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1 GENERAL INTRODUCTION

1.1 BACKGROUND TO THE STUDY

The most extensive vegetation systems in the Zambebian dry deciduous woodlands are the teak woodlands on the Kalahari sands (Pearce 1986; King *et al.* 2000 and Geldenhuys & Golding 2008). *Baikiaea-Guibourtia-Pterocarpus* woodlands, also called the Zambezi teak woodlands, are part of the Zambebian 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 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. 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 origin (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; Ferguson 1996; 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 2001 and 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 (Pearce 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 (Pearce & Gumbo 1993; Pearce 1993, Zambia) and from research (Pearce 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. 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 *Baikiaea-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.

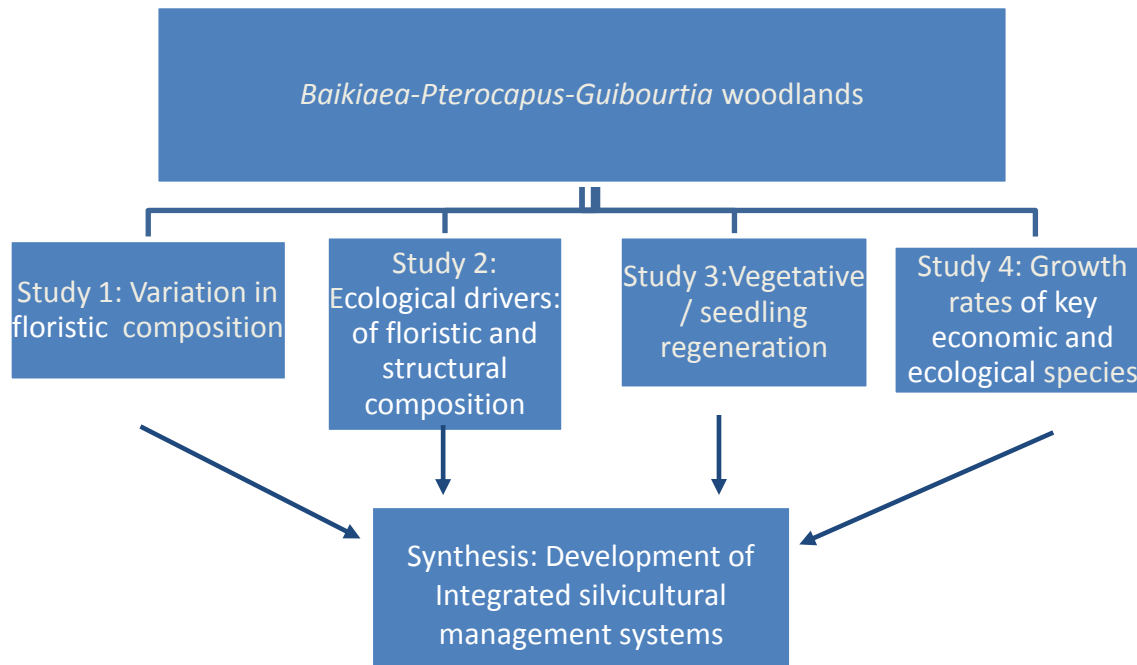


Figure 1.1: Conceptual framework for the study in four disturbance regimes to develop generalized and integrated silvicultural management systems for the *Baikiaea-Guibourtia-Pterocarpus* woodlands.

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-Guibourtia-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 ≥ 15 cm and 5.0 – 14.9 cm 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 ≥ 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* Fresc., *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; Pearce & 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). Pearce & 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 15 years 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 (19°16'20 S and 27°56'36E) and Tsholotsho (19°46'00 S and 27° 45' 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 amorphous 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).

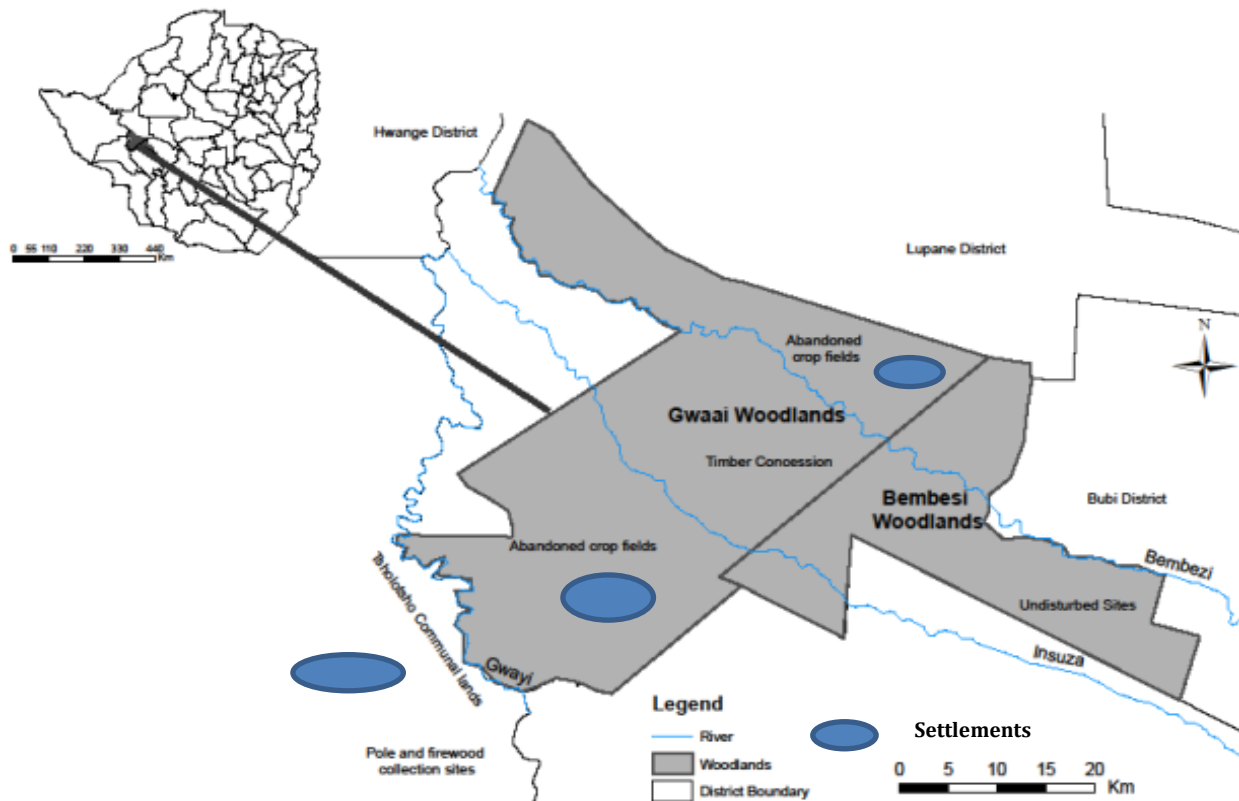


Figure 2.1: Location of *Baikiaea-Guibourtia-Pterocarpus* woodlands of north western Zimbabwe. The blue ovals indicate where settlements are found in the study area.

