.6	12.8	14.1	2.1	-
Baph mas	-	-	-	4.6	28.8	2.8	8.1	27.4	19.0	21.2	21.4	-	3.8
Bauh pet	-	5.8	-	-	5.6	18.1	12.0	-	12.1	11.7	35.2	-	2.6
Comb api	-	-	1.9	-	24.4	4.0	-	-	7.7	-	-	11.8	12.9
Comb col	-	10.9	3.9	1.1	-	2.4	1.5	1.4	-	13.8	-	20.0	6.3
Comb mol	-	1.3	2.3	1.1	-	2.0	2.0	12.3	24.6	4.6	-	19.9	10.4
Comm mos	-	-	-	-	-	18.8	-	3.3	-	1.4	-	-	1.7
Ochn pul	-	11.0	14.2	-	13.8	4.8	-	8.6	-	-	7.4	3.4	3.4
Pter ang	-	3.7	-	-	3.1	-	-	-	4.0	-	-	-	22.7
Pseu map	-	5.3	-	-	-	-	13.6	2.6	-	-	-	-	-
Sear ten	14.7	1.3	1.9	3.7	-	-	1.5	-	-	-	-	-	-
Term ser	-	12.5	-	-	-	-	13.6	-	-	10.2	7.5	4.7	3.4
Vang inf	32.1	-	17.3	-	-	-	-	1.4	-	6.4	-	1.6	-
Grew mon	6.0	11.5		3.7	-	-	2.0	-	2.5	8.8	4.8	3.4	-
Grew fla	22.3		2.8	7.2	13.1	1.1	-	8.3	1.6	-	7.5	4.2	5.1
Stry coc	-	-	7.6	-	3.7	1.4	3.5	-	-	-	-	1.0	-
Julb glo	-	-	-	-	7.5	-	-	2.4	-	-	-	-	-
Phil vio	-	-	-	-	-	-	1.5	-	-	-	-	9.3	11.0
Eryt afr	-	-	-	-	-	-	-	-	-	-	-	2.4	5.7
Pelt afr	-	-	-	-	-	-	-	-	-	-	-	-	9.3

* See Appendix 2.1 for complete names

2.3.2.4 Relationship between tree and regeneration communities

Each tree regeneration community occurs in a range of tree communities, and each tree community contains a range of tree regeneration communities (Table 2.9).

Table 2.9: Relationship between tree and regeneration communities in *Baikiaea-Guibourtia-Pterocarpus* woodlands of north-western Zimbabwe.

Tree communities		Regeneration communities												
		1.1	1.21	1.2211	1.2212	1.2221	1.2222	2.11	2.121	2.122	2.21	2.22	3.0	4.0
	Plots	5	9	12	33	13	10	7	13	9	10	6	11	8
1.1	5	1	2		1	1								
1.2	16	2	4	7		1					2			
2.111	3			1		2								
2.112	8						2	2	2			2		
2.12	27					4	3	4	4	1		2	6	3
2.211	11					2	3			1	1		3	1
2.212	21	2	1	3	7	1			1	1	3			2
2.22	18			1	7	1			4	2	2		1	
3.111	4						2		1				1	
3.112	6		2		2			1		1				
3.12	23				16				1	2	1	2		1
3.2	4					1				1	1			1

2.3.2.5 Species diversity across the identified tree and regeneration communities

In general, the tree communities were composed of a larger number of species than the regeneration communities, but species richness also showed much variation within these two categories between the sub-communities (Table 2.10).

The Shannon Weiner species diversity index differed significantly among tree communities (Table 2.10, Analysis of Variance F statistic = 2.462; df = 11; p = 0.007). However, the Post Hoc results indicate that almost all communities had similar species diversity indices except for *P. angolensis-G. coleosperma* (2.111) and *B. plurijuga* 1 (3.12) sub communities. *P. angolensis-G. coleosperma* (2.111) sub community had the highest species diversity index, with plots from stages 1 and 3 of pole and firewood collection sites and abandoned crop fields (Appendix 2.2 and Table 2.2). Communities with plots from undisturbed sites had low species diversity. The lowest species diversity was recorded in *B. plurijuga* 1 (3.12) sub community with plots from young stands under recovery (stages 1 and 2) of pole and firewood collection sites and abandoned crop fields (Appendix 2.3). The differences in Shannon Weiner species diversity index among regeneration communities were insignificant (Table 2.10, Analysis of Variance F statistic = 1.681; df = 12; p = 0.07). The Post Hoc results indicate that almost all communities had similar species diversity indices except for *V. infausta-G. flavescens-B. plurijuga* (1.1) and *B. plurijuga (*1.2212) sub communities. The highest species diversity was recorded in *V. ainfausta-G. flavescens-B. plurijuga* (1.1)sub community, with plots from stages 3 and 4 of pole and firewood collection sites. Communities with plots from undisturbed sites had low species diversity. Lowest species diversity was recorded in *B. plurijuga* (1.2212) sub community with a mixture of plots from different disturbance factors (Appendix 2.3, Table 2.6).

Table 2.10: Differences in species diversity (mean ± standard error) across the identified tree and regeneration communities. Values with different superscript letters within columns differ significantly (Tukey's HSD; P < 0.05).

Community	Tree species diversity	Species richness	Regeneration community	Regeneration species diversity	Species richness
1.1	0.15 ± 0.02^{a}	9	1.1	0.25 ± 0.04^{ab}	6
1.2	0.08 ± 0.02^{a}	20	1.21	0.15 ± 0.02^{a}	15
2.111	0.18 ± 0.03^{ab}	8	1.2211	0.12 ± 0.03^{a}	11
2.112	0.13 ± 0.03^{a}	15	1.2212	0.06 ± 0.01^{ac}	11
2.12	0.08 ± 0.02^{a}	28	1.2221	0.21 ± 0.04^{a}	8
2.211	0.13 ± 0.03^{a}	16	1.2222	0.12 ± 0.03^{a}	13
2.212	0.07 ± 0.02^{a}	26	2.11	0.12 ± 0.03^{a}	14
2.22	0.08 ± 0.02^{a}	22	2.121	0.13 ± 0.04^{a}	14
3.111	0.17 ± 0.04^{a}	10	2.122	0.18 ± 0.04^{a}	9

3.112	0.13 ± 0.04^{a}	10	2.21	0.17 ± 0.03^{a}	12
3.12	0.05 ± 0.03^{ac}	13	2.22	0.18 ± 0.04^{a}	8
3.2	0.11 ± 0.07^{a}	7	3.0	0.12 ± 0.02^{a}	18
			4.0	0.16 ± 0.02^{a}	14
$F_{11, 170}$ =2.462			$F_{12, 140}$ = 1.68		
P value	0.007			0.07	

2.4 DISCUSSION

2.4.1 Vegetation classification

The study has revealed that plots from the least development stages (1 and 2) of different disturbance systems aggregated into similar communities, with each community having plots from different disturbance regimes. Similarly, plots from advanced development stages (3 and 4) of concession area sites, pole and firewood collection sites and previously cultivated fields also aggregate into communities mostly associated with undisturbed stands, but which are different from the communities of the early stages. This was shown for both tree and regeneration communities. This shows that stand development in these woodland ecosystems converge to more similar mature communities. The study showed that plots with similar intensity of disturbance tend to have similar species composition in their early recovery, with aggregation into similar communities, similar to the results presented by Childes & Walker (1987). As such stands develop without further disturbance, their species composition converged to that of undisturbed sites. Concession areas' stages 3 and 4 showed a higher percentage of plots aggregating with plots from undisturbed sites while pole and firewood collection sites showed a lower percentage. The intensity of disturbance in concession areas is less compared to pole and firewood collection sites and abandoned crop fields. This is so because of the single tree selection system that is practiced during harvesting operations. Only trees of specific species (usually *B. plurijuga, G. coleosperma* and *P. angolensis)* that have attained a diameter limit of >25cm have been harvested. The rest are left to grow to maturity for the next harvesting entry. However, in pole and firewood collection sites, trees are usually harvested in groups for a variety of products by local communities.

Pterocarpus angolensis was able to regenerate in heavily disturbed areas and in the undisturbed sites where no timber harvesting is allowed. These findings are consistent with other studies that concluded that *P. angolensis* (shade intolerant species) performs well in cleared areas. Land clearing would result in total exposure of plants to light (Boaler 1966; Werren *et al.* 1995 and Graz 1996). However total exposure to light might also result in wilting of seedlings and the ground drying out quickly and this might retard plant growth. Land clearing can also result in reduced competition for moisture and nutrients thus contributing to good performance of the species that grow in cleared areas. In a study by Syampungani (2009), *P. angolensis* performed well in charcoal production and slash & burn activities. He further suggested that opening the forest land may also result in reduced effects of allelopathy arising from interaction between species.

Clear-felling during land preparation and length of cultivation of other crops in the abandoned crop fields might also result in variation in species composition. This suggests that long term cultivation removes existing rootstocks and seed banks of key species in the soil, hence impacting on the regeneration of key species. Fast growing species such *Combretum* species dominate the high utilization sites (Backeus *et al*. 2006). Feldpausch *et al*. (2004) concluded that, the rate of above-ground biomass accumulation is fastest in the first 2 decades of forest cultivation and declines thereafter. This suggests that long periods of intensive use or disturbance can retard biomass accumulation in secondary growth of tropical dry forests (Chidumayo & Gumbo 2013) Also, long term cultivation may result in soil nutrient depletion that can further retard the regeneration and growth of trees. What then must we do to recover the key species? This might imply that forest managers should consider short term cultivation of crops in areas that have been harvested so as to allow regeneration of key species in the abandoned areas. Woodland management options in these areas should aim to create a mosaic of woodland and cultivation. A comprehensive program is necessary to monitor the levels of cultivation and the impacts on woodland recovery.

2.4.2 Differences in species diversity in tree and regeneration communities

High species diversity in pole and firewood and abandoned crop fields advanced stages could be explained by the fact that the resource utilization patterns at these sites resulted in the creation of large canopy gaps and many different species can occupy the created gaps and establish themselves. Communities comprising of plots from undisturbed sites and early development stages of abandoned fields, and pole and firewood collections sites showed low species diversity. The canopy tree species suppress other tree species growing in the undisturbed sites hence low species diversity. There is little free space on the forest floor for other tree species to grow in undisturbed sites. It is only the big mature trees that are retained at these sites. Frequent fires in these woodlands may also keep the plants to < 0.5 m height.

High species diversity for regeneration communities was in a community that mainly comprised of plots from pole and firewood collection sites. However, this community was dominated by *V. infausta* and *G. flavescens.*

2.4.3 Relationship between communities in ordination space

The DCA results indicated that the underlying site factors explain little variation (as shown by low cumulative percentage) in the identified communities, suggesting that recovery from disturbance with different disturbance factors may explain more of such variation. Differences in species composition from the identified communities are mainly driven by disturbance factors (recovery from different intensities of disturbance as seen by the aggregation of plots from different disturbance regimes) or other environmental factors not studied in this study. The nature of disturbance, magnitude and age since disturbance cessation has a great impact on species composition. A study by Childes & Walker (1987) in Hwange National Park concluded that both the edaphic and disturbance factors influence the classification of vegetation into nine main vegetation groups. In this study, environmental and physical factors were not studied to show their influence on vegetation composition. The low variation explained by axis 1 and 2 in DCA results did not justify further investigation of the different factors on species composition. The low percentage variation explained by axis 1 and 2 in both tree and regeneration communities suggest a random distribution of species in communities. This might be explained by the different combinations of plots from different disturbance factors hence a clear-cut grouping of species is not possible.

Combretum and *B. plurijuga* 2&3 communities' plots were grouped close together because the two communities mainly comprised of plots from advanced development stages. The two communities were clearly separated from *B. plurijuga* 1 community that mainly comprised of least development stages. However, *Combretum* community, comprised of plots from stages 2, 3 and 4 of concession areas, pole and firewood collection sites and abandoned crop fields, was clearly separated from *B. plurijuga* 2&3 community that comprised of all the plots from undisturbed sites. *B. plurijuga* 2&3 community had all the key species of the *Baikiaea-Guibourtia-Pterocarpus* woodlands as compared to the *Combretum* community that mainly comprised of *Combretum* species and *Terminalia* species. This community did not have undisturbed sites' plots but was dominated by stages 2 and few stage 3 and 4 of different disturbance regimes. This suggests that this community was under recovery from disturbances as compared to *B. plurijuga* 2&3 community that is mature community with fewer disturbances. Also, *B. plurijuga* 1 community comprising of the least developed stages was dominated by *B. plurijuga* 1 and *B. petersiana.* The same pattern was observed with regeneration communities were *B. plurijuga* and *B. massaiensis* communities that comprised of advanced stages of development and undisturbed sites' plots but *Combretum* and *P.angolensis* communities were close together. They mainly comprised of abandoned crop fields' plots. *B. plurijuga* community comprising of undisturbed sites plots with a high prevalence of *B. plurijuga* while *P.angolensis* community comprising of stages 3 and 4 of abandoned crop fields had a high prevalence of *P. angolensis.* This implies that, the type and intensity of disturbance had a great influence on species assemblages and hence community aggregation.

2.5 CONCLUSION

The study concludes that, even if the sites provide a potential for woodland of a specific type to develop, community aggregation is mainly influenced by utilization systems. The intense land use systems of clearing for crop cultivation and to a lesser extent harvesting for poles and firewood may be necessary disturbances for the rejuvenation of the *Baikiaea-Guibourtia-Pterocarpus* woodlands. The key commercial species, especially *B. plurijuga*, was important in most sub-communities for both tree and regeneration communities, while *P. angolensis* was important in heavily disturbed sites of pole and firewood collection sites and abandoned crop fields. *G. coleosperma* was important in tree communities that comprised of plots from undisturbed sites and stages 3 and 4 of concession area and abandoned fields. These sites showed evidence of fire and hence negatively affecting the regeneration population of the species. The species had low importance values in regeneration communities where it occurred. Results from this study suggest that the system is resilient even when severely disturbed by clearing for crops and harvesting for poles. The intense disturbance factors are necessary components to rejuvenate the *Baikiaea-Guibortia–Pterorcapus* woodlands. This suggests that recovery of resources at advanced stages of abandoned fields favor the characteristic species composition of the ideal *Baikiaea-Guibortia-Pterocarpus* woodlands.

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Appendix 2.1: List of identified tree species (stems of ≥5 cm DBH), species code; family; local and species occurrence (1- rare; 2- occasional; 3- common; and 4 – abundant) recorded. Species authority is indicated between brackets (based on Van Wyk *et al*. 2012).

Species	Species code	Family	Local name	Species Occurrence
Acacia ataxacantha DC.	Acac ata	Fabaceae	Uthathawu	2
Acacia erioloba E.Mey.	Acac eri	Fabaceae	isinga	1
Acacia galpinii Burtt Davy	Acac gal	Fabaceae	Umthungabayeni	1
Acacia nigrescens Oliv.	Acac nig	Fabaceae	Umkhaya, umkhayamhlophe	1
Acacia nilotica (L.) Willd. ex Delile	Acac nil	Fabaceae	Umlaladwayi	1
Afzelia quanzensis Welw.	Afze qua	Fabaceae	Umkamba	2
Albizia tanganyicensis Baker F.	Albi tan	Fabaceae	Umphaphama	1
Baikiaea plurijuga Harms	Baik plu	Fabaceae	Umkusi	4
Baphia massaiensis Taub.	Baph mas	Fabaceae	Umbhondo	2
Bauhinia petersiana Bolle	Bauh pet	Fabaceae	Imondo	3
Brachystegia spiciformis Benth.	Brac spi	Fabaceae	Igonde	2
Burkea africana Hook.	Burk afr	Fabaceae	Umnondo	2
Combretum apiculatum Sond.	Comb api	Combretaceae	Umbhondo	4
Combretum collinum Fresen.	Comb col	Combretaceae	Umkhosikazi	4
Combretum imberbe Wawra	Comb imb	Combretaceae	Umtshwili	1
Combretum molle R.Br. ex G.Don	Comb mol	Combretaceae	Umbhondo	3
Commiphora mollis (Oliv.) Engl.	Comm mol	Burseraceae	Iminyela	2
Commiphora mossambicensis (Oliv.) Engl.	Comm mos	Burseraceae	Iminyela lentaba	3
Croton gratissimus Burch.	Crot gra	Euphorbiaceae	Iboyane	2
Dalbergia melanoxylon Guill. & Perr.	Dalb mel	Fabaceae	Umbambangwe	2
Dichrostachys cinerea (L.) Wight & Arn.	Dich cin	Fabaceae	Ugagu	2
Diplorhynchus condylocarpon (Mull.Arg.) Pichon	Dipl con	Apocynaceae	Inkankamasane	2
Erythrophleum africanum (Welw. ex Benth.) Harms	Eryt afr	Fabaceae	Umsenya	2
Eucalyptus camaldulensis Dehnh	Euca cam	Myrtaceae	Umgamudeleni	1
Flacourtia indica (Burm.f.) Merr.	Flac ind	Salicaeae	Umqokolo	1
Grewia flavescens Juss.	Grew fla	Tiliaceae	Umtewa, umklampunzi, umnaba	2
Grewia monticola Sond.	Grew mon	Tiliaceae	Umhlabampunzi, umpumpulwane, umtewa	2
Guibourtia coleosperma (Benth.) J.Leonard	Guib col	Fabaceae	Umchibi	1

Species	Species code	Family	Local name	Species Occurrence
Julbernardia globiflora (Benth.) Troupin	Julb glo	Fabaceae	Munondo, umtshonkwe	2
Kirkia acuminata Oliv.	Kirk acu	Kirkiaceae	Umvimila	2
Ochna pulchra Hook.	Ochn pul	Ochnaceae	Umnyelenyele	2
Parinari curatellifolia Planch. ex Benth.	Pari cur	Chrysobalanaceae	Umbula, umkuna	1
Peltophorum africanum (Sond)	Pelt afr	Fabaceae	Umkahla, umsehla	1
Philenoptera violacea (Klotzsch) Schrire	Phil vio	Fabaceae	Ichithamuzi, idungamuzi, iphanda	2
Pseudolachnostylis maprouneifolia Pax	Pseu map	Phyllanthaceae	Umqobampunzi	2
Pterocarpus angolensis DC.	Pter ang	Fabaceae	Umvangazi	3
Schinziophyton rautanenii (Schinz) Radel.-Sm.	Schi rau	Euphorbiaceae	Umgoma, mgonwa, umganuompobola	3
Sclerocarya birrea (A.Rich.) Hochst.	Schl bir	Anacardiaceae	Umganu	2
Searsia lancea (L.f.) F.A.Barkley	Sear lan	Anacardiaceae	Inhlokotshiyane	1
Searsia tenuinervis (Engl.) Moffett	Sear ten	Anacardiaceae	Uchane	1
Strychnos cocculoides Baker	Stry coc	Loganiaceae	Umkhemeswane	1
Strynchnos pungens Soler.	Stry pun	Loganiaceae	Umgwadi, umgwai	1
Terminalia sericea Burch. ex DC.	Term ser	Combretaceae	Umangwe	3
Vangueria infausta Burch.	Vang inf	Rubiaceae	Umthofu, umviyo	2
Vitex payos (Lour.) Merr.	Vite pay	Lamiaceae	Umtshwankela	1
Ziziphus mucronata Willd.	Ziz muc	Rhamnaceae	Umphafa, umpasamala	2

Appendix 2.2: TWINSPAN classification of trees ≥5 cm DBH based on number of stems per plot.

```
Landuse&stage  PPPPP PPPPPPPAAAAAAACC PAA PPPPPPPP AAPPPPPPPPAACPPPPPPPPPPPPPP AAAAACCPPP  PPPPPAAACCCCCCCCCPPPP  PCCCCCCPPAPPPPPPCC ACCC PPACC PPAAAAAAAAPPPPPPPAAAAAA PPPA
               FFFFF FFFFFFFFFFFFFFAA FFF AAAAAAAA FFAAAAAAAAAFFAAAAAAAAAAAAAA FFFFFAAAAA  AFFFFFFFAAAAAAAAAAAAFF AAAAAAAAFFFAAAFFAA FAAA FFFAA FFFFFFFFFFFFFFFFFFFFFFF FFFF
               33344 2223344224444422 313          34         332              23344222    2333334223333344   22  4444444243    4444  4223 22333 11111111111122241222222 1112

                                          11111111   111111111   1111111111111         11 1                111   111111    111  11
               22233 1177512233576788 235 11124123 670111113445662223333333444 5756777822 4226668889999999901311 900000012362223300 7889 11688   344444444   112345 455    5
               62534 4502433456549305 777 47911169 679025687029587890123456456 8661589102 3012372380123567883819 901234529203450167 1464 08497 249012345676786788919802 1353

    Eryt  afr  ----- ---2------------ --2 -------2 --------1----------1------- ---------- ---2-2------1--------- -----------------1 ---- ----- ----------------1------- ---- 0000
    Phil  vio  ----- 2--------------- --- -------- ----------------1---------- ---------- ---------------------- ------------------ ---- ----- ------------------------ ---- 0000
    Dich  cin  --21- ---------------- 1-- -------- --------------------------- ---------- ---------------------- ------------------ ---- ----- ------------------------ ---- 00010
    Comb  api  -2-44 ----33423---1--- --- -------- 22-11-212-1-321232-21132--3 11-------- ---------------------- ---------1-------- ---- ----- ------------------------ ---- 00010
    Kirk  acu  1---1 ---------------- --- -------- -------2------------------- --1------- ---------------------- ---------1-----2-- ---- ----- ------------------------ ---- 00011
    Sear  ten  ----- ---1------------ --- -------- -------------1------------- 1--------- ---1------------------ ------------------ ---- ----- ------------------------ ---- 00011
    Acac  gal  ----- ---2------------ --- -------- --------------------------- ---------- ---2------------------ ------------------ ---- ----- ------------------------ ---- 00011
    Acac  nig  ----- ---1------------ --- -------- --------------------------- ---------- ---1------------------ ------------------ ---- ----- ------------------------ ---- 00011
    Julb  glo  ----- ---------------- --- -------- --------------2243222-31-2- ---------- ---------------------- ------------------ ---- ----- ------------------------ ---- 00100
    Brac  spi  ----- ---------------- --- -------- --2------2------1-2-1--2--- ---------- ---------------------- ------------------ ---- ----- ------------------------ ---- 00100
    Pseu  map  ----- ----1----------- --- -----211 ------1-1------------------ ---------- ----------1----------- -----------------1 ---- ----- ------------------------ ---- 001010
    Pelt  afr  ----- ---------------- --2 -------- --------------------------- ---------- -----2---------------- ------------------ ---- ----- ------------------------ ---- 001011
    Pari  cur  ----- ---------------- --- -------- -------------1------------- 1--------- ---------------------- ------------------ ---- ----- ------------------------ ---- 001011
    Comb  imb  ----- ---------------- --- -------- --------1------------------ ---------- ---------------------- -----------------1 ---- ----- ------------------------ ---- 001011
    Pter  ang  ----- ---------------- 224 1-212323 1---21-21-233-21-1--211122- ---2------ ---2-2----1-1112-111-- --11-11---1------- ---- --1-- ------------------------ ---- 001011
    Guib  col  ----- ---------------- --2 33233434 --4444322421-23222-31-12232 221-2--321 2--22-32222223323344-- --3--------------- -1-- ----- ------------------------ ---- 001011
    Zizi  muc  -2--- -------1-------- --- ------22 --------------------------- ---------- -----------------2---2 --------------11-3 ---- ----- ------------------------ ---- 0011
    Dipl  con  ----- ---------------- --- -------- --------------------------- ---------- ----------------2----- --2-1------------- ---- ----- ------------------------ ---- 0011
    Crot  gra  ----- ---------------- --- -------- -------------1------------- ---------- ------------2--------- 2-11121----------- ---- ----- ------------------------ ---- 0011
    Baik  pl3  ----- -----2---------- --- 23442323 -34443344241233313411233233 ---1-21-23 22222--11211--212333-- 434344332324444344 ---2 ----- ------------------------ ---- 0011
    Ochn  pul  ----- ---------------- --- ----2--- -------------1------------- 11-------- ---------------------- ---2-------------- ---- ----- ---------------------1-- 1--1 010
    Grew  mon  ----- ---------------- --- -----2-- ---2--------2-------------- ---------- -----------------22--- ------------------ ---- ----- -----------------------2 ---- 010
    Baik  pl2  ----- -----2------1-22 --- -1----2- 31-2221122125--111212122221 43-322222- 2433443354434434442455 233432243234222222 2214 44442 ------------------------ ---- 010
    Comb  mol  -11-- ------1---21-2-- --2 -------- --1------1--122----12------ 2-1-1--1-- -1---2------11---21--- --1---3-------1--- ---- --1-- ----------------------12 ---- 011
    Burk  afr  ----- ---------------- --- -------- -----------------1-2------- --1------- ---------------------- ------1----------- ---1 ----- ------------------------ ---- 011
    Afze  qua  ----- ---------------1 --- -------1 ---2--1-------------------- ---------- ---------------------- ------------------ ---- ----- ------------------------ ---- 011
    Comb  col  ----- -44315524-44233- --- -------2 221--122-22213-11-222---2-1 332223222- 2----1-1-112-222--1--- 12---11---------23 3223 ---22 ------------------------ ---- 011
    Acac  ata  -1--- ------1--------- --- -------- --------------------------- ---------- ------1--2------------ ---------------2-- ---- ----2 ------------------------ ---- 10
    Schl  bir  --2-- --------1------- --- -------- --------------------------- ---------- ---------------------- ------------------ ---- ----- ----------------------1- ---- 10
    Term  ser  ----- 2222--------2-22 --1 -------- -----------1------------1-- ---22---12 1------1-------------- -------2---------- ---- 2-1-1 ------------------------ ---- 10
    Flac  ind  ----- ---------------2 --- -------- --------------------------- ---------- -------------2-------- ------------------ ---- ----- ------------------------ ---- 110
    Comm  mos  1---- 3------------222 --- -------- 1---1--11-1----1----------- --2---32-- ----------1-11-1----1- 221222----------1- -222 1---- -------------1------1--- ---- 110
    Baph  mas  ----- ---------------- --- -------- ---1-----1----1------------ ---------- -----------1------112- 2----------------- ---- ----- ------------------1-222- ---- 11100
    Bauh  pet  ----- ---------------- --- -------- 2-3------------------------ ---------- -------2----2----2---- ----------------22 --22 ----- -----------------------2 2222 11100
    Comm  mol  ----- ---------------- --- -------- --------------------------- ---------- -------1-------------- ------------------ ---- ----- ---------------------2-- ---1 11101
    Acac  eri  ----- ---------------- --- -------- --------------------------- ---------- ---------------------- ------------------ -2-- ----1 ------------------------ ---- 11101
    Vang  inf  ----- ---------------- --- -------- --------------------------- ---------- ---------------------- ------------------ ---- ----- 1----------------------- -12- 11101
    Baik  pl1  ----- ----31-------233 --- ------1- ---1---1--11-----1-12--1-1- 1----432-3 --312343424434214-3--- 2211121-22121-212  4424 44443 332331223214454444455454 34-4 11101
    Schi  rau  -2--- ---------------- --1 -2-12--- ------------2-------------- --1-22-1-- -----1----1-1--------- ------------------ --1- 2---- --------------------112- ---- 1111
               00000 0000000000000000 000 00000000 000000000000000000000000000 0000000000 0000000000000000000000 000000000000000000 1111 11111 111111111111111111111111 1111 Level
               00000 0000000000000000 111 11111111 111111111111111111111111111 1111111111 1111111111111111111111 111111111111111111 0000 00000 000000000000000000000000 0000 Level2
               00000 1111111111111111 000 00000000 000000000000000000000000000 1111111111 1111111111111111111111 111111111111111111 0000 00000 000000000000000000000000 1111 Level3
               00000 0000000000000000 000 00000000 111111111111111111111111111 0000000000 0000000000000000000000 111111111111111111 0000 00000 111111111111111111111111      Level4
                       00000000000000 000 11111111 000000000000000000000000000 0000000000 1111111111111111111111 000000000000000000 0000 11111 000000000000000000000000      Level5
  Communities   1.1       1.2        2.111   2.112             2.12               2.211          2.212                 2.22        3.111 3.112      3.12                3.2
```

Pseudospecies cut levels are 0, 3, 5, 15, and 25. Species with one occurrence were excluded from the table. The different land use systems (AF for abandoned fields, PF for pole & firewood areas, CA for concession areas, and PA for protected areas) in lines 1 and 2, and stages (1, 2, 3 or 4) in line 3 are shown at the top of this table.

