The natural regeneration of woody plants on abandoned fields in north-eastern Namibia

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Thesis submitted in fulfilment of the requirements for the degree of Master of Natural Resources Management at the Namibia University of Science and Technology

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Declaration

I, Remmie Hilukwa hereby declare that the work contained in the thesis, entitled: The natural regeneration of woody plants on abandoned fields in north eastern Namibia, is my own original work and that I have not previously in its entirety or in part submitted it at any university or other higher education institution for the award of a degree.

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List of Acronyms

BS	Base saturation
CEC	Cat-ion exchange capacity
HWSD	Harmonized World Soil Database
MRPP	Multiresponse Permutation Procedure
MVSP	Multi-Variate Statistical Package
NLME	Nonlinear Mixed-Effect Model
OC	Organic carbons
SPSS	Statistical Package for the Social Sciences
SASSCAL	Southern African Science Service Centre for Climate Change and Adaptive Land Management” (SASSCAL)

Acaeri	*Acacia erioloba*
Acaeru	*Acacia erubescens*
Acafle	*Acacia fleckii*
Acaheb	*Acacia hebeclada*
Acakir	*Acacia kirkii*
Acamel	*Acacia mellifera*
Acanig	*Acacia nigrescens*
Acaspp	*Acacia* species
Acator	*Acacia tortilis*
Albant	*Albizia anthelmintica*
Albbre	*Albizia brevifolia*
Baiplu	*Baikiaea plurijuga*
Bapmas	*Baphia massaiensis*
Baupet	*Bauhinia petersiana*
Berdis	*Berchemia discolor*
Bosalb	*Boscia albitrunca*
Burafr	*Burkea africana*
Comcol	*Combretum collinum*
Comeng	*Combretum engleri*
Comimb	*Combretum imberbe*
Commos	*Combretum mossambicense*
Commsp	*Commiphora* species
Comspp	*Combretum* species
Comzey	*Combretum zeyheri*
Crogra	*Croton gratissimus*
Cropse	*Croton pseudopulchellus*
Diaeng	*Dialium engleranum*
Diccin	*Dichrostachys cinerea*
Diccym	*Dichapetalum cymosum*
Diolyc	*Diospyros lycioides*
Elatra	*Elaeodendron transvaalense*
Eryafr	*Erythrophleum africanum*
Eucspp	*Euclea* species
Greave	*Grewia avellana*
Grebio	*Grewia bicolor*
Grefal	*Grewia falsistipula*
Grespp	*Grewia* species

Guicol	*Guibourtia coleosperma*
Gymsen	*Gymnosporia senegalensis*
Hyppet	*Hyphaene petersiana*
Melspp	*Melhania species*
Ochpul	*Ochna pulchra*
Ozooka	*Ozoroa okavangoensis*
Ozopan	*Ozoroa schinzii*
Pecleu	Pechuel-loeschea leubnittziae
Pelafr	*Peltophorum africanum*
Phinel	*Philonoptera nelsii*
Piltho	*Piliostigma thonningii*
Psedek	*Pseudolachnostylis dekindtii*
Schrau	*Schinziophyton rautanenii*
Sclbir	*Sclerocarya birrea*
Seaspp	*Searsia* species
Seaten	*Searsia tenuinervis*
Seclon	*Securidaca longepedunculata*
Strcoc	*Strychnos cocculoides*
Strpun	*Strychnos pungens*
Swamad	*Swartzia madagascariensis*
Terpru	*Terminalia prunioides*
Terser	*Terminalia sericea*

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Dedication

This thesis is dedicated to my husband Jason K. Hilukwa, my son Tuhafeni Ndapameka Hilukwa and my beautiful daughter Ndayamo M. Tunohole Hilukwa. Thank you for your support and understanding. You are the best.

Abstract

Agricultural practices such as land clearing for subsistence farming are some of the largest disturbances to the natural regeneration of woody plants, important for future forest structure and composition. Farmers of the Mashare constituency in the Kavango East region of Namibia fallow their fields for a period ranging from 1 to 25 years. Regeneration can be expected when crop fields are fallowed. This study aimed to determine the potential of woodlands to recover naturally after deforestation, and the optimal conditions for this recovery on fallow agricultural fields.

The results of this study showed that the duration of fallowing did not have a significant effect on species diversity of the aboveground woody plants and the soil seedbank amongst the agricultural fields under fallowing. However, the results showed that methods of ploughing resulted in a significant difference in species diversity of the aboveground woody plants on fallow fields (Mann-Whitney U test, p=0.038). The fallow fields ploughed using traditional methods were found to be more diverse, compared to mould board ploughs. This could be attributed to the minimal disturbance to the plants and the soils structure, when compared to the mould board ploughs. Furthermore, the results of the soil seed bank showed no significant differences in species diversity between the fallow fields and remnant forest vegetation. However this study found significant differences in species diversity of woody plants, between above-ground vegetation of the fallow fields and the remnant forest vegetation (Mann-Whitney U test, p=0.001). The remnant forest vegetation showed higher woody plant diversity and it could be as result of the diverse microsites and the mature plants that can facilitate plant regeneration.

The results of species composition of the aboveground vegetation, have indicated that more than half the woody species were common between fallow fields and remnant forest vegetation (Jaccard Index of Similarity, 51%).The fallow field's contained more species not occurring on remnant forest vegetation and this could be attributed to the regeneration of earlier successional species including pioneer species that colonize and invade disturbed soils. Furthermore, the results of the soil seed bank showed a low similarity (33%) in species composition of the woody plants between the fallow fields and remnant forest vegetation. The variation could be attributed to seed dispersal and seeds persistence in the soil. The soil seed bank of the fallow fields still constituted seeds of the previous vegetation.

This study also found that vegetation structure showed a significant relationship between the association of growth form and the type of fields (fallow or remnant) (Chi-square Test of association, p=0.000). This can be attributed to the open niches on fallow fields allowing regeneration of woody plants.

The classification result of this study revealed four woody plant associations and one outlier: *Baikiaea plurijuga* - *Strychnos cocculoides*, *Combretum zeyheri - Baphia massaiensis*, *Acacia erioloba - Diospyros lycioides* and *Acacia tortilis – Combretum imberbe.* Ordination partitioned five communities along the two axes, confirming the classification result. Axis one contributs 74% to the total variation of the associations. The Spearman's rank-order correlation showed that the woody plants were associating based on the top soil characteristics such as organic carbon (77%), cat-ion exchange (68%), slope (65%) and distance from the river (-0.898%).

The result of the soil seed bank showed that 45% of all seeds retrieved were viable and the viability of the seed varied among species. The differences could have occurred due to more seed obtained from the *Combretum engleri* and the Grewia species which were not viable.

In conclusion, this study showed that fallowing favoured the regeneration of woody plants, but species exploited for timber (*Pterocarpus angolensis*, *Baikiaea plurijuga*, *Burkea africana* and *Guibourtia coleosperma*) were represented in limited numbers. Assisted regeneration of these species is therefore recommended.

Key words: fallow fields, species diversity, aboveground vegetation, soil seed bank, seed viability.

1. INTRODUCTION

1.1 Background

Woodlands are landscapes dominated by tall trees and relatively sparse understory vegetation (Jürgens *et al.* 2010). Woodlands are ecologically important as they regulate water flows, and also stabilize soils and the climate (FAO, 2016). These ecological processes can only happen if the woodlands continue to regenerate (Borghetti and Giannini 2009). The dry woodlands of north-eastern Namibia are important for the livelihood of the local people. According to Brown and Mujetenga (2010), the dry woodlands support 70% of the people that live along the Okavango River through resources such as habitat, water, arable agriculture and pastures. Specifically, the woodlands provide direct benefits such as harvesting of wood for carving, construction and energy (Pröpper *et al.* 2010, De Cauwer *et al.* 2013, Strohbach 2013a).

As much as people form part of the woodlands, the heavy reliance on natural resources and the agricultural practices pose a threat to plant species populations. Agricultural activities such as land clearance have been found to disturb the natural regeneration process of plants in north eastern Namibia (Pröpper *et al.* 2010). Natural regeneration is the recruitment of a plant population arising from seed and seedling establishments or vegetative growth without assistance (Kalema 2010).

This study was conducted at the Mashare constituency to establish if the woodlands naturally regenerate and recover after land clearing. The Mashare constituency forms part of the Kavango Woodlands, of which most inhabitants around the area depend on subsistence agriculture for a living. The rural farmers practice subsistence farming on a permanent cropping basis with short term (1-2 years) to long term (5 =/> years) fallowing (Kasinda 2016). Fallowing is a period when an agricultural field has not been cultivated and the field has been abandoned temporarily. During the fallow period the woody species may naturally regenerate provided that the environmental conditions are conducive. This study focuses on the potential of natural regeneration of woody plant species on the Fallow fields in the Mashare constituency. The study on regeneration of woody plants, considered target variables such as species diversity, growth forms (seedlings, coppices, shrubs and trees), species composition, seed densities and seed viability. Species diversity is defined as a function of the number of species present and the evenness with which the individuals are distributed among these species (Hurlbert 1971).

Woodland studies have become an important topic for Namibia as the country is faced with the challenge of finding the balance between resource uses and population increases. The Namibian government through the Forest Strategic Plan for 2011-2015 has called for more research on the natural regeneration of woody species that are commercially exploited, especially *Pterocarpus angolensis, Burkea africana, Guibourtia coleosperma* and *Baikiaea plurijuga* (Ministry of Agriculture, Water and Forestry 2011). This study was funded by SASSCAL, task 038. The task addresses research on forest regeneration, growth rates, threats, and trends in different forest types.