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,

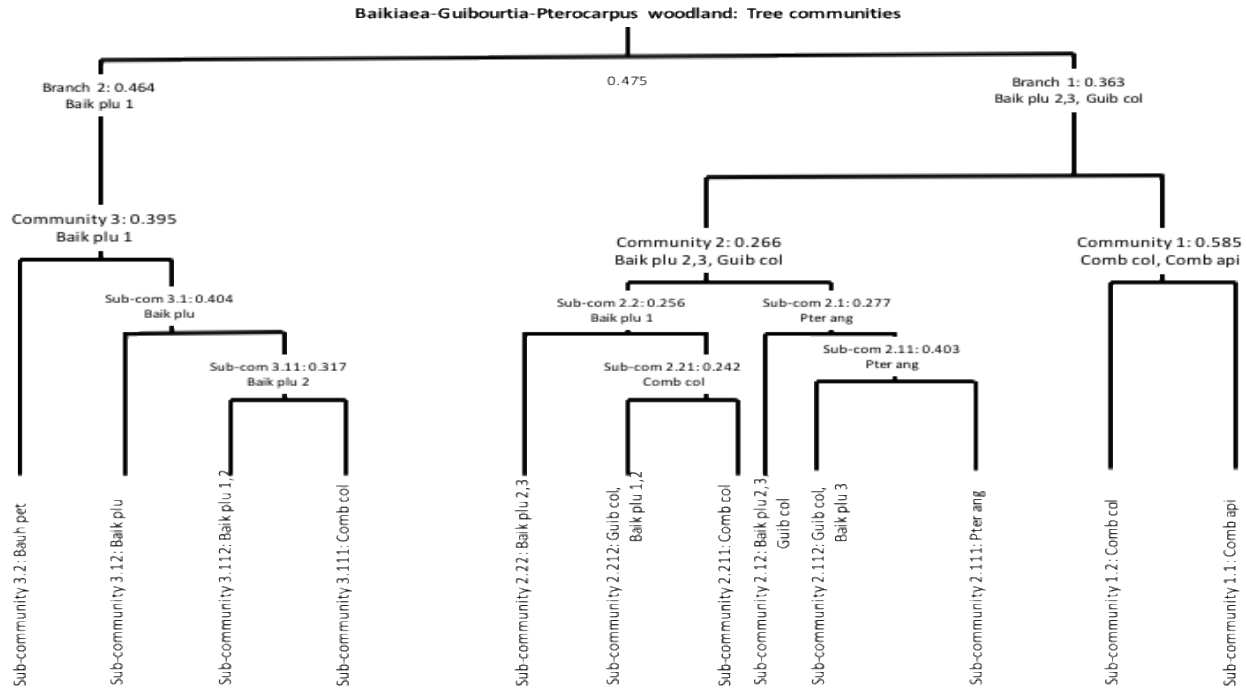


Figure 2.2: Schematic relationships between communities and sub-communities of tree stands in *Baikiaea-Guibourtia-Pterocarpus* woodlands based on TWINSpan output table (Appendix 2.2). The eigenvalues at each subdivision and indicator species for the sub-communities are shown. See Appendix 2.1 for complete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

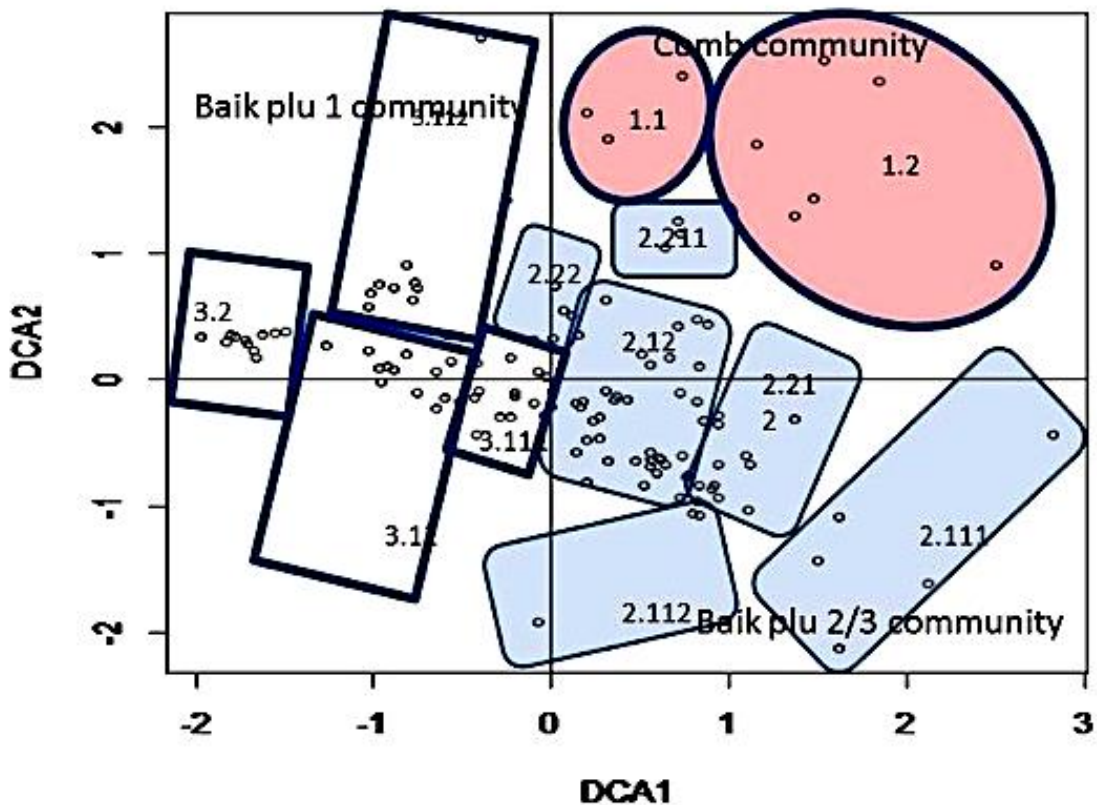


Figure 2.3: DCA ordination diagram of plots for the different tree communities and sub-communities. The community names and sub-community codes are indicated within the different colored blocks. See Appendix 2.1 for complete species names.