Appendix 2.3: TWINSPAN classification of stems <5 cm DBH based on number of stems per plot.

```
Landuse&stage CPPPP AACCPPPCC PPPPPPAACC PPPPPPPPPPPAAAAAAAAAAACCCCCPPPPPP PCCCCCCCCPPP PACCCCPPP PAPPPPPP PPAACPPPPPP PPPPPPCCC CPPAPPPA PPPAAA PPAAAAAAAAAA PAAPPAAA
              AFFFF FFAAFFFAA FFFFFFFFAA FFFFFFFFFFFFFFFFFFFFFFAAAAAAAAAAA FAAAAAAAAAAA FFAAAAAAA FFAAAAAA FFFFAAAAAAA AAAAAAAAA AFFFAAAF AAAFFF FFFFFFFFFFFF AFFAAFFF
              32233 342423222 1112333424 1111223344411111111111422344      443333344    422234    42       44222             334 2232   2    222 223333334444  33  444

                                       1                        1111111       111111        11   111111     1111111 111111111 1   111  111                         1  11
              91122 5689 2377     112891     12222333333344445678890111122 288889000224 367799913 35122342 44570011123 899003334 02344480 234455 115667566765 56736723
              21535 440680047 1239692286 456731469145678901239963591127823 846780023170 258914509 31968217 45054834547 937593483 69527817 066923 047070616135 88302251


    Pseu map  ----- --33----- ---------- --------------------------------- ------------ 1-23-2-22 -------- -------1-1- --------- -------- ------ ------------ -------- 0000
    Comm mos  ----- --------- ---------- --------------------------------- -33333333--- --------- -------- ----3------ --------- 1------- ------ ------------ ---1---- 0000
    Crot gra  ----- --------- ---------- --------------------------------- ----13------ ----3---- -------- ----1------ --------- -------- ------ ------------ -------- 0000
    Flac ind  ----- --------- ---------- ---------------------------11---- ---------22- --------- -------- -------1--- --------- -------- ------ ------------ -------- 0000
    Baik plu  -1-13 -33311132 3332121433 323113313132331213114343333433333 133333333533 133332344 -------- -323-332223 333333333 1-12-334 44---- ----3------- -------- 000100
    Dich cin  -1--- ----11--- ---1------ --------------------------------- ------------ --------- -------- ----------- --------- -------- ----11 ------------ -------- 000100
    Sear ten  --3-2 ----1---- ---1------ ------1-1------------------2----- ------------ -1------- -------- ----------- --------- -------- ------ ------------ -------- 000100
    Vaun inf  3-222 --------- -111-1131- --------------------------------- ------------ --------- -------- ---------1- --------- ----3-3- ------ 2----------- -------- 000101
    Stry coc  ----- --------- --1----22- --------------------------------- -----------1 --1--1--- ------1- ----------- --------- -------- ------ ----1------- -------- 000101
    Dipl con  ----- --------- ---------- ------------------------1-1------ ------------ -3------- -------- ----------- --------- -------- ------ -----------3 -------- 00011
    Bauh pet  ----- --111---1 ---------- --------------------------------- 1313-2313311 2222-22-- -3------ ----------- 1-123-23- ----4314 543334 ------------ -2------ 001
    Baph mas  ----- --------- ---------- ------------------------1-111---- --1----1---- ---11-111 --213331 33322223332 --3333333 3333-333 332333 ------------ ---3---- 010
    Julb glo  ----- --------- ---------- --------------------------------- ------------ --------- ---1-2-- -----3----- --------- -------- ------ ------------ -------- 010
    Ochn pul  ----- 3233----- 1---1--332 --------------------------------- -1----1---11 --------- 123----1 1-1--22---2 --------- -------1 -111-- -11-1------- 11------ 011
    Grew fla  -1311 --------- ---------- --------1---------------1-1-2--11 1----------- --------- 1---2-2- ---2-3---23 1-------- -------2 -2--3- 21--------2- --2---2- 011
    Term ser  ----- 22221-13- ---------- --------------------------------- ------------ -2-22-222 -------- ----------- --------- 1111-3-3 -3-1-- -------2-2-2 11------ 011
    Grew mon  2---- 33---1--1 ---------- --------------------11------1---- ------------ -2------- -------- ----------- 3-------- 3131---2 -2---- --1-1------2 -------- 011
    Acac ata  ----- ----1--33 ------1--- --------------------------------- ------------ --------- -------1 1-121------ ---1--1-- -------- ---111 -1-222------ -------- 10
    Comb col  ----- 11322-1-- ---1-1---- --------1------------------------ ---1----1--- -1------- -------- ---1------- --------- 232333-- ------ 3122223333-1 32------ 10
    Comb mol  ----- --------1 ---1------ --------------------------------1 -----3------ -2------- -------1 11--33---13 33143-433 -1-1--1- ------ --2222333332 --33---2 10
    Acac nil  ----- --------- ---------- ---------------------2----------- ------------ --------- -------- ----------- --------- --1----- -1---- -1------1--- -------- 10
    Guib col  ----- -1------- ---------- ---------------------2----------- ------------ --------- -------- 1---------- --------- -------- ------ 1--2-------- -------- 110
    Cucu met  ----- 11------- ---------- --------------------------------- ------------ --------- -------- ----------- --------- -------- ------ -----1---1-- -1------ 11100
    Comb api  ----- --------- -----1---- --------------------------------- 1---------11 --------- -2--232- ----------- ----31-31 -------- ------ ---3-3-2123- 3331---- 11101
    Phil vio  ----- --------- ---------- --------------------------------- ------------ -1------- -------- ----------- --------- -------1 1--2-1 ------------ -------- 11101
    Eryt afr  ----- --------- ---------- --------------------------------- ------------ --------- -------- ----------- --------- -------- ------ --1-1------- -------- 11101
    Schi rau  ----- --------- ---------- --------------------------------- ------------ --------- -------- ----------- --------- -------- ------ -------3-341 333----- 11101
    Pter ang  ----- --22----- ---------- --------------------------------- ------------ --------- ---1---- ----------- -----1--3 -------- ------ ------------ 3313-133 1111
    Pelt afr  ----- --------- ---------- --------------------------------- ------------ --------- -------- ----------- --------- -------- ------ ------------ 33---1-- 1111

              00000 000000000 0000000000 000000000000000000000000000000000 000000000000 000000000 00000000 00000000000 000000000 00000000 000000 111111111111 11111111 Level 1
              00000 000000000 0000000000 000000000000000000000000000000000 000000000000 000000000 11111111 11111111111 111111111 11111111 111111 000000000000 11111111 Level 2
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Communities     1.1     1.21      1.2211              1.2212                   1.2221       1.2222     2.11      2.121       2.122      2.21    2.22      3.0          4.0
```

Pseudospecies cut levels were 0, 3, 5, 15, and 25. Species with one occurrence. The different land-use systems (AF for abandoned fields, PF for pole & firewood areas, CA for concession areas, and PA for protected areas) in lines 1 and 2, and stages (1, 2, 3 or 4) in line 3 are shown at the top of this table.

3 ECOLOGICAL DRIVERS OF FLORISTIC AND STRUCTURAL COMPOSITION OF *BAIKIAEA-GUIBOURTIA-PTEROCARPUS* WOODLAND COMMUNITIES IN NORTH – WESTERN ZIMBABWE

Abstract

Suitable conditions for the regeneration of key ecological and economic canopy tree species are a key to sustainable management of forests and woodlands for diverse products and services. A study in Gwaai and Tsholotsho *Baikiaea-Guibourtia-Pterocarpus* woodlands assessed the ecological drivers of floristic and structural composition of the woodland communities based on four development stages towards maturity, under different disturbance regimes. A total of 150 nested circular plots were sampled (30 plots in timber concessions which had no stage 1, and 40 plots each in abandoned crop fields, pole and firewood collection sites, and in protected areas (comprising of mature stands only). Diameter and height were measured for all stems of tree species with a stem diameter at breast height (DBH) ≥15 cm in the whole plot (0.283 ha) and trees 5.0-14.9 cm DBH in a 0.04 ha concentric plot. Stems <5 cm were counted by species in the inner concentric plot of 0.01 ha of the nested plots. The data were used to analyse stand dynamics at two scales. Correspondence analysis in SPSS Version 21 Statistical Package was performed to analyse grain status for nine tree communities. Grain analysis determines the relationship between the composition of canopy species in the regeneration and canopy of the same stands, i.e. scale of ecological processes at community level. Stem diameter class profiles were analysed in STATISTICA version 7 to determine the ratio of regeneration to mature trees of individual canopy tree species across the 9 tree communities, i.e. diameter size distribution and status of all key tree species at population level with identification of their regeneration constraints. Most species were able to regenerate close to their adults (fine grain) in *Combretum apiculatum-Dichrostachys cineria*, *P. angolensis-G. coleosperma*, *Baikiaea plurijuga* 2-*B. plurijuga* 3 and *B. plurijuga* 2-*B. plurijuga* 1 sub communities while in *C. collinum-C. apiculatum*, *B. plurijuga* 3- *G. coleosperma-B. plurijuga* 2, *G. coleosperma-B. plurijuga* 2- *C. collinum*, *B. plurijuga* 3-*B. plurijuga* 2 *and B. plurijuga* 1-*B. plurijuga* 2-*C. collinum* sub communities, the species could not regenerate close to their adults (coarse grain). All the communities showed inverse J-shaped profiles with high densities in smaller stem diameter classes (1.0-9.9 cm) and low stem density in larger size classes implying that there is ample regeneration in all the subcommunities studied. *Baikiaea plurijuga* is the only species that occurred in all sub-communities. The species showed bimodal distributions with high densities at two diameter classes hence showing two peaks as compared to the bell-shaped distribution that only has one peak. This implies that the species experiences sporadic or irregular seedling establishment resulting in fluctuations in stocking density. The remaining two sub-communities were only presented by one size class. *Pterocarpus angolensis* and *Guibourtia coleosperma* were important in sub-communities with plots from undisturbed sites, pole and firewood collection stands and abandoned crop fields, and showed bell-shaped, irregular and bimodal profiles. The study concludes that intense distubances are the major ecological drivers of the *Baikiaea-Guibourtia-Pterocarpus* woodlands as shown by the grain status and stem diameter distributions.There is therefore need for silvicultural systems that will promote the regeneration and recruitment to larger size classes of all the key species in the woodlands.

Key words: Forest grain, stem diameter distributions, regeneration, recruitment

3.1 INTRODUCTION

Suitable conditions for the regeneration of key ecological and economic canopy tree species are a key to sustainable management of forests for diverse products and services. However, many forest ecologists, forest managers, local communities and other resource users, utilize forest resources without an understanding or knowledge of the specific requirements for regeneration, establishment and growth of key species in an ecosystem. In many parts of the world, no silvicultural management is applied in the indigenous forest and woodland ecosystems. The ecosystems are left to manage themselves yet they are comprised of trees of different size and age, and species with different requirements for regeneration, establishment and growth. The requirements of each species are not understood. It is assumed that all species in an ecosystem have similar requirements for regeneration, growth and that they respond in a similar manner to different disturbances. Walker (1985), Frost *et al*. (1986) and Scoones (1990) emphasized the importance of considering the possible responses to disturbance of ecosystems as a whole, as well as the individual species within them. Knowledge on the requirements of key species is of paramount importance in ensuring proper management of the species and/or ecosystems and hence the continued existence of the species to future generations. Sustainable resource use management of a specific forest requires that its biodiversity (species composition and stand structure) and ecological processes be maintained (Geldenhuys 2009). One therefore needs to understand how the forest regenerates and establishes itself, and the necessary conditions for growth of the system. The analytic tools to help with such understanding are forest grain analysis of tree communities and of stem diameter class distributions of key species across tree communities (Geldenhuys 2009).

The drivers of different ecosystems need to be understood. For example, moist evergreen forests generally function through relative shade tolerance (Brokaw 1987; Midgley *et al*. 1990; Liu & Hytteborn 1991; Everard *et al*. 1995; Geldenhuys 1996; Schnitzer *et al*. 2005), whereas the drier deciduous woodlands generally function through adaptation to fire and/or grazing/browsing (Geldenhuys 1977; White 1983; Scholes & Walker 1993 and Chidumayo 1997). In most areas of Africa, the silvicultural systems that should be associated with the harvesting of timber are generally not implemented. The practices applied are generally not aligned with the ecological characteristics of the particular forest system or the specific targeted species (Geldenhuys 2005).

After a disturbance or certain practices, other species may regenerate to eventually dominate the system (Seydack *et al*. 1995; FAO 2003 and Geldenhuys 2005). For example, Geldenhuys (2009) noted that total protection against fire in *Baikiaea-Guibourtia-Pterocarpus* woodlands in north-western Zimbabwe caused a total lack of regeneration of the initially dominating and fire-tolerant *Pterocarpus angolensis* and resulted in the dense regeneration of the fire-sensitive *Baikiaea plurijuga* (a different timber species with a different market), and that sustainable forest management is impossible without appropriate silvicultural management systems, i.e. to ensure regeneration, establishment and growth of at least the harvested species. The fire regime changed from burning every 2 years in the early dry season to burning every 5 years in the same season. To improve *B. plurijuga* regeneration, burning should be done every 5 years in the early dry season and fire extinguished in between this cycle. On the other hand, Geldenhuys (2009) has recoemmended that, to improve regeneration of *P. angolensis*, burning should be done every 2years and the fire should be allowed to burn out.

Grain is the relative similarity between the composition of canopy species in the regeneration and in the canopy of the same stand so as to gain understanding on the scale of forest disturbance-recovery processes (Geldenhuys 2009). It is important to know whether tree species in the current canopy can regenerate under that canopy and associated conditions, or they need other conditions to regenerate and grow through the seedling to sapling to pole to small tree stages (Geldenhuys 2009). There is also need to ascertain if the key ecological and/or economic species are replacing themselves or they are being replaced by other species especially after a disturbance. Grain analysis can determine whether the forest is coarse (with major disturbances), intermediate or fine (minor disturbances) grained though this may change over time. Coarse-grained evergreen forests tend to have at least some areas which are dominated by shade-intolerant species (former large canopy gaps). Similarly, coarse-grained seasonal woodlands are dominated by fire-intolerant species (responding to exclusion of fire or cooler fires). When plotted in ordination space, coarse grained forests or woodland should show clear separation of plots according to whether species are intolerant of shade or fire. In fine-grained forests most species can regenerate close to adults or with regular fires, and therefore there are no great differences in species composition or size-class distributions amongst plots. In other words the successional process occurs on a small spatial scale in fine-grained forests. West *et al*. (2000)

noted that grain is a useful measure that can be used in forest conservation since forests with similar grain would have similar dynamics and hence they can be managed in the same manner (Everard *et al*. 1995).

Stem diameter distributions of stands represent the population structure of a stand or species, and indicate whether a species or stand is expanding, stable or declining (Geldenhuys 1993, 2009). Stem diameter distribution is an important variable in developing sustained use management systems. It can also be used as a basis for monitoring stand development after harvesting operations as it can be used to predict age, state of the forest, and regeneration status, requirements and constraints of key species (Geldenhuys 1993, 1996). Inverse J-shaped distributions reflect a stable steady state where all age classes are represented. It means that recruitment is continuous and mortality is distributed throughout the age classes. This is usually the common structure for shade tolerant species or fire tolerant species (West *et al*. 2000; Geldenhuys 2009). A flat profile is usually common for shade intolerant species i.e. small number of trees decreasing progressively with increasing diameter (Geldenhuys 1993). The bell-shaped stem diameter distribution is typical of species that require different conditions than those prevailing in the system e.g. species that require the control or elimination of fire in the deciduous woodlands such as fire sensitive species like *B. plurijuga*, or large gaps for light-demanding pioneer tree species. Regeneration events of such species occur at infrequent intervals (Geldenhuys 2009).

No study has been done to predict the grain of the *Baikiaea-Guibourtia -Pterocarpus* woodlands in Zimbabwe. The stem diameter distributions under different disturbance factors have not been studied. Very little has been documented on the dynamics and ecological drivers of the *Baikiaea-Guibourtia-Pterocarpus* woodlands, yet resource utilization continues without such knowledge. There is therefore little basis for generalization about the *Baikiaea-Guibourtia-Pterocarpus* woodland community structure and dynamics. The main objective of this study was to assess the ecological drivers of floristic and structural composition of woodland communities under different disturbance factors. The following questions guided data collection and analyses:

(i) What are the main ecological drivers, or scale of the ecological processes, differentiating the different woodland communities within the study area?

(ii) What is the population status of key canopy species in different communities based on their stem diameter distributions across the different disturbance factors?

(iii) What are the regeneration requirements or constraints in determining resource status for the major ecological and economic species?

3.2 MATERIALS AND METHODS

3.2.1 Description of study area

The study was conducted in the Gwaai and Tsholotsho indigenous *Baikiaea-Guibourtia-Pterocarpus* woodlands of north-western Zimbabwe (Figure 3.1). Gwaai forest (19º16^{1}20 S and 27º56^{1}36E) and Tsholotsho (19º46^{1}00 S and 27º 45^1 00 E) (JAFTA & Forestry Commission 2001) are both located in the Matabeleland North Province (Figure 3.1) and are classified under natural region IV according to the agro-ecological land classification of Zimbabwe (Bradley & Dewees 1993). Altitude ranges between 1010 and 1055m (JAFTA & Forestry Commission 2001). These areas were chosen because of the existence of different utilizations systems sought in the study.

Geology and soils

Kalahari sands are deep, unconsolidated, and well-drained sands of Aeolian origin, red/orange, pink or buff coloured, structure-less, with a high proportion of fine dust, and are physically and chemically uniform (Mushove *et al.* 1993). They cover the bulk of the study area. The underlying geology is of sedimentary rocks overlying Karoo basalt and sedimentary deposits (JAFTA & Forestry Commission 2001), comprising mainly grits, sandstones, siltstones and basalts (Judge 1986). The forest soils are derived from the parent materials, and belong to the regosol group in the amorphic soil order (Nyamapfene 1991, as cited by Gambiza 2001). The common soil type in the valleys is locally known as 'isibomvu', i.e. red sand soils. These are moderately well-drained, deep and highly favoured for agriculture.

Climate

The study area is characterized by three distinct seasons: cool dry season from April to August; hot dry season from October to November; and wet season from mid-November to March

(Figure 3.2) (Forestry Commission 1999; JAFTA & Forestry Commission 2001). The short and erratic wet season is usually characterised by dry spells and sporadic droughts (Nemarundwe & Mbedzi 1999). Mean annual temperature is 21.5ºC, with mean monthly temperature ranging from 15°C (June to September) to 25°C (October to December) (Nyamapfene 1991; JAFTA & Forestry Commission 2001). Ground frosts are experienced especially in the valleys in most years between May and September (JAFTA & Forestry Commission 2001).

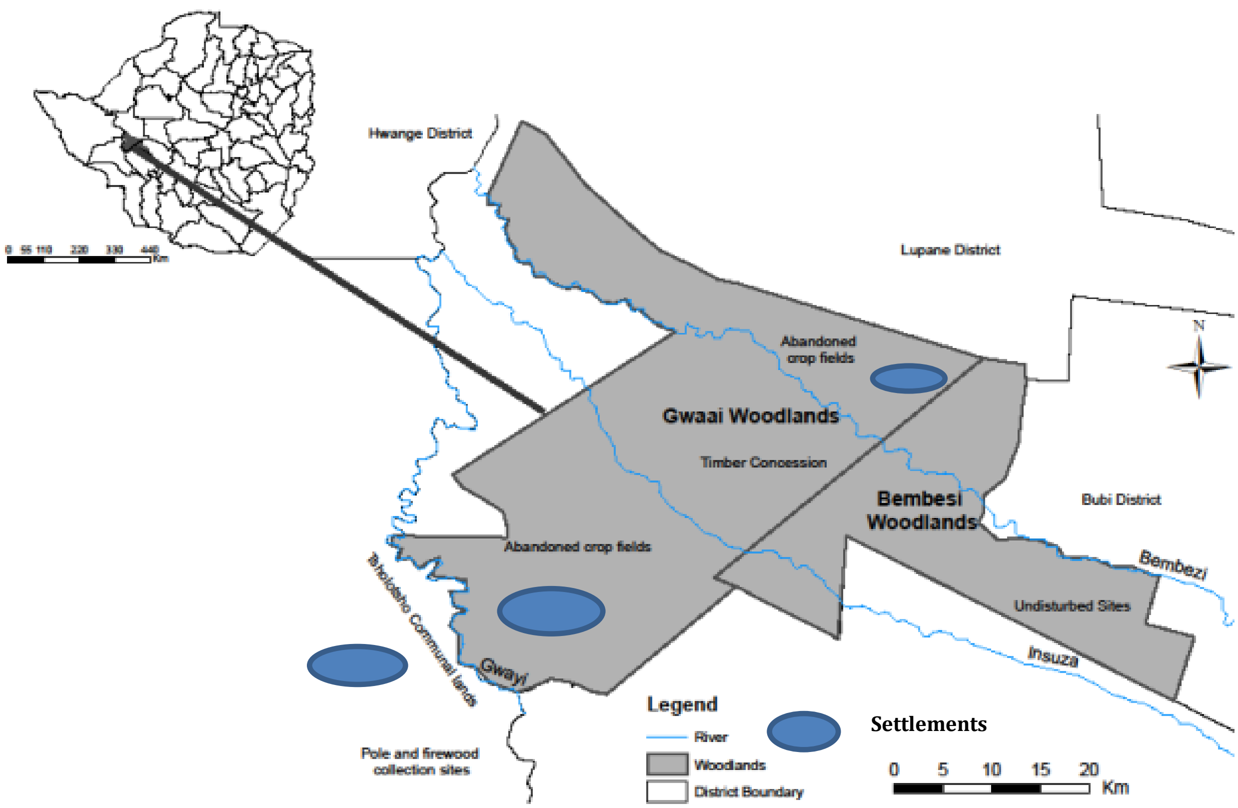

Figure 3.1: Location of the study area in Matabeleland North in Zimbabwe. The blue ovals indicate where settlements are found in the study area.

Vegetation

Six main vegetation types characterise the study area (JAFTA & Forestry Commission 2001): *Baikiaea-Guibourtia-Pterocarpus* woodland mainly occurs as closed to open woodland on the Kalahari sands. The tree vegetation is dominated by *Baikiaea plurijuga*, in association with *Pterocarpus angolensis*, *Guibourtia coleosperma*, *Burkea africana*, *Erythrophleum africanum*, *Combretum collinum, Croton gratissmus, and Schinziophyton rautanenii* (JAFTA & Forestry Commission 2001). Other common sub-canopy species are *Combretum zeyheri*, *Commiphora marlothii*, *Ochna pulchra*, *Baphia massaiensis*, *Terminalia sericea* and *Bauhinia petersiana* (Gambiza 2001). Common grasses are *Pogonathria fleckii*, *Aristida stipitata*, *A. pilgeri*, *Triraphis schlechteri*, *Tristachya rehmanii*, *Eragrostis species* and *Digitaria pentzii* (Gambiza 2001; Dube 2005). *Brachystegia* woodland mainly occurs along the upper Bembesi river characterised with shallower soils and more silt. *Colophospermum mopane* woodland is characterized by either stunted or multi-stemmed *C. mopane* trees. The woodland is mainly found along rivers or river valleys on alluvial soils that are poorly drained and highly erodible (JAFTA & Forestry Commission 2001). Vleis (a grassy or marshy wetland, mostly covered by water during the rainy season) are dominated by a single layer of grasses. Trees may be absent, or occur isolated along vlei fringes (JAFTA & Forestry Commission 2001). *Pterocarpus angolensis* (in association with *Burkea africana*) belts occur as localised stands inside the *Baikiaea-Guibourtia-Pterocarpus* woodlands. *Guibourtia coleosperma* woodland is mainly characterised by the dominance of *G. coleosperma* and scattered *B. plurijuga* trees.

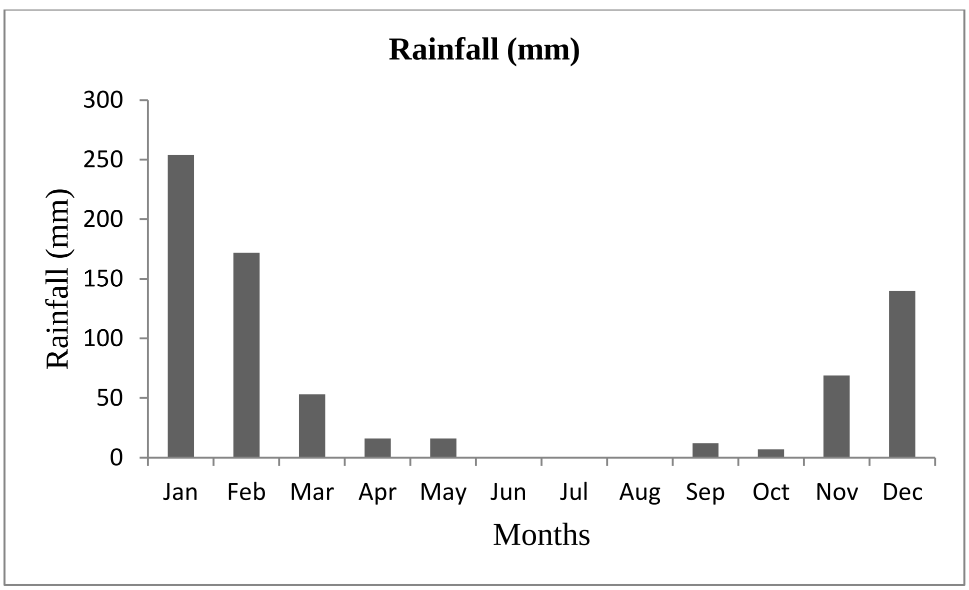

Figure 3.2: Rainfall patterns in the study area (JAFTA & Forestry Commission 2001).

3.2.2 Methodology

3.2.2.1 Data collection

Four utilization systems were identified: protected area (PA), single-tree timber harvesting in concession areas (CA), pole and firewood collection (PFC), and abandoned crop fields under recovery (AF). Protected area, concession area and abandoned field sites were located in Gwaai woodlands and Pole and firewood collection sites were found in Tsholotsho communal woodland areas. Four stand development stages were identified in each disturbance regime, based on the height of the vegetation as the main criterion. Stage 1 height was <2 m; Stage 2 height was 2.1-5 m; Stage 3 height was 5.1-8 m; and Stage 4 height was >8 m. A total of 150 nested circular plots were sampled, with 40 plots each in abandoned crop fields, in pole and firewood collection sites and in the protected areas (which only had stage 4 or mature stands), with 30 plots in the concession areas (which had no stage 1 stands). In each area selected for sampling (disturbance factor x stand development stage; four mature stands in protected areas), five points each were sampled along two parallel 500 m long transects, with a separating distance of 100 m between the sample plot mid-points along the transects. Four tree size categories were defined for sampling: A seedling is a plant with <1 m height. A sapling is a plant between a height of 1 m and a diameter of <1 cm DBH (stem diameter at breast height, i.e. 1.3 m above ground level). A pole is a plant of 1-5 cm DBH. A tree is a plant of ≥5 cm DBH. Three nested circular plots of different size were used to sample trees by size categories around the same center point: the main plot of 30 m radius (0.283 ha) was used to record trees ≥15 cm DBH (stem diameter at breast height, i.e. at 1.3 m above ground level) by species, DBH and height; a plot of 11.3 m radius (0.04 ha) was used to record trees 5.0-14.9 cm DBH by species, DBH and height; and a 5.65 m radius plot (0.01 ha) was used to count seedling, sapling and pole stems <5 cm DBH by species. A caliper was used for measuring DBH and a clinometer was used for measuring tree height.