1.2 Problem statement

An increasing human population is putting pressure on the woody plants and the woodlands in north-eastern Namibia (Strohbach 2013a, De Cauwer *et al.* 2016a). This has caused agricultural fields to expand into terrace slopes which are not suitable for crop farming (Strohbach 2013a). Land clearing for subsistence crop farming has thus resulted in the reduction of forests and woodlands, with only little natural vegetation remaining on riverbanks and the alluvial plains of the Mashare area (De Cauwer 2014a).

The Namibian government is faced with the challenge of managing the woodland resources in the country. As a result, a Forest Research Strategy Plan for Namibia was developed and one of the key research problems that need immediate attention is the poor level of natural regeneration of commercially exploited species (Ministry of Agriculture, Water and Forestry 2011). Tree species such as *Pterocarpus angolensis, Baikiaea plurijuga* and *Burkea africana* are used locally as well as commercially for income generation. Efforts have been made to regenerate the timber species (*P. angolensis* and *B. plurijuga)* in government nurseries and the results have shown that the seedling success rate of these species is very low (Ministry of Agriculture , Water and Forestry 2011). Therefore the government is seeking ways to improve the regeneration of woody plant species.

It is important to establish if the woody plants are regenerating by assessing the plant growth aboveground as well as to assess the viability of the soil seed bank. Therefore the aim of this study is mainly to understand if the woodland can recover without intervention.

1.3 Conceptual framework

The conceptual framework (figure 1) shows the variables measured in this study and the methods used to assess them. In order to understand woody plants regeneration on Fallow fields, this study considered species diversity, species composition, and vegetative structure as important variables. Other variables of importance included seed density and seed viability of the soil seed bank in the study area. Data on the regeneration of woody plants were obtained from fallow fields and remnant forest vegetation in the Tjeye, Mashare, Katondo, Muroro, Mupapama and Mausivi villages of the Mashare Constituency.

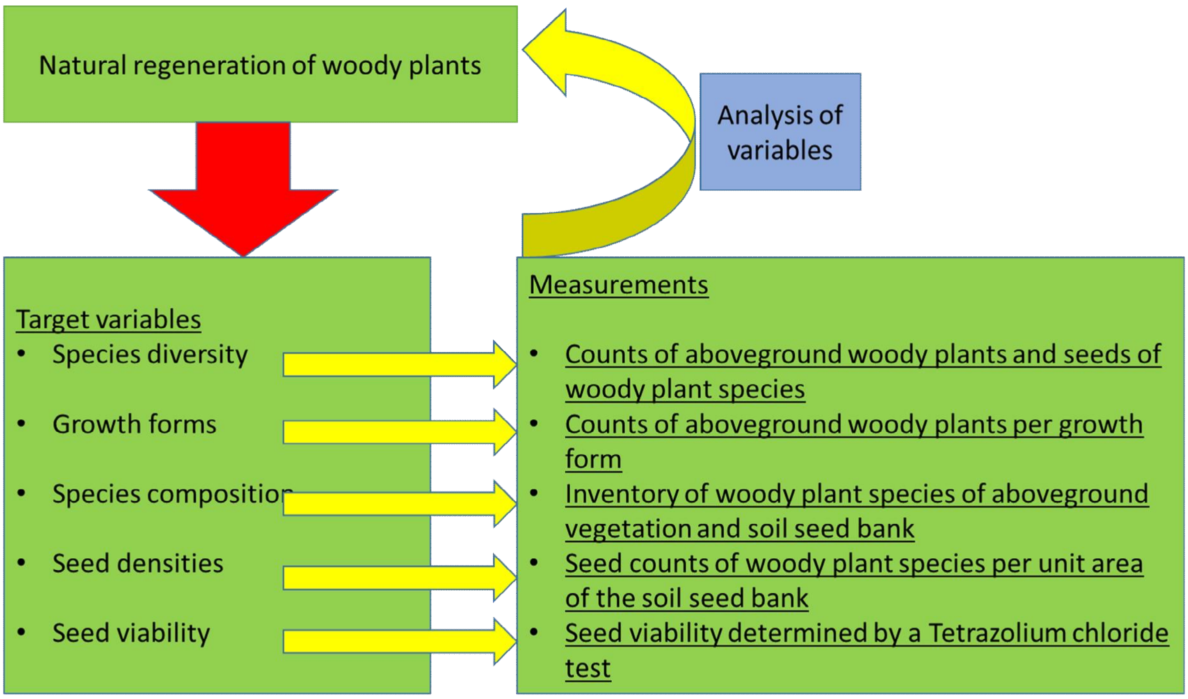

Figure 1: Natural regeneration of woody plants and the variables considered for this study

1.4 Aims and objectives

The aim of this study is to determine the potential of woodlands to recover naturally after deforestation, and the optimal conditions for this recovery on fallow agricultural fields in the Kavango East region of north-eastern Namibia.

1.5 Specific objectives and hypotheses

Objective 1: To determine the above ground species diversity of woody plants regenerating on fallow fields depending on the duration of fallowing and method of cultivation.

Hypothesis 1

H_0: Duration of fallowing does not affect species diversity of woody plants on fallow fields.

Hypothesis 2

H_0: Ploughing methods do not influence species diversity of the fallow fields.

Objective 2: To compare the aboveground species diversity of woody plants between fallow fields and remnant forest vegetation.

Hypothesis 3

H_0: Species diversity of woody plants is not different between the fallow and the remnant forest vegetation.

Objective 3: To assess the species diversity and seed density of the soil seed bank on fallow fields depending on the duration of fallowing.

Hypothesis 4

H_0: Duration of fallowing does not affect species diversity and seed density of the soil seed bank of the fallow fields.

Objective 4: To compare the soil seed bank's species diversity of woody plants between between Fallow fields and remnant forest vegetation.

Hypothesis 5

H_0: There is no significant difference in the species diversity of soil seed bank between the fallowed and the remnant forest vegetation.

Objective 5: To compare species composition of the aboveground vegetation and the soil seed bank between the Fallow fields and the remnants.

Hypothesis 6

H_0: There is no similarity in species composition of the aboveground vegetation and the soil seed bank between the fallow and the remnants fields.

Objective 6: To investigate the relationship of the aboveground vegetation structure (seedlings, coppices and shrubs) and the type of fields of the Mashare area.

Hypothesis 7

H_0: Structure does not associate with the type of fields (fallow and remnant forest vegetation).

Objective 7: To investigate the relationship between aboveground vegetation and environmental factors of the Mashare area.

Hypothesis 8

H_0: Environmental factors have no influence on the aboveground vegetation and species composition of the Mashare area.

Objective 8: To determine the viability of woody plant seeds collected from the soil seed bank of all fields under study.

Hypothesis 9

H_0: Seed recovered from the fields studied are not viable.

2. LITERATURE REVIEW

2.1 Woodlands of the Kavango regions in Namibia

The dry woodland savannas of Namibia are landscapes dominated by tall trees and relatively sparse understory vegetation (Jürgens *et al.* 2010). Namibian woodlands occur in river valleys, on plains and hills (Mendelsohn and Obeid 2005a).

The Kavango east and Kavango west regions (formerly the Kavango region of Namibia) fall under the north eastern Kalahari Woodlands, also referred to as the Broadleaf Woodlands (Mendelsohn and Obeid 2005a). Giess (1971) described the vegetation of Kavango as Tree Savanna and Woodland (see figure 2). The Kalahari Woodlands receives on average 600 mm rainfall per annum (Ministry of Agriculture, Water and Forestry 2011) and are situated in the area with the highest mean rainfall in Namibia.

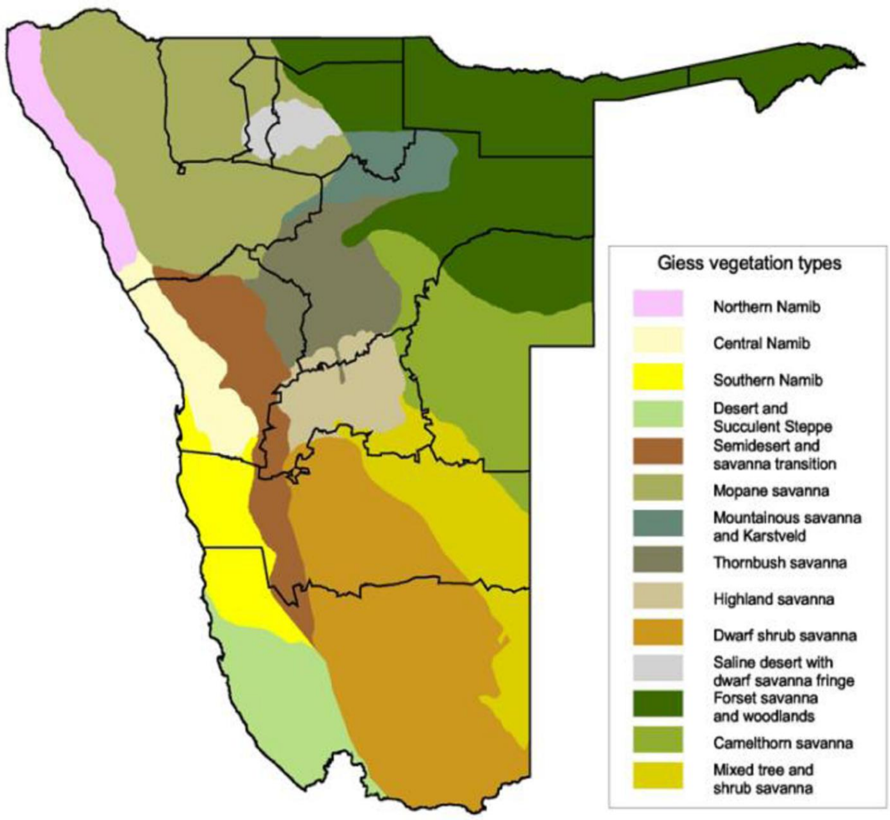

Figure 2: The vegetation zones of Namibia (Giess1971)

The Kavango woodlands growing on the deep Kalahari sands contain the bulk of the trees (estimate of 125 trees per hectare) in Namibia (Ministry of Agriculture, Water and Forestry

2011). The woodlands contain important species that provide wood and timber in the country. The important species are *Pterocarpus angolensis, Baikiaea plurijuga, Terminalia sericea, Acacia erioloba and several Combretum* species (Mendelsohn and Obeid 2005a).