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	

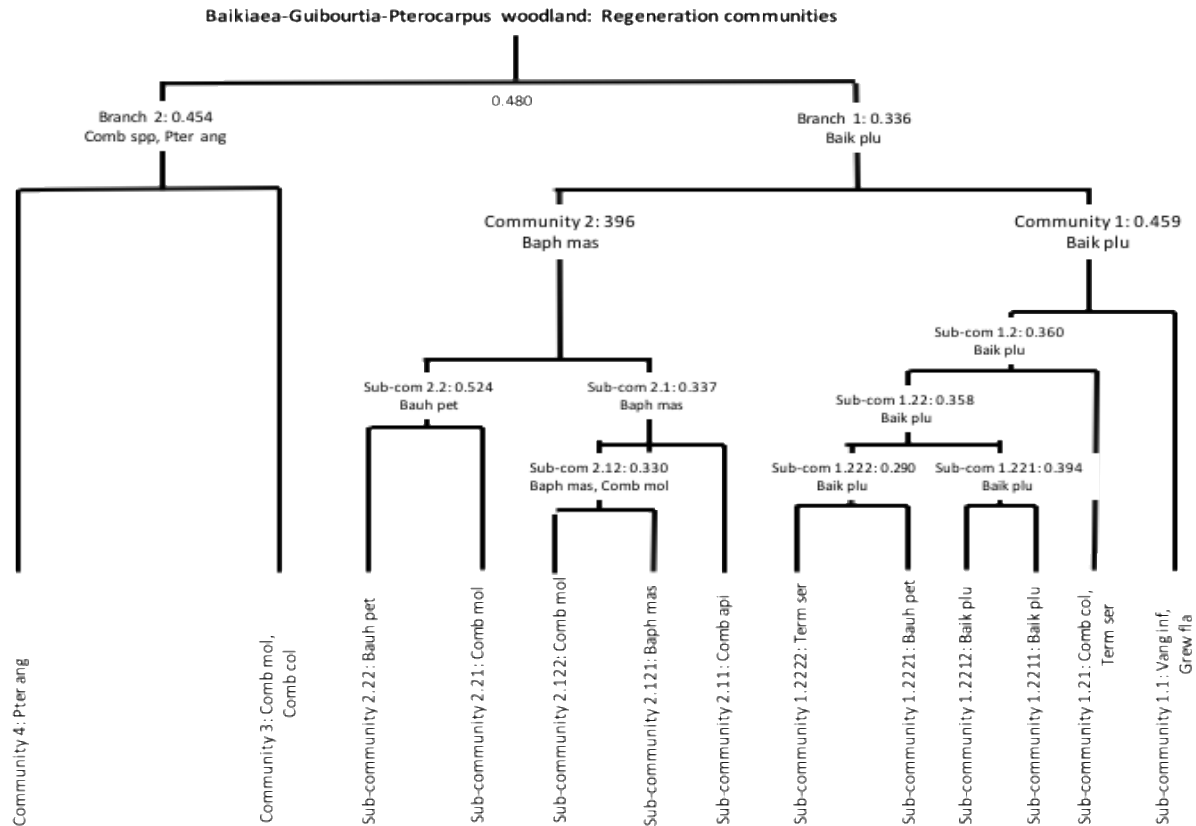


Figure 2.4: Schematic relationship between communities and sub-communities of tree regeneration in *Baikiaea-Guibourtia-Pterocarpus* woodlands based on TWINSPLAN output table (Appendix 2.3). The Eigenvalues at each subdivision and indicator species for the sub-communities are shown.

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).

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

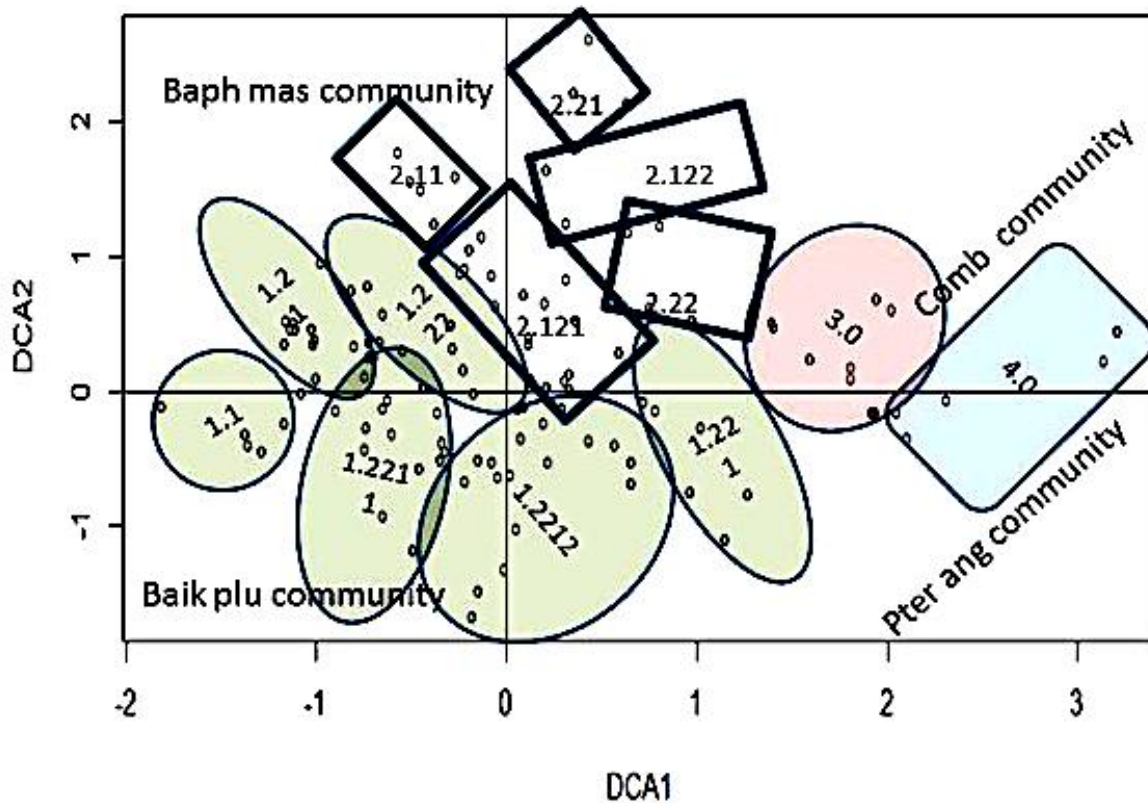


Figure 2.5: DCA ordination diagram of plots for the different regeneration communities and sub-communities. The community names and sub-community codes are indicated within the different colored blocks.

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 *Combretum* 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 $\geq 5\%$ 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	Plots	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
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. infausta-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 \pm 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 \pm 0.02 ^a	9	1.1	0.25 \pm 0.04 ^{ab}	6
1.2	0.08 \pm 0.02 ^a	20	1.21	0.15 \pm 0.02 ^a	15
2.111	0.18 \pm 0.03 ^{ab}	8	1.2211	0.12 \pm 0.03 ^a	11
2.112	0.13 \pm 0.03 ^a	15	1.2212	0.06 \pm 0.01 ^{ac}	11
2.12	0.08 \pm 0.02 ^a	28	1.2221	0.21 \pm 0.04 ^a	8
2.211	0.13 \pm 0.03 ^a	16	1.2222	0.12 \pm 0.03 ^a	13
2.212	0.07 \pm 0.02 ^a	26	2.11	0.12 \pm 0.03 ^a	14
2.22	0.08 \pm 0.02 ^a	22	2.121	0.13 \pm 0.04 ^a	14
3.111	0.17 \pm 0.04 ^a	10	2.122	0.18 \pm 0.04 ^a	9

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

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

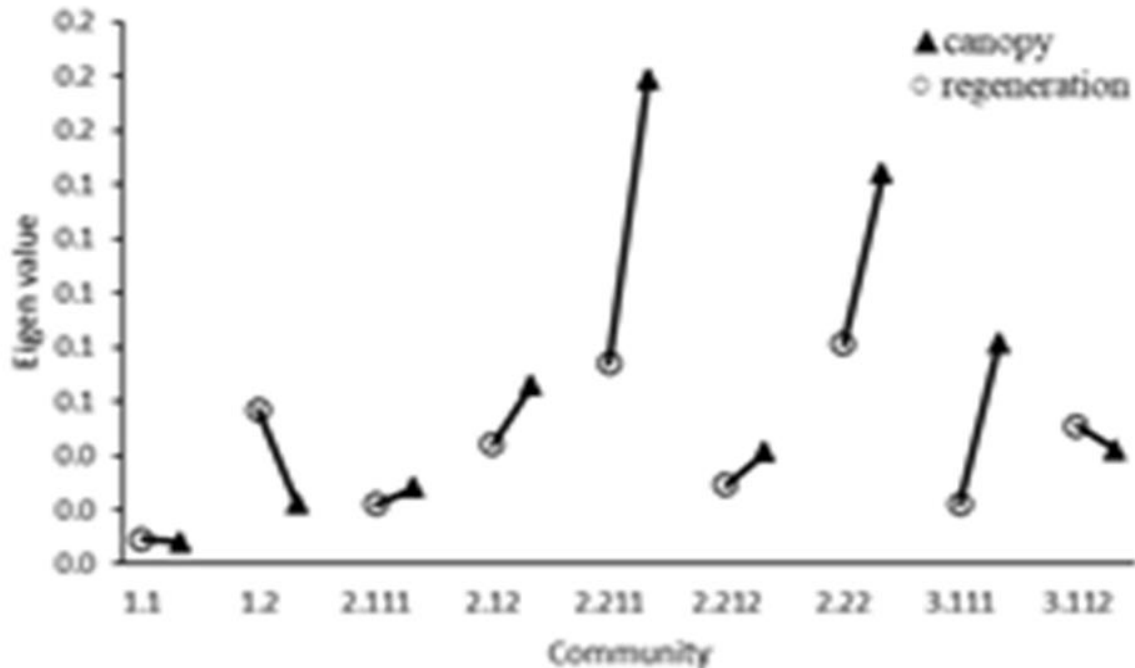


Figure 3.3 Correspondence Analysis ordination of the mean scores for composition of canopy trees (≥ 15 cm DBH) and regeneration (stems 1.0 to 9.9 cm DBH), of canopy tree species, for nine tree sub-communities of the *Baikiaea-Guibourtia-Pterocarpus* woodlands.