3.2.2.2 Data analysis

The plant communities identified in chapter 2 were examined for grain analysis and stem diameter distributions. *B. plurijuga* 3-*G. coleosperma*-*P. angolensis* (2.112), *B. plurijuga* 1 (3.12) and *B. plurijuga* 1-*B. petersiana* (3.2) sub communities had few stems either in the regeneration or canopy categories, and were excluded from the grain analysis. Grain analysis focused on canopy tree species in the collected data. The inventory data were duplicated, and all data for stems not considered as of canopy tree species, were removed from the duplicate data set, as well as canopy tree species with only a few stems recorded. The data of canopy tree species for each plot were then split into two subsets, contained as two separate plots: Canopy plot of trees with a DBH of ≥15 cm, arbitrary considered as trees in the canopy; Regeneration plot of trees with a DBH of 1.0 to 9.9 cm DBH, arbitrary considered as trees in the regeneration. This data set was subjected to Correspondence analysis (CA), performed in SPSS version 21 to predict grain for the sub-communities. STATISTICA version 7 was used to analyse stem diameter distributions of key ecological and/or economic species and other canopy species over different sub-communities. The stem diameter distributions were calculated for 5 cm wide stem diameter classes, to determine their resource status and regeneration requirements or constraints.

3.3 RESULTS

3.3.1 Grain analysis in the identified communities

The ordination diagram from the grain analysis of the *Baikiaea-Guibourtia-Pterocarpus* woodlands (Figure 3.3) indicates a fine grain (small distance between regeneration and canopy plots) for *C. apiculatum-D. cineria* (1.1), *P. angolensis-G. coleosperma* (2.111), *B. plurijuga* 2-*B. plurijuga* 3-*G. coleosperma* (2.212) *and B. plurijuga* 2-*B. plurijuga* 1 (3.112) sub-communities.. These sub-communities mainly comprised of plots from stage 3 of all resource use systems and a few from undisturbed sites (Table 3.1). *C. collinum-C. apiculatum* (1.2), *B. plurijuga* 3-*G coleosperma-B. plurijuga* 2 (2.12), *G. coleosperma-B. plurijuga* 2-*C. collinum*(2.211), *B. plurijuga* 3-*B. plurijuga* 2 (2.22) *and B. plurijuga* 1-*B. plurijuga* 2-*C. collinum* (3.111) sub communities depicted coarse grain (large distance between regeneration and canopy plots). These sub-communities comprised of mature stands from undisturbed sites and stages 4 from different disturbance regimes (Table 3.1). The key canopy species in the *Baikiaea-Guibourtia-Pterocarpus* woodlands are *B. plurijuga, P. angolensis, G. coleosperma, S. rautanenii* and *C. collinum*. *B. plurijuga* regenerated in both fine and coarse grained communities but the species showed more regeneration (stems <10 cm DBH) in fine-grained communities, while *G. coleosperma* had more regeneration in coarse-grained communities *C. collinum-C. apiculatum* (1.2), *G. coleosperma-B. plurijuga* 2-*C. collinum* (2.211) and *B. plurijuga* 3-*B. plurijuga* 2 (2.22). *P. angolensis* showed high regeneration in fine-grained *B. plurijuga* 2-*B. plurijuga* 1(3.112) and *B. plurijuga* 2-*B. plurijuga* 3-*G. coleosperma* (2.212) sub communities. The species also regenerated in coarse-grained *G. coleosperma*-*B. plurijuga* 2-*C. collinum* (2.211) and *B. plurijuga* 1-*B. plurijuga* 2-*C. collinum* (3.111) sub communities.

Table 3.1: Grain status for each sub-community and distribution of plots from different disturbance factors

Disturbance factor and stand development stage	Number of plots by Tree Communities									Total plots
	1.1	1.2	2.111	2.12	2.211	2.212	2.22	3.111	3.112	
Protected area	-	-	-	22	3	3	4	-	-	32
Concession area stage 4	-		-	-	-	2	8	-	-	10
Pole-firewood stage 4	2	2	-	-	-	-	4	-	-	8
Abandoned field stage 4	-	5	-	1	2	1	-	1	-	10
Concession area stage 3	-		-	-	-	7	-	1	2	10
Pole-firewood stage 3	3	2	1	-	-	3	-	-	-	9
Abandoned field stage 3	-	-	1	3	2	2	1	-	1	10
Concession area stage 2	-	2	-	1	3	2	-	2	-	10
Pole-firewood stage 2	-	3	-	-	-	1	1	-	2	7
Abandoned field stage 2	-	2	-	-	1	-	-	-	-	3
Abandoned field stage 1	-	-	1	-	-	-	-	-	-	1
Total plots	5	16	3	27	11	21	18	4	5	110
Grain status*	F	C	F	C	C	F	C	C	F	

Grain status: C = Coarse grain; F = Fine grain

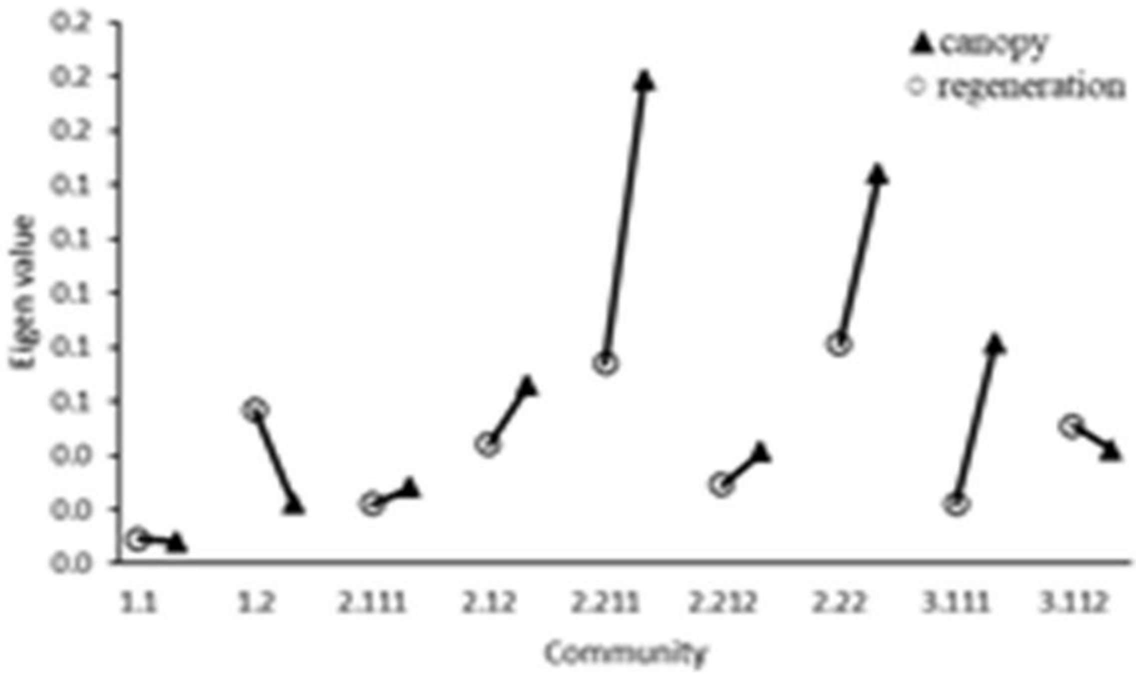

Figure 3.3 Correspondence Analysis ordination of the mean scores for composition of canopy trees (≥15 cm DBH) and regeneration (stems 1.0 to 9.9 cm DBH), of canopy tree species, for nine tree sub-communities of the *Baikiaea-Guibourtia-Pterocarpus* woodlands.

3.3.2 Stem diameter distribution at community level

This study recorded 8476 stems in the 110 sampled plots, with 58% belonging to the 1.0-4.9 cm stem diameter class, 19% to the 5-9.9 cm stem diameter class and 14% belonging to the 10-14.9 cm stem diameter class. Large diameter stems represented less than 1% of the total number of stems enumerated (Table 3.2). *P.angolensis-G. coleosperma* (2.111) sub-community recorded the highest stem density followed by *B. plurijuga* 2-*B. plurijuga* 1(3.112) and *G. coleosperma-B. plurijuga* 2-*C. collinum* (2.211) sub-communities. These sub-communities comprised of plots from the heavily disturbed sites of pole-firewood harvesting and abandoned crop fields. The lowest stem density was recorded in *B. plurijuga 3-G. coleosperma-B. plurijuga* 2 (2.12) sub-community comprising of 81% of plots from undisturbed sites followed by *C. apiculatum-D. cineria* (1.1) sub-community. These communities recorded the lowest stem density in the 1.0-4.9 cm diameter class (Table 3.2). In general, almost all sub-communities showed inverse J-shaped profiles (Table 3.2). However, *C. apiculatum-D. cineria* (1.1), *C. collinum-C. apiculatum* (1.2), *P. angolensis-G. coleosperma* (2.111) and *B. plurijuga* 2-*B. plurijuga* 3- *G. coleosperma* (2.212) sub-communities showed a bell-shaped profile when the 1.0-4.9 cm diameter class is ignored. Some sub communities had peaks in some classes depicting bimodal distributions, such as *C. apiculatum-D. cineria* (1.1), *B. plurijuga* 2-*B. plurijuga* 3- *G. coleosperma* (2.212), *G. coleosperma-B. plurijuga* 2-*C. collinum* (2.211), *B. plirijuga* 1-*B. plurijuga* 2-*C. collinum* (3.111) sub-communities and to some extent *B. plurijuga* 2-*B. plurijuga* 1 (3.112) sub community (Table 3.2).

Table: 3.2. Stem diameter class distribution of stems across 5-cm wide stem diameter classes for the different tree communities in *Baikiaea-Guibourtia-Pterocarpus* woodlands of North-western Zimbabwe.

Upper limit of stem diameter class, cm	Community								
	1.1	1.2	2.111	2.12	2.211	2.212	2.22	3.111	3.112
	Number of stems per hectare								
4.9	229.0	811.2	500.0	263.0	961.3	270.2	454.8	635.5	783.3
9.9	37.2	53.1	358.3	2.8	168.9	36.9	209.7	212.5	507.8
14.9	50.0	71.9	583.3	1.9	102.3	54.8	100.1	162.5	85.0
19.9	10.6	9.1	70.7	2.7	41.6	11.4	21.1	61.0	31.1
24.9	5.7	4.9	27.1	2.1	31.2	3.2	28.1	16.8	50.2
29.9	9.9	0.7	4.7	4.2	17.3	0.3	17.1	6.2	2.8
34.9	4.2	0.2	2.4	5.2	47.6	4.7	12.8	71.6	0.7
39.9	0.7	-	0.3	6.2	28.7	0.3	5.5	22.1	0.7
44.9	-	0.7	-	1.3	9.6	0.3	1.6	23.9	0.7
49.9	-	-	-	0.8	5.1	-	0.4	5.3	0.0
54.9	-	-	-	1.0	1.9	0.2	-	0.9	0.7
59.9	-	-	-	-	-	-	0.2	2.7	-
64.9	-	-	-	1.4	-	0.2	-	1.8	0.7
> 65	-	-	-	0.4	1.3	0.2	-	-	-
Total	347.3	951.8	1546.8	293.0	1416.8	382.7	851.4	1222.8	1463.7

3.3.3 Population status of important tree species

Baikiaea plurijuga was prominent in all the nine sub-communities, but had a high stem density in DBH classes 1.0-4.9, 5.0-9.9 and 10.0-14.9 cm (Figure 3.4). The species is also prominent in the bigger stem diameter classes e.g. 30.0-34.9, 35.0-39.9 and 44.9+ cm size classes in *G. coleosperma-B. plurijuga* 2-*C. collinum* (2.211) and *B. plirijuga* 1-*B. plurijuga* 2-*C. collinum* (3.111) sub communities. The species showed bimodal diameter distributions with two peaks at varying stem diameter classes in most sub-communities of *B. plurijuga* 2&3 and *B. plurijuga* 1 communities (Figure 3.4). These sub-communities comprised of plots from different stages of different land use systems. *C. apiculatum-D. cineria* (1.1) sub-community had stems only in the 1.0-4.9 cm diameter size class. The sub-community comprised of plots from stages 3 and 4 (Stage 1 height was <2 m; Stage 2 height was 2.1-5 m; Stage 3 height was 5.1-8 m; and Stage 4 height was >8 m) of pole and firewood collection sites. *G. coleosperma* and *P. angolensis* occured mainly in *B. plurijuga* 2&3 community, but are also present in the two sub-communities of *B. plurijuga* 1 community.

Guibourtia coleosperma also occured in one sub-community of *Combretum* community (Figure 3.4). The species only regenerated in three sub-communities {*C. collinum-C. apiculatum* (1.2), *G. coleosperma-B. plurijuga* 2-*C. collinum* (2.211) and *B. plurijuga* 3-*B. plurijuga* 2 (2.22)}. These sub-communities mainly comprised of plots from stages 4, 3 and 2 of pole and firewood collection sites, abandoned crop fields, concession areas and undisturbed sites. No stems were recorded in 1.0-4.9 cm diameter class in 4 sub-communities (*B. plurijuga* 3-*G. coleosperma-B. plurijuga* 2 (2.12), *B. plurijuga* 2-*B. plurijuga* 3-*G. coleosperma* (2.212), *B. plurijuga* 1-*B. plurijuga* 2-*C. collinum* (3.111) *and B. plurijuga* 2-*B. plurijuga* 1 (3.112). Most of these communities comprised of more plots from undisturbed sites e.g. *B. plurijuga* 3-*G. coleosperma-B. plurijuga* 2 (2.12) sub-community. The species showed bell-shaped profiles in this community. Bimodal distributions were shown in sub-communities *G. coleosperma-B. plurijuga* 2-*C. collinum* (2.211), *B. plurijuga* 2-*B. plurijuga* 3-*G. coleosperma* (2.212) and *B. plurijuga* 3-*B. plurijuga* 2 (2.22). An inverse J-shaped distribution was shown in *B. plurijuga* 1-*B. plurijuga* 2-*C. collinum* (3.111) sub-community. Some communities had this species in only one diameter class e.g. *C. apiculatum-D. cineria* (1.1) and *B. plurijuga* 2-*B. plurijuga* 1 (3.112) sub communities.

Pterocarpus angolensis occurred in seven sub-communities (Figure 3.4) that mainly comprised of plots from undisturbed sites, stages 3 and 4 of abandoned crop fields, pole and firewood collection sites and concession areas. The species did not regenerate in sub-communities dominated by plots from undisturbed sites; rather bigger size classes were dominant e.g. *B. plurijuga* 3-*G. coleosperma-B. plurijuga* 2 (2.12) sub-community that comprised of 81% of plots from undisturbed sites (Table 3.1). An inverse J-shaped profile was shown in this community. The species regenerated in sub-communities where disturbance from pole and firewood, cultivation and single-tree timber-harvesting was prominent e.g. *G. coleosperma-B. plurijuga* 2-*C. collinum* (2.211), *B. plurijuga* 2-*B. plurijuga* 3-*G. coleosperma* (2.212), *B. plurijuga* 3-*B. plurijuga* 2 (2.22), *B. plurijuga* 1-*B. plurijuga* 2-*C. collinum* (3.111) and *B. plurijuga* 2-*B. plurijuga* 1 (3.112) sub communities. Irregular profiles with missing size classes were shown in these sub-communities except *G. coleosperma-B. plurijuga* 2-*C. collinum* (2.211) sub-community that showed a bimodal distribution.

All three key species (*B. plurijuga, G. coleosperma* and *P. angolensis*) showed inverse J-shaped curves at landscape level (when all communities are combined). *B. plurijuga* occurred in all the size classes, but has a high stem density in DBH classes 1.0-4.9, 5.0-9.9 and 10.0-14.9 cm (Figure 3.5). The number of stems decreases with increasing size classes producing a typical inverse J shaped curve, but with a hump around 30 to 45 cm DBH (Figure 3.5). *G. coleosperma* occurred in all diameter size classes except in the 59.9 cm diameter size class. The species has high stem density in the 4.9 cm diameter size class. Stem density also decreases with increasing size classes resulting in typical inverse J shaped curve; and is very similar in shape to the *B. plurijuga* size class distribution but at a slightly lower level. *P. angolensis* showed a similar profile but had no stems larger than 49.9 cm.

Combretum collinum, *C. molle* and *C. apiculatum* had high densities in the first four diameter size classes (1.0 – 29.9 cm DBH) as compared to bigger size classes, while *Schinziophyton rautanenii* had more stems in the higher size classes (Figure 3.6). *C. collinum* showed inverse J-shaped profiles in sub-communities *C. collinum-C. apiculatum* (1.2), *B. plurijuga* 2-*B. plurijuga* 3-*G. coleosperma* (2.212), *B. plurijuga* 1-*B. plurijuga* 2-*C. collinum* (3.111) and *B. plurijuga* 2-

B. plurijuga 1 (3.112) sub communities and bell-shaped profiles in *P. angolensis-G. coleosperma* (2.111) sub-community. *S. rautanenii* showed irregular profiles in *B. plurijuga* 2-*B. plurijuga* 3-*G. coleosperma* (2.212), *B. plurijuga* 2-*B. plurijuga* 1 (3.112) and *G. coleosperma-B. plurijuga* 2-*C. collinum* (2.211) sub-communities.

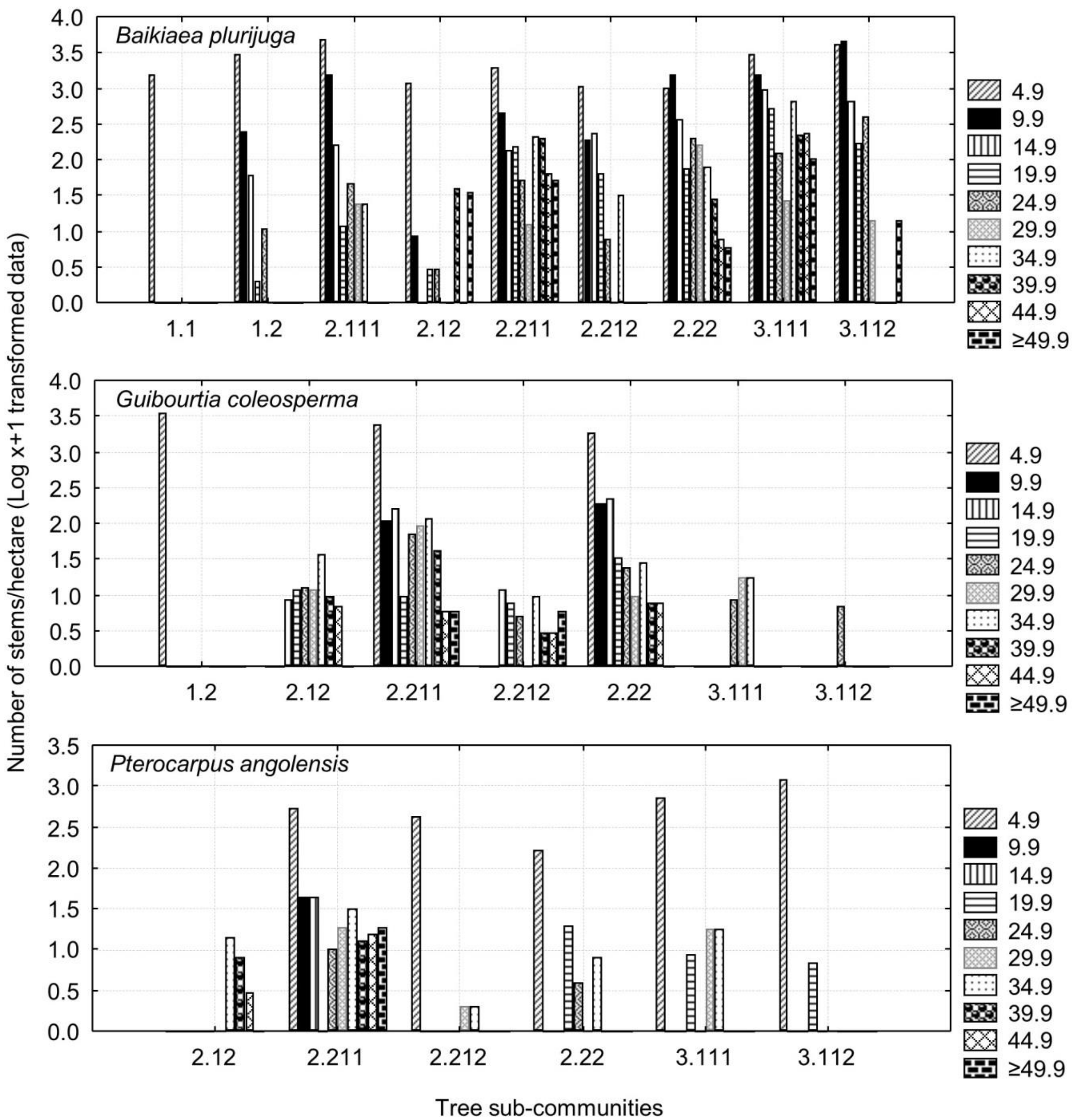

Figure 3.4: Stem diameter distributions for the key species in different tree communities in *Baikiaea-Guibourtia-Pterocarpus* woodlands of North-western Zimbabwe.

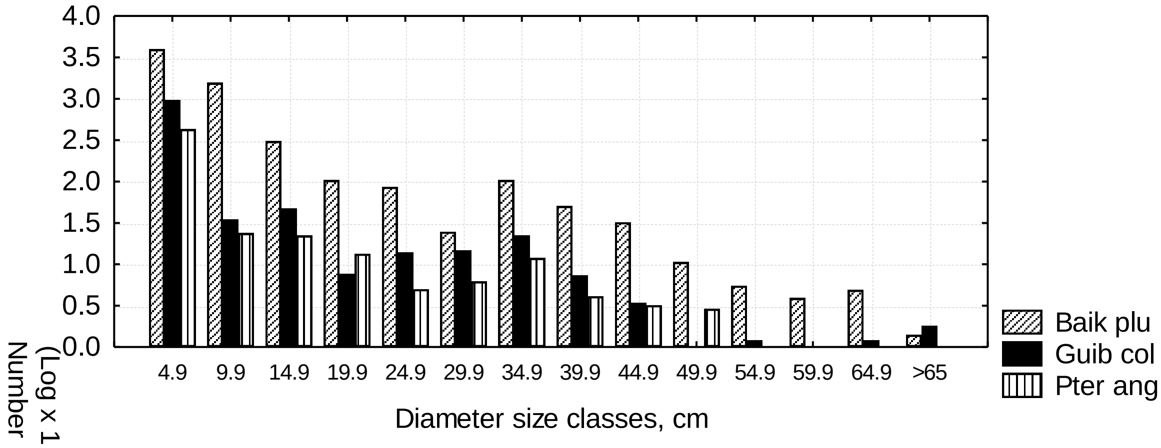

Figure 3.5: Stem diameter distributions for the key species at landscape level (with all communities combined) in *Baikiaea-Guibourtia-Pterocarpus* woodlands of North-western Zimbabwe. The stem diameter classes show the upper limit of each class.

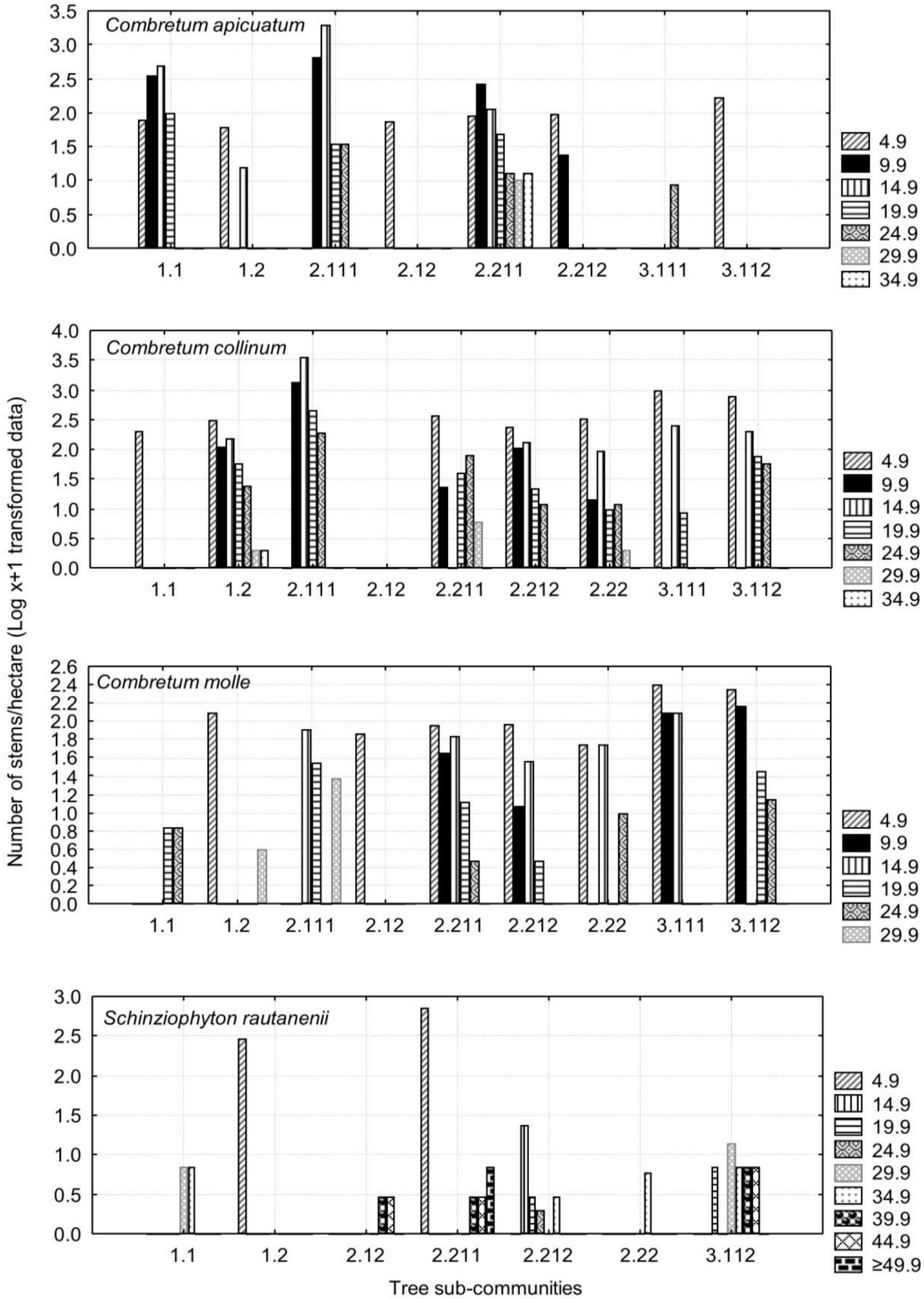

Figure 3.6: Stem diameter class distributions for other canopy species in different tree communities in *Baikiaea-Guibourtia-Pterocarpus* woodlands of North-western Zimbabwe

3.4 DISCUSSION

3.4.1 Grain analysis in the identified communities

The study has shown a fine grain status for communities that comprise mostly of plots of advanced stand development stages 3 of concession areas, pole and firewood collection sites and abandoned crop fields. This suggests that regeneration of the canopy tree species of these stands is adequate within these stands of advanced development stages. The question is whether these species recruit continuously under the closed canopy of these stands or whether the canopies of these stands are relatively open to enable the regeneration to establish or to persist in the absence of fire. The main regenerating species in the fine-grained communities is *B. plurijuga* (relatively intolerant to fire) as compared to *G. coleosperma*, *P. angolensis* and other canopy species. The increase in the regeneration of *B. plurijuga* was a result of the control and/or elimination of fire in the woodlands. This action also resulted in reduced regeneration and growth of *P. angolensis* (relatively tolerant to fire) (Geldenhuys 2009). The exclusion of fire in woodlands mainly promotes regeneration of *B. plurijuga* and *G. coleosperma* (fire sensitive species) (Geldenhuys *et al.* 2004). Prescribed burning during the early dry season is a management strategy implemented by the Forestry Commission to reduce fuel loads and hence reduce the incidence of intense fires during the late dry season (Gambiza *et al*. 2005). The stem diameter distributions for *B. plurijuga* in the fine-grained sub communities such as *C. apiculatum-D. cineria* (1.1), *P. angolensis-G. coleosperma* (2.111), *B. plurijuga* 2-*B. plurijuga* 3-*G. coleosperma* (2.212) and *B. plurijuga* 2-*B. plurijuga* 1 (3.112) (from advanced stages of development of all disturbance regimes) suggest that the species is able to regenerate and persist with a relatively open canopy as a result of cultivation and harvesting for poles and firewood in the fine-grained communities. The density of large stems (large diameter classes) in these fine-grain communities for *B. plurijuga* is comparable to the coarse-grained communities. This could be because the stands are still recovering and developing towards maturity after the disturbances. The large gaps opened when clearing for agriculture and harvesting for poles and firewood may be responsible for these observations. *P. angolensis* and *Combretum molle* also regenerated in the fine-grained stands with inverse J shaped profiles. Clearing for agriculture and harvesting for poles and firewood result in a relatively open canopy allowing more light on the forest floor resulting in enhanced regeneration of several species. Opening of the canopy stimulates germination of the soil-stored seed reserves as the temperature and light intensity increase and the growth of seedlings and saplings is also enhanced as a result of an increase in resource supply (light, moisture and nutrients). Also, the exposure of stumps to sunlight enhances their coppice effectiveness (Reader & Bricker 1995). Regeneration could be from seeds, or stumps that have been exposed to light when the canopy is opened. *P. angolensis* (shade intolerant species) performs well in cleared areas because of total exposure to maximum light (Boaler 1966; Werren *et al.* 1995; Graz 1996). Land clearing results in more space available to the growing plants hence there is reduced competition for resources such as space, moisture and nutrients thus contributing to good performance of the species in such areas. In a study by Syampungani (2009), *P. angolensis* performed well in cleared areas for charcoal production and slash & burn activities. Species that regenerate in these open stands are able to grow and persist in sites with relatively open canopies. Trees of different species may be able to regenerate from rootstocks, seed dispersal from neighboring trees, or some may grow from advanced regeneration already present on the forest floor in the concession areas.