Brown and Mujetenga (2010a) found that most people in Kavango live along a 10 kilometre wide ribbon of the river where there is water availability, suitable pastures and fertile soils. Further away from the river the woodlands are extensively used for grazing and harvesting of wood/poles, and they are regularly burnt to facilitate grazing as well as hunting (Pröpper *et al.* 2010, Strohbach 2013a, De Cauwer *et al.* 2014). People mostly occupy the edge of omurambas which is the non-perennial riverbed, where soils are more fertile compared to the dune sands, and where most boreholes are situated (Kowalski *et al.* 2013, Strohbach 2013a). The magnitude of human influence on the woodlands is a key factor contributing to the loss of biodiversity (Jürgens *et al.* 2010), in this case tree species. Studies by Graz (2004) also found that continuous harvesting affected important tree species such as *Burkea africana, Baikiaea plurijuga*, *Pterocarpus angolensis, Guibourtia coleosperma, Schinziophyton rautanenii,* and *Combretum collinum*. Therefore, there is a need to establish if such important species are naturally regenerating back into the woodlands that are deforested as a result of subsistence crop farming.

2.2 Natural regeneration of trees of the Kavango woodlands in Namibia

According to the Ministry of Agriculture, Water and Forestry (2011), the regeneration of key timber species should be investigated as the country has no commercial timber producers. Various studies pointed out that the natural regeneration of plants are affected by the climate, soil, fires, elevation, historic and human influence (Mendelsohn and Obeid 2005b, Bakhoum, Ndour *et al.* 2012). The arid conditions prevailing in Namibia and soil factors such as nutrients and the ability to hold water are some of the key factors that are limiting the growth of woody plants (Ministry of Agriculture, Water, and Forestry 2011).

Natural regeneration in the dry woodland savanna is defined as the population recruitment arising from seed and seedling establishment or vegetative growth (Kalema 2010). Regeneration is indicated by seedlings and saplings composition, distribution and density (Borghetti and Giannini 2009, Tsheboeng and Murray-Hudson 2013). Studies by Benayas *et al.* (2008) found that natural regeneration is often slow as a result of seed dispersal limitations and adverse environmental conditions which limit tree establishment. According to Borghetti and Giannini (2009), the cycle of natural vegetation recruitment may be negatively influenced at different stages of the plant life cycle. The juvenile stage of a woody species may be impacted by the availability of space for seedling germination and subsequently seedling growth resulting in high mortalities (Borghetti and Giannini 2009).

The process of natural regeneration is important because it ensures continuous supply of seedling and saplings growing into trees, that can provide timber and non woody products (Selanniemi *et al.* 2000). The non woody products may include products such as edible fruits, berries, roots, honey, medicine, and fodder, which form part of the community livelihoods. Apart from that, the woodland also provides ecological functions such as the stabilisation of soils and climate (FAO 2016). The woody vegetation also regulates water flows, provides shelter, and habitat for pollinators and the natural predators of agricultural pests (FAO 2016).

2.2.1 Modes of regeneration

a) Vegetative regeneration (Asexual regeneration)

Vegetative regeneration involves reproduction through coppicing, tubers, and suckering from parent plants. This type of regeneration produces offspring that are genetically the same as the stump it is regenerating from. According to Bakhoum *et al.* (2012), vegetative regeneration occurs as a responsive adaptive mechanism and an adaptation strategy by sexually reproducing plant species following disturbances (e.g. harvesting or tree/branch fall) and climatic changes which affect sexually reproducing species. Hence vegetative reproduction is often a sign of pressure on the woody species, commonly caused by anthropogenic activities, drought, wildfires, and predation (Bakhoum *et al.* 2012).

Re-sprouting as a mode of vegetative regeneration refers to shoots growing from the stem or stem base on a woody plant following damage (Kalema 2010). Species that have the ability to sprout have a surviving meristem and a well-established root system with stored reserves to support growth or reproduction (Bond and Midgley 2001). Such plants are usually multi-stemmed and they can coppice from a single stump (Zida *et al.* 2009). Different plant species may sprout at different stages of development such that some sprout at a juvenile stage and others at a mature stage. Even so, some species lose the ability to re-sprout when they reach maturity, while others sprout vigorously at that stage (Bond and Midgley 2001).

In the case of the woodland savanna species in the Kavango East and Kavango West regions of Namibia, multiple sprouts occur from a single stem, as has been observed during the fieldwork phase of this study in *Baikiaea plurijuga, Pterocarpus angolensis* and *Burkea africana* but also from multi-stemmed shrubs such as *Baphia massaiensis*, *Bauhinia petersiana, Combretum zeyheri, Combretum collinum* and *Terminalia sericea*.

The effectiveness of re-sprouting from a stump varies from species to species, and factors such as the size and age at the time of cutting, the height of stump and how much was cut off affect re-sprouting (Luoga *et al.* 2004). Additionally, the site characteristics (shallow or deep soils) and the type of tools used (sharp or blunt) to cut the species also play a role. Luoga *et al.* (2004) also reported that coppicing occurs before the onset of the rains when there is sufficient moisture to enable recovery from cutting. Species such as *Combretum molle* and *Pterocarpus angolensis* have been reported to re-sprout vigorously after cutting (Luoga *et al*. 2004).

Furthermore, Bond and Midgley (2001) have also noted that savannas are known to experience frequent fires and this is almost a prerequisite for juvenile woody plant survival. Fire has been reported to cause coppicing of woody species by killing the adult trees especially of the *Burkea africana* (Wilson and Witkowski 2003). Species such as *Combretum molle* and *Pterocarpus angolensis* have been reported to re-sprout vigorously after cutting (Luoga *et al.* 2004).

Plants that sprout tend to have fewer seeds with low seed viability rates and smaller seed banks. These seeds also have a poorer survival rate (Bond and Midgley 2001). *Burkea africana* is reported to produce a relatively large number of seeds (Wilson and Witkowski 2003), but most of them are affected by borer beetle. Furthermore, plants that sprout also have slower growth and maturation rates when compared to seed regenerators. Species that have the ability to coppice are said to grow fast following disturbance compared to recovery from seedlings. However, depending on the situation, seedling densities can be higher than the coppice densities (Luoga *et al.* 2004, Ehrensperger *et al.* 2013a).

Nevertheless, studies by Bakhoum *et al.* (2012) found that the vegetative mode of regeneration in view of genetic erosion does not preserve and maintain plant populations. It also does not reproduce enough coppices to guarantee good stands of vegetation when compared to seed regeneration (Wilson and Witkowski 2003, Bakhoum *et al.* 2012). Therefore, natural regeneration by seeds becomes very important and it is discussed in the following sections.

b) Seed regeneration (Sexual regeneration)

Sexual reproduction in (flowering) plants occurs when pollen grain is transferred from the male anther of a flower to the female stigma to produce seeds, which is the offspring that ensures the existence of plants. Natural regeneration by seeds produces individuals that are genetically different from the parent plant. The genetic variability of the offspring enable plants to evolve and survive the prevailing climatic conditions (Mng'omba *et al.* 2007). Therefore the seeds are vital sources of starting materials for breeding and genetic improvement (Mng'omba *et al.* 2007).

Regeneration by seeds depends on the capability of parent trees to produce enough viable seed (Graz 2004). Subsequently, the success of germination and seedling growth depends on environmental factors, for example, weather and site conditions, competition between species and predation (Mng'omba *et al.* 2007), as well as human influences such as habitat destruction which may negatively affect the soil seed bank size and diversity (Finegan and Nasi 2004). The authors proffer that these factors may reduce the contribution of regeneration by seeds to the re-establishment of trees growing to maturity during fallow periods. Woodlands cleared for cultivation or burning were found to rely on soil seed bank for plant regeneration (Ehrensperger *et al.* 2013).

1. Soil seed bank

Soil seed banks are defined as the seeds that can remain dormant for a period of time in the soil until their germination is triggered by an environmental change (Esmailzadeh *et al.* 2011).

The seed composition in the soil is related to seed production, and how long each seed persists in the soil (Cox and Allen 2008, Gioria *et al.* 2012). This means that the soil seed bank represents a partial record of plant communities in response to changing conditions through time (Cox and Allen, 2008). It further represents a form of dispersal in space and time permitting the colonization of new localities (Gioria *et al.* 2012). Many plant communities depend on soil seed banks for population regeneration and recovery. Soil seed banks are therefore a critical aspect of both restoration and conservation, especially in disturbed areas.