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. plurijuga* 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

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

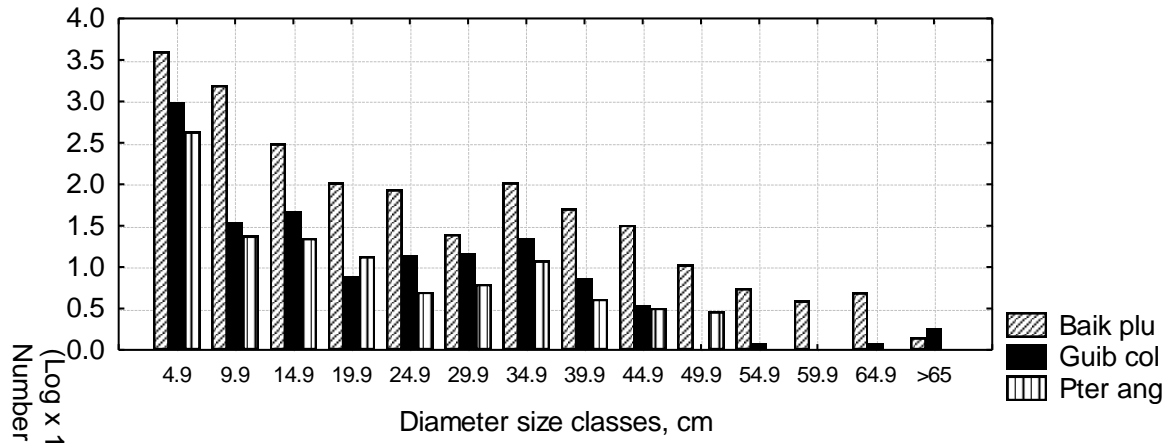


Figure 3.5: Stem diameter distributions for the key species at landscape level (with all communities combined) in *Baikiaea-Guibourtia-Pterocarpus* woodlands of North-western Zimbabwe. The stem diameter classes show the upper limit of each class.

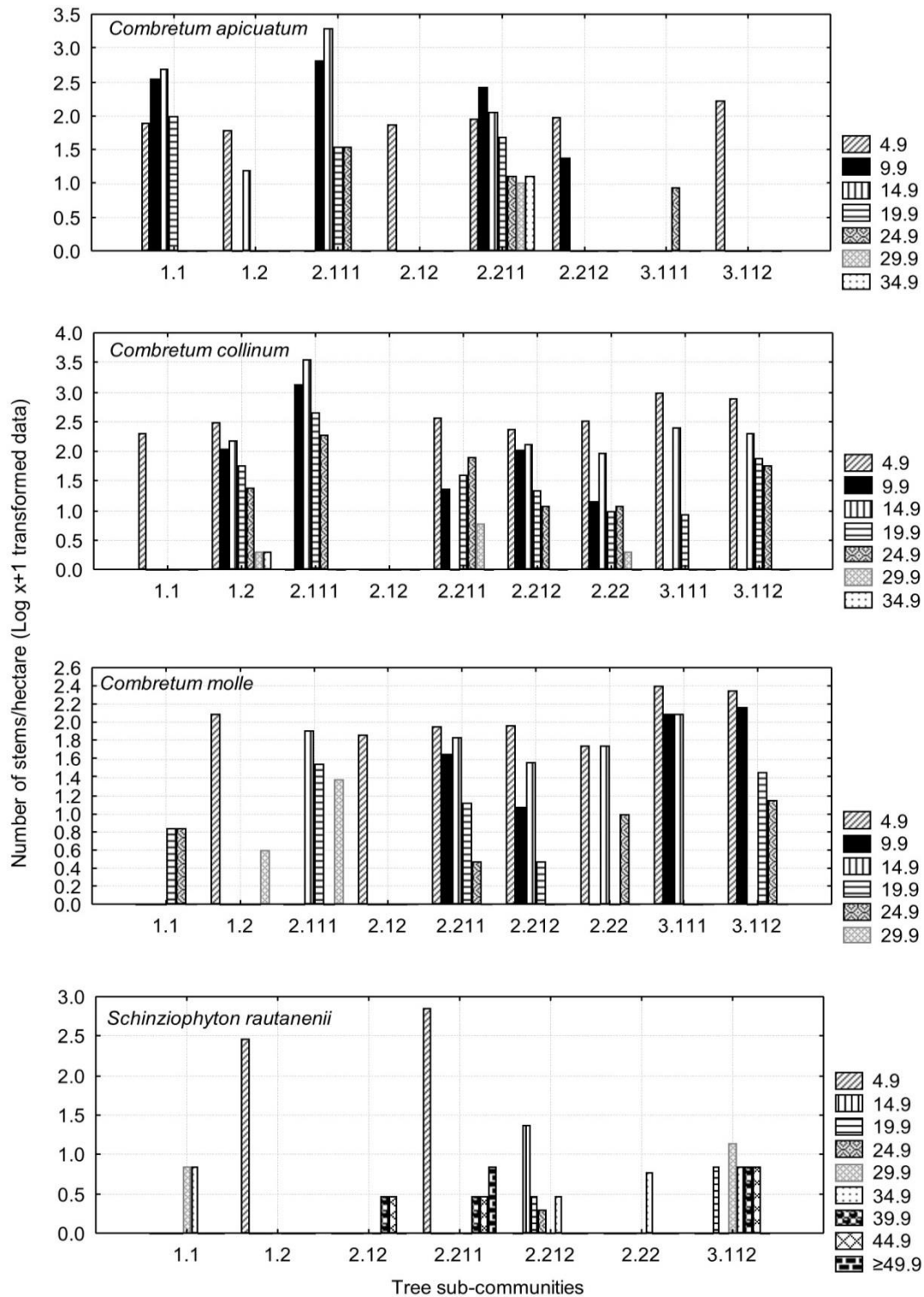


Figure 3.6: Stem diameter class distributions for other canopy species in different tree communities in *Baikiaea-Guibourtia-Pterocarpus* woodlands of North-western Zimbabwe

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.