Coarse grain was evident for sub-communities mostly with plots from undisturbed sites and stages 4 and a few from stages 3. It means that species are not able to regenerate near their adults in these sub-communities. The big stems suppress the growth of new plants under the closed canopy when no harvesting of resources is allowed in these sites, and fire is excluded. *B. plurijuga* and *P. angolensis* showed inverse J-shaped profiles in the coarse-grained communities. *P. angolensis* did not regenerate in *B. plurijuga* 3-*G. coleosperma-B. plurijuga* 2 (2.12) subcommunity with more than 80% of plots from undisturbed sites. This suggests that the resource use patterns and stand conditions in this community do not favor the regeneration of the species. *G. coleosperma* only regenerated in the coarse-grained communities that are dominated by advanced stages of development and undisturbed sites. *G. coleosperma* showed high regeneration in the coarse-grained sub communities' e.g. *C. collinum-C. apiculatum* (1.2) and *G. coleosperma-B. plurijuga* 2-*C.collinum* (2.211) which had more than 55% of plots from stages 2 and 3 of different utilization systems, but low regeneration in communities with more than 50% of plots from stages 4 and undisturbed sites. This suggests that the species requires a relatively open canopy to regenerate and grow. The species also regenerates well when fire is controlled or eliminated (Geldenhuys *et al*. 2004). Regeneration in communities with more plots from stages 4 and undisturbed sites could have been from rootstocks or lateral roots of the mature trees in these stands or from advance regeneration that is already present on the forest floor. The canopy cover in these stands is relatively high when compared with the fine-grained communities because of the presence of mature trees in these stands. It is, therefore, likely that there is not enough light in such stands for regeneration of *G. coleosperma* to establish and grow. The regeneration may be suppressed stems under canopy of larger stems/trees. The stem diameter distributions show that the communities had very few or no stems of *G. coleosperma* in the <10 cm diameter class. The fires that occur in the woodlands may further retard the growth of the regenerating plants into the bigger size classes.

3.4.2 Stem diameter distributions at community and population level

In this study, all sub-communities showed inverse J-shaped profiles suggesting stable state communities. High stem density was shown in sub-communities consisting of plots from heavily disturbed sites of abandoned fields and pole and firewood collection sites while the lowest stem density was recorded in those communities with the majority of plots from undisturbed sites. This suggests that resource utilization promotes growth of new plants compared to areas with closed canopy cover where no resource utilization is permitted. Large canopy trees are more likely to suppress growth of regenerating plants in these communities as shown by low stem densities in the 1.0-4.9 cm stem diameter class. However, such stem diameter distributions include stems of different tree species, and may not show the population status of individual species.

Different species have characteristic stem diameter distributions which indicate success or failure of their regeneration and establishment and hence their population status (Geldenhuys 1993). *B. plurijuga* showed bimodal profiles with high densities in two stem diameter classes. A high density in the 1.0-4.9 cm diameter class suggests that the species is able to regenerate well in most sub-communities. This means that the prevailing conditions in this woodland favor the regeneration and growth of *B. plurijuga* as compared to other key species. The control or elimination of fire in these woodlands resulted in reduced regeneration and growth of *P. angolensis* and led to improved regeneration and growth of *B. plurijuga*, a fire sensitive species (Geldenhuys 2009). This was also evident in this study, since *B. plurijuga* dominated all the communities and *P. angolensis* had the least stocking density in all the communities. *P. angolensis* showed inverse J-shaped profiles in one community with 81% of plots from undisturbed sites. However, the species showed poor regeneration in this community suggesting that the stand conditions, resource use management (total protection with no harvesting allowed), and the control of fire, have a negative impact on regeneration of the species. The species regenerated adequately with irregular profiles in communities with plots from the heavily disturbed sites of pole and firewood collection sites and abandoned crop fields. This is because the species is light-demanding and requires cleared areas for it to regenerate adequately (Boaler 1966; Werren *et al.* 1995; Graz 1996; Syampungani 2009). This suggests that larger-scale disturbance and large gaps are likely to maintain regeneration of this species. In northern Namibia, in undifferentiated woodland (White 1983), the fire-tolerant *P. angolensis* showed the inverse J-shaped stem diameter distribution, whereas the fire-sensitive *B. plurijuga* showed the bell-shaped stem diameter distribution (Geldenhuys 1993). In this study both species showed inverse J-shaped profiles in most sub-communities where they occurred, reflecting stable, steady-state populations.

The low densities of *P. angolensis* in larger stem diameter classes might be due to the fact that timber loggers and poachers target the species for its strong and durable wood or the species cannot be recruited to larger size classes for various reasons, but likely the exclusion of fire. The harvesting of the large stems creates gaps in the canopy and in the absence of disturbances; young plants can grow in the canopy gaps. The question would be weather *P. angolensis* seedlings are growing in the gaps or other species are growing. Therefore, the combination of these factors threatens the survival of the species. Similar observations were made by Nduwamangu & Malimbwi (1997) in Tanzania where *P. angolensis* had very low stocking density due to harvesting for window and door frames. Therefore, if the exploitation of such a species continues unchecked, it can be costly to the timber industry. This can result in non-availability of merchantable stems of the species being over-exploited even if the species have ample regeneration. Studies by Grundy & Cruz (2001) (Mozambique); Mudekwe (2006) (Zimbabwe) and Syampungani (2009) (Zambia) have revealed that the commonly harvested species depicted unstable populations and had missing size classes. This scenario is also shown in this study for almost all the dominant species where bigger size classes were missing. Studies in South African semi-arid lowveld by Shackleton *et al*. (2005) showed low densities for species such as *Ziziphus mucronata*, *Diospyros mespiliformis* that were ring-barked for medicinal purposes.

Guibourtia coleosperma showed inadequate regeneration in all communities where it occurred as shown by low stem densities in the 1.0-4.9 cm diameter class. The bell-shaped distribution for *G. coleosperma* suggests that the species requires different conditions than those prevailing in the system (Geldenhuys 1993).

The information from this study could be considered in planning for the harvesting of species. In future, other species may be required to be utilized, and forest enrichment of species showing poor regeneration may be necessary. The information in this study could be used to guide, firstly whether a species is suitably abundant to be subjected to utilization, and secondly, how it could be harvested so as to allow its regeneration.

3.5 CONCLUSION

The three key species, *B. plurijuga*, *G. coleosperma* and *P. angolensis*, all depicted stable populations in most communities and all also at landscape level. Intense disturbances (cultivation and harvesting for poles and firewood) seem to be major ecological drivers of the *Baikiaea-Guibourtia-Pterocarpus* woodlands as shown by the grain status and stem diameter distributions. The grain status and stem diameter distributions in the different communities suggest that the species require some larger disturbances, such as with cultivation and harvesting for poles and firewood to promote regeneration and growth to higher size classes. There is therefore need to incorporate such disturbance factors in the silvicultural management systems of the woodlands so as to promote regeneration and recruitment to larger stem diameter classes for all the key species, especially *G. coleosperma and P. angolensis*. The fire management plan in the woodlands also needs to be revised as it has been noted that the control of fire has resulted in the increased regeneration and growth of *B. plurijuga*, as compared to the other two key species.

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4 DISTURBANCE IMPACTS ON REGENERATION OF KEY ECOLOGICAL AND/OR ECONOMIC SPECIES IN THE *BAIKIAEA-GUIBOURTIA-PTEROCARPUS* WOODLANDS OF NORTH-WESTERN ZIMBABWE.

Abstract

A study was carried out in the *Baikiaea-Guibourtia-Pterocarpus* woodlands of North-western Zimbabwe to investigate the mode of regeneration of key species under different disturbance regimes eight years after cessation of disturbance. The disturbance regimes included no disturbance (protection), timber concession (timber harvesting), pole and firewood harvesting, abandoned crop fields (after clearing for agriculture), and burning (fire disturbance). Influence of stump diameter and height on regeneration factors was also investigated. For each disturbance regime, six main plots of 100 m x 100 m each (a total of 30 plots) were systematically laid out for the assessment of regeneration. The main plots were placed at 20 m intervals within the disturbance regime site. In each main plot, 10 m wide transects, with a separating distance of 5 m between transects, were surveyed for seedlings and saplings of the target species, resulting in 7 transects per main plot, 42 transects in each study site, and a total of 210 transects. At least 100 plants of each target species: *Baikiaea plurijuga, Guibourtia coleosperma and Pterocarpus angolensis*. The identified seedlings and saplings of the target species were excavated to record the number of seedlings without a rootstock (i.e. just grown from seed) or with a rootstock. Cut stumps were identified in all the study sites. Diameter of the stumps was measured at the cut surface. The height of sprouting shoots was measured from their origin at the base. There was a significant association between each target species and mode of regeneration (χ^2 = 27,642, P<0.001). In general, most plants regenerated from rootsuckers as compared to other regeneration modes. Stump diameter has a negative influence on number of sprouts for *B. plurijuga* and *P. angolensis*, but a positive influence on sprout height for all species. Stump height has a positive influence on sprout height for *G. coleosperma* and *P. angolensis*. The study therefore concludes that disturbances are necessary in facilitating the sprouting and growth of suppressed shoots. Stump height and diameter influence the ability of stumps to regrow vegetatively through sprouting. Weak relationships between stump diameter/stump height and coppice density and the shoot height suggest that there are other factors that greatly affect vegetative regrowth through coppicing.

Key words: Disturbance, recruitment, sprouting

4.1 INTRODUCTION

What can we do to improve the regeneration and population status of key species in indigenous woodland ecosystems where no silvicultural management systems are applied? In plantation systems, regeneration is planned, established and monitored. However, in natural woodlands and forest ecosystems we rely on natural regeneration (renewal of a tree crop by self-sown seed or vegetative regrowth) which may fail in some seasons. No silvicultural interventions are applied to enhance the growth of the regenerated plants. How then can we attain successful regeneration of key species in natural woodland ecosystems? We need adequate regeneration because the future of forest and woodland ecosystems and sustainable resource use are dependent on successful regeneration of key ecological and/or economic species. It is therefore important to assess the response (regeneration and growth) of key individual species to different disturbance factors. *Baikiaea plurijuga*, *Guibourtia coleosperma* and *Pterocarpus angolensis* are the most harvested species in the *Baikiaea-Guibourtia-Pterocarpus* woodlands (Chigwerewe 1996; JAFTA & Forestry Commission 2001). Understanding the modes of regeneration of these species is of paramount importance to ensure their continued existence. Therefore, forest managers, harvesting foresters and harvesting crews need to understand the most appropriate land management practices that would prompt optimal regeneration of each key species. The common mechanisms of regeneration of different species in the woodlands include advance regeneration (seedling banks), current-year seedlings; seedling sprouts that occur after seedling shoot dieback (including sprouts from underground rootstocks), coppice or sprouts from stumps of mature trees and root suckers that arise from lateral roots (Timberlake *et al*. 2010).

Concerns have been raised over the future availability and possible extinction of some species, especially *P. angolensis*, in Zimbabwe (Bradley & Dewees 1993; Clarke *et al*. 1996). Woodcarvers in South Africa indicated that the species is becoming rare (Steenkamp 1999). Also, low seedling recruitment rates during both germination and the suffrutex stage (Boaler 1966; Schwartz *et al*. 2002; Caro *et al*. 2005) and unsustainable rates of harvesting (Scwartz *et al*. 2002; Caro *et al*. 2005) further threatens populations of the species. Most studies have reported adequate regeneration of *B. plurijuga* (Chigwerewe 1996; Gambiza 2001; Dube 2005). The species has been seen to be taking over *Baikiaea-Guibourtia-Pterocarpus* woodlands after policy changed from controlled burning to total protection (Geldenhuys 2009). Vegetation changed from domination by *P. angolensis* to dense regeneration of *B. plurijuga*. The few studies that have been carried on *G. coleosperma* indicated that regeneration and growth of the species is slow (Lemmens *et al*. 2008).

Different disturbance regimes influence regeneration and recruitment of species differently. The ability to sprout after severe injury from disturbances such as herbivory, fire, floods, logging or drought is vital, especially for the *Baikiaea-Guibourtia-Pterocarpus* woodland species which are subjected to disturbances all the time (Mudekwe 2007). Seedlings and sprouts face frequent and severe fire damage that can retard their recruitment into the tree layer. Between fires, seeds have to germinate and build enough root reserves to survive the next fire. However, given that fires usually occur frequently (Scholes & Walker 1993), sprouts would need to grow rapidly to escape damage. On cleared and abandoned land, regeneration often takes place but the speed of woodland recovery depends on the methods used in clearing, the sources available for regeneration and site history (type, frequency and intensity of stress and/or disturbance) (Geldenhuys & Golding 2008). Furthermore, studies on regeneration of *Baikiaea-Guibourtia-Pterocarpus* woodlands of north-western Zimbabwe concluded that competition for moisture and light from undergrowth makes survival beyond the first dry season very low (Calvert 1986). There is, therefore, need to improve regeneration, recruitment and growth of key species in these woodlands. Moreover, the current utilization of the woodlands ignores the natural disturbance-recovery processes of the key species and their adaptation to survive the natural disturbance-recovery processes (Geldenhuys 2009). Individual species respond differently to disturbances such as fire, herbivory and logging and treating them similarly might have adverse implications on the regeneration and recruitment of some species.

The possibility of raising seedlings of *P. angolensis* for enrichment planting has been reported as impossible by some authors (Boaler 1966; Van Daalen 1991). In an early attempt to determine the feasibility of raising *P. angolensis* seedlings, Boaler (1966) conducted a comprehensive study of the ecology of the species but concluded that silvicultural problems occurred at all stages of development. These include difficulties in opening pods without damaging seeds, low rates of germination, annual dieback of seedlings, competition from other trees over sunlight, effects of fire, slow rates of tree growth, and delayed seed production. In Zambian trials of *B. plurijuga*, repeated blanking was required for the first few years to cope with early losses that were experienced (Piearce 1993). He emphasized that even if seed germination is good, subsequent survival can be very poor. It has also been reported that attempts to raise *G. coleosperma* in plantations has failed, mainly because of poor germination, and poor establishment of seedlings, mainly due to desiccation, frost and herbivory (Lemmens *et al*. 2008). The results from these studies suggest that sustainable management of natural populations for these species is necessary.

Many studies have been carried out to investigate the regeneration of *B. plurijuga* after disturbances such as fire and logging (Calvert & Timberlake 1993; Gambiza 2001; Dube 2005) and *P. angolensis* (Boaler 1966; Van Daalen 1991; Schwartz *et al* .2002; Caro *et al*. 2005; Ncube & Mufandaedza 2013). However, little research has been conducted on regeneration of *G. coleosperma* (Lemmens *et al*. 2008) and other disturbance factors (clearing for agriculture and harvesting for poles and firewood) have not been considered. No study has been carried out to assess how disturbances hinder or promote regeneration of key species in woodlands under different disturbance regimes. Such studies have been done in the Miombo woodlands of Zambia (Syampungani *et al*. 2010). Gambiza (2001) looked at the influence of fire, logging and herbivory on the growth of *B. plurijuga* while Dube (2005) only focused on the effects of logging at different periods on the growth and regeneration of *B. plurijuga*. Ncube & Mufandaedza (2013) studied the effects of fire on coppice shoot production and growth of *B. plurijuga* and *P. angolensis*. It is therefore necessary to assess and analyze the regeneration mechanisms/modes that are prompted by each type of disturbance.

Regeneration in forest and woodland trees occurs through either sexual (reproductive) or vegetative means (Timberlake *et al*. 2010). Reproductive regeneration is the primary mode of regeneration, which transfers the variation in genetic pools, resulting from reproductive processes of pollination (Wood 1986), through seed dispersal and germination, and establishment of seedlings and their recruitment, into the tree phase. Vegetative regeneration is the secondary mode of regeneration that developed as an adaptive response to damage or stress resulting from frequent fires, frost and browsing. Vegetative regeneration occurs through sprouting or resprouting (root suckers or stem suckers), with sprouting shoots developing into the tree phase from pre-existing trees damaged by fire, browsing, cutting, etc. (Timberlake *et al*. 2010). Such vegetative regeneration maintains the genetic pool of the parent plants (Wood

1986). There are different types of vegetative regeneration, named after the origin of the new growth from the damaged/stressed parent plant (Timberlake *et al*. 2010). For example, vegetative regeneration could be through sprouting from the trunk (trunk suckers or stem sprouts), sprouting from specialized underground stems (lignotubers and rhizomes), sprouting from roots (root suckers), opportunistic sprouting from layered branches, root-stock sprouting from underground swollen rootstocks (Kramer & Kozlowski 1960), and basal sprouting developing above-ground at the base of the cut or damaged stem.

Satisfactory regeneration of dominant species forms the backbone for sustainable forest management. The best harvesting techniques and management practices in the post-harvest area are those that promote regeneration of the harvested species. For example, adhering to optimum diameter classes within which particular species have high coppicing effectiveness would provide for enhanced coppicing ability for many woodland species. This study concentrated on the regeneration of *B. plurijuga, G. coleosperma* and *P. angolensis* because they are the most harvested species in the woodlands (Chigwerewe 1996).

This study seeks to investigate how different disturbance regimes, such as timber harvesting, pole and fuel-wood harvesting, crop cultivation and burning, influence regeneration of key species

The following questions guided data collection and analysis:

- Under which form of regeneration does each of the key species perform best?
- How does the number of sprouts and sprout height vary amongst different regeneration modes, under different disturbance regimes?
- How does stump diameter (small to large) influence the number of sprouts and sprout height development for each of the key species?

4.2 MATERIALS AND METHODS

4.2.1 Study area

The study was conducted in the Gwaai and Tsholotsho indigenous *Baikiaea-Guibourtia-Pterocarpus* woodlands of north-western Zimbabwe (Figure 4.1). Gwaai woodlands ($19^{o}16^{1}20$ S and $27^{o}56^{1}36$E) and Tsholotsho ($19^{o}46^{1}00$ S and 27^{o} 45^{1} 00 E) (JAFTA & Forestry Commission

2001) are both located in the Matabeleland North Province and are classified under natural region IV according to the agro-ecological land classification of Zimbabwe (Bradley & Dewees 1993). Altitude ranges between 1010 and 1055 m (JAFTA & Forestry Commission 2001). These areas were chosen because of the existence of different utilization systems sought in the study.

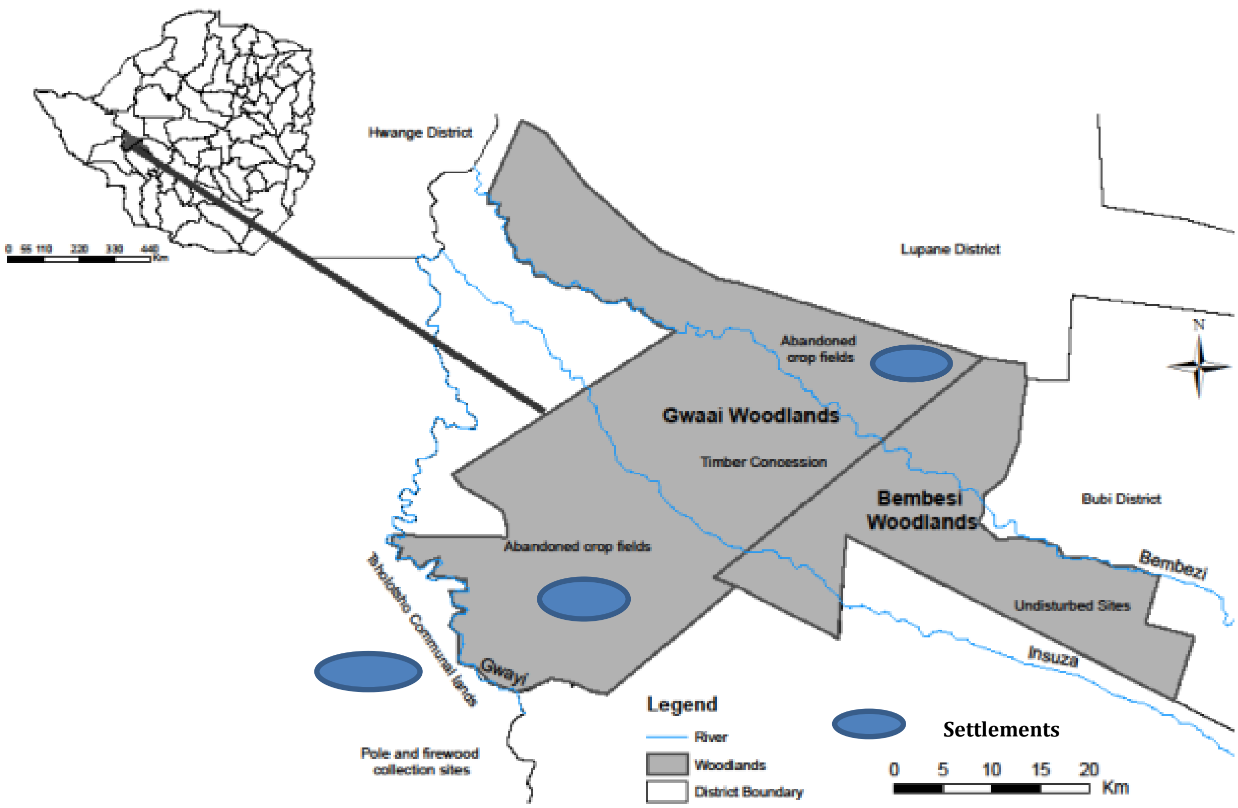

Figure 4.1: Location of the study area in Matabeleland North in Zimbabwe. The blue ovals indicate where settlements are found in the study area.

Geology and soils

The study area is situated on Kalahari sands which are strongly uniform, both physically and chemically, having high permeability and low consistency (Nyamapfene 1991). The sands are unconsolidated, red/orange, and pink or buff coloured, with no structure and with a high proportion of fine dust. The sands comprise of deep and well-drained sands of the regosol group derived from sandstone (Nyamapfene 1991).

Climate

The study area is characterized by three distinct seasons: cool dry season from April to August; hot dry season from October to November; and wet season from mid-November to March (Figure 4.2) (JAFTA & Forestry Commission 2001). The short and erratic wet season is usually characterised by dry spells and sporadic droughts (Nemarundwe & Mbedzi 1999). Mean annual temperature is approximately 21.5ºC. Mean monthly temperature ranges from 15°C (June to September) and 25°C (October to December) (Nyamapfene 1991; JAFTA & Forestry Commission 2001). Ground frosts are experienced, especially in the valleys, in most years between May and September (JAFTA & Forestry Commission 2001).

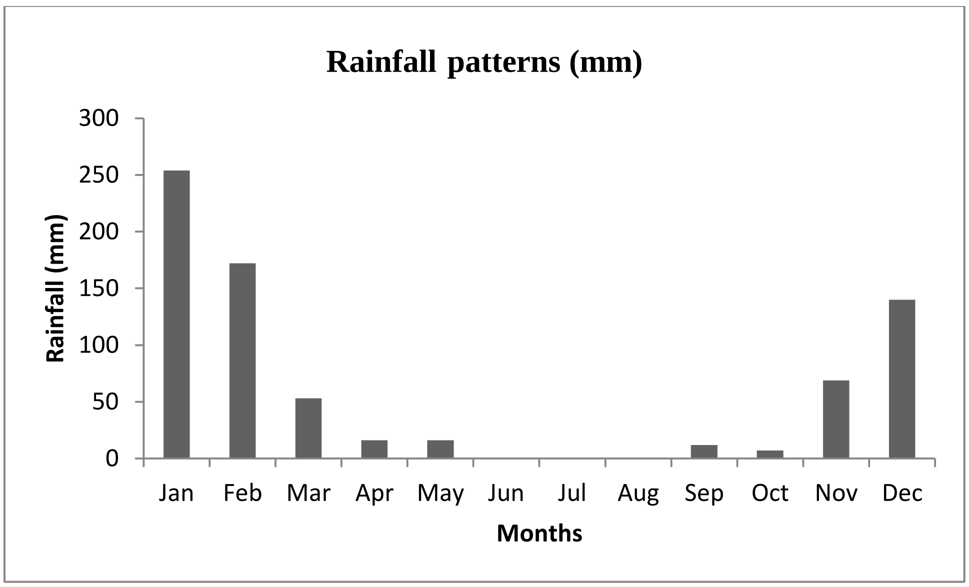

Figure 4.2 Rainfall patterns in the study area (JAFTA & Forestry Commission 2001).

Vegetation

The study area is characterised by the following six main vegetation types (JAFTA & Forestry Commission 2001): *Baikiaea-Guibourtia-Pterocarpus* woodland mainly occurs as closed to open woodland on the Kalahari sands. The tree vegetation is dominated by *Baikiaea plurijuga* growing in association with *Pterocarpus angolensis, Guibourtia coleosperma, Burkea africana, Erythrophleum africanum, Combretum collinum, Croton gratissmus, and Schinziophyton rautanenii* (JAFTA & Forestry Commission 2001). Other common sub-canopy species are *Combretum zeyheri, Commiphora marlothii, Ochna pulchra, Terminalia sericea* and *Bauhinia petersiana* (Gambiza 2001). The shrub species are *Baphia massaiensis, Grewia flavescens and Grewia monticola.* Common grasses are *Pogonathria fleckii, Aristida stipitata, A. pilgeri, Triraphis schlechteri, Tristachya rehmanii, Eragrostis species* and *Digitaria pentzii* (Gambiza 2001; Dube 2005).