The formation of seed banks occurs through overlapping generations of seed from individuals that reproduce periodically (Gioria *et al.* 2012). The seeds survive by going through a dormancy state before they germinate (Mng'omba *et al.* 2007). The duration of seeds to remain in the soil without germinating has led to the recognition of different categories of soil seed banks. Transient seed banks are those species with seeds that remain in the soil for less than a year (Bakker *et al.* 1996). The persistent seed bank consists of those species whose seeds remain in the soil for up to five years (Cox and Allen 2008, Esmailzadeh *et al.* 2011). Moreover, Bakker *et al.* (1996) state that the regeneration of degraded plant communities in the framework of restoration ecology is likely to come from the persistent soil seed bank. Soil seed banks are important as they facilitate the coexistence of potentially competing species and mitigate the effects of inter-and intra-specific competition (Rodrigo *et al.* 2012). As a result, many species are able to live together as they vary in response to the changing environmental conditions and the use of resources (Rodrigo *et al.* 2012). This means that soil seed banks average out the effects of environmental heterogeneity, especially when either reproduction or establishment failed completely (Fenner and Thompson 2005). Seed dormancy and germination are important characteristics of a soil seed bank and this will be discussed in the next paragraph.

2. Seed dormancy and germination of species of the Kavango woodlands

Seed dormancy is defined as an adaptation to respond to unpredictable weather conditions which may not fully support the germination process up to plant establishment (Murdoch and Ellis 2000). The ability for a seed to remain dormant is a way to escape unpredictable environment such as bare grounds and swamps. After treating the dormancy, the most critical stages in the life history of plant populations are seed germination and seedling survival. Germination is defined as the emergence of the embryo from the seed through a variety of anabolic and catalytic activities (Mng'omba *et al.* 2007). Seed germination and seedling establishment are important stages because they determine the composition of the future vegetation in a particular area. Both stages are affected by biotic factors such as temperature, moisture, air, and mineral resources in the soil (Ellis *et al.* 1985). Additionally, biotic factors such as the interval of seed production, seed dispersal, predation, and seed quality also affect seed germination and seedling establishment. The leguminous trees of the woodland savanna produce seeds with hard seed coats, exhibiting physical dormancy for most species (Zida *et al.* 2005).

2.3 Factors that influence natural regeneration of woody plants

It is very important to understand tree recruitment for their distribution in nature, which involves seed dispersal, germination and seedling establishment (Burke 2005). The occurrence of woody plants, specifically trees in woodlands, is determined by climate, soils, fire, elevations, historical and human influence (Graz 2004, Burke 2005, Mendelsohn and Obeid 2005). The influences on the woody plants can be experienced as a single factor or in combination with other factors. These factors also influence the number of individuals to occur and the life form in which it appears in (Mendelsohn and El Obeid 2005). Therefore, the role each factor plays varies from place to place and it is also different depending on the age of the trees. Studies by Wang *et al.* (2012) found that the structure and the functioning of the savanna ecosystem are largely determined by water availability, disturbance (e.g. fire, herbivory) and nutrient availability. Regeneration of Fallow fields in arid and semiarid areas is mostly affected by harsh environmental conditions such as full sunlight, high temperatures, high evaporation rates and the temperature fluctuating regimes (Hooper *et al.* 2005). Barriers to woodland regeneration in Fallow fields often include lack of propagules and the prevailing fire regimes (Hooper *et a*l. 2005). Therefore, the regeneration process is affected by many factors such as the seed sources, the microsites, and the micro-environment. Brien *et al.* (1998) found that plants will regenerate where they can tolerate the climatic conditions, but other factors such as the macro-scale variability in physiography and long-distance dispersal constraints, meso- to micro-scale variability in the soil and micro climates as well as competition have an effect.

Natural regeneration in the dry woodland savanna is defined as the population recruitment arising from seed and seedling establishment or vegetative growth (Kalema 2010a). Natural regeneration depends on the availability of space for seedling germination and subsequently seedling growth (Borghetti and Giannini 2009) as well as biotic factors such as animal browsing and human disturbances, that negatively affect the establishment and early survival of woody seedlings (Kreyling *et al.* 2008). The factors will be discussed in detail in the following paragraphs.

2.3.1 Climatic factors

Studies by Burke (2002) indicated that landforms and the disturbance regimes seem to be the major environmental contributing factors to the occurrence of the vegetation of the Kavango regions. Nevertheless, the climate plays a significant role in defining the distribution of the vegetation (Burke 2002). A combination of broad-scale bioclimatic variables such as rainfall and temperature have shown a good correlation between the distribution ranges and the environmental variables of the key timber species such as *Pterocarpus angolensis, Guibourtia coleosperma, Burkea africana* and *Baikiaea plurijuga* (Burke 2005). Thus Namibian woody plants are largely affected by rainfall, temperature, and frost.

2.3.2 Biological factors affecting seed regeneration

The woodland structures are influenced by seed dispersal agents, seed predators and herbivores through plant recruitment (Finegan and Nasi 2004, Kankam and Oduro 2012). The seed dispersal agents were found to influence the abundance and the diversity of tree species (Finegan and Nasi 2004). Seed dispersal is the movement of seeds away from parent plants usually by animal agents or by wind, water or intrinsic explosive mechanisms (Wang *et al.* 2012). Seed dispersal is an important process which links the end of the reproductive cycle to adult plants with the establishment of their offspring (Wang and Smith 2002). It influences plant processes such as the colonization of new habitats and the maintenance of species diversity. The dispersal process allows seeds to escape competition of parent plants and predation, hence increasing the chance of reproduction if environmental factors are conducive (Wang and Smith 2002).

The physical nature of the seeds plays a big role in seed dispersal as it can influence to what extent the seeds can move away from the parent plant. Some woody species produce seeds that are heavy and mostly need secondary dispersers for movement to other microsites (Wang and Smith 2002). The seeds often experience dispersal limitations because of the lack of vectors to carry the seeds, for instance the *S. rautanenii* is dispersed by elephants (Graz 2002). The seeds tend to drop under the mother trees as dispersers are confined to national parks. Dispersal by livestock can also be limited as the fields lack good stands of grass and shrubs to attract them. Therefore regeneration by some species may be limited on the Fallow fields.

2.3.3 Human influences to natural regeneration of woody plants

Land use conversion affects both the amount and spatial pattern of woodland habitats, which in turn can affect the ecological function and future development of that particular habitat (Odada *et al.* 2009). Increasing the expansion of agricultural practices such as cultivation, livestock rearing as well as the extraction of tradable resources leads to land degradation as experienced in the Woodland Savannah of the Kavango Region (Pröpper *et al.* 2010). Arable agriculture was found to largely contributes to the loss of biodiversity, habitat fragmentation, dislocation of wild fauna (Brown and Mujetenga 2010a, Wala *et al.* 2012) and the loss of usable water resources (Rakstina *et al.* 2004, Benayas *et al.* 2007a). Most people in the woodlands depend on natural resources for their survival. However, the usage of woody resources is often not in harmony with the time needed for such woody plants to recover.

A. The importance of subsistence agriculture for livelihood

Subsistence agriculture is basically when local farmers (rural people) grow their farm produce under rain fed agriculture and rear cattle, goats and chicken for survival (Gröngröft, Luther-Mosebach, Landschreiber, and Eschenbach 2013, Kowalski *et al.* 2013). The Okavango east and west regions are characterised by subsistence farming and the regions contain the highest number of poor people (Namibia Statistic Agency 2011).

Subsistence farming through cultivation is done under rain fed agricultural systems (Pröpper et al. 2010) and the farm produce is sold and used in exchange for other crop species. Previous studies have shown that because yields are normally low, surpluses are rare and the markets are small (Brown and Mujetenga 2010a).

Apart from crop farming. the rural communities of the Kavango regions also heavily depend on the woodlands for the natural resources for food, fire wood, poles for construction and carving (Strohbach and Petersen 2007), as well as grazing for their domestic animals.
The impact of high demand on natural resources for subsistence farming in the woodlands were found to have caused loss of biodiversity (Benayas *et al.* 2007a, Pröpper *et al.* 2010). The loss of biodiversity is expected to continue with population increases which will further lead to more land clearing, especially in the Kavango east region (Pröpper *et al*. 2010). This means that the woodland species composition will continue to be affected by human activities.

B. Human activities that affect the natural regeneration of woody plants

Natural regeneration is important for the ecosystems and the livelihood of the people. Although the woody resources are needed by the communities as a means of survival, the unsustainable harvesting of woody resources has an impact on the species and site class distribution (Graz 2004).

In some cases, disturbances play a pivotal role in maintaining natural communities and species diversity, but it depends on the severity of the disturbances. Research by Fenner and Thompson (2005) found that moderate disturbances promote species diversity as it reduces strong dominant species and as a result also reducing competition. The extreme disturbances were found to reduce the renewal of longer-lived species, which reduces species diversity (Fenner and Thompson 2005). Studies by Mendelsohn and Obeid (2005) recorded overharvesting of *Pterocarpus angolensis* since 1940. Moreover, a recent study by Van Holsbeeck et al. (2016) has revealed that *P. angolensis* needs 95 - 100 years to reach a harvestable size of 45 cm diameter at breast height (DBH). Other tree species such as *Baikiaea plurijuga, Schinziophyton rautanenii, Terminalia sericea, Combretum psidioides,* and *Burkea africana* have been affected by the degree of human disturbances (De Cauwer 2013).