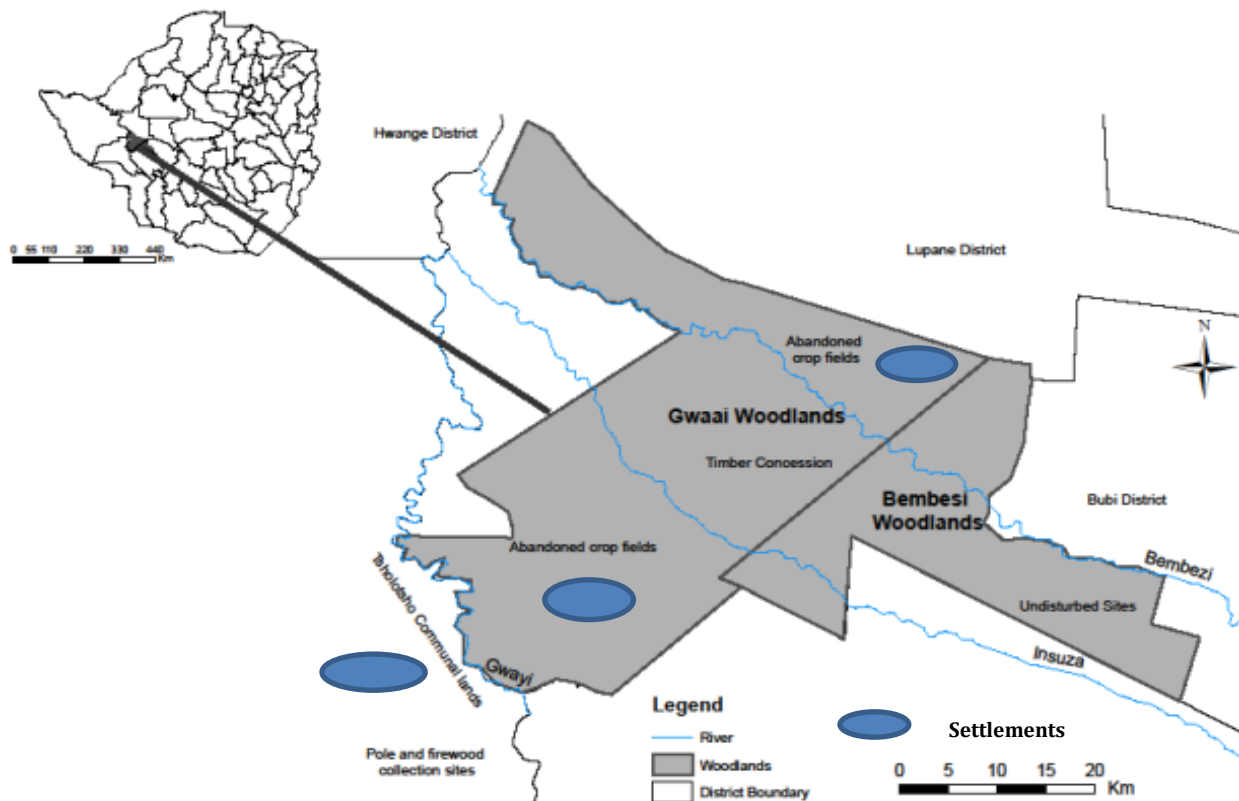


Figure 4.1: Location of the study area in Matabeleland North in Zimbabwe. The blue ovals indicate where settlements are found in the study area.

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 21.5°C. Mean monthly temperature ranges from 15°C (June to September) and 25°C (October to December) (Nyamapfene 1991; JAFATA & Forestry Commission 2001). Ground frosts are experienced, especially in the valleys, in most years between May and September (JAFTA & Forestry Commission 2001).

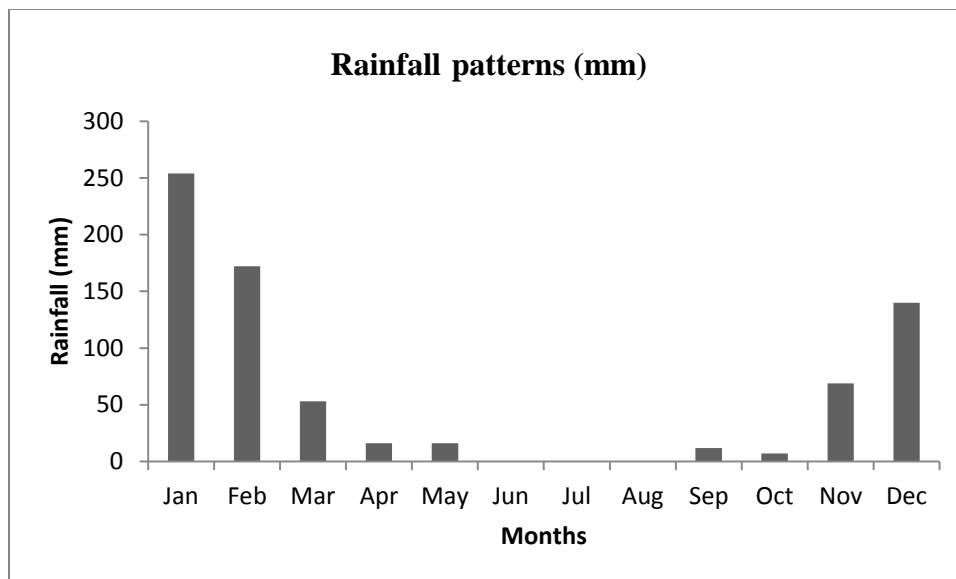


Figure 4.2 Rainfall patterns in the study area (JAFTA & Forestry Commission 2001).

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*

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.

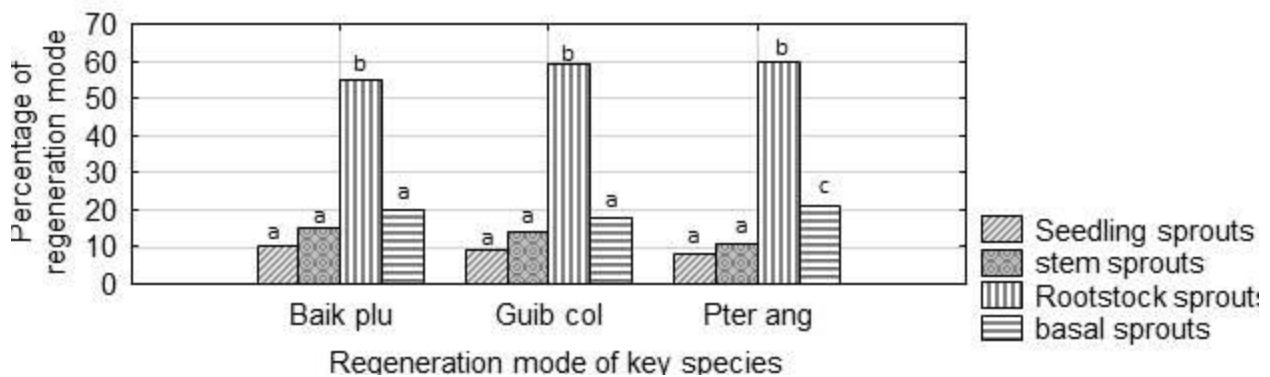


Fig 4.3: Percentage of total number of sprouts originating from (seedlings, stem or trunk - stem sprouts, rootstock - rootstock sprouts and cut or damaged stumps - basal sprouts) for the key species (Baik plu - *Baikiaea plurijuga*, Guib col - *Guibourtia coleosperma* and Pter ang - *Pterocarpus angolensis*). 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).