Brachystegia woodland mainly occurs along the upper Bembesi River (JAFTA & Forestry Commission 2001). The area has shallower soils and contains more silt compared to where *Baikiaea-Guibourtia-Pterocarpus* woodland occurs. In other parts of the study area, *Brachystegia spiciformis* is found growing in association with *B. boehmii* and *Julbernardia globiflora, Ochna spp., Terminalia sericea* and *Burkea africana.*

Colophospermum mopane woodland is characterized by either stunted or multi-stemmed *C. mopane* trees. The woodland is mainly found along rivers or river valleys on alluvial soils that are poorly drained and highly erodible (JAFTA & Forestry Commission 2001). It is almost a mono-specific woodland with tree species of *Combretum imberbe, C. hereroense* and *Dalbergia melanoxylon* growing in association with it. Common grasses in this woodland are *Setaria incrassate, Panicum coloratum, Themeda triandra* and *Digitaria eriantha.*

Vleis are dominated by a single layer of grasses. Trees may be absent, isolated and are generally found along vlei fringes (JAFTA & Forestry Commission 2001). The amount of grass cover depends mainly on the degree of grazing, primarily by wild animals.

Pterocarpus angolensis belts occur as localised stands inside the *Baikiaea-Guibourtia-Pterocarpus* woodland. The belts are dominated by *P. angolensis* in association with *Burkea africana.* These belts are believed to have evolved through fire.*Guibourtia coleosperma* woodland is mainly characterised by the dominance of *G. coleosperma* and scattered *B. plurijuga.*

4.2.2 Methodology

4.2.2.1 Sampling design and data collection

Five study sites were selected, each representing a specific disturbance type (protected woodland, timber concession area, pole and firewood collection sites, abandoned crop fields, and burnt sites). In each site, early development stage 2 sites (height was 2.1-5 m) of 8 years old (age since disturbance cessation) were identified (except in protected areas that only had mature stands). At each utilization site, six main plots of 100 m x 100 m each (a total of 30 plots) were systematically laid for the assessment of regeneration. The main plots were placed at 20 m intervals within each utilization site. The distance between the main plots meant that the plots could be treated as independent samples (Geldenhuys & Van der Merwe 1988; Sullivan *et al*. 1995). This would also help avoid possible dilemmas of dealing with experimental units with touching edges (Wong *et al*. 2001). In each main plot, 10 m wide transects, with a separating distance of 5 m between transects, were surveyed for seedlings and saplings of the target species, resulting in 7 transects per main plot, 42 transects in each study site and a total of 210 transects. At least 100 plants of each target species (*Baikiaea plurijuga, Guibourtia coleosperma* and *Pterocarpus angolensis*) were sampled. The identified seedlings and saplings of the target species were excavated to record the origin of the sprouts, i.e. from seed (regeneration from seedlings), or root (root sprout), or swollen underground rootstocks (rootstock sprouts/rootsuckers), or above ground at the base of the cut stem (basal sprouts) or from up the stem/trunk (stem sprouts). The numbers of sprouts and height of tallest sprout on each identified plant were recorded. Diameter of the identified stumps was measured at the cut surface. The height of sprouts was measured from their origin at the base.

4.2.2.2 Data analysis

Correspondence analysis in SPSS version 21 was performed to assess the mode of regeneration associated with each utilization system. Chi-square test was used to test mode of regeneration associated with each of the target species. Differences in proportions were also tested using a Z test followed by a Bonferroni test. Differences in the number of sprouts and sprout height amongst regeneration modes were tested using One-way Analysis of Variance (ANOVA), at 5%

level of significance. *Post hoc* analysis for variables with significant differences was carried out using Tukey's Honestly Significant Difference (HSD). Regression analysis was performed to establish the relationship between different plant attributes (stump diameter and height, and number of sprouts and sprout height).

4.3 RESULTS

4.3.1 Mode of regeneration for the three key species

The key species regenerated through four modes of regeneration (regeneration from seedlings, stem sprouts, rootstock sprouts and basal sprouts). Results showed a significant association between species and mode of regeneration ($_{\chi}{}^{2} = 27.64$ $p < 0.001$). The three species' regenerated from rootstock sprouts (rootsuckers) and to lesser extent through basal sprouts (Figure 4.3). Less than 10% of plants for each species regenerated from seedlings (Figure 4.3). Regeneration from stem sprouts was also low for the three species (15%, 14% and 11%) of *B. plurijuga*, *G.coleosperma* and *P. angolensis* respectively.

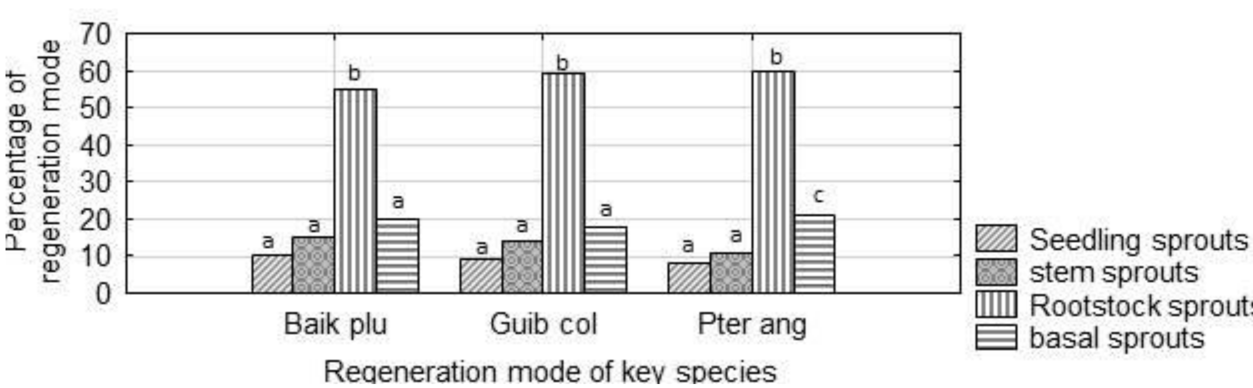

Fig 4.3: Percentage of total number of sprouts originating from (seedlings, stem or trunk - stem sprouts, rootstock - rootstock sprouts and cut or damaged stumps - basal sprouts) for the key species (Baik plu - *Baikiaea plurijuga*, Guib col - *Guibourtia coleosperma* and Pter ang - *Pterocarpus angolensis*). Each superscript (a, b, c) denotes a subset of regeneration mode categories whose column proportions do not differ significantly from each other at 5% level of significance.

Each target species has an association with a specific mode of regeneration under each disturbance category (Figures 4.4 and 4.5). 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. For example, *B. plurijuga* regenerated from rootsuckers and basal sprouts in timber concessions and in abandoned crop fields, the species regenerated from basal sprouts, rootstock sprouts and stem sprouts (Figure 4.4). In the protected areas, *G. coleosperma* is associated with regeneration from stem sprouts, rootstock sprouts and basal sprouts. The species was not recorded in pole and firewood collection sites as shown by the large distance between the species and disturbance factors (Figure 4.4). *P. angolensis* is mostly associated with regeneration from basal sprouts and rootstock sprouts in the burnt sites (Figure 4.4).

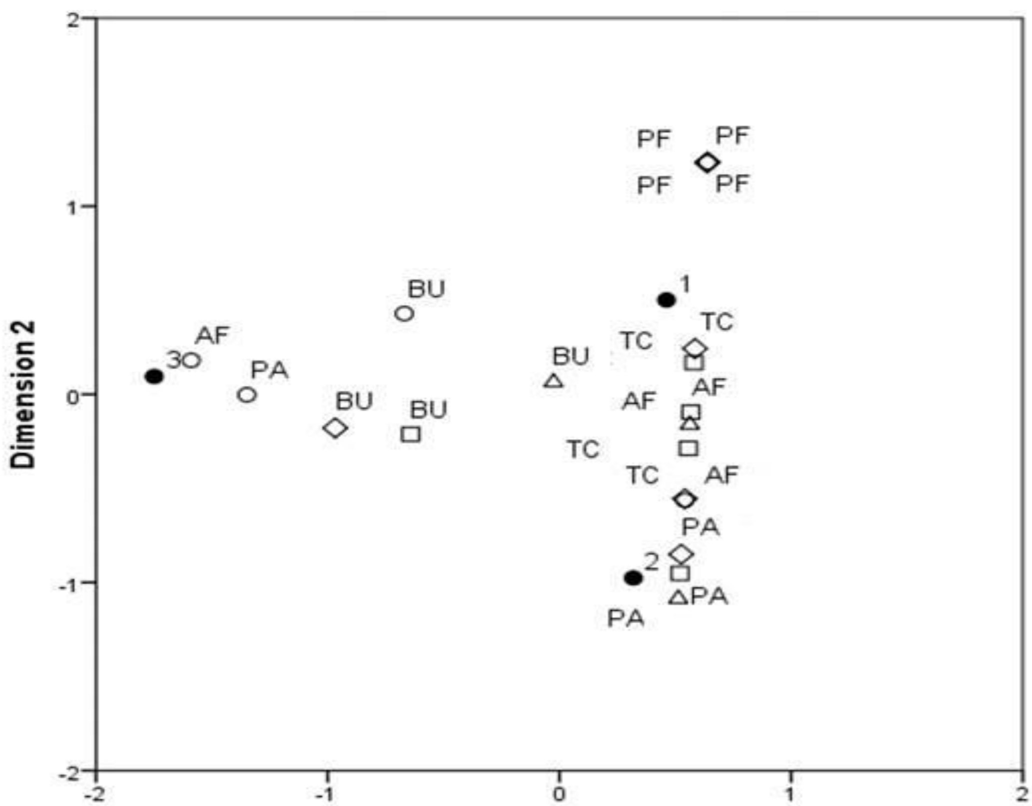

Figure 4.4 Correspondence analysis (CA) scatter plot showing the association of different disturbance regimes to regeneration modes (PA- protected area, TC – timber concession , PF- pole and firewood, AF- abandoned crop fields, , BU- burnt area). 1, 2 and 3 represent *B. plurijuga*, *G. coleosperma* and *P. angolensis* respectively. The different symbols represent the regeneration mode: circle = seedlings, triangle = stem sprouts, square = rootstock sprouts and diamond = basal sprouts.

Regeneration through seedling is located far from *B. plurijuga* and *G. coleosperma* in the ordination space, suggesting that regeneration from seedlings is low for the species. The χ^2 test results showed that regeneration mode of the three target species is dependent on disturbance regime (*B. plurijuga*- χ^2 = 225.66 p<0.001, *G. coleosperma*- χ^2 = 158.62 p<0.001 and *P. angolensis*- χ^2 =144.01 p<0.001. *B. plurijuga* regenerated in all disturbance regimes. The three species mainly regenerated from rootsuckers as compared to other modes of regeneration (Figure 4.5). Basal sprouts were not recorded in the undisturbed sites.

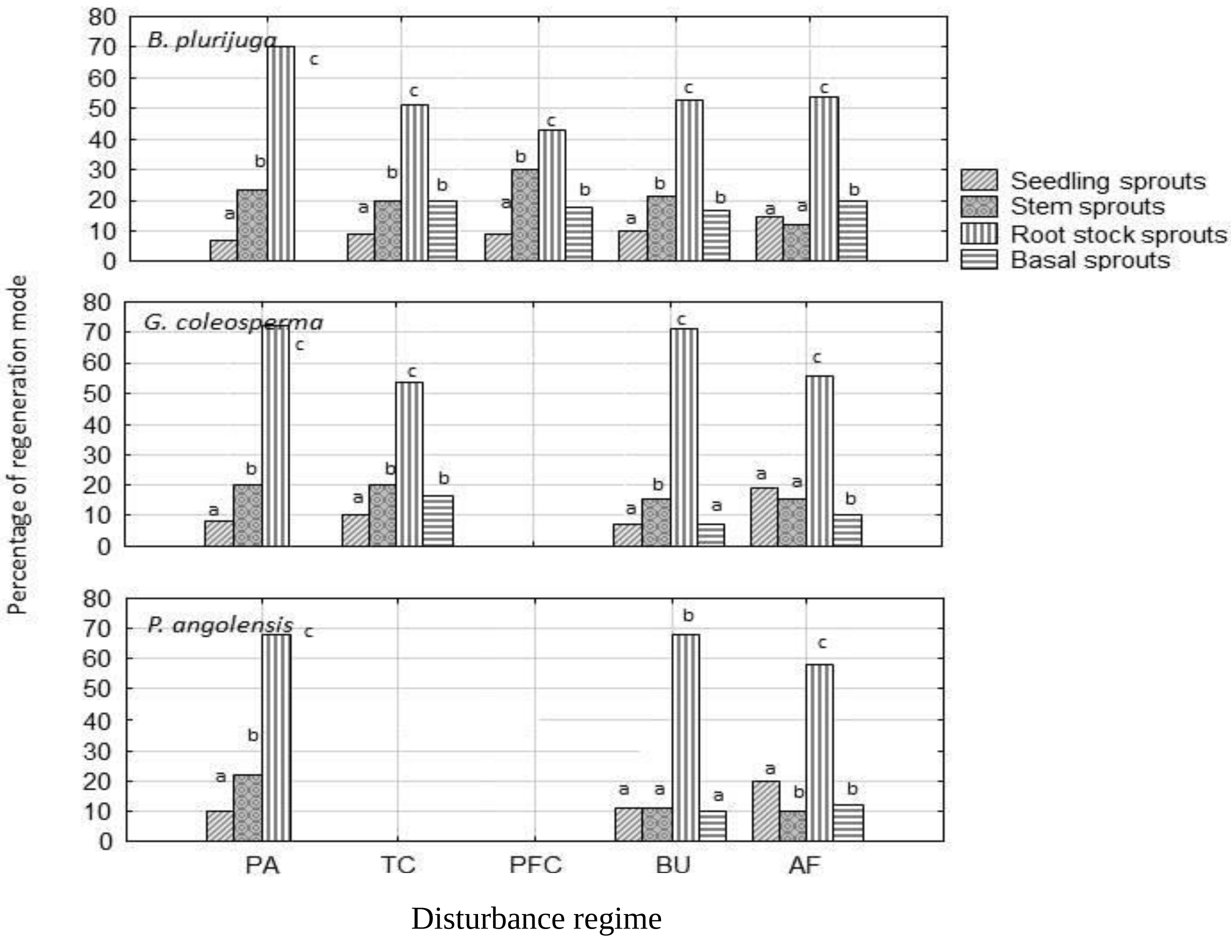

Figure 4.5 Modes of regeneration for the targeted species (*B. plurijuga*, *G. coleosperma* and *P. angolensis*) under each disturbance regime (PA- Protected area, TC-Timber concession area, PFC- Pole and firewood collection sites, AF- Abandoned crop fields, and BU-Burnt areas). Each superscript (a, b, c) denotes a subset of regeneration mode categories whose column proportions do not differ significantly from each other at 5% level of significance.

4.3.2 Influence of mode of regeneration on number of sprouts and sprout height of targeted species

Different modes of regeneration showed significant differences in sprout density for the three species ($p < 0.001$) (Table 4.1). Largest number of sprouts was produced when the three species regenerated through rootstock sprouting (root suckers) and basal sprouting. Results showed that the number of sprouts produced by the three species was not statistically different ($p>0.05$) when regenerating through seedlings, stem sprouts and rootstock sprouting, but were different when the species regenerated through basal sprouting. Different modes of regeneration showed significant differences in sprout height for *B. plurijuga* and *G. coleosperma* ($p<0.001$) (Table 4.1) but not for *P. angolensis*. Tallest sprouts were produced when the species regenerated through rootsuckers. Significant differences in sprout height occured when plants regenerated through seedlings; stem sprouting and basal sprouting for the 3 species studied. Insignificant differences were shown when regeneration occurred through rootsuckers. *P. angolensis* produced the tallest shoots.

4.3.3 Influence of stump diameter and stump height on shoot parameters

Stump diameter has a significant negative influence on number of sprouts for *B. plurijuga* (P value <0.05) and an insignificant negative influence on *P. angolensis* ($p>0.05$) (Figure 4.6). As stump diameter increases, number of sprouts decreases, meaning that bigger stumps produce fewer sprouts in *B. plurijuga* and *P. angolesis*. The opposite is true for *G. coleosperma* were a significant positive relationship was shown ($p<0.05$). Most sprouts are produced in the 5 to 20 cm DBH class. As stump diameter increases, sprout height also increases for all the key species ($p<0.05$) (Figure 4.6). Tallest sprouts are produced in 5 to 25 cm DBH class for *B. plurijuga* and *G. coleosperma*, and 7 to 15 cm DBH class for *P. angolensis*. Weak positive correlations exist between stump diameter/stump height and different shoot parameters as shown by low R^2-values. Stump height has a significant negative influence on number of sprouts for *B. plurijuga* and a positive significant influence on *G. coleosperma* ($p<0.05$). An insignificant influence was shown on both parameters for *P. angolensis* ($p>0.05$). Generally tall stumps produce fewer and shorter sprouts (Figure 4.7). High sprout numbers and tall coppices were shown on stumps of 5 to 20 cm height classes except for *B. plurijuga* (5-30 cm class).

Table 4.1: Shoot attributes for sample plots across different regeneration modes (mean ± standard error) and significant levels from one-way ANOVA with unequal sample size tests.

Species	Regeneration mode				
	SR	StS	RS	BS	P value
	Sprout density (stems/ha)				
Baikiaea plurijuga	1.00 ± 0.0^{cA}	1.79 ± 0.1^{bA}	2.25 ± 0.0^{aA}	2.03 ± 0.1^{abA}	**0.001**
Guibuortia coleosperma	1.00 ± 0.0^{bA}	2.06 ± 0.2^{aA}	2.44 ± 0.1^{aAB}	2.28 ± 0.1^{aAB}	**0.001**
Pterocarpus angolensis	1.00 ± 0.0^{cA}	1.84 ± 0.4^{bA}	2.58 ± 0.1^{aB}	2.59 ± 0.1^{aB}	**0.001**
P value	0.05	0.44	0.05	**0.001**	
	Sprout height (m)				
Baikiaea plurijuga	1.25 ± 0.0^{bdA}	1.34 ± 0.3^{bCA}	1.64 ± 0.0^{aA}	1.33 ± 0.0^{bA}	**0.001**
Guibuortia coleosperma	1.18 ± 0.1^{bdA}	1.20 ± 0.0^{bcB}	1.64 ± 0.0^{aA}	1.32 ± 0.1^{bA}	**0.001**
Pterocarpus angolensis	1.67 ± 0.1^{aB}	1.53 ± 0.1^{aC}	1.51 ± 0.1^{aA}	1.91 ± 0.21^{aB}	0.05
P value	**0.001**	**0.001**	0.07	**0.001**	

Significant values are indicated in bold. Values with different superscript letters (a, b, c) within rows differ significantly and values with different superscript letters (A, B, C) within columns differ significantly (Tukey's HSD; $P < 0.05$). Regeneration modes are SR-seedling regeneration; StS- stem sprouts; RS- rootstock sprouts and BS- Basal sprouts.

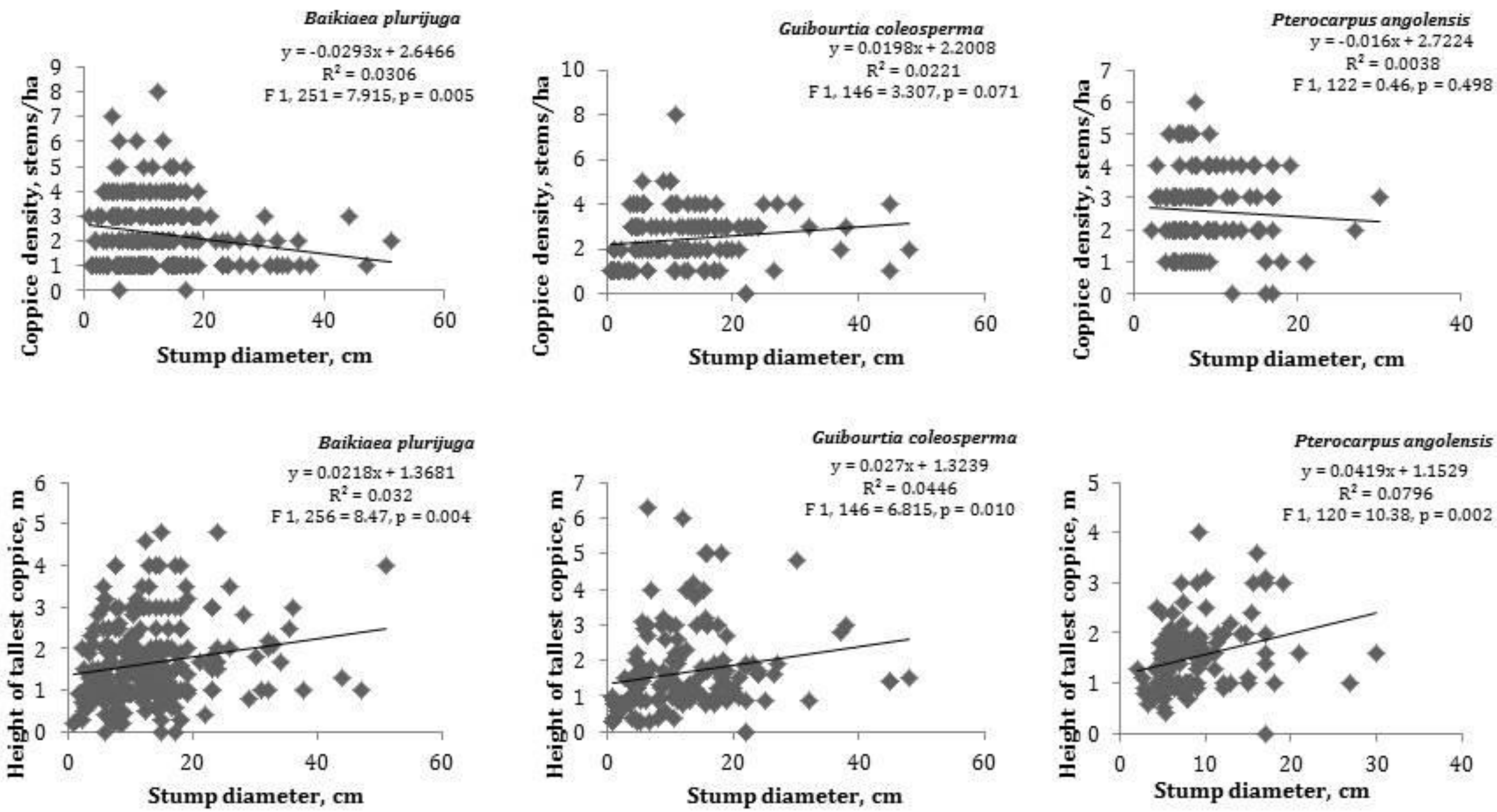

Figure 4.6: Influence of stump diameter on sprout density and sprout height for the three key species

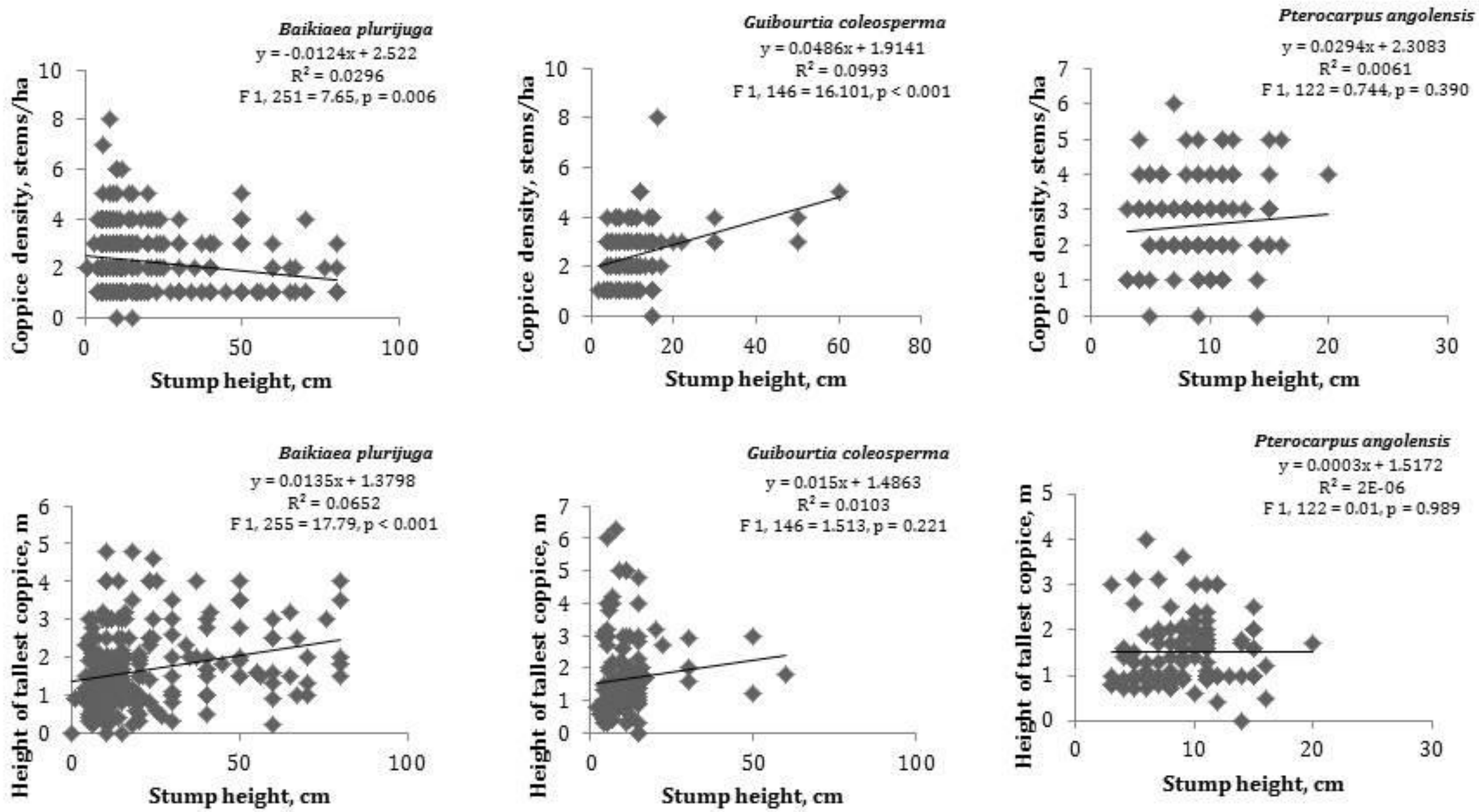

Figure 4.7: Influence of stump height on sprout density and height for the three key species.