The vegetative regeneration of the woodlands can be recovered from pre-existing seedlings and shoots sprouting from stumps of woody plants (Ehrensperger et al. 2013a). Additionally, woodlands cleared for cultivation is expected to recover from viable soil seed bank of the surrounding vegetation. In the event of disturbances such as land clearing for agriculture, few strips of natural vegetation remain, which are termed remnants for this study. A study by Stelli (2011) found that seed densities were influenced by the availability of trees, seeds and microsite characteristics (seed volume, mass, and the sphericity). However earlier studies Alelign et al. (2007) in Ethiopia found that surrounding vegetation had little influence on seed production. Additionally, the authors found low plant density in many species which led to a reduction in species evenness of the woody plants. Furthermore remnant vegetation were found to be ineffective seed sources because of the scarcity of pollinators to produce fertile seeds (Alelign *et al.* 2007, Eilu and Obua 2007). Similarly, a study by Mengistu *et al.* (2005a) on bare grounds after disturbances, found few species and low seed densities. The difference as indicated by Hooper et al. (2005) could be as result of the distance from the woodland as it may may vary with species dispersal mechanisms and site factors (Hooper *et al.* 2005).

a) Land clearing practices

According to Strohbach (2013), the valley bottom from the Okavango River is extensively (90%) used for arable agriculture. This means more land has been cleared for subsistence crop farming. Land clearing along the Kavango river was first recorded in 1943 (Pröpper *et al.* 2010), but it continued further inland as new routes and boreholes were supplied by the government. Recently the expansion of fields into terrace slopes for subsistent agricultural cultivation has been driven by a shortage of land, rather than the suitability of the area for crop farming (Strohbach 2013a, De Cauwer *et al.* 2016c). Therefore, the valley bottom from the Okavango River comprised few species with little variation as result of high human interference in these areas (Strohbach 2013).

According to Pröpper *et al.* (2010), land clearing in the Kavango regions is carried out during the spring month of September and October by both men and woman. Importantly, valuable trees (*Guibourtia coleosperma, Strychnos cocculoides, Baikiaea* plurijuga, *Burkea africana* and *Pterocarpus angolensis*), used for shade, fruits, and timber were not cleared (Personal observation). The Acacia species were cleared from the agricultural fields because of their thorns which hinder the field preparation process. The cleared material was either used for fire wood, fencing or burnt (Personal observation). Studies by Kowalski *et al.* (2013) found that burning of cleared material was done from October to November and the ashes were used to enhance soil fertility.

b) Land preparation

During the first rains, farmers plough their fields using traditional hoe-based cultivation or ox-drawn ploughs as well as mould board ploughs on tractors to prepare soils for planting (Kowalski *et al.* 2013). Weeding as part of land preparation is normally carried out before the planting season and again after seedling establishment. During weeding, the herbaceous and grass plants are completely removed (uprooted) and burnt (Theilade *et al.* 2001, Kowalski *et al.* 2013). The removal of vegetation in general is to avoid competition with crop species versus all other wild species (tree/shrub, bushes, herbaceous and grass species).

Modern ploughing (Mouldboard ploughs) using tractors can provide advantages when compared to the traditional ploughing as it is fast and can cover a large area per day. According to Hibsher *et al.* (2013) cultivation effects the regeneration by seeds by altering the vertical distribution of seeds in the soil as well as those with unassisted dispersal mechanisms. Modern ploughs were found to disfavours rhizomatous species as it uproots below-ground vegetative components. The continued cultivation and weeding leads to loss of soil productivity and deteriorates soil water conditions (Integrated Environmental Consultants Namibia 2011; Ministry of Environment and Tourism 2013). Therefore, continued cultivation reduces and eliminates woody regrowth, unless the agricultural fields are fallowed.

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c) Fallowing of agricultural fields

Studies by Pröpper *et al.* (2010) found that people in the Kavango west and east regions practice permanent cultivation on plots but expand the edges for more land. Some subsistence farmers were found to own 2 or more fields on one or more flood plains (Brown and Mujetenga 2010b) which can be worked on depending on the availability of rain and the manpower. This means that some fields are left to fallow. In Namibia, fallowing is abandoning the field by ceasing cultivation on the field and resting it for a while. Studies by Kowalski *et al.* (2013) have shown that the fields in the Kavango are cultivated with irregular short term fallowing ranging between 1 to 2 years. A resent study by Kasinda (2016) found that fallow periods in the Mashare area range from 1 year to 25 years. Studies by Kowalski *et al.* (2013) also revealed that farmers fallow their fields as the primary fertility management measure. Other reasons communicated showed that fields are fallowed in the event rains were received late or when the fields performed poorly during the previous years. Fields are also fallowed in the absence of animal draught power which is important in the cultivation of the fields (Kowalski *et al.* 2013). Therefore the farmer's age, accessibility to the fields, late rains and the characteristics of field were found to have influence the decision to fallow the fields (Kowero *et al.* 2003, Rakstina *et al.* 2004, Benayas *et al.* 2007a).

2.4 Plant succession

The study of plant succession is important to the understanding of the functioning and dynamics of system production of trees and bushes in woodlands (Bakhoum *et al.* 2012). Therefore, the regeneration of woody plants on previously cultivated fields depends on the presence of early succession species that are able to colonize an area quickly (Cramer *et al.* 2008, De Cauwer 2014).
The organisation of plant individuals that form a strand of plant associations is defined as vegetation structure which normally includes species, tree size and sex (Graz 2004). Plant forms are also regarded useful for vegetation structures as it provides information on the regenerating vegetation as well as those that have survived to that growth stage (Kabajani 2016a). This study considered vegetation structure as the number of woody species and their growth forms (seedlings, coppices, shrubs and trees as well as seeds) recorded from the aboveground vegetation and the soil seed bank. Trees are defined as plants with a single stem and shrubs are defined as plants that are multi-stemmed (Strohbach and Strohbach 2004). Coppices are suckers from roots or shoots growing out of stumps that have been cut or parts removed and seedlings are free standing of the newly emerged plants (Rawat *et al.* 2014).

Some studies have used Size Class Distribution (SCD) of trees and shrubs as an indicator of vegetation change (Lykke 1998, Kabajani 2016a). Studies by Lykke (1998) indicated that a vegetation structure with a flat SCD indicates a lack of regeneration and a declining population. The author also indicated that a flat SCD may mean that there is a rapid growth in small size classes and a high survival rates. According to various authors, vegetation structure that shows an inverse J- shape distribution indicates that there is a sustainable regeneration taking place (Christensen 1977, Vetaas 2000). This means that there are more individuals recorded for the small size classes (juvenile woody plants) than in the larger classes. Studies by Iipinge (2016) found a typical inverse J-shape curve when they studied the Aloe population at the National Botanical Garden and the Aloe trial.

According to Benayas *et al.* (2007), when agricultural land is abandoned it provides open spaces under secondary succession which are colonized by pioneer vegetation. The authors further indicated that when large agricultural areas are abandoned at the same time, it leads to vegetation homogeneity and a reduction in landscape heterogeneity. A secondary forest is defined as that formed as a consequence of the human impact on forest lands especially when cleared for agricultural purposes and then left to fallow for 1 year to 23 years (Brown and Lugo 1990). Studies by Finegan and Nasi (2004) found that Fallow fields were characterised by re-sprouting and the secondary forest deriving from it. Finegan and Nasi (2004) found that during the early stages of fallowing, plant succession is characterised by high species diversity which is gradually lost under progressive years. This study observed early successional species such as *Dichapetalum cymosum, Senna occidentalis, Sesamum spp., Pechuel-loeschea leubnittziae, Tribulus terrestris, Acrotome inflata* and *Datura inoxia*. The longer fallow periods were found to be beneficial to crop farmers as more yields were harvested (Finegan and Nasi 2004). Studies by Mendelsohn and Obeid (2005b) in the Kavango woodlands found species of the secondary vegetation such as the *Terminalia sericea* to grow near the river but it also grows anywhere. Studies by De Cauwer (2013) found that *Combretum psidioides* tree communities were located near homesteads and boreholes, indicating their preference to disturbed soils. The climax vegetation such as the *Pterocarpus angolensis* and *Burkea africana* were found to be located far from human influences, next to the non-perennial riverbeds (Strohbach and Petersen 2007).

Lemenih and Teketay (2006) studies found that regeneration of woody plants on farmer's fields can be a challenge, because the isolated trees found may produce infertile seeds. The isolated trees were found to be aging and they are often monoecious and the distance between the isolated trees may acts as a barrier to the fertilization process (Lemenih and Teketay 2006). In addition, the inter-specific interactions with surrounding vegetation, environmental modification, seedling bank, availability of resources and dispersal limitation determines the vegetation recovery on the Fallow fields (Cramer *et al.* 2008, Tambara *et al.* 2012). Furthermore, studies by Lemenih and Teketay (2006) found low rates (5.7%) in seed viability after seven years of cultivation indicating that cultivation may hinder the plant succession process.

2.5 Management interventions

The Namibian National Development Plan 4 focuses on agriculture as a priority area for growth and as a means to increase household food security (Office of the President 2011). It is important to strike a balance between population and resource use, in order to maintain the biological diversity we depend on. At least the Ministry of Agriculture, Water and Forestry has developed various policies that strive for the sustainable use of resources in the agricultural fields such as the Green Scheme Policy of 2008, National Rangeland Management Policy and the Namibia National Strategic Action Plan (NNSAP) on Plant Genetic Resource for Food and Agriculture of 2015.

The NNSAP specifically advocates for smart agricultural methods now that we are affected by climate change. Conservation agriculture as one of the climate smart efforts has been introduced to help farmers increase their food production without further expansion of fields. Conservation farming has been tested in the Caprivi region where farmers have increased their yields from 800 tons to 1500 tons per ha in one season (Brown and Mujetenga 2010). The method involves minimum tillage through digging small holes in the ground at set intervals (Brown and Mujetenga 2010). The minimum tillage methods using rippers have been suggested (Ministry of Environment and Tourism 2013). The ripper method improves percolation, food development, and crop yield. The ripper creates depressions which can be used year after year, as such it allows the adjacent soils to remain undisturbed, and subsequently the weeds on the sides become mulch and ground cover (Brown and Mujetenga 2010). This method encourages the growth of woody species because of minimum disturbances to the fields in general. Namibia is expected to experience an increasing water deficit; as such farmers need to adopt water saving technologies and crop improvement, and the choice of crops is imperative (Ministry of Environment and Tourism 2013).