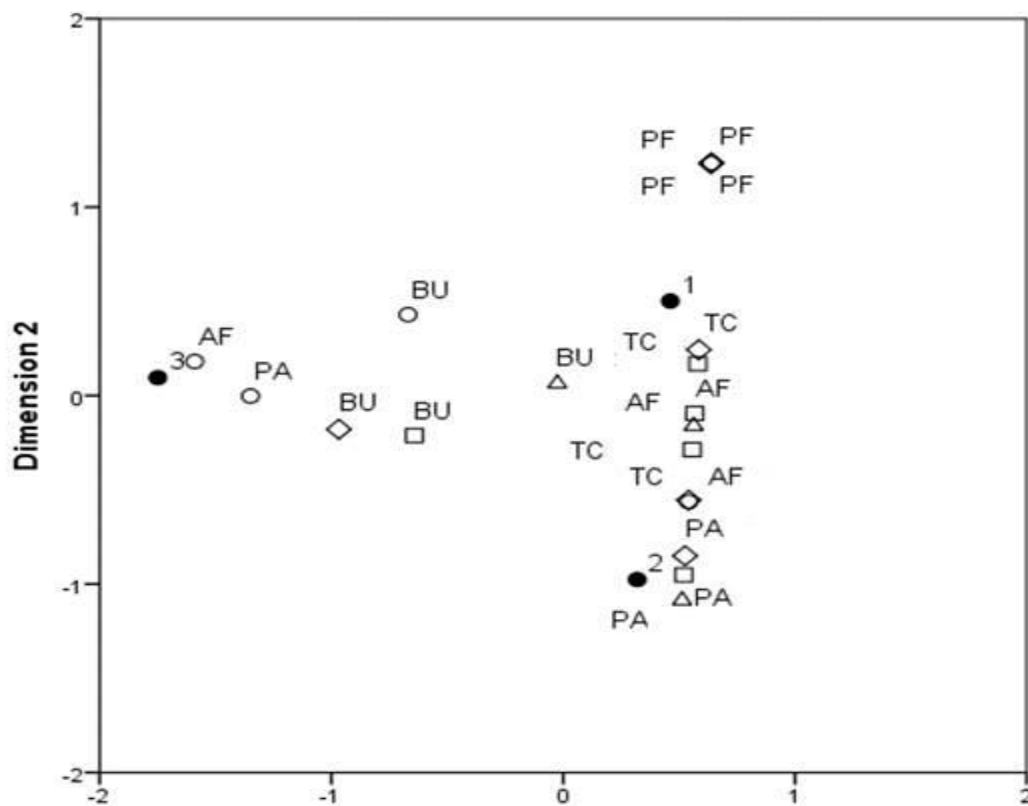


Figure 4.4 Correspondence analysis (CA) scatter plot showing the association of different disturbance regimes to regeneration modes (PA- protected area, TC – timber concession , PF- pole and firewood, AF- abandoned crop fields, , BU- burnt area). 1, 2 and 3 represent *B. plurijuga*, *G. coleosperma* 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*- $\chi^2 = 225.66$ $p < 0.001$, *G. coleosperma*- $\chi^2 = 158.62$ $p < 0.001$ and *P. angolensis*- $\chi^2 = 144.01$ $p < 0.001$). *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.

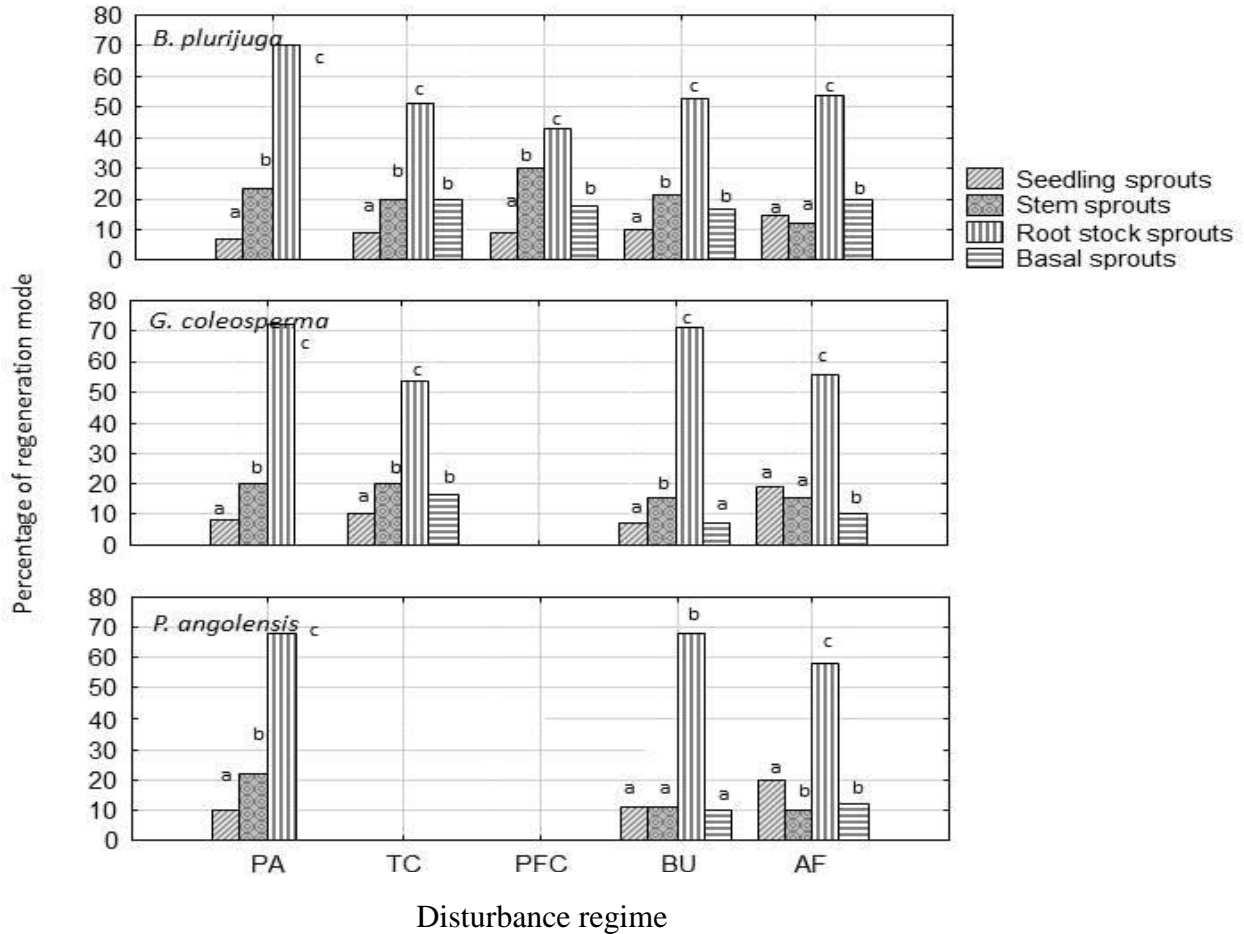


Figure 4.5 Modes of regeneration for the targeted species (*B. plurijuga*, *G. coleosperma* and *P. angolensis*) under each disturbance regime (PA- Protected area, TC-Timber concession area, PFC- Pole and firewood collection sites, AF- Abandoned crop fields, and BU-Burnt areas). Each superscript (a,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

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 \pm standard error) and significant levels from one-way ANOVA with unequal sample size tests.