4.4 DISCUSSION

4.4.1 Mode of regeneration in each land use system and each targeted species

Piearce (1993) highlighted that the primary establishment of *Baikiaea-Guibourtia-Pterocarpus* woodland species is mainly from seed and thereafter the species maintain their populations by displaying vegetative regrowth from sprouting, either from roots, rootstock, stem or trunk or from cut stumps. Regeneration by seedlings is therefore minor in relation to the vegetative regrowth modes (secondary mode of regeneration) that dominate the dynamics of these woodlands. Seedling germination may be good but subsequent survival can be very poor as a result of several factors affecting the growth of the seedlings. Tybrik (1991) concluded that fire, drought and browsing are the major constraints on survival of natural regeneration. Such disturbance factors restrict the recruitment of seedlings into tree stages. This might explain the low levels of regeneration from seedling in all disturbance regimes. Frequent fires would therefore result in death of seedlings and saplings and hence restrict seedling regeneration. In some cases dwarf vegetation (gullivers) may develop, as the seedlings cannot be recruited to the next height classes. The plants would develop underground rootstock storage systems through which they persist as suppressed vegetation. When the area is cleared, by devastating fires, cropping or clearing of poles and firewood, the rootstocks would sprout to produce fast-growing shoots. This might explain why rootsuckers were many in heavily disturbed sites (pole and firewood collection sites, abandoned crop fields and burnt sites). The mode of regeneration was also prominent in undisturbed and timber concession areas because there are a considerable number of big diameter trees which can support rootstocks that are large enough to support sprouting in the undisturbed areas (because there is no harvesting of timber) and timber concession areas (the single tree selection harvesting system allows some big trees to be left during harvesting operations so that they grow to harvestable sizes) (Calvert & Timberlake 1993). The big trees in these sites also provide seeds for natural regeneration but because of the shade from the canopy of the big trees, there would be reduced light penetration to the ground reducing seed germination and shoot growth (Geldenhuys & Golding 2008). The shoots growing under the canopy of big trees may remain suppressed for years and would grow fast when the canopy is opened through disturbances. Trees, shrubs, and herbaceous plants may compete with delicate tree seedlings and shoots of needed sunlight and moisture (Jeffries 1997). Basal sprouting was evident in all disturbance regimes except the protected area because no cutting of trees is permitted in these areas. However, rootstock sprouting was high because of the extensive rooting system from large trees in undisturbed sites. Vegetative regrowth through sprouting from various means has therefore become an adaptation through which the indigenous species persist in the woodlands.

In this study, *P. angolensis* regenerated mainly from rootsuckers in the protected areas, burnt areas and abandoned crop fields. Low rates of germination, annual dieback of seedlings, competition from other trees over sunlight, effects of fire, slow rates of tree growth, and delayed seed production have been reported to contribute to poor regeneration in *P. angolensis* (Van Daalen 1991). Low seedling recruitment rates during both germination and the suffrutex stage have been reported for *P. angolensis* (Boaler 1966; Schwartz *et al*. 2002; Caro *et al*. 2005). Caro *et al*. (2005) highlighted that seedling mortality was as a result of fire and high densities of browsing ungulates. In this study, the species only regenerated in the undisturbed sites, burnt sites and abandoned crop fields through rootstock sprouting. However, shoots produced in the undisturbed sites grow much slower than those that grow in the cleared areas. The observations in this study are consistent with studies that concluded that the species regenerates and grows well in cleared areas (Graz 1996; Syampungani 2008) and burnt areas (Geldenhuys 1977, 2009; Chidumayo 1988; Fillemon 2015). Exposure to light, reduced competition for moisture and nutrients may contribute to the good performance of this species in opened up areas such as in abandoned crop fields and pole and firewood collection (Syampungani 2008). Occasional fires have been found to maintain good regeneration of *P. angolensis* (Geldenhuys 1977; Chidumayo 1988). However, repeated fires would result in death of seedlings if the fire has high intensity, dwarf seedlings and coppices are produced from stumps that are repeatedly burnt by fires. This can be attributed to the fact that *P. angolensis* has a lengthy suffrutex stage of about 10 years or more (Boaler 1966; Piearce 1993). During this stage, the leading shoot of seedling dies back annually, whilst the root system develops massively until it has sufficient vigour to support a permanent stem. This form of regeneration is commonly undervalued (Piearce 1993). Dieback may be triggered by water stress, fire; drought and browsing. Mortality has been shown to be high in natural regeneration of *P. angolensis* for which 96% of seedlings may die before succeeding the suffrutex stage (Vermeulen 1990). This would reduce or delay recruitment of seedlings to higher size classes as a result of mortality due to a number of factors such as fire and heavy browsing by animals (Caro *et al*. 2005).

4.4.2 Influence of stump diameter on regeneration attributes

Most dry forest species are able to regenerate vegetatively as reported in South African savanna (Shackleton 2000; Kaschula *et al*. 2005); the miombo ecoregion (Luoga *et al*. 2004; Chirwa *et al*. 2014); Sudanian savanna–woodlands of West Africa (Ky-Dembele *et al*. 2007; Dayamba *et al*. 2011)**,** Zambezi teak woodlands in Zimbabwe (Gambiza 2001; Dube 2005; Ncube & Mufandaedza 2013) because most tropical dry forest species generally have extensive vertical and horizontal root systems that facilitate recuperation after cutting (Mistry 2000). Number of sprouts decreased with increase in stump diameter for *B. plurijuga* and *P. angolensis*. Number of sprouts per stump increased with increasing stump diameter for *G. coleosperma*. Sprouting is influenced by the amount of food reserves accumulated in the stump, and/or the activity of underground buds, which in turn depends on stump diameter. Miura & Yamamoto (2003) and Knox & Clarke (2005) showed that larger stumps have much more food reserves and more extensive rooting system resulting in the production of more sprouts. This study showed that the highest number of coppices was produced for stumps that had a diameter between 10 and 20 cm and the number decreased as the stumps increased in diameter. This is in agreement with observations by Ncube & Mufandaedza (2013) in the same woodland type; the 10 to 20 cm stump diameter classes produced more sprouts. Hawley (1949) stated that, the sprouting ability of trees decreases as they become older and larger in diameter. Kramer and Kozlowsky (1960) suggested that this could be due to the fact that, the number of sprouts per stump increases with diameter until the increase in bark thickness begins to hinder the emergence of dormant buds. Aaron (1956) revealed that cutting smaller trees induces the formation of adventitious buds that lead to the emergence of many small sprouts on the edges of the stumps. However, sprouts originating from adventitious buds are usually of poor quality and thus are not a reliable method to regenerate a forest stand (Evans 1992). Also, it should be noted that many sprouts on a stump can reduce shoot vigor due to competition among shoots in a given stump (Khan & Tripathi 1989). This would therefore call for silvicultural interventions by forest managers, to thin coppicing stumps so that only those shoots with more vigor are left to develop on each stump. This would ensure that resources are not wasted on the shoots with less vigor. Although bigger diameters have reduced number of sprouts, they are much preferred because in any case more sprouts self-thin themselves leaving one or two sprouts that will grow to become utilisable (Handavu *et al*. 2011). Coppice and sucker regrowth is however usually inferior (Chidumayo 1992). Most of the indigenous species growing in the woodlands are sun loving, therefore, the plants that regenerate in the patches created by disturbances would result in even aged stands but some trees will grow faster than the others. During harvesting operations, the bigger stems would be selected for harvesting and the suppressed ones would be left behind to grow to harvestable sizes. Gonah (1994) pointed out that the current lower utilisable limit for the key species is 25 cm. Cutting more trees using the group felling system instead of single tree selection would enable the stems to sprout vigorously and grow faster as a result of better light conditions after the opening of the canopy.

A positive relationship between stump height and number of sprouts was also found for *G. coleosperma and P. angolensis,* which is consistent with several studies in the tropics and subtropics (Mishara *et al*. 2003). Within the southern African savannas, a number of studies reported the influence of stump height on re-sprouting ability of the Zimbabwean miombo (Mushove & Makoni 1993) and South African (Shackleton 2001) and Zambian (Handavu *et al*. 2011) miombo woodlands. The effect of stump height can be attributed to availability of more reserved food and dormant buds on longer stumps. Stump height determines the buds that will form on a stump. Stump surface area for sprout development increases with increasing cutting height (Huang 1990). Results from this study are consistent with observations by Ncube & Mufandaedza (2013) that number of coppices decreases with an increase in stump height for *B. plurijuga.* Number of coppices and tallest sprouts were high for stumps that had a height between 10 and 20 cm. The current recommended stump height by the Forestry Commission is 15 cm. Cutting too low on the stem of the tree may encourage fungal infection because of moisture from the ground or stump decay (Shackleton 2000). However, Shackleton (2001) cautioned that the positive effects of increased cutting height must be balanced against the loss of useful woody biomass that is left behind and also the low-quality coppices that results. The coppices that sprout on tall stumps are prone to wind and bird breakage (Gambiza 2001). These coppices form a bushy appearance thus they would not be commercially utilisable (Canadell & Lopez-Soria 1998). The small branches that will develop from these coppices will be less vigorous and therefore low production of seeds, hence making them further useless for regeneration (Chidumayo 1992). However, Kays & Canham (1991) suggests that it is the combination of all these factors that has a significant influence on the coppice shoot production. They state that the most vigorous sprouts arise from relatively young stumps cut close to the ground in late fall or winter when there are food reserves stored in the roots. As such, it is necessary to consider all the important factors to improve coppice shoot production key species in the woodlands.

4.5 CONCLUSION

The study has shown that *Baikiaea-Guibourtia-Pterocarpus* woodlands regenerate mainly from rootstock sprouts (root suckers) as compared to basal sprouts, regeneration by seedlings and stem sprouts in all disturbance regimes studied. The study therefore concludes that disturbances that cause the opening of canopy and more light penetration to the forest floor are required to facilitate sprouting and growth of suppressed shoots in these woodlands. The study also revealed that stump height and diameter influence the ability of the stump to sprout. Weak relationships between stump diameter / stump height and sprout density suggest that there are other factors that affect successful vegetative regrowth of stumps. Such factors may include: many external factors and practical management measures, such as cutting season, cutting method, site quality, rotation length and the density and spacing of the stumps. There is a need to maintain the 15 cm stump height, both to reduce timber wastage and to allow adequate regeneration. A low, cleanly cut stump without tearing the bark from wood is ideal. The study therefore concludes that forest managers need to adopt disturbance regimes that promote regeneration of at least key species in the woodlands.

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5 ANALYSIS OF GROWTH RINGS TO DETERMINE AGE AND MEAN RADIAL GROWTH OF SELECTED *BAIKIAEA-GUIBOURTIA-PTEROCARPUS* SPECIES FROM REGROWTH STANDS UNDER DIFFERENT DISTURBANCE REGIMES AFTER POLE/ FIREWOOD HARVESTING AND ABANDONED CROP FIELDS, NORTH-WESTERN ZIMBABWE

Abstract

Disturbances play a pivotal role in the recovery and growth of many forest and woodland species. The main aim of this study was to determine the reliability of tree growth rings in age determination and mean radial growth of re-growing woodland stands. The research assisted in understanding the growth patterns of the key commercial timber species of the *Baikiaea-Guibourtia-Pterocarpus* woodlands. The information from this study will therefore help in the development of proper tree management schemes. The study was conducted in the Gwaai indigenous *Baikiaea- Guibourtia-Pterocarpus* woodlands of north-western Zimbabwe. The research concentrated on three key timber species, *Baikiaea plurijuga*, *Guibourtia coleosperma*, and *Pterocarpus angolensis,* in three different sites (abandoned crop fields, pole and firewood collection sites and undisturbed woodland). Tree rings were counted in stem cross-sections of 20 samples of different ages for each species in each disturbace regime. On one hand, the relationship between age and growth rings, showed a very strong correlation ($p<0.0001$) on the other hand a poor correlation between diameter and number of growth rings. This showed that growth rings and not diameter can be used to determine the age of all three key timber species. Mean annual ring width was significantly different between species within the same disturbance category ($P < 0.005$) within a specific stand age. Growth was highest in abandoned crop fields, compared to pole and firewood collection sites. The study therefore concludes that disturbance regimes can promote and prompt optimal growth of at least key species in the woodlands.

Key words: Dendrochronology, mean radial growth, tree rings, *Baikiaea plurijuga*, *Guibourtia coleosperma*, *Pterocarpus angolensis*

5.1 INTRODUCTION

Growth patterns are key to the formulation of sound forest management systems in terms of annual allowable cut and cutting cycles in natural forest and woodland systems. The relationship between stem diameter and stand age of key tree species and the variation in growth rate between different stand conditions should guide good silvicultural management. Several authors have reported that attempts at plantation cultivation of indigenous species have not been successful, for example *P. angolensis* (Boaler 1966; Van Daalen 1991), *B. plurijuga* (Piearce 1993) and *G. coleosperma* (Lemmens *et al*. 2008). How then can forest managers determine the age and growth rates of indigenous species when it has been reported that most tropical species rarely produce anatomically distinct growth rings when compared with clear rings in many temperate species (Lilly1977; Celander 1983)? The absence of clearly identifiable annual growth rings in tropical species has made it difficult for forest managers to effectively determine age, growth rates, cutting cycles and sound forest management systems for the indigenous forest and woodland systems (Grundy 1995; Geldenhuys 2005).

Some tropical and sub-tropical tree species are capable of producing growth rings which correlate with age (Fahn *et al*. 1981; Gourlay & Barnes 1994; Grundy 1995; Stahle *et al*.1999; Geldenhuys 2005; Ngoma *et al*. 2017). Annual growth rings have been used in the past by forest managers in determining the age of Miombo woodlands in Zambia (Fanshawe 1956; Syampungani *et al*. 2010) and in Zimbabwe (Grundy 1995; Stahle *et al*. 1999). Grundy (1995) did a 4-year study on stems of unknown management history. Syampungani *et al*. (2010) showed that ring counts can be used in age determination, with a strong correlation between growth rings, known stand age, and stem diameter, for three Miombo woodland species. *Baikiaea plurijuga* was studied in Zambia by Miller (1952) in reference to the determination of age and rotations and by Ngoma *et al*. (2017) in terms of dendrochronological potential. Both Miller (1952) and Ngoma *et al*. (2017) highlighted that *B. plurijuga* shows clear annual growth rings. Stahle *et al*. (1999) studied the correlation between the growth rings in *Pterocarpus angolensis* and seasonal climatic data, using evidence from phenology, ring anatomy and cross-dating. However, they did not analyze the relationship between the number of growth rings, age of the study site and stem diameter.

Most investigations of growth rate, using growth rings, have been based on coring (Stahle *et al*. 1999) or whole discs (Gourlay 1995; Ngoma *et al*. 2017) or a combination of the two.

Grundy (1995) based her study on damaging the cambium and cutting the cross section of the stems to allow for counting of growth rings. Gourlay (1995) and Grundy (1995) based their studies on observations at 1.3 to 1.4 m height from the ground. Coring species with dense wood may be difficult and at times the operator may miss or fail to reach the pith.

Very few studies have been done to determine the influence of different disturbance factors on mean radial growth of key species in *Baikiaea-Guibourtia-Pterocarpus* woodlands of Zimbabwe. Dendrochronology of key species such as *P. angolensis* in Sikumi and Mzola gazetted forests in Matabeleland (Stahle *et al.* 1999) and *B. plurijuga* in Zambia (Miller 1952; Ngoma *et al*. 2017) have been studied. Age determination using growth rings of *G. coleosperma*, a key species in the *Baikiaea-Guibourtia-Pterocarpus* woodlands of north western Zimbabwe, has not yet been considered. There is a real need to understand growth patterns of key species under different disturbance factors (utilization practices). Forest managers need to adopt utilization practices in line with woodland disturbance regimes to ensure prompt, adequate regeneration and fast growth of key species. Tree ages hold key information for the development of sustainable forest management schemes, as they give indications on the time required to replace harvested trees. Such data are very useful when assessing species potential and sustainable timber exploitation. The question to be answered by this study is "can we use growth rings, diameter or both in age determination for the key species of *Baikiaea-Guibourtia-Pterocarpus* woodlands?"

The main objective of this study was to determine how reliable is the use of growth rings or diameter or both in age determination, i.e. what the relationship is between the number of growth rings, stem diameter and tree age of selected sites. The following research questions guided data collection and analysis

- Can the individual growth rings be reliably differentiated on cut stems of key tree species in the woodlands?
- Is the number of growth rings the same in larger and smaller stems in a stand of known age?
- Is there a relationship between the number of growth rings, stem diameter and stand age of a selected site, and can such a relationship be used for reliable stand age determination?
- How does the mean radial growth of key tree species vary in different disturbance factors?

5.2 MATERIALS AND METHODS

5.2.1 Description of study area

The study was conducted in the Gwaai and Tsholotsho indigenous *Baikiaea-Guibourtia-Pterocarpus* woodlands of north-western Zimbabwe (Figure 5.1). Gwaai forest ($19^{o}16^{1}20$ S and $27^{o}56^{1}36$E) and Tsholotsho ($19^{o}46^{1}00$ S and 27^{o} 45^{1} 00 E) (JAFTA & Forestry Commission 2001) are both located in the Matabeleland North Province and are classified under natural region IV according to the agro-ecological land classification of Zimbabwe (Bradley & Dewees 1993). Altitude ranges between 1010 and 1055 m above mean sea level (JAFTA & Forestry Commission 2001). These areas were chosen because of the existence of different utilization systems sought in the study.

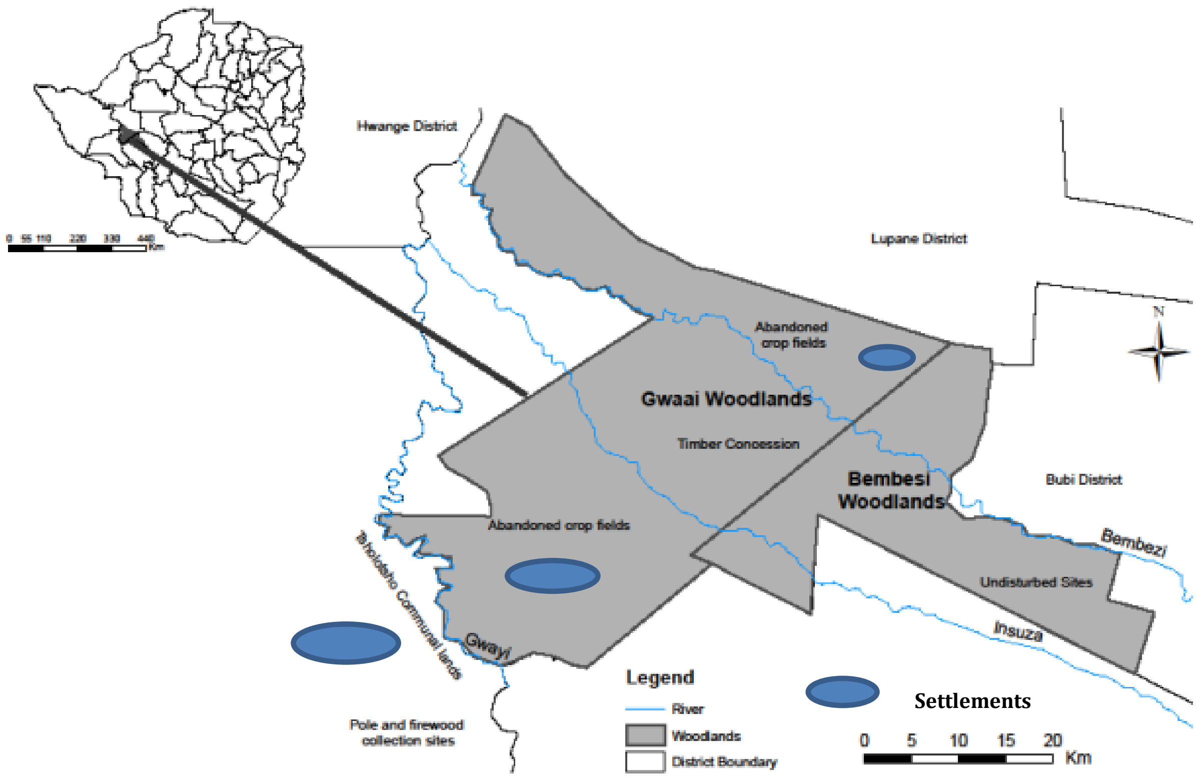

Figure 5.1: Location of the study area in Matabeleland North in Zimbabwe. The blue ovals indicate where settlements are found in the study area.

Geology and soils

The study area is situated on Kalahari sands, which are strongly uniform, both physically and chemically, having high permeability and low consistency (Nyamapfene 1991). The sands are unconsolidated, red/orange, and pink or buff coloured, with no structure and with a high proportion of fine dust. The sands comprise of deep and well-drained sands of the regosol group derived from sandstone (Nyamapfene 1991).

Climate

The study area is characterized by three distinct seasons: cool dry season from April to August; hot dry season from October to November; and wet season from mid-November to March (Figure 5.2) (JAFTA & Forestry Commission 2001). The short and erratic wet season is usually characterised by dry spells and sporadic droughts (Nemarundwe & Mbedzi 1999). Average monthly rainfall over the 26 year period is presented in bars in Figure 5.2. The highest rainfall was recorded in 2005/2006 followed by year 2000/2001 and 1995/1996 and least amount of rainfall was recorded during the drought years of 1994/1995, 2002/2003 and 1992/1993 rainfall seasons (Figure 5.2). Mean annual temperature is 21.5ºC, with mean monthly temperature ranging from 15°C (June to September) to 25°C (October to December) (Nyamapfene 1991; JAFTA & Forestry Commission 2001). Ground frosts are experienced especially in the valleys in most years between May and September (JAFTA & Forestry Commission 2001).

Vegetation

Six main vegetation types characterise the study area (JAFTA & Forestry Commission 2001): *Baikiaea-Guibourtia-Pterocarpus* woodland occurs as closed to open woodland on Kalahari sand. The tree vegetation is dominated by *Baikiaea plurijuga*, in association with *Pterocarpus angolensis, Guibourtia coleosperma, Burkea africana, Erythrophleum africanum, Combretum collinum, Croton gratissmus, and Schinziophyton rautanenii* (JAFTA & Forestry Commission 2001). Other common sub-canopy species are *Combretum zeyheri, Commiphora marlothii, Ochna pulchra, Terminalia sericea* and *Bauhinia petersiana* (Gambiza 2001). The shrub species are *Baphia massaiensis, Grewia flavescens and Grewia monticola.* Common grasses are *Pogonathria fleckii, Aristida stipitata, A. pilgeri, Triraphis schlechteri, Tristachya rehmanii, Eragrostis species* and *Digitaria pentzii* (Gambiza 2001; Dube 2005). *Pterocarpus angolensis* belts occur as localised stands inside the *Baikiaea-Guibourtia-Pterocarpus* woodland. The belts are dominated by *Pterocarpus angolensis* in association with *Burkea africana.* These belts are believed to have evolved through fire.*Guibourtia coleosperma* woodland is mainly characterised by the dominance of *G. coleosperma* and scattered *B. plurijuga.*

Brachystegia woodland (generally considered as Miombo woodland) occurs along the upper Bembesi River (JAFTA & Forestry Commission 2001), in areas with shallower soils, containing more silt than in areas of *Baikiaea-Guibourtia-Pterocarpus* woodland. In other parts of the study area, *B. spiciformis* grows in association with *B. boehmii* and *Julbernardia globiflora, Ochna spp, Terminalia sericea* and *B. africana.*

Colophospermum mopane woodland is characterized by either stunted or multi-stemmed *C. mopane* trees, along rivers or river valleys on alluvial soils that are poorly drained and highly erodible (JAFTA & Forestry Commission 2001). It is almost a mono-specific woodland with tree species of *Combretum imberbe*, *C. hereroense* and *Dalbergia melanoxylon* growing in association with it. Vleis are dominated by a single layer of grasses. Trees may be absent or isolated and are generally found along vlei fringes (JAFTA & Forestry Commission 2001). The amount of grass cover depends mainly on the degree of grazing, primarily by wild animals

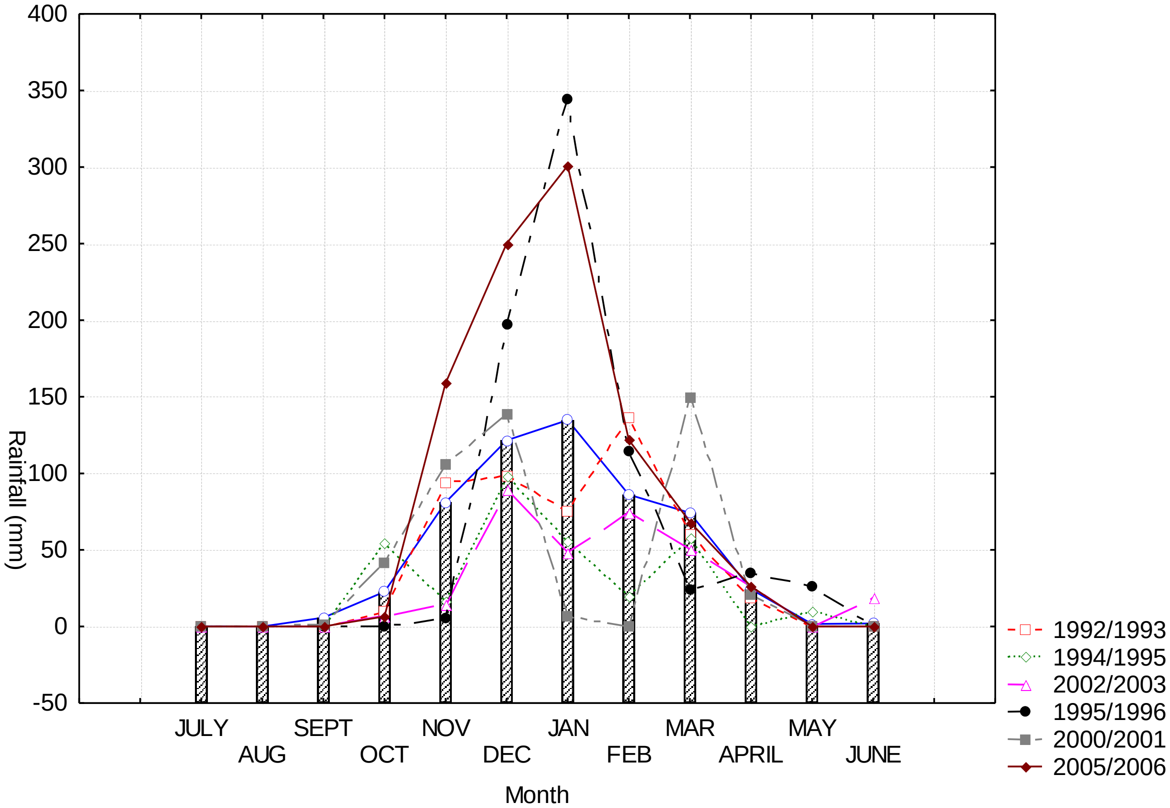

Figure 5.2: Mean annual rainfall from 1990 to 2015 (bars) and for years with highest (1995/1996, 2000/2001 and 2005/2006) and lowest (1992/1993, 1994/1995 and 2002/2003) rainfall, shown as lines, over the 26 year period.

Utilization systems

In the communal areas of Tsholotsho, people harvest trees on an open-access regime for domestic and commercial use (Matose 2002). Trees of different sizes are cut, using axes at different heights for various purposes such as fuel wood, construction, fences, and curios among others. Large canopy gaps are created if groups of trees are removed in the pole and firewood collection sites (personal observation). Forest settlers, living inside the forest reserves, grow maize, sorghum and other crops on their fields. After the harvesting season, the debris from maize is collected and fed to cattle during the dry season; some farmers leave the debris on the field floor while others burn the debris. The agricultural fields are abandoned after many years (40 years or less) of cultivation. Fields are abandoned when they are old and are not producing sufficient yield (Mutsiwegota & Mudekwe 1998). Trees of different species grow on the abandoned fields from seed or through sprouting from rootsuckers.

5.2.2 Methodology

5.2.2.1 Data collection

The data were collected in areas of known age after crop cultivation and pole and firewood collection had been terminated and in undisturbed woodland (unknown age). In each study area, sites of the following ages (8 years, 17 years and 25 years) were selected for study. These were based on the last date since disturbance cessation (i.e. 2008, 1999 and 1992 respectively). The information on stand age was obtained from the local communities around the study areas and also from Forestry Commission records. Plots were sampled in the undisturbed sites to have stems of similar heights as in the development stages of the disturbed sites. In each site of specific age, 20 trees per selected species (*B. plurijuga, G. coleosperma* and *P. angolensis*) were selected for sampling. The sampling approach of fixed length - Variable width of Walker (1976) was adopted. The plots had a fixed length of 50 meters; sampling would stop (at any width) when the required number of trees for the three species was reached, i.e. 60 stems (20 stems per species) per site of specific age, resulting in a total of 180 stems for each disturbance regime, and an overall total of 540 stem sections. A Global Positioning System (GPS) was used to record the positions of the plots in the field. The following general information was recorded at each site.