Grazing management such as matching carrying capacity of fields to the number of livestock can be exercised in order to reduce the pressure on the regeneration of woody species from uncontrolled grazing.

Other management interventions include the introduction of management plans and appropriate technologies to regulate the harvesting of woody species by community members (Neelo *et al.* 2013). This promotes the desirable regeneration of woody species with appropriate and sustainable utilization. A selection of Fallow fields for long term studies on vegetation recovery can be done in partnership with farmers.

Importantly, people need to be made aware of the status of the population structure, regeneration, and the perpetuation of woody species in those areas in order to promote responsible management and the utilization and conservation of the species (Neelo *et al.* 2013).

Agroforestry is one of the conservation agriculture methods used to encourage farmers to integrate important trees that aid in achieving good production. The reintroduction of tree species that are important to the people of the Kavango regions can be planted and managed by the communities themselves, assisted by interested researchers from various institutions. Tree integration with crop farming improves soil fertility through organic matter inputs (phosphorus, exchangeable bases). The trees improve the microclimate weakening radiation, air temperature, wind speed and evaporation into the air (Bakhoum *et al.* 2012). Species such as *Faidherbia albida* are good species that can be used for soil fertility. Other tree species are used as fodder for browsing by animals. Therefore, agroforestry increases productivity and product diversification. Efforts through agroforestry can also be used deliberately to plant woody plants that are important for soil fertility, shade, and the production of poles and fodder to enhance the livelihood of the communities (SPGRC 2014).

3. MATERIAL AND METHODS

3.1 Description of the study area

3.1.1 Location

The study was conducted on Fallow fields and remnant forest vegetation in the Mashare constituency, 40km east of Rundu town in the Kavango east region (see Figure 3). The term "remnant" in this study refers to a strip of land in the neighbourhood of agricultural fields that has not been ploughed before and contains more forest vegetation when compared to the cultivated fields. Moreover, FallowFallow fields are fields previously used for subsistence crop cultivation and are temporarily abandoned.

The Mashare constituency consists of seven villages (Figure 4) and the study was carried out in six of them: Tjeye, Mashare, Katondo, Muroro, Mupapama and Mausivi (Kowalski *et al.* 2013). The Mashare constituency is characterized by its position next to the meandering Okavango River, which has resulted in floodplains which are beneficial to the farmers in terms of crop farming. The Okavango River also cuts through the Kalahari dune area.

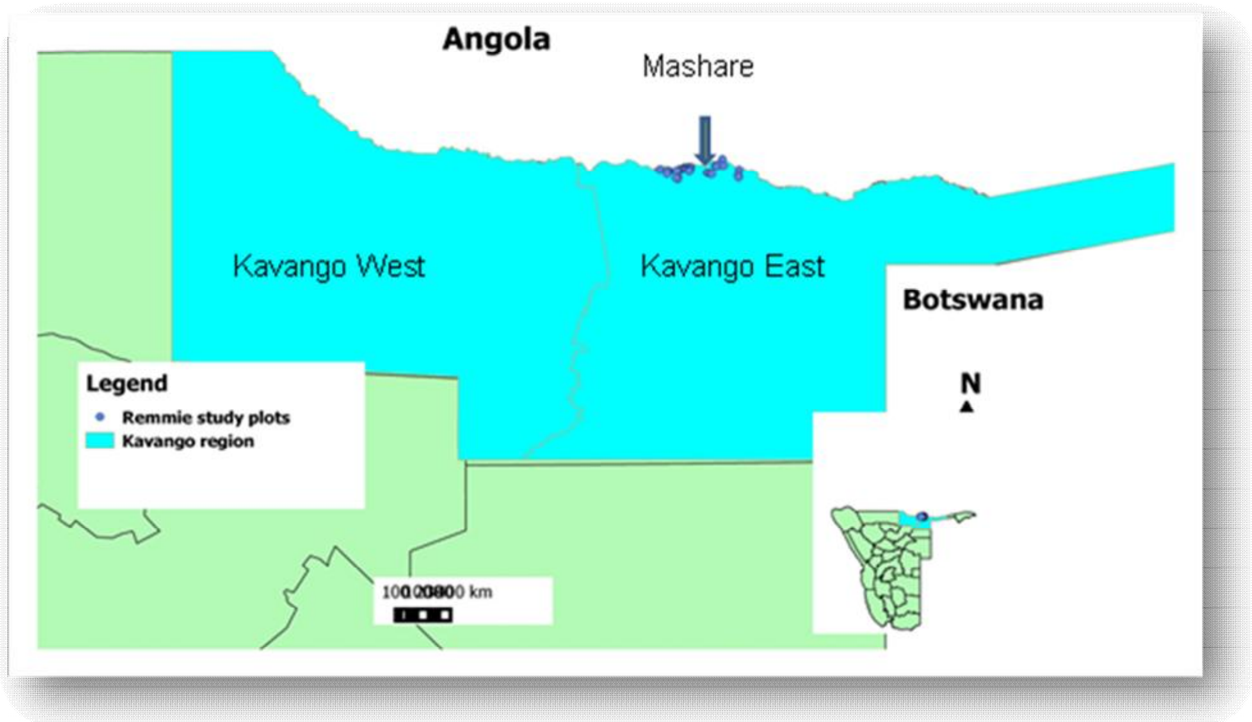

Figure 3: The Kavango West and East regions of north-eastern Namibia. The study was conducted in Mashare constituency in the Kavango east region. The dots indicate the study plots.

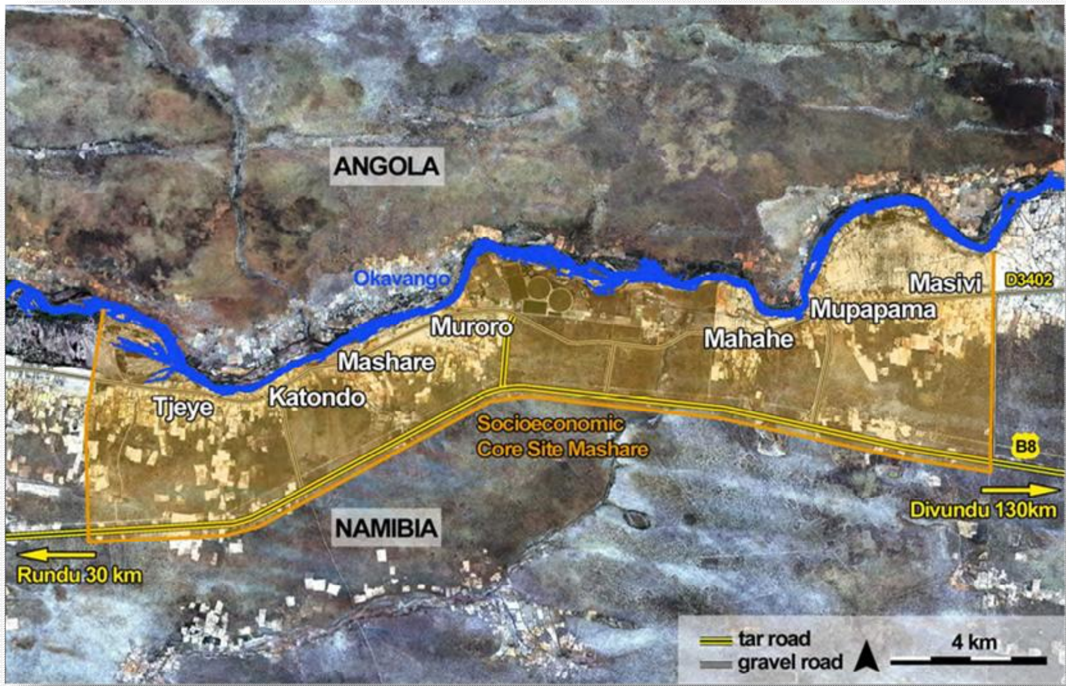

Figure 4: The light orange marked area shows the borders of Mashare constituency in Kavango east with the seven villages starting with Tjeye and ending with Mausivi (Kowalski *et al*. 2013). The Blue line indicates the Okavango River.

3.1.2 Geology, soils and vegetation

The Mashare area is 1090m above sea level. The geology of the Mashare area is characterized by leistocene Kalahari sands and Holocene river sediments (Gröngröft *et al.* 2013, Revermann and Finckh 2013). Topographically, three major landscapes are recognized, namely: recent flood plains which cover about 15% of the study area, old flood plains and the Kalahari dune area which covers 15% and 80% respectively (Gröngröft, *et al.* 2013).

In general, the lithology of Mashare is made up of unconsolidated sands and loams (Gröngröft *et al.* 2013), though soils also differ with topography. The old flood plains are made up of soils that have lost their fluvial deposits, mainly of rubic arenosols and Petriluvic Calcisols origin. The recent flood plains are characterized by deposits of fresh sediments which mostly consist of clay fluvisols and arsenic gleisol soils while the Kalahari dune area is dominated by arenosols (Gröngröft *et al*. 2013)

Similarly, the vegetation also varies across the different topographical units. Plant species mostly occurring on the flood plains include *Acacia erioloba*, *Combretum imberbe, Acacia nigrescens, Peltophorum africanum* and *Dichrostachys cinerea*. Furthermore, the Kalahari dune area is dominated by *Pterocarpus angolensis, Burkea africana, Schinziophyton rautanenii, Baikiaea plurijuga, Guibourtia coleosperma* and *Ochna pulchra* (De Cauwer 2013a).