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

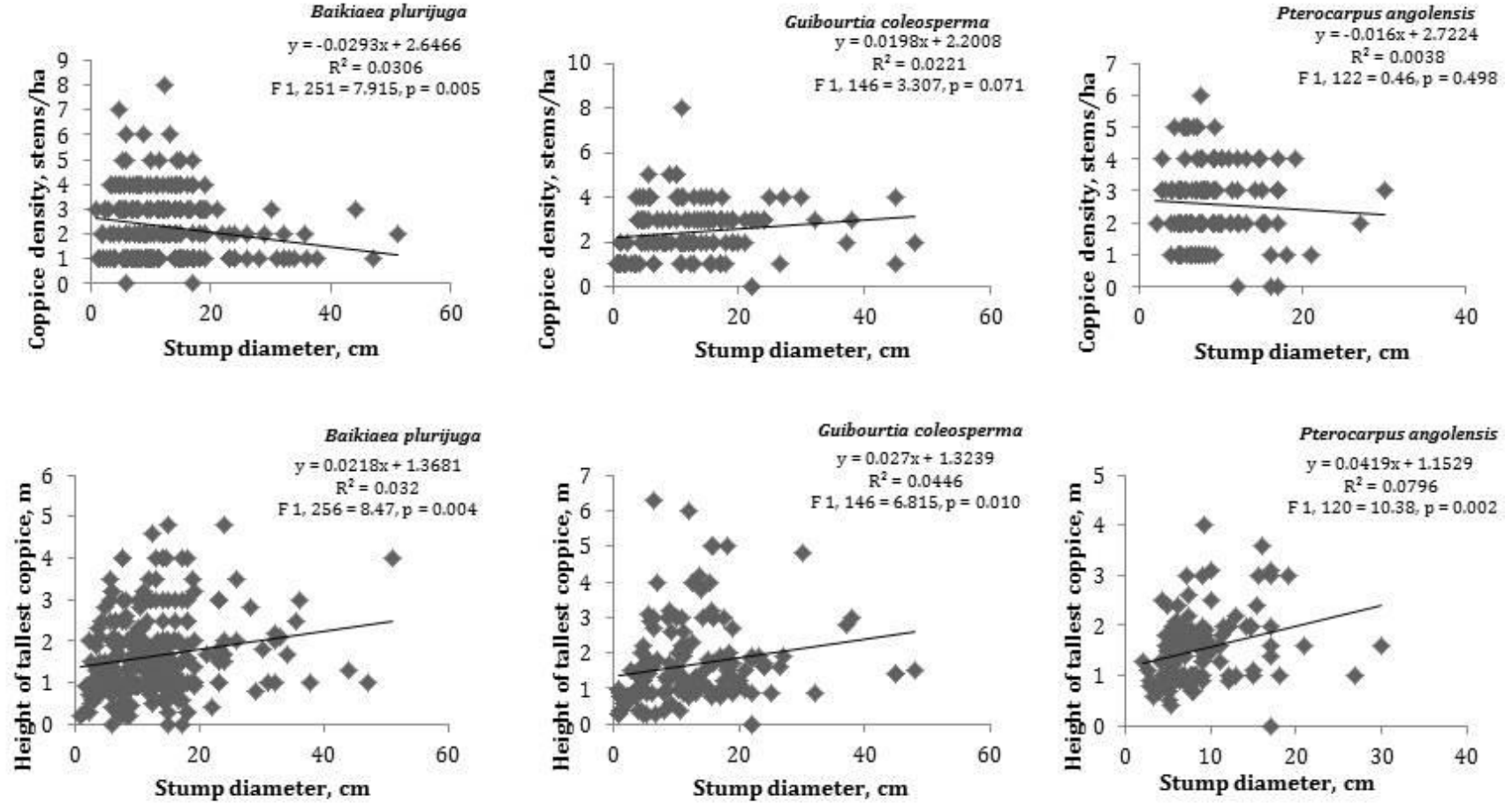


Figure 4.6: Influence of stump diameter on sprout density and sprout height for the three key species

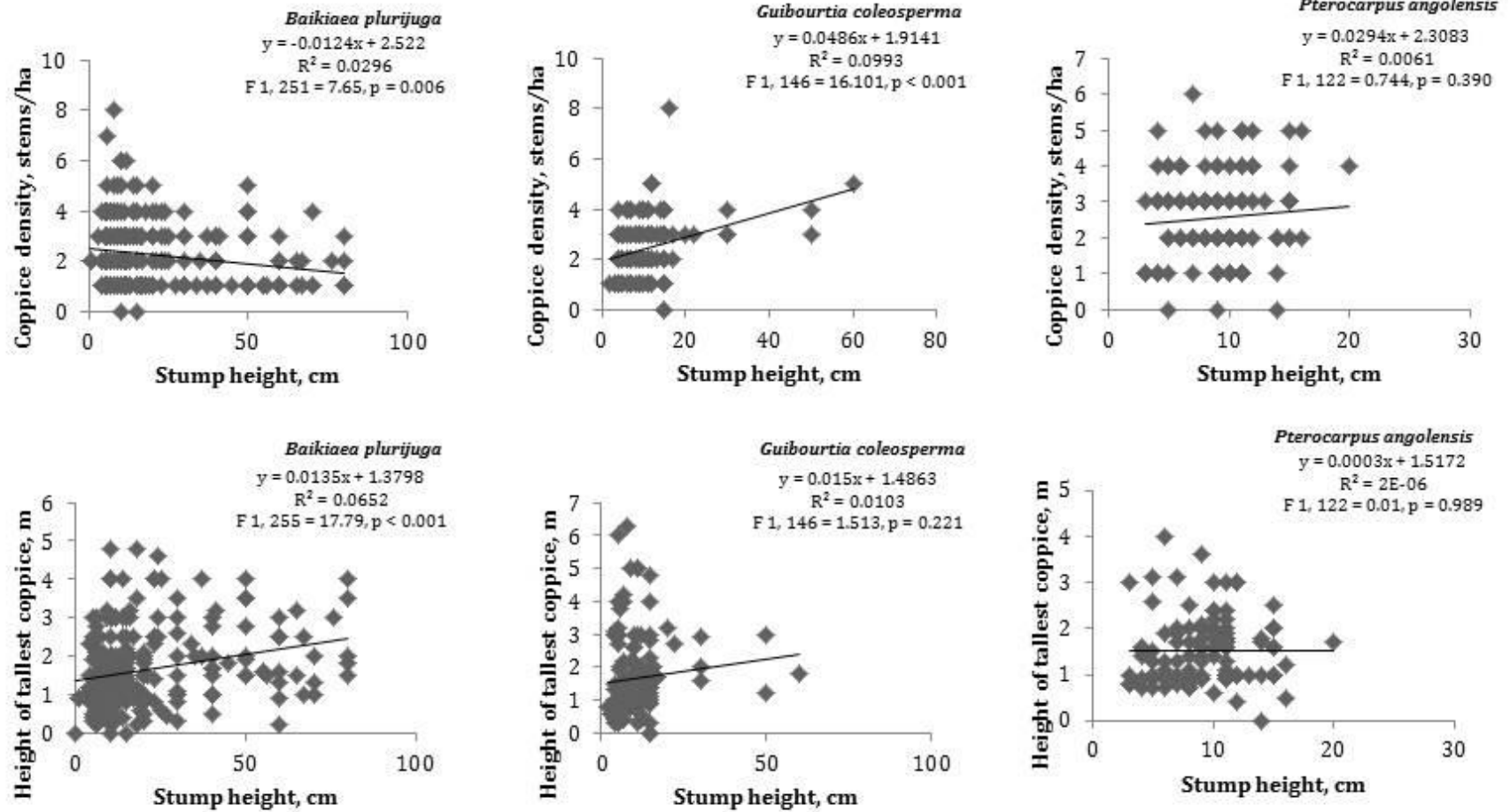


Figure 4.7: Influence of stump height on sprout density and height for the three key species.

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 disturbance 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* (Pearce 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 (Lilly 1977; 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.

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°16'20 S and 27°56'36E) and Tsholotsho (19°46'00 S and 27° 45' 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.