(i) Study area, Study site name, Recorder name and Date

(ii) GPS coordinates: Latitude ^{o}S, Longitude ^{o}E (X and Y coordinates).

(iii) Condition of surrounding natural vegetation (the appropriate answer was selected):

a. Height (m): 1 = <2; 2 = 2 - 5; 3 = 5 - 10; 4 = 10 - 20; 5 ≥ 20

b. Stand cover: 1 = 0 - 30%; 2 = 30 - 50%; 3 >50%.

c. Date when cutting or cropping was abandoned (to determine possible stand age)

(iv) Relevant information for the site that would be useful for the interpretation of the growth ring development.

Single-stemmed trees with a normal, well-formed stem and with no stem defects in the lower 1 m of the stem were selected for sampling (Figure 5.3). The assumption was that the *Baikiaea-Guibourtia-Pterocarpus* woodland species are light-demanding. That means that a stand that developed after cultivation or harvesting of poles and firewood, would be composed of even-aged trees of different species. Smaller and larger stems would have the same number of rings and hence the same age. Trees with smaller stems would be suppressed trees. Each tree develops growth rings, with each ring consisting of a broader part of lighter wood (faster growth, possibly during the rainy period) and a narrower part of darker wood (slow to no growth, possibly during the dry period.

For each selected tree, data on the following were recorded before the tree was cut and after it had been cut:

(i) Tree number (to accompany the collected stem section)

(ii) Species

(iii) Diameter at breast height (DBH, in cm) at 1.3 m above ground level

(iv) Tree height (m)

(v) Diameter (cm) for stem section (DS)

(vi) Number of visible annual growth rings for section at ground level (RS).

(vii) Bark thickness (mm) on two opposite sides of the stem section.

Each stem was cut as low down to ground level as possible, with a horizontal smooth cut. A section of 1 cm thickness was cut at the bottom end of the stem. The site name, species code, tree number and section diameter were recorded on the backside of the stem section. After collection, all cut sections were left to dry out under tree shade for further analysis of the growth rings. When sufficiently dried out, the surface of the unmarked side of a stem section was smoothed, using a belt-sanding machine, with coarse sandpaper. On each smoothened surface, three lines (radii) were drawn from the core to the bark of the cut sections and clearly

Figure 5.3: Selection of stems of each tree.

visible rings were traced and counted from the outside (current date) of each stem section. The position of every 5th ring along the lines was marked (Figure 5.4 and 5.5) so as to identify false and partial rings. Ring-width (growth over one year) of the three species in the selected sites was determined by placing a ruler along each of the three radii (1, 2 and 3) with the zero point on the ruler at the outer edge of the bark (Figure 5.5). The width (mm) of each growth ring was measured using the ruler along each radius. The width of each ring was then calculated by averaging the ring widths from the three radii.

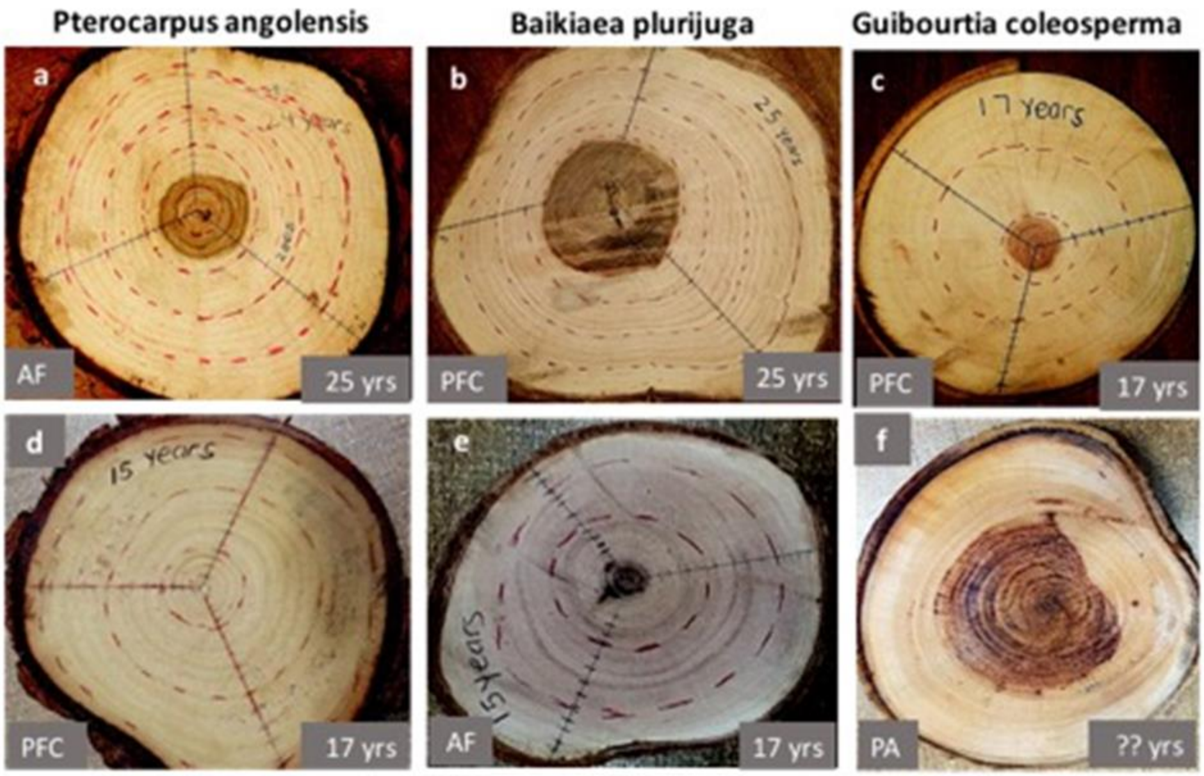

Figure 5.4: Six smoothed stem sections (two of each species) with three lines drawn with a sharp pencil from the center to the edge (except for section f). Along each line, every 5th growth ring from the edge was marked on the pencil line. AF - Abandoned crop fields; PFC = Pole and Firewood collection; PA = Protected Area.

Figure 5.5: Measurement of ring width along each radius

5.2.2.2 Data analysis

STATISTICA statistical package version 7.0 (StaSoft inc, 1984 - 2006) was used for data analysis. The Simple Regression Model was used to test for relationships between number of rings and age; and stem diameter and number of rings, for the key species. The Bonferroni test in STATISTICA was used to determine the relationship that exists in growth rates within species under different disturbances, and also between different species under similar disturbances.

5.3 RESULTS

5.3.1 Relationship between number of growth rings and stand age since disturbance cessation

The growth ring boundaries were reasonably distinct for *P. angolensis*, as shown in Figure 5.4a & d for respectively a 25-year old abandoned crop field (AF) site and a 17-year old pole and firewood collection (PFC) site, and for *B. plurijuga*, as shown in Figure 5.4b & e for respectively a 25-year old PFC site and a 17-year old AF site. *G. coleosperma* did not show very distinct growth rings as shown in Figure 5.4c & f for respectively a 17-year old PFC site and a protected area (PA) site. Less clear rings were typical of the discs from mature woodlands (Figure 5.4d &e). The number of growth rings showed a strong positive linear relationship with stand age in both pole and firewood sites ($r^2 = 0.976$; $P < 0.01$; slope of curve = 0.97; n = 180) and abandoned crop fields (r^2 = 0.98; $P < 0.01$; slope of curve = 0.99; n = 180) regrowth stands (Figure 5.6). Some discs from pole and firewood collection sites had 1 or 2 extra rings whilst those from abandoned crop fields had 1 or 2 fewer rings (Figure 5.6). However, the discs from mature woodland of the same diameter as those from the regrowth stands did not show any distinct growth rings (Figure 5.4d, e).

5.3.2 Relationship between the number of growth rings and DBH

All the species studied showed weak correlation between the number of growth rings and the DBH of a tree, in both abandoned crop fields (r^2 = 0.51; $P < 0.01$; slope of curve = 1.02; n = 180) and pole and firewood collection sites (r^2 = 0.46; $P<0.01$; slope of curve = 0.63; n = 180) regrowth stands (Figure 5.7).

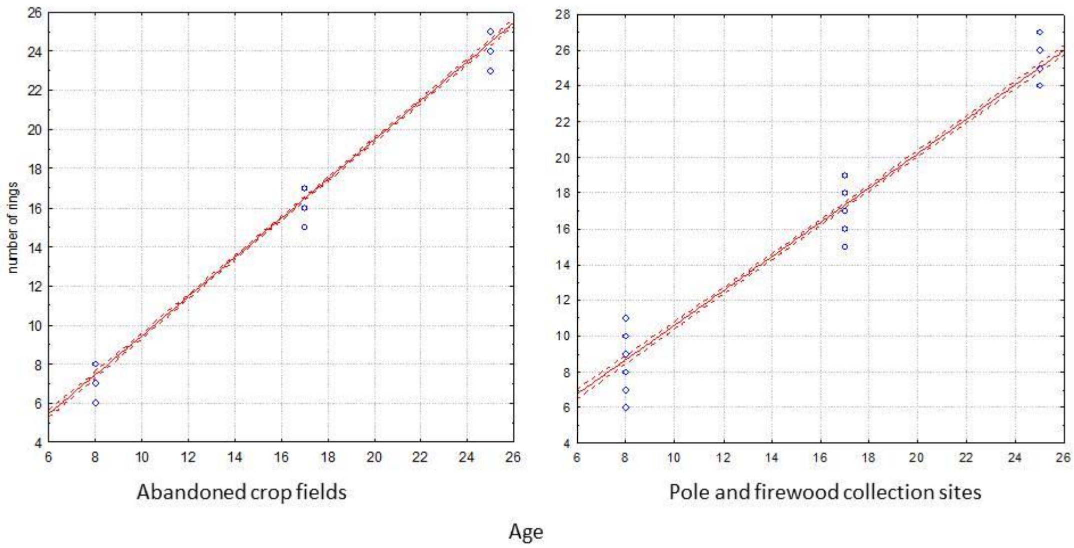

Figure 5.6: The positive linear relationship between stand age and the number of growth rings in regrowth stands after different years after abandoning pole and firewood collection and crop cultivation.

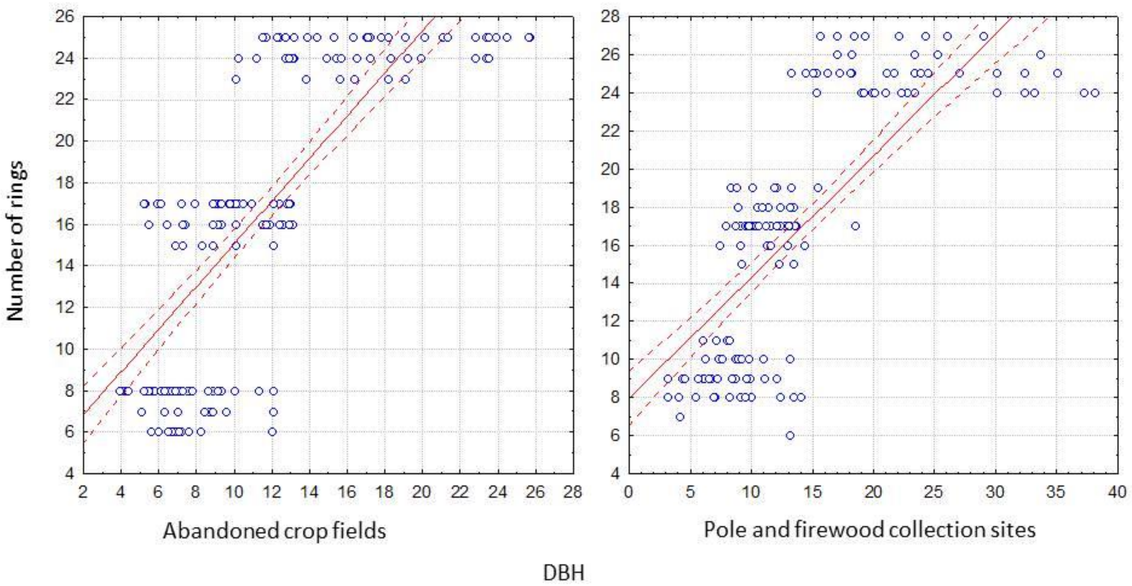

Figure 5.7: The relationship between DBH and number of growth rings in regrowth stands after different years after abandoning pole and firewood collection and crop cultivation

Diameter growth was also assessed for the three species across the different disturbance regimes. Results showed a range in diameter growth from 0.88 – 1.13 cm/year for *B. plurijuga*; 0.95 – 1.13 cm/year for *G. coleosperma* and 0.97 – 1.11 cm/year for *P. angolensis* (Table 5.2). Analysis of Variance results showed significant differences in diameter growth amongst the disturbance regimes ($F_{(2,539)} = 49.2617$; $p<0.0001$) with abandoned fields having the highest diameter growth. All species showed no significant difference in diameter growth ($p>0.05$) in the abandoned crop fields and pole and firewood collection sites whilst the opposite is true for undisturbed sites ($p<0.001$). The Post-hoc Tukey test results showed that the three species had significant differences in diameter growth across the three disturbance regimes (*B plurijuga* ($F_{(2,177)} = 26.45$, $p <0.0001$); *G. coleosperma* ($F_{(2,177)} = 25.85$, $p <0.0001$); *P. angolensis* ($F_{(2,177)} = 11.47$, $p <0.0001$). The species had high diameter growth in the abandoned crop fields. *B. plurijuga* recorded the least diameter growth in the undisturbed sites (Table 5.2). *G. coleosperma* and *P. angolensis* recorded the least growth rates in pole and firewood collection sites and undisturbed sites.

5.3.3 Mean radial growth in abandoned crop fields' and pole and firewood collection regrowth stands

Table 5.1 shows the mean annual ring widths observed in individual key species in pole & firewood and abandoned crop-field regrowth stands. Mean annual ring width was significantly different between species within the same disturbance category (P <0.005) with stand age. *P. angolensis* exhibited the highest mean width growth amongst the key species, with the mean ring width of 5.3 mm (10.6 mm growth per year) in pole and firewood regrowth stands and 5.8 mm (11.6 mm growth per year) in abandoned crop-field regrowth stands. Generally, the rings are wider in the youngest stands in all three species (Table 5.1). Thereafter, the ring width tends to decrease as the stands get older. However, there is no significant difference in mean ring width within the same species under different disturbance factors.

Table 5.1: Mean radial growth of selected key *Baikiaea-Guibourtia-Pterocarpus* woodland species under different disturbances

Species	Mean annual ring width, mm							
	Stand category and age							
	Pole & firewood regrowth stands Age in yrs				Abandoned crop-field regrowth stands Age in yrs			
	8	17	25	Mean	8	17	25	Mean
Baikiaea plurijuga	4.8± 0.3	4.4± 0.2	4.3±0.2	4.5± 0.6	5.2± 0.2	4.9±0.3	4.6± 0.3	4.9± 0.7
Guibourtia coleosperma	5.0± 0.2	4.7± 0.3	4.6± 0.4	4.8± 0.4	5.4± 0.3	5.2±0.6	4.8±0.5	5.1± 0.5
Pterocarpus angolensis	5.7± 0.4	5.3± 0.3	5.0± 0.2	5.3± 0.5	6.2± 0.2	5.8±0.4	5.3± 0.6	5.8± 0.9

Table 5.2: Differences in mean diameter growth (cm/year) (mean ± standard error) for the three key species across three disturbance regimes. Values with different superscript letters within columns and rows differ significantly (Tukey's HSD; P < 0.05).

	Abandoned fields	Pole and firewood collection sites	Undisturbed fields	P value
B. plurijuga	1.13 ± 0.15^{a}	1.04 ± 0.23^{b}	0.88 ± 0.19^{c}	P<0.001
G. coleosperma	1.13 ± 0.14^{a}	0.95 ± 0.14^{b}	0.99 ± 0.15^{b}	P<0.001
P. angolensis	1.11 ± 0.11^{a}	0.97 ± 0.14^{b}	0.97 ± 0.25^{b}	P<0.001
P value	p>0.05	P>0.05	P<0.001	

5.4 DISCUSSION

5.4.1 Stand age-rings and DBH-rings relationships for the key species

Results from this study showed that *B. plurijuga* and *P. angolensis* showed distinct growth rings as compared to *G. coleosperma.* Grundy (2006) concluded that *Brachystegia spiciformis* form distinct annual rings while Syampungani *et al.* (2010) concluded that

Julbernadia paniculata, *Brachystegia floribunda* and *Isoberlinia angolensis* showed clear annual rings for both charcoal and slash and burn regrowth stands of Miombo woodlands. They concluded that ring counts could be used in determining the age of Miombo regrowth stands. The three selected species (*B. plurijuga*, *G. coleosperma* and *P. angolensis*) in this study showed that growth rings can be used as a good estimate for stand age in both pole and firewood and abandoned crop-field regrowth stands. Results suggest that there is about 1 or 2 missing growth rings in abandoned crop fields and there is an additional ring in pole and firewood collection sites. This shows that a tree in a 25year old abandoned crop field will have 24 or 23 rings and a tree in pole and firewood regrowth will have 26 or 27 rings. An additional ring in pole and firewood regrowth stands may be attributed to the fact that young plants are left behind during harvesting for poles and firewood. Missing rings in abandoned crop fields may not be attributed to the occurrence of drought as the pole and firewood regrowth stands in the same area did not show the same patterns. They may be attributed to the constant removal of seedlings or sprouts during cultivation. Delayed germination of plants, when the fields are abandoned, could explain why some plants had missing rings**.** Delayed stem development may also be due to shoot die back as a result of frequent fires in woodlands.

The high correlation between number of growth rings and stand age may be attributed to the strong seasonality in both temperature and precipitation experienced in the north-western parts of Zimbabwe (JAFTA & Forestry Commission 2001). The woodlands are deciduous, with trees losing leaves during the dry season and grow leaves before the onset of the rainy season. Borchert (1991) highlighted that, the seasonality in flowering, leaf flush and leaf fall suggests that radial growth is restricted to the summer wet season. Stahle *et al*. (1999) suggested that strong seasonality results in annual ring formation. A study by Geldenhuys (2005) suggested that the strong and consistent diameter growth of free growing stems in regrowth stands contributes to the clear and wider rings. This could explain why stems from abandoned crop-field regrowth stands showed wider rings and that stems from undisturbed sites did not show clear rings. *P. angolensis* and *B. plurijuga* had clear rings, thus their cambial growth develops distinctively every year. However, growth rings for *G. coleosperma* are not very distinct, suggesting that the species has poor cambial growth.

The study has revealed a weak significant relationship between diameter at breast height and the number of growth rings, in all three selected sites. This implies that the bigger and smaller stems showed the same number of rings. The smaller stems are the suppressed trees and the bigger stems are the fast-growing and vigorous stems. This implies that DBH cannot be used as a reliable estimate of stand age. This contradicts the findings by Syampungani *et al*. (2010). They concluded that DBH can be used as a reliable predictor of stand age for *J. paniculata*, *B. floribunda* and *I. angolensis*. This might be so because only bigger stems were selected for the counting of rings. The smaller stems were not considered.

5.4.2. Mean radial and diameter growth

The three species showed a significant difference in mean annual ring width and diameter growth across the disturbance factors, with abandoned crop fields recording the highest (ring width and diameter growth) as compared to pole and firewood collection sites. This suggests that annual width and diameter growth is good in cleared areas, and that trees in open areas grow much faster than in mature stands. Total exposure to light and reduced competition for moisture and nutrients also contribute to the good performance of trees (Syampungani 2008). In the undisturbed stands, there is competition for space, light, moisture and nutrients between the young plants and the older trees. This was also observed in Mozambican Miombo woodlands (Geldenhuys 2005). Relative growth tend to decline with age of trees, as also mentioned by Johnson & Abrams (2009), since these stands are mainly composed of old and mature trees.

Diameter growth recorded in this study is higher compared to other studies conducted in the same woodlands, for example, Calvert (1986) reported a mean annual increment of 1.78 mm for *B. plurijuga*, Mushove *et al*. (1993) reported 1.5 mm. and SAREC (1996) reported 1.25 to 2.04 mm for *B. plurijuga*, 1.02 to 2.37 mm for *G. coleosperma* and 1.30 to 2.72 mm for *P. angolensis*.FAO pilot studies on forest data gathering and analysis, reported 1.75 mm DBH increment for *B. plurijuga*, 2.11 mm DBH increment for *G. coleosperma* and 2.00 mm DBH increment for *P. angolensis*. Grundy (2006) reported a mean growth of 0.27cm/year for *B. spiciformis* trees in an area protected from fire and human disturbance.

5.5 CONCLUSION

The identification of annual growth rings in *B. plurijuga, G. coleosperma* and *P. angolensis* for both pole and firewood collection and abandoned crop-field regrowth stands has important implications for forest ecology and management of *Baikiaea-Guibourtia-*

Pterocarpus woodlands. The study concludes that individual growth rings of *P. angolensis* and *B. plurijuga* and not *G. coleosperma* can be reliably differentiated on cut stems and hence can be used in determining the age of *Baikiaea-Guibourtia-Pterocarpus* woodlands. The study also concludes that the number of growth rings was not statistically different in larger and smaller stems in a stand of known age. Trees growing in suppressed stands did not show clear rings compared to free-growing trees. The study also concludes that annual growth rings, and not diameter at breast height, can be used as a good estimate of stand age in both pole and firewood and abandoned crop-field regrowth stands. The mean annual ring width and diameter growth data has shown that trees that grow in open areas (outside undisturbed woodland) grow much faster than trees growing under the canopy of the undisturbed woodlands. Such information would be very useful when used together with the climatic data for all the calendar years involved and also an understanding of the disturbance and other biological factors that the land was exposed to in order to relate the growth rings and growth data with drought frequencies and the disturbance factors. However, it can be noted from this study that too many stems were cut to determine stand age and this could be avoided if forest managers would monitor closely forest activities and growth of trees in stands of known age since disturbance cessation; hence tree age can be estimated without having to cut them. Harvesting of trees may be concentrated on the big stems so as to open more space for the suppressed stems. Mean radial and diameter growth information generated from the study will help in size predictions of the key *Baikiaea-Guibourtia-Pterocarpus* species in that the study has provided a means of collecting growth data in both pole and firewood sites and abandoned crop fields. The current data may be supplemented with other growth rate data for trees of known age. However, care must be taken in the use of growth rings and growth rate data in areas that experience drought, as it has been shown (Stokes & Smiley 1968) that drought results in missing growth rings. The study therefore concludes that forest managers need to adopt disturbance regimes that prompt optimal growth of at least key species in the woodlands.

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6 LINKING DISTURBANCES TO SUSTAINABLE MANAGEMENT OF THE *BAIKIAEA-GUIBOURTIA-PTEROCARPUS* WOODLAND ECOSYSTEMS OF NORTHWESTERN ZIMBABWE

Abstract

We need silvicultural management systems based on the natural disturbance-recovery processes to integrate multiple-use practices in the natural tree resources to address local needs and global concerns. There are many arguments around the negative impacts of disturbances and their role in sustainable forest management. A variety of policies and acts that protect woodland and forest ecosystems from interference by local communities have been formulated. However, the disturbance-recovery processes underlie the adaptations of species to develop from disturbed situations, through different stages towards maturity, and hence the biodiversity and productivity of these systems. They are the key elements in developing silvicultural management systems that can help improve the management of our woodlands, and the population status of key ecological and economical species of these systems. Results from this study call for a change in perception and attitude, from that disturbances are bad, towards considering that they are important components of woodland management to rejuvenate the regeneration and growth of the *Baikaiea-Guibourtia-Pterocarpus* woodland ecosystems. This chapter summarizes and synthesizes information from various studies undertaken to determine the regeneration and recovery potential and growth of *Baikiaea-Guibourtia-Pterocarpus* woodland under different disturbance factors. It characterizes the *Baikiaea-Guibourtia-Pterocarpus* woodland response to these disturbances based on grain analysis and the diameter size class profiles exhibited at both population and community levels. It also compares these with the undisturbed woodland. The research revealed that even if the sites provide a potential for woodland of a specific type to develop, community aggregation is mainly influenced by disturbance-recovery processes. The *Baikiaea-Guibourtia-Pterocarpus* woodland is dominated by mostly light-demanding species that require large gaps for regeneration establishment and development. Community grain status based on canopy species (relative scale of disturbance-recovery processes), and stem diameter distributions of key tree species in the different communities, suggested that the main tree species perform better with larger disturbances with better light conditions than under the closed canopy. Disturbances such as with cultivation and harvesting for poles and firewood, promote the regeneration and growth of these species to higher size classes. They are required to facilitate sprouting and growth of suppressed shoots in these woodlands. The study concludes that clearing for cultivation and harvesting for poles and firewood are important components to which the woodland ecosystem is adapted to. 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 *Baikiaea-Guibourtia-Pterocarpus* woodland diversity and productivity.

Keywords: Sustainable management, silvicutural management

6.1 INTRODUCTION

Poor resource use management strategies (White 1983; Ferguson 1996; Geldenhuys 1997; 2003; Mapaure & Ndeinoma 2011) combined with pressures from increasing population densities (Mapaure & Ndeinoma 2011), have led to the decline of many African forest and woodland ecosystems. A number of reports and papers presented at conferences, in proceedings (Victoria Falls 1992, Zambia) and from research (Piearce 1986; Gambiza 2001; JAFTA & Forestry Commission 2001; Mufandaedza 2002 & Dube 2005) have expressed the need for interventions to save the *Baikiaea-Guibourtia-Pterocarpus* woodlands as a result of reduction in extent and stocking densities of key species in these woodlands. Also, many authors (Mather 1992; Bradley & Dewees 1993; Mather & Needle 2000; Gambiza 2001and Dube 2005) have condemned disturbances, especially deforestation, because they lead to massive loss of biodiversity and productive forest. These conclusions have led to the formulation of a variety of policies and acts that protect woodland and forest ecosystems from interference by local communities for crop cultivation and harvesting of poles and firewood in preference to single tree harvesting. There are conflicting conclusions about the effects of selective logging and clear cutting on forest ecosystems. Many ecologists and foresters concluded that single tree harvesting is the best harvesting system as it leads to minimal negative impacts on forests and woodlands. On the contrary, Gatti *et al.* (2014) showed that selective logging has serious negative impacts that could lead to forest degradation especially when long term effects are considered. Wu & Loucks (1995) showed that the direct relationship between the area of forest lost and species lost over-estimates the reality on the ground because many species tend to survive in the remaining clumps of forest. Ding *et al.* (2016) concluded that selectively logged sites showed faster recovery than clear cut sites. This is in contrast to the findings from this study.

The occurrence of a wide range of species over areas previously deforestated has been reported by several authors (Fairhead & Leach 1998; Sillitoe 1998; Fox *et al*. 2000; Gatti *et al.* 2014; Ding *et al.* 2016). This therefore calls for the need to classify the disturbances based on their associated impacts both at stand and population levels for particular woodland ecosystems. This approach may help to understand the implications of each disturbance and also how such a disturbance may be incorporated into sustainable forest management. Three categories of disturbance have been defined (Hansen & Walker 1985; Geldenhuys 2011; Syampungani *et al.*

2016): a Non Event (NE) is when the frequency or intensity is too minor to elicit a response; an Incorporated disturbance (ID) is when the entity (individual, population, community, ecosystem and landscape) is adapted to the scale of a disturbance event which then becomes necessary to maintain the entity in its present state; and a Disaster (D) is when the scale of the disturbance forces the entity into a new state. Geldenhuys (2011) stated that the interaction between the regime (frequency of occurrence, area of impact and intensity) of a particular disturbance and the habitat within which a suite of species live, determine how the species adapt to survive in that particular environment. This is what contributes to the vegetation and biodiversity patterns we see in ecosystems and landscapes around us. Thus, the main type of disturbance becomes the driver of the system. Perhaps, what is important is to understand the contribution of each disturbance factor in the rejuvenation of the woodlands and how each disturbance can be incorporated into sustainable forest management.