3.1.3 Climate and weather

The rainfall data of Mashare, as indicated by the Southern African Science Service Centre for Climate Change and Adaptive Land Management" (SASSCAL) have indicated that rainfall has been sporadic for the past years. On average, 47.4 mm were received in 2012, followed by 216.3 mm in 2013 and 621.8 mm in 2014 (Figure 5) (SASSCAL WeatherNet 2017). The highest temperatures of 27 ^{o}C were recorded in October and the lowest temperature of 17 ^{o}C was recorded in July 2014 (Figure 5).

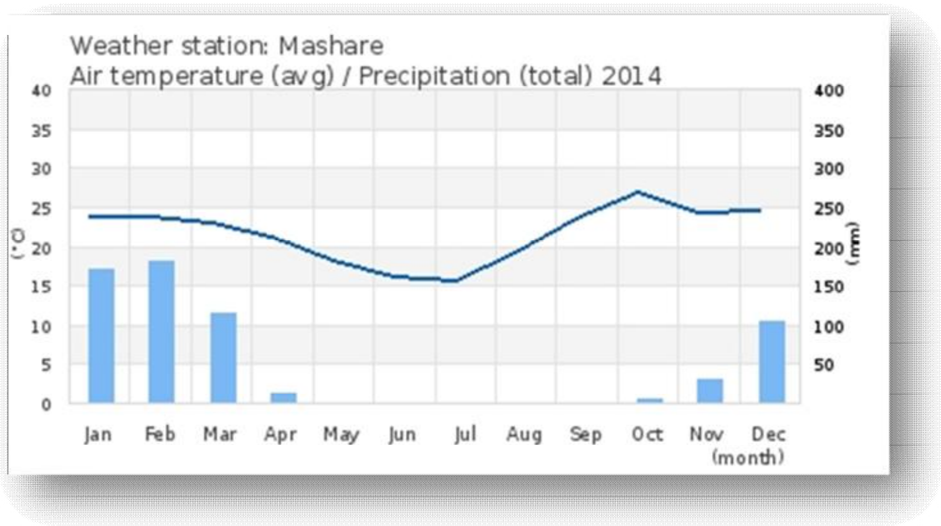

Figure 5: Rainfall and air temperature recorded in 2014 for the Mashare area (SASSCAL WeatherNet 2017).

3.1.4 People, land cover and land use

The population of Kavango East and Kavango West regions of Namibia has increased by about 10% between 2001 and 2011, from 202 694 in 2001 to 223 352 inhabitants (Namibia Statistic Agency 2011). Since rural people in these regions mostly rely on subsistence farming for their livelihood (Namibia Statistic Agency 2011), the population rise has resulted in increased land clearing for crop farming. Although 70% of the population of these two regions has been living along the river (Brown and Mujetenga 2010), settlements have expanded further inland into the dune areas. According to Mendelsohn (2009), land clearing for subsistence agriculture has increased by more than 260% from 26,140 ha to 94,550 ha between 1943 and 1996. In the meantime, the government of Namibia has also improved the services further inland by providing services such as new boreholes and new roads (Ministry of Agriculture 2011). Additionally, wealthier farmers with large cattle herds have also established new cattle posts further inland, which have later become small villages (Mendelsohn 2009).

In the Mashare area, there are about 518 households and a population of more than 3 216 individuals (Kowalski *et al*. 2013). The authors also added that 95% of the people use fire wood as the prime energy source. Additionally, about thirty-four percent (34%) of people in this area have no formal education and only 13% completed secondary schooling (Pröpper *et al.* 2015). The major crop species planted in this area include *Pennisetum glaucum*, *Zea mays*, and *Sorghum bicolor* as well as *Hibiscus sabdariffa* (Pröpper *et al.* 2010). Farmers also practice mixed cropping where major crops are planted together with secondary crops such as legumes and pumpkins (Kowalski *et al*. 2013).

Livestock farming, predominantly cattle production is a key component of the subsistence livelihoods. Some 150 000 cattle and 65 000 goats have been documented for the Kavango East and Kavango West regions (Brown and Mujetenga 2010). The rural people depend on livestock for ploughing, as a source of meat, milk and other products.

3.2 Data ccollection

The study targeted selected FallowFallow fields and remnant forest vegetation in the Mashare area (Table 1).

Table 1: The villages and the number of fields sampled from

Village	Number of fields
Gove	2
Katondo	6
Mashare	9
Mausivi	4
Mupapama	8
Murororo	5
Shighuru	7
Tyeye	5

3.2.1 Field positioning

Crop fields in the Mashare constituency range in size from 3-5 hectares. Owners who have more than one field do not cultivate them at the same time; it is therefore easy to differentiate between fallow fields and active fields (Figure 6). The study focused on only one hectare of the farmers' fields as has been done in previous studies (Esmailzadeh *et al.* 2011, Neelo *et al.* 2013b). A hectare was regarded as the sizeable area suitable for the purpose of this study. The sites chosen indicated no signs of active cultivation.

Figure 6: Differences between active and fallow fields (picture taken from Google Earth, March 2014).

This study applied a similar experimental design as given by Esmailzadeh *et al*. (2011), with a few modifications. In this design, one (1) hectare areas were selected in each field, in which quadrats and circles (Figure 7) were demarcated for the measurements of specific target variables. Within these one hectare areas, five quadrats each measuring 2m x 2m were outlined (Figure 7), in which soil seed bank data were collected. Additionally, these quadrats were overlapped with circles measuring 5.6m radius (fixed radial distances) for aboveground vegetation data sampling. Although Esmailzadeh *et al*. (2011) used four quadrats on their one hectare fields, this study outlined five quadrats per hectare. The same procedure was followed to survey the remnant sites, though only two quadrats and two circles could be sampled, mainly because most remnants encountered in this study were merely a narrow strip of natural vegetation surrounding the fields.

In total, forty six (46) fallow fields and thirteen (13) remnants were sampled, totalling 256 quadrats and 256 circles.

At each surveyed site, counts of aboveground woody vegetation and counts of seeds collected from the soil seed bank were determined for each species encountered. Specifically, species composition, richness, and abundance of each woody plant species represented were determined. The exact location was determined and recorded using a geographic positioning system (GPS) for all the sites that were surveyed. Other attribute data such as social information (village and farmers names), types of ploughing implements (hoes, oxen and mouldboard ploughs) and environmental variables (duration of fallow, age of fields, month of collection, altitude) were also collected at each site. Additional environmental variables such as distance from the river and top soil data (sand, pH, organic carbon, cation-exchange, base saturation) were extracted from the Harmonized World Soil Database.

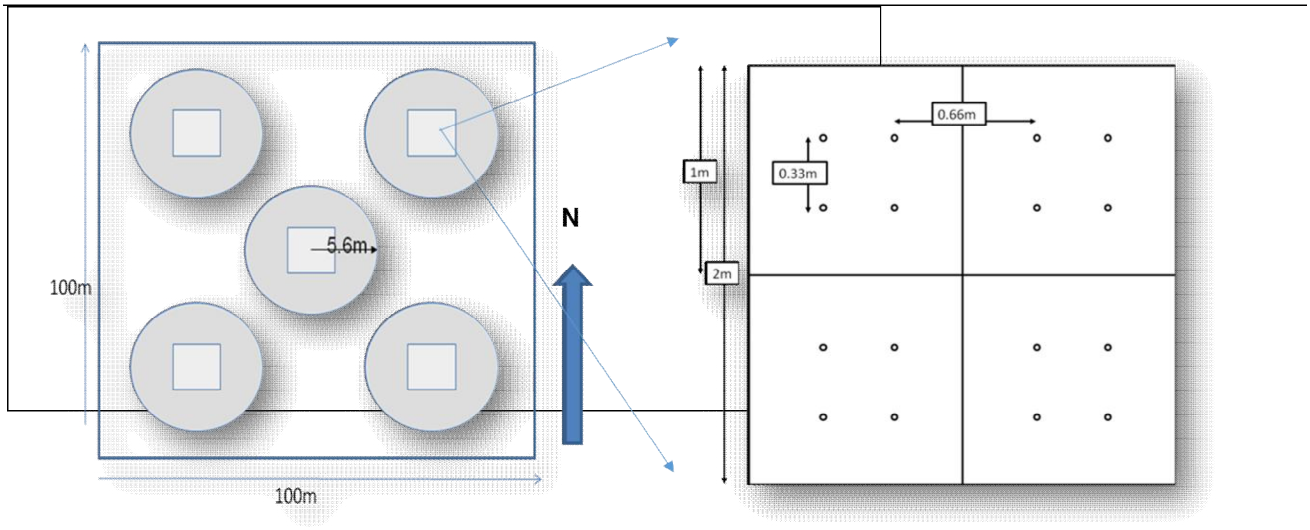

Figure 7: Distribution of $4m^2$ quadrats in the 1 ha fields used for collecting soil seed bank data and 5.6m circles used for collecting data of aboveground vegetation on the fallow fields. The magnified quadrats show the layout of sub-quadrats with the position of the soil cores used for soil seed bank data collections. The remnants were also surveyed using the same quadrats and circles. The Figure is not to scale.

3.2.2 Soil seed bank sampling

Sampling of the soil seed bank was conducted in the $4m^2$ quadrats at each site. The quadrats were further subdivided into four $1m^2$ sub-quadrats. In each $1m^2$, four soil samples were collected for soil seed bank sampling, using 12cm deep aluminium and steel tins measuring a diameter of 10.5cm (Figure 8 and 9) (Stein *et al.* 2008). In this procedure, the entire open tin is manually pressed into the soil in order to collect the soil sample as a 'core'. Each $4m^2$ quadrat thus yielded 16 soil samples, amounting to 18400 soil samples from 230 quadrats in the fallow fields and 416 soil samples from the 26 quadrats surveyed in the remnants. The reason for subdividing larger quadrats is to consider the spatial variability of the soils (Olano *et al.* 2002, Mengistu *et al.* 2005, Dreber and Esler 2011).