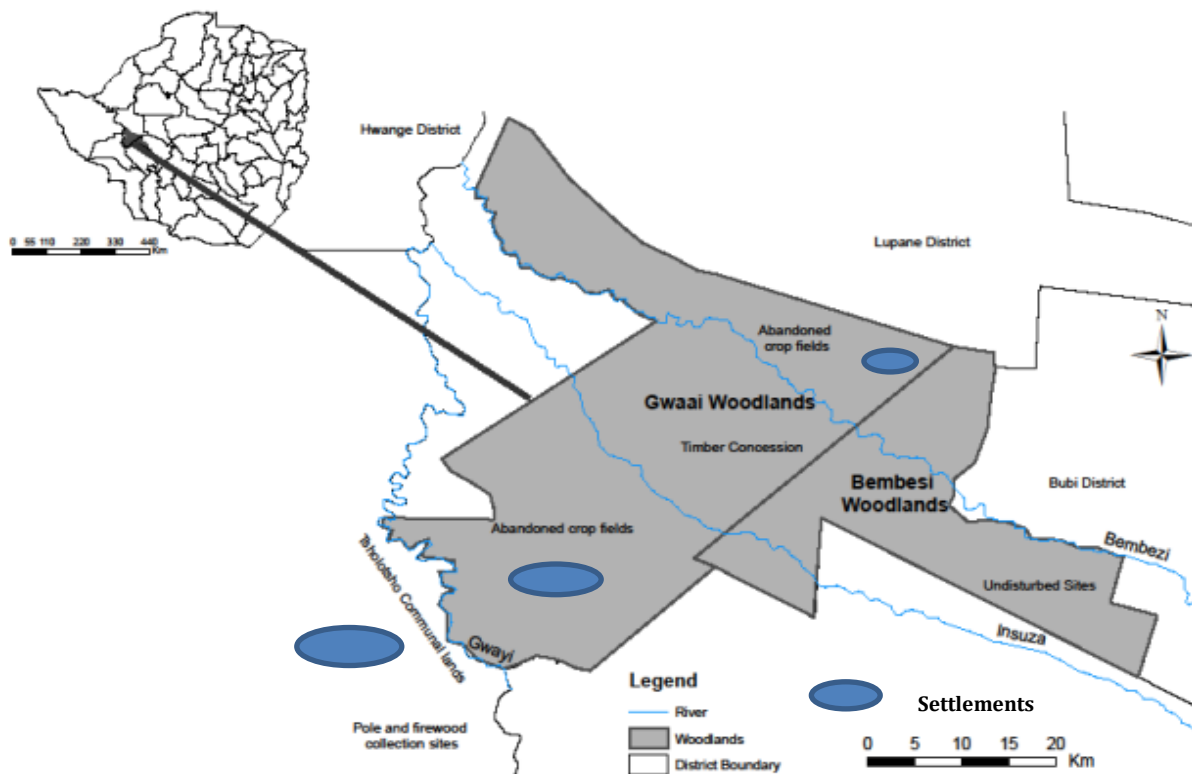


Figure 5.1: Location of the study area in Matabeleland North in Zimbabwe. The blue ovals indicate where settlements are found in the study area.

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

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



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).

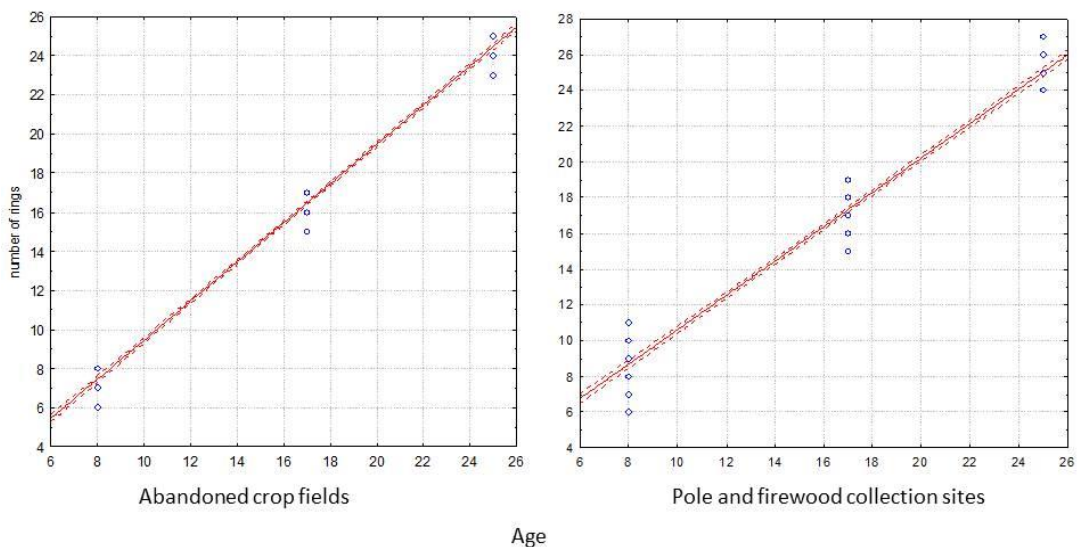


Figure 5.6: The positive linear relationship between stand age and the number of growth rings in regrowth stands after different years after abandoning pole and firewood collection and crop cultivation.

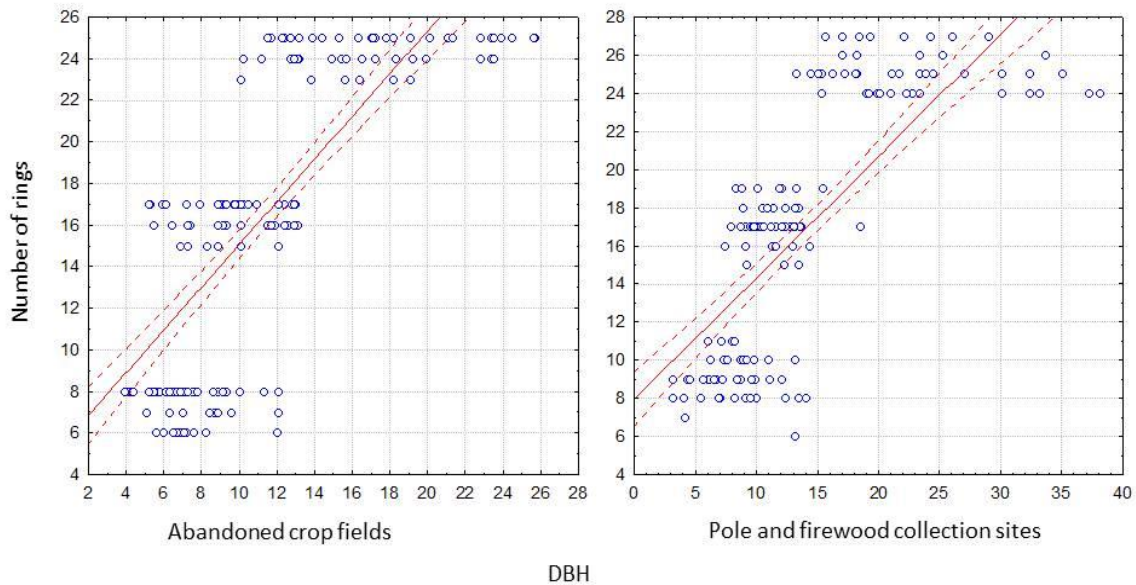


Figure 5.7: The relationship between DBH and number of growth rings in regrowth stands after different years after abandoning pole and firewood collection and crop cultivation

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				Abandoned crop-field regrowth stands			
	Age in yrs				Age in yrs			
	8	17	25	Mean	8	17	25	Mean
<i>Baikiaea plurijuga</i>	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
<i>Guibourtia coleosperma</i>	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
<i>Pterocarpus angolensis</i>	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
<i>B. plurijuga</i>	1.13 ± 0.15 ^a	1.04 ± 0.23 ^b	0.88 ± 0.19 ^c	$P < 0.001$
<i>G. coleosperma</i>	1.13 ± 0.14 ^a	0.95 ± 0.14 ^b	0.99 ± 0.15 ^b	$P < 0.001$
<i>P. angolensis</i>	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

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-*

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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 *Baikiaea-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, silvicultural management

6.1 INTRODUCTION

Poor resource use management strategies (White 1983; Ferguson 1996; Geldenhuys 1997; 2003; Mapaire & Ndeinoma 2011) combined with pressures from increasing population densities (Mapaire & 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 (Pearce 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 2001 and 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 overestimates 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 deforested 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.*

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

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)

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

The three key species (*B. plurijuga*, *G. coleospema* 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 inverse 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 than 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 (Schwartz *et al.* 2002; Caro *et al.* 2005), further threatens populations of the species. Geldenhuys *et al.* (2004) and Lemmens *et al.* (2008) have also

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 where 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.*

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.