The study attempted to develop a new understanding of the disturbance impacts on floristic composition, diversity, regeneration and recovery potential of the *Baikiaea-Guibourtia-Pterocarpus* woodlands and of the selected key species when exposed to timber harvesting (single tree selection), harvesting for poles and firewood (group harvesting) and crop cultivation (clear-felling). These disturbances vary in intensity and in effects on the individual species and the systems. Timber harvesting involves the removal of some trees (mature trees of good form), with some opening of the canopy (small gaps). Harvesting for poles and firewood removes most of the trees (large gaps), while cultivation removes all the trees and involves soil tillage which may continue intermittently over several years before the fields are abandoned. These practices bring into context the classification of the different disturbance factors in *Baikiaea-Guibourtia-Pterocarpus* woodlands based on their impacts at both population (species) level and stand (ecosystem) level. This chapter assesses how the results from the individual studies (chapter 2 to 5) answered the research questions posed to achieve the specific and overall objectives posed for the study. The chapter reviews and synthesizes the information on disturbance impacts on floristic composition and diversity of the *Baikiaea-Guibourtia-Pterocarpus* woodland, ecological drivers of floristic and structural composition *Baikiaea-Guibourtia-Pterocarpus* woodlands, disturbance impacts on the regeneration of key ecological/or economic species in *Baikiaea-Guibourtia-Pterocarpus* woodlands, and age and growth rate determination of key species of the

Baikiaea-Guibourtia-Pterocarpus woodlands that have been under single tree selection, pole and firewood harvesting and cultivation. In conclusion, the new understanding of disturbance impacts on composition and diversity, regeneration and recovery potentials and growth rates is assessed with a view to effectively integrate these disturbance factors in sustainable forest management of the *Baikiaea-Guibourtia-Pterocarpus* woodlands.

6.2: EVALUATION OF METHODOLOGICAL ISSUES USED FOR THE STUDY

Four specific studies were conducted in the *Baikiaea-Guibourtia-Pterocarpus* woodlands of north-western Zimbabwe, to examine different parts of this overall study: Disturbance impacts on their floristic composition and diversity (Chapter 2); Ecological drivers of their floristic and structural composition (Chapter 3); Disturbance impacts on regeneration of their key ecological and/or economic species (Chapter 4); and Age and growth rate determination using growth rings of selected species (Chapter 5). Assessment of *Baikiaea-Guibourtia-Pterocarpus* woodland dynamics under different resource-use practices was important to provide for the new understanding of the regeneration and recovery potentials and growth of the woodlands (Chapters 2 to 5). As indicated earlier, each of these resource use practices has different impacts on the woodlands and key species, and therefore triggers different responses in this woodland ecosystem. This requires a comparison of the responses of different species to these different disturbance factors. The post-utilization stands and their recovery stages over time are highly variable in both plant stocking and species composition (Strang 1974; Stromgaard 1985). Timber harvesting does not involve clearing of the woodland and the stem density does not change from pre-harvested stands. Patches of cleared areas emerge after group harvesting of trees in poles and firewood sites, but that does not disturb the soil and root systems. Hence almost even-aged plants grow in the patches, with some of the big stems left standing in the forest stand. Cultivation result in total clearing of woodland stands, resulting in almost even-aged regrowth in the abandoned crop fields. Very few mature trees are left scattered for shade. The recovery of these stands results in dense regrowth of small stems which gradually grow taller with reduction of stem density through natural thinning.

Sampling was done in stand development stages (Chapter 2) so as to understand how the different disturbance factors affect regeneration and growth at different stem densities and height. Four development stages were identified (Chapter 2) and pre-determined, using height as the main criterion. Stage 1 height was <2 m; Stage 2 height was 2.1-5 m; Stage 3 height was 5.1-8 m; and Stage 4 height was >8 m. The stages in this development process are primarily based on stem density and stand height. Such identification and definition of stand development stages had not been done for *Baikiaea-Gurbourtia-Pterocarpus* woodlands. Sampling in different development stages meant that some species would have high stocking densities in some stages compared to others. This resulted in sampling some species as surrogate species e.g. *B. plurijuga* was subdivided into three surrogate species (subsets of stems of the same species representing different diameter classes), based on stem diameter: *B. plurijuga* class 1 = 5-10 cm DBH, *B. plurijuga* class 2 = 10.1-30 cm DBH and *B. plurijuga* class 3 = >30 cm DBH. This was done to differentiate plots with a high number of stems <5 cm DBH from plots with a low number of stems >30 cm DBH. This meant that *B. plurijuga* could be represented by three surrogate *B. plurijuga* species in a nested plot sampling.

Young regrowth stands tended to have many stems of almost the same age while the older more advanced stands have fewer stems (Chapter 3). 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. The plots may be too large and time consuming and therefore impractical for the young, dense regrowth stands (Mark & Esler, 1970; Syampungani *et al*. 2010a). The use of nested circular plots avoided measuring too many plants in one stand development category with too few stems in other age categories. Diameter and height were measured for all stems of tree species with a stem diameter at breast height (DBH) ≥15 cm in the larger plot (0.283 ha) and trees 5.0-14.9 cm DBH on a 0.04 ha plot. Stems <5 cm were counted by species in the inner circle (0.01 ha) of the nested plots. The traditional methods of fixed plot sizes 100 m by 100 m were used in determining regeneration strategies of key species in each utilization system. The 1 ha plots were used so as to try and capture as many seedlings and saplings as possible because the study required at least 100 plants of each species in each disturbance regime. The use of transects within the main plots was implemented for sequential and orderly sampling.

The fast growth of *Baikiaea-Guibourtia-Pterocarpus* woodland species in regrowth stands of known area provided a means to determine growth rates of trees, because of the relatively even-aged stands. In order to provide information necessary for determining cutting cycles in the *Baikiaea-Guibourtia-Pterocarpus* woodlands, the growth rings and growth rates of selected key species of *Baikiaea-Guibourtia-Pterocarpus* woodland were determined (Chapter 5). The method provided for important improvements on past approaches, by cutting the selected stem discs as low down to ground level as possible so as to capture maximum number of growth rings (see Chapter 5).

6.3 *BAIKIAEA-GUIBOURTIA-PTEROCARPUS* WOODLAND VEGETATION RECOVERY AFTER HUMAN DISTURBANCE

6.3.1 Disturbance impact on composition and diversity over time

Different resource use practices have different impacts on the *Baikiaea-Guibourtia-Pterocarpus* woodland ecosystem and key species, and therefore trigger different responses. In Chapter 2, plots from different disturbance factors were classified into communities. Plots with similar species assemblages aggregated into communities. The study showed that plots with similar intensity of disturbance tend to have similar species composition, hence an aggregation into communities (Table 2.2; Appendix 2.2). As stands grow to later development stages, the intensity of disturbance tends to decrease, hence the species composition of these stands will converge to that of undisturbed sites, for example, plots from stages 3 and 4 of the concession area and abandoned crop fields showed a higher percentage of aggregation with plots from undisturbed sites compared to pole and firewood sites. The plots were dominated by *B. plurijuga* 2 & 3, *G. coleosperma* (Appendix 2.3). Plots that have been recently abandoned after harvesting of poles and firewood and cultivation and in their early development stages also aggregated into communities. These communities were dominated by *B. plurijuga* 1, *Combretum apiculatum, C. collinum* and *Bauhinia petersiana. P. angolensis* had high importance values in communities with plots from abandoned crop fields and undisturbed sites (Table 2.4). This suggests that this species is able to regenerate in heavily disturbed areas. The species was also present in the undisturbed sites of mainly large trees, because no timber harvesting is allowed. These findings are consistent with other studies that concluded that *P. angolensis* (shade intolerant species) performs well in cleared areas because of total exposure to maximum light (Boaler 1966; Werren *et al.* 1995; Graz 1996). Clear-felling during land preparation and length of cultivation of other crops in the abandoned crop fields might also result in variation in species composition and dominance of *Combretum* species, *Baphia massaiensis and Bauhinia species.* This suggests that long term cultivation removes existing rootstocks and seed banks of key species in the soil. Cultivation of crops in the woodlands seems to be necessary in the rejuvenation of the woodlands as seen by the high percentage of aggregation with plots from undisturbed sites, especially in the least developed stages in regeneration communities and stages 3 in tree communities. The relationships are also confirmed by the spatial distribution of tree communities, sub-communities and their plots in ordination space (Figure 2.3 and 2.5). Results from the DCA ordination suggested that the underlying site factors explain little variation in the identified communities, suggesting that recovery from disturbance with different disturbance factors may explain more of such variation. Differences in species composition from the identified communities are mainly driven by disturbance factors (recovery from different intensities of disturbance) and not environmental factors as seen by the aggregation of plots from different utilization systems. The nature of disturbance, magnitude and age since disturbance cessation (recovery period) has a great impact on species composition.

Communities comprising of plots mainly from previously pole and firewood harvesting sites and abandoned fields in stages 3 and 4 showed high species diversity. This could be explained by the fact that the resource utilization patterns at these sites resulted in the creation of large canopy gaps and many different pioneer species can occupy the created gaps and establish themselves. The findings are consistent with the conclusion that vegetation removal leads to rapid growth which leads to increased species diversity (Syampungani *et al.* 2016). Communities comprising of plots from undisturbed sites and early development stages 1 and 2 of abandoned fields and pole and firewood collection sites showed low species diversity. Least mean diversity in communities with plots from undisturbed sites could also suggest that the canopy tree species suppress other shade-intolerant tree species or the woody species growing there.

6.3.2 Ecological drivers of floristic and structural composition of the woodlands

Grain analysis and stem diameter distributions are analytic tools used in understanding the ecological processes and conditions necessary for regeneration and growth of ecosystems and key species within them (Geldenhuys 2009). Fine grain (most canopy tree species regenerate close to their adults) was shown for sub-communities with plots mainly from up to stage 3 of development, of all land use systems (Table 3.1). Coarse grain (most canopy tree species do not regenerate close to their adults) was shown for sub-communities with plots from undisturbed sites and stage 4 of development. The question is whether these species recruit continuously under the closed canopy of these stands or whether the canopies of these stands are relatively open to enable the regeneration to establish or to persist in the absence of fire. The main regenerating species in the fine-grained communities is *B. plurijuga* (relatively intolerant to fire) as compared to *G. coleosperma*, *P. angolensis* and other canopy species. It is assumed that the increase in the regeneration of *B. plurijuga* was a result of the control and/or elimination of fire in the woodlands. This action also resulted in reduced regeneration and growth of *P. angolensis* (relatively tolerant to fire) (Geldenhuys 2009). Coarse-grained communities mainly consisted of plots from undisturbed sites, suggesting that the canopy of the mature stand suppresses the regenerating plants. *P. angolensis* did not regenerate in a sub-community that had more than 80% of plots from undisturbed woodland. This is so because the species does not grow well where there is competition from other plants but does so in well-cleared areas (Boaler 1966; Werren *et al.* 1995; Graz 1996; Syampungani *et al*. 2016). It is assumed that the resource use patterns and stand conditions in this community do not favor the regeneration of the species. The big stems in the coarse-grain communities, suppress the growth of new plants under the closed canopy when no harvesting of resources is allowed in these sites, and fire is excluded. When fires do run through these mature stands, they tend to burn back the coppice regeneration. *B. plurijuga* and *P. angolensis* showed inverse J-shaped profiles in the coarse-grained communities. *G. coleosperma* showed high regeneration in the coarse-grained sub communities' e.g. *C. collinum*-*C. apiculatum*, *G. coleosperma*-*B. plurijuga* 2-*C. collinum* which had more than 55% of plots from stages 2 and 3 of different land use systems, but showed low regeneration in communities with more than 50% of plots from stages 4 and undisturbed sites (Table 3.1). Regeneration in communities with more plots from stages 4 and undisturbed sites could have been from rootstocks or lateral roots of the mature trees in these stands or from advance regeneration that is already present on the forest floor. The canopy cover in these stands is relatively high when compared with the fine-grained communities because of the presence of mature trees in these stands. It is, therefore, likely that there is not enough light in such stands for regeneration to establish and grow. The regeneration may be suppressed stems under canopy of larger stems/trees.

The diameter class profiles exhibited by individual stands and species previously under a particular disturbance, allowed for the characterization of such a disturbance. The profiles explain the resultant influence of a particular disturbance at either stand or population levels (Peter 2005). For example, almost all sub-communities showed inverse J-shaped profiles (Table 3.2), except for *P. angolensis-G. coleosperma* sub-community, which showed a bell-shaped profile. *C. apiculatum-D. cineria*, *C. collinum-C. apiculatum* and *B. plurijuga* 2- *B. plurijuga* 3-*G. coleosperma* sub communities also showed bell-shaped profiles when the 1.0-4.9 diameter class is ignored. Some communities had peaks in some classes depicting bimodal distributions, such as sub-communities *C.apiculatum-D. cineria*, *B. plurijuga* 3-*G. coleosperma-B. plurijuga* 2, *G. coleosperma- B. plurijuga* 2-*C. collinum*, *B. plurijuga* 1-*B. plurijuga* 2-*C. collinum* and to some extent *B. plurijuga* 2- *B. plurijuga* 2 (Table 3.2). Many of the smaller stems did not regenerate from seed. They are either young regrowing stems from coppice growth, after maybe a fire, or some tree falls, or they are suppressed small stems. So they are not really regeneration that would become trees.

The bell-shaped profile, which is typical in communities with plots from undisturbed sites and stages 3 and 4 of concession areas and pole harvesting sites (Table 3.2), showed that *Baikiaea-Guibourtia-Pterocarpus* woodland ecosystem is composed of populations which experience sporadic or irregular seedling establishment and that it requires large gaps to become established (DWAF 2005; Peter 2005). Syampungani (2008) suggested that such profiles could be a result of fluctuations in stem stocking between diameter classes close to each other. These fluctuations may be attributed to infrequency in regeneration which results in notable peaks or ‘valleys’ in diameter classes. The infrequency in regeneration may be attributed to the effect of periodic fires that the *Baikiaea-Guibourtia-Pterocarpus* woodlands are exposed to.

The three key species (*B. plurijuga, G. coleopspema* and *P. angolensis*) showed inverse J-shaped profiles at landscape level. This suggests that at a larger scale, the disturbance factors result in stable populations with high levels of regeneration. However, when the individual species were studied at community level, some species, for example *B. plurijuga* and *P. angolensis*, showed inverse J-shaped profiles in fine grained communities, suggesting that because of the even-aged regrowth, some trees (relatively fewer) grow faster than most other stem, with the majority of stems being somewhat suppressed, resulting in the invers J-shaped profile . The stocking density for larger diameter classes was low in the fine-grain communities for *B. plurijuga* as compared to the coarse-grained communities. This could be due to the fact that the stands are still recovering and developing towards maturity after the disturbances. *G. coleosperma* showed inadequate regeneration in all communities where it occurred, as shown by low stem densities in the 1.0-4.9 cm diameter class. The bell-shaped distribution for *G. coleosperma* suggests that the species requires different conditions than those prevailing in the system (Geldenhuys 1993).

It can therefore be concluded that opening up *Baikiaea-Guibourtia-Pterocarpus* woodland canopy, which also results in reduction in competition for nutrients and water, is necessary as it stimulates and enhances seedling and sapling development. This explains why seedlings and saplings of key species occur in larger numbers in communities with plots from heavily disturbed sites after cultivation, and harvesting of poles and firewood, as compared to communities with plots from undisturbed sites and timber concession areas. This also explains why *P. angolensis* could not regenerate in a community with more that 80% of plots from undisturbed sites.

6.3.3 Regeneration requirements and strategies of key species in the woodlands

We need adequate regeneration because the future of forest and woodland ecosystems and sustainable resource use are dependent on successful regeneration of key ecological and/or economic species. Concerns have been raised over the future availability and possible extinction of some species, especially *P. angolensis*, in Zimbabwe (Bradley & Dewees 1993; Clarke *et al.* 1996). Low seedling recruitment rates (Boaler 1966; Schwartz *et al.* 2002; Caro *et al.* 2005), and unsustainable rates of harvesting (Scwartz *et al*. 2002; Caro *et al.* 2005), further threatens populations of the species. Geldenhuys *et al.* (2004) and Lemmens *et al.* (2008) have also reported on inadequate and slow regeneration of *G. coleosperma.* Many studies have reported on adequate regeneration of *B. plurijuga* (Chigwerewe 1996; Gambiza 2001; Dube 2005). This study therefore assessed the response (regeneration and growth) in each disturbance regime and the key individual species (*B. plurijuga, G. coleosperma* and *P. angolensis)* to different disturbance factors. The study showed that the three species mainly regenerated from rootstock sprouting (root suckers) as compared to other modes of regeneration (Figure 4.3; 4.5). Regeneration from seedlings is minor in relation to the vegetative regrowth modes (secondary mode of regeneration) that dominate the dynamics of these woodlands. Piearce (1993) highlighted that the primary establishment of *Baikiaea-Guibourtia-Pterocarpus* woodland species is mainly from seed and thereafter the species maintain their populations by displaying vegetative regrowth from sprouting, either from roots, rootstocks (root suckers), stems or trunks, and from cut stumps.

Results showed that regeneration mode of the three target species is dependent on the resource use strategy applied, suggesting that forest managers, harvesting foresters and harvesting crews need to understand the most appropriate disturbance regime that promote optimal regeneration of each key species. For example, *P. angolensis* and *G. coleosperma* sprouted mostly in the burnt sites and cleared areas (Figure 4.5), as reported for this and other woodland systems by Geldenhuys (1977, 2009); Chidumayo (1988) and Fillemon (2015) for burnt sites, and Graz (1996) and Syampungani *et al*. (2016) for cleared areas. This suggests that burning and clearing are important factors in the regeneration of these species. The study also revealed that stump height and diameter influence the ability of the stump to sprout. Weak relationships between stump diameter / stump height and sprout density suggest that there are other factors that affect successful vegetative regrowth of stumps. Many external factors and practical management measures, such as cutting season, cutting method, site quality, rotation length and the density and spacing of the stumps have been shown to influence coppicing behaviour (Kays & Canham 1991). For example, cutting during the active growing period increases mortality and decreases growth, as compared to dormant season cutting (Ncube & Mufandaedza 2013). There is a need to maintain the 15 cm stump height (in the concession areas), both to reduce timber wastage and to allow adequate regeneration. A low, cleanly cut stump without tearing the bark from wood is ideal. The study therefore concludes that disturbances that cause the opening of canopy and more light penetration on the forest floor are required to facilitate sprouting and growth of suppressed shoots in these woodlands. Forest managers need to adopt disturbance regimes that prompt regeneration of at least key species in the woodlands

6.3.4 Use of growth rings in age determination of key species in woodlands of North-western Zimbabwe.

The growth rates of *Baikiaea-Guibourtia-Pterocarpus* woodland trees have been reported to be very low (Mushove *et al*. 1993; Gambiza 2001; JAFTA & Forestry Commission 2001). Additionally, several authors have reported varying annual mean increments for the key species in these woodlands. For example, Calvert (1986) reported a mean annual increment of 1.78 mm for *B. plurijuga*, Mushove *et al*. (1993) reported 1.5 mm and SAREC (1996) reported 1.25 to 2.04 mm for *B. plurijuga*, 1.02 to 2.37 mm for *G. coleosperma* and 1.30 to 2.72 mm for *P. angolensis*. FAO pilot studies on forest data gathering and analysis, reported 1.75 mm DBH increment for *B. plurijuga*, 2.11 mm DBH increment for *G. coleosperma* and 2.00 mm DBH increment for *P. angolensis*. However, these studies did not determine age of the different species using growth rings. Results showed that *P. angolensis* exhibited the highest mean radial growth amongst the key species, with the mean ring width of 5.3 mm (10.6 mm growth per year) in pole and firewood regrowth stands and 5.8 mm (11.6 mm growth per year) in abandoned crop-field regrowth stands. *B. plurijuga* exhibited the lowest mean radial growth amongst the key species, with the mean ring width of 4.5 mm (9.0 mm growth per year) in pole and firewood regrowth stands and 4.9 mm (9.8 mm growth per year) in abandoned crop-field regrowth stands. Syampungani *et al.* (2010) showed that *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 Miombo key species that were studied. Generally, the ring width is high in the youngest stands in all three species (Table 5.1). Thereafter, the ring width tends to decrease as the stands get older. Results showed a range in diameter growth from 0.88 – 1.13 cm/year for *B. plurijuga*; 0.95 – 1.13 cm/year for *G. coleosperma* and 0.97 – 1.11 cm/year for *P. angolensis* (Table 5.2). Hence, the current study showed that growth rings, and not DBH, can be used as a good estimate for stand age in regrowth stands of both pole and firewood and abandoned crop fields. The assumption is that *Baikiaea-Guibourtia-Pterocarpus* species are sun-loving; hence they would perform better in cleared areas than in undisturbed sites. This implies that the bigger and smaller stems showed the same number of rings. The smaller stems are the suppressed trees and the bigger stems are the fast-growing and vigorous stems.

The study also showed that regrowth stands from abandoned crop fields, exhibited the highest mean radial growth amongst the key species. Ring width is high in the youngest stands in all three species (Table 5.1), thereafter; the ring width tends to decrease as the stands get older. This suggests that ring width growth is good in cleared areas, i.e. that trees in open areas grow much faster than in mature stands. Total exposure to light and reduced competition for moisture and nutrients also contribute to the good performance of trees (Syampungani 2010b). In the undisturbed sites, there is competition for space, light, moisture and nutrients between the young plants and the older trees. Relative growth tend to decline with age of trees (Johnson & Abrams 2009), as also shown by Geldenhuys (2005) for Mozambican Miombo woodland. It can therefore be concluded that the trees which develop from either abandoned crop fields or pole and firewood collection 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 cycles in *Baikiaea-Guibourtia-Pterocarpus* woodlands.

6.3.5 Integrating different disturbance factors into sustainable forest management of *Baikiaea-Guibourtia-Pterocarpus* woodland

There is need for paradigm shift in the management of indigenous woodland ecosystems in Africa and around the world, from one that assumes that forest and woodland ecosystems can naturally manage themselves to one that advocates for silvicultural management of the indigenous tree species within the ecosystems. Currently, the management practices applied in the woodlands is not aligned with the specific requirements for the individual species and the systems itself; they do not consider the recovery processes after a disturbance (Geldenhuys 2009). The individual studies have shown that harvesting pole and firewood and clearing for cultivation and later abandoning the field is a necessary component in the rejuvenation of the *Baikiaea-Guibourtia-Pterocarpus* woodlands and its key species. This is in contrast to the current conclusions that the woodlands comprise of uneven-aged trees, meaning that clear-felling is not feasible in such ecosystems. Results from this study suggest that there is need to cut groups of trees in areas were selective harvesting (for timber or poles) of the mature trees has occurred. Local farmers can then be allowed to cultivate around these areas for 2 or 3 years (as it has been suggested that long-term cultivation depletes rootstocks and nutrients in the soil) and later abandon the field to allow for the regeneration and growth of key species, such as *P. angolensis* that regenerates well in cleared areas. The species does not regenerate well when there is competition from other vegetation. Long-term cultivation is not advised as this would result in the depletion of the seed bank and rootstocks available in the soil. This would result in the growth and regeneration of species other than the key species. The study has also shown that clearing allows more light penetration on the forest floor resulting in increased regeneration and growth rates. This justifies the need to incorporate such disturbance factors in a more controlled manner in the management of the *Baikiaea-Guibourtia-Pterocarpus* woodlands

There is need for the application of tending operations (thinning and pruning) in the cleared areas so as to maintain the regenerated population. Thinning operations would help control stand density and hence reduce competition by removing the suppressed and unhealthy plants. The thinned stems could be used for poles of different size. Branch pruning of retained stems will result in the production of single straight stems, and hence better quality poles and timber is produced. Currently no silvicultural tending operations are applied in the woodlands, resulting in the development of multi-stemmed plants with crooked stems, which produce poor-quality timber.

6.4 CONCLUSIONS AND RECOMMENDATIONS

Firstly, the study has revealed that even if the sites provide a potential for woodland of a specific type to develop, community aggregation is mainly influenced by utilization systems. Secondly, almost all sub-communities showed inverse J-shaped profiles (Table 3.2) i.e. with high densities in smaller stem diameter classes (1.0-9.9 cm) and low stem density in larger size classes. This implies that *Baikiaea-Guibourtia-Pterocarpus* woodland has ample regeneration. However, *C. apiculatum-D. cineria*, *C. collinum-C. apiculatum*, *P. angolensis-G. coleosperma* and *B.*

plurijuga 2-B. plurijuga 3-*G. coleosperma* sub-communities showed bell-shaped profiles when the 1.0-4.9 cm diameter class is ignored. Also the grain status and stem diameter distributions in the different communities suggest that the species require some larger disturbances, such as with cultivation and harvesting for poles and firewood, to promote regeneration and growth to larger size classes. Such disturbance factors result in the creation of large canopy gaps that are necessary for the regeneration and growth of suppressed stems of the *Baikiaea-Guibourtia-Pterocarpus* woodlands. This is so because the timber species, like many other *Baikiaea-Guibourtia-Pterocarpus* woodland species are light-demanders and would therefore require more light to regenerate and grow. Additionally, opening up 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 *Baikiaea-Guibourtia-Pterocarpus* woodland show to be adapted to recover more effectively and productively from abandoned crop fields and pole and firewood collection sites. Cutting cycles should be based on growth rate of the selected species. The study concludes that clearing for cultivation and harvesting for poles and firewood are important components to which the woodland ecosystem is adapted to. 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 *Baikiaea-Guibourtia-Pterocarpus* woodland diversity and productivity. Some disturbances, such as through various resource use practices, if controlled, to maintain a balance between different stages of recovery, may contribute to the maintenance of a diverse and dynamic woodland system.

This study has shown the importance of intergrating controlled disturbance systems into silvicultural management practices in order to promote regeneration and growth of key species of the *Baikiaea-Guibourtia-Pterocarpus* woodlands. It is important to note that there is need for further studies on the importance of different disturbance systems on the regeneration and growth of the *Baikiaea-Guibourtia-Pterocarpus* woodland. This is important so as to produce a comprehensive silvicultural management plan to the policy makers so as to attain better management of the woodlands. The study has acknowledged lack of other important variables not studied that could be a source of variation in community aggregation. Such factors include soil properties (soil texture, soil nutrients, soil pH, and soil moisture), landscape features (aspect and slope), and wood properties, which were not assessed in this study. The influence of such factors on community aggregation needs to be studied in order to understand all possible factors affecting community aggregation. Other important recommended studies include:

- Influence of thinning and pruning operations on stem form and diameter growth of stems in the different disturbance systems.
- Light requirements and seed biology of key species in relation to seed germination requirements vs sprouting in the *Baikiaea-Guibourtia-Pterocarpus* woodlands.
- Determination of soil seedbank dynamics in order to determine the impact of length of cultivation on the disturbed sites. The current study recommended short cultivation periods in the disturbed sites. The question is how many years of cultivation could be allowed to maintain good regeneration of key species of the *Baikiaea-Guibourtia-Pterocarpus* woodlands?
- Influence of human population density and location on the regeneration and growth of key species of the *Baikiaea-Guibourtia-Pterocarpus* woodlands, i.e. what their impact over the long-term could be in terms of resource use, and maintaining such natural resources in their midst.

6.5 REFERENCES

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