Figure 8: Layout of sub-quadrats showing the position of where the soil cores (colourful markings) were taken. These cores were used for collecting soil seed bank data. Picture with two assistants at Tyeye village.

The collection of intact soil cores was challenging at sites with loose and dry sandy soils. At these sites, the soil seed bank sampling method was altered slightly and samples were collected by merely scooping the top soil up with a small garden trowel. The soil sample included the litter layer or the top soil layer that often contains seeds (Esmailzadeh *et al*. 2011). Sites located in depressions presented different challenges such as the manual pressing of the tins into the soil to obtain the sought 12cm depth soil core which proved to be difficult. At these sites, a small garden trowel was used to dig and collect a soil sample to the depth of 12cm. The total weight of each soil sample was ±500g.

The seeds and fruits of woody plants present in each soil sample were separated through sieving (Figure 9). This was done in the field to avoid the transportation of heavy bags of soil to Windhoek which is over 700km away from the study site. The recommended sieve size for the soil seed bank sampling of woody plant species is 1mm to 2mm sieves (Mengistu *et al.* 2005b, Dreber and Esler 2011) and these were used in this study. Sieving was done by placing the 2mm sieve on top of the 1mm sieve. Seeds and fruits present were identified to species level, counted and recorded on a datasheet. Thereafter, the seeds were stored in a paper bag which was assigned a unique reference number, reflecting the respective sub-quadrat. The seeds were then transported to the National Botanical Research Institute (NBRI), where they were stored in the cold room at 15 ^{0}C. At the NBRI, the seeds and fruits were cleaned before further tests and processing were carried out.

A seed guide as shown in Appendix D was developed to assist in seed identification as the appearance of the seeds can be different when recovered from soils, especially if they have been buried for some time. The seeds were split into two simple age categories: old and new.

Figure 9: The tools used to collect soil seed bank data: 500g peach tin, a garden trowel, measuring tape and the yellow marker. The 2mm and 1mm sieves (placed on top of each with 1mm at the bottom) were used to recover the seeds from the sand.

3.2.3 Aboveground vegetation sampling

Sampling of the aboveground vegetation in this study was carried out within the 5.6m radius circles positioned over the quadrats (Graz 2014), as in Figure 7. The total area per circle is 98.52m^2 which is approximately 100m^2. Within each circle, all woody species present were listed, and their individuals were counted and recorded according to their growth form (tree, shrub, coppice and seedling) (Esmailzadeh, *et al.* 2011, Neelo *et al.* 2013b). For this study, trees are defined as plants with a single stem with a minimum height of 5 meters, and shrubs are defined as plants that are multi-stemmed with a height from 1 meter up to 5 meters (Strohbach and Strohbach 2004). Coppices are defined as suckers from roots or shoots growing out of stumps that have been cut or parts removed and a seedling is defined as a free standing young plant (Strohbach and Strohbach 2004). In addition, mature woody plant species (trees and shrubs), found immediately next to the defined circles under study were recorded per species, and tallied as well.

For plant species that could not be identified in the field, voucher specimens were collected for identification at the National Herbarium of Namibia (WIND).

3.3 Viability testing

The viability of a seed refers to its ability to germinate and it is often represented by the number of seeds which are alive and can develop successfully into mature plants, given the appropriate conditions (Sawma and Mohler 2002). Seed viability is important to determine the likelihood of woody plants to germinate on the fallow fields. In this study, seeds were tested for viability using the Tetrazolium Chloride Test (TZ test). The TZ test is based on the absorption of Tetrazolium chloride in living plant tissues. Red staining is an indication of living cells, while dead or non-viable seeds remain unstained (Muhammad and Khalil 2013). Therefore, seeds showing active respiration turn red and they are considered "viable". The intensity of the stain indicates the strength of respiratory activity in the seeds. The darker stained seeds indicate that they are strongly viable while a light pink colour indicates a seed with reduced viability (Ellis *et al.* 1985, AOSA 2012). Tetrazolium Chloride (Figure 10) is a 1% solution of 2, 3, 5-Triphenyl Tetrazolium Chloride. It is prepared by using 1g Tetrazolium salt to 100 ml distilled or tap water with a recommendation of the pH of the solution to be around 7.0 for good staining to show (Ellis *et al.* 1985, AOSA 2012, Muhammad and Khalil 2013).

To perform the TZ test, seeds are first imbibed or soaked in distilled water for 24 hours. Imbibition is very important as it softens the seed tissues of the seeds prior to cutting and it activates the enzyme system. It also assists the seed to take up the TZ for staining (Ellis *et*

al. 1985, ISTA 2006, Muhammad and Khalil 2013). After 24 hours of soaking, the seeds were placed on a petri dish and cut longitudinally in the middle, aiming to slice the embryo in half, using a blade. A TZ test was then carried out on these pre-conditioned half seeds. The halved seeds were placed in a colourless solution of Triphenyltetrazolium chloride and immediately put in a dark incubator at a temperature of 30º C for 2 hours to allow staining (Muhammad and Khalil 2013). The viability assessment was performed under stereoscopic magnifying glasses (10X) to identify viable and non-viable embryos (Clemente *et al.* 2012).
The seeds were then classified according to the staining pattern of the embryo and the intensity of the colorations. The categories at which stained seeds were compared are: 1) totally stained 2) partially stained and 3) unstained (Matthews and Powell 2006). During data analysis, totally stained and partially stained seeds were combined into one category of stained seeds (indicating viability) for comparison to the unstained group. Results were expressed as the percentage seeds containing living tissue.

Figure 10: The tetrazolium chloride powder used for staining the bisected seeds recovered from soil seed banks from study fields at Mashare constituency

3.4 Data analysis

This study used various statistical analysis packages to explore the data for suitable statistical tests, namely:- Statistical Package for the Social Sciences (SPSS) version 23, the Multi-Variate Statistical Package (MVSP) version 3.22, PC-Ord version 6 and R Project for Statistical Computing, version 3.22.

The Shapiro-Wilk Normality Test in SPSS was used to test the species diversity data for normality. The data was not normally distributed hence a non-parametric test, the Mann-Whitney U test was used to compare significant differences in species diversity of woody plants, at alpha 0.05 between fallow fields and remnant forest vegetation. The Nonlinear Mixed-Effect Model (NLME) was used to test for significance effect on the duration of fallowing to species diversity of the aboveground woody vegetation and the soil seed bank. Similarly, the NLME was also used to test the effect of duration of fallow on seed density of the seeds that were collected from the soil seed bank.

3.4.1 Species Diversity

Species richness was determined by counting the number of different species in all sampling units i.e. quadrats and circles. All counts per species and per field for the aboveground vegetation and the soil seed bank were summarised using PivotTables in Excel. The data matrix was then used to determine species diversity (Appendix A) using the Shannon-Wiener Diversity Index (H) using the formula $H' = -pi \, \Sigma \ln pi$. Where pi is the proportion of individuals found in species i. For a well-sampled community, the proportion as pi = ni/N, where ni is the number of individuals in species i and N is the total number of individuals in the community. The p_is is expected to be between zero and one, the natural log makes all of the terms of the summation negative, hence the inverse of the sum is taken (Magurran 2004).

A Nonlinear Mixed-Effect Model (NLME) was used to test for significance in species diversity of woody plants of the above ground vegetation and the soil seed bank based on the duration the fields were fallowed. It should be noted that for data analysis, only 33 fields were used for the aboveground vegetation species diversity in fallow fields. Similarly only 23 fields were used for the soils seed bank data to analyse the diversity within fallow fields based on duration of fallowing as well as the density of seeds within the fallow fields. The numbers of fields used for analysis varies, because not all fields had a score for the variables in question. Therefore, these data require the use of a nonlinear function that contains a statistical treatment that will include both fixed (treatment) and random (experimental unit) effects (Peek *et al.* 2002). The NLME test was regarded suitable test because the nature of the data is nonlinear, complex and consists of repeated measurements recorded from the same experimental unit. Mixed effect models are built to deal with messy data and allows all data to be used regardless of sample sizes, structured data, and many covariates to fit (Peek *et al.* 2002). The random (experimental unit) effects are the categorical grouping factors being controlled.

The following formula was used to derive the statistics from the NLME on species diversity of woody plants within the fallow fields and it is presented as follows:
NLME: (lme (H~ Duration, random = ~1 | Pair, data = MSc.data)). Where H = Shannon-Wiener species diversity index, Duration = fallow duration categories (1-2 years, 3-4 years and 5 >/= above years), which is the fixed effect, Random = ~1 | Pair equals random effect which is the location of each pair indicated by 1, 2, 3.
The same formula was used to analyse the woody plants species diversity of the soil seed bank.

The NLME statistical analysis was also used to derive test statistics on the effect of duration on the woody plant seed density using the following formula:
NLME: (lme (Density~ Duration, random = ~1 | Pair, data = MSc.data)). Where Density = Seed density per m^2, Duration = fallow duration categories (1-2 years, 3-4 years and 5 >/= above years), which is the fixed effect, Random = ~1 | Pair equals random effect which is the location of each pair indicated by 1, 2, 3.

A Mann-Whitney U Test was used to test for significant differences in species diversity aboveground vegetation between the 46 fallow fields and the 13 remnants. Similarly the effect of ploughing methods on species diversity, were computed using a Mann-Whitney U Test and only 30 fallow fields had a score on the type of ploughing methods. During analysis, the oxen, hoe, oxen / hoe ploughing methods were all converted into one category for comparison with the mouldboard on tractors ploughing method. A Mann-Whitney U Test was also used to test for significant difference in species diversity of the soil seed bank between 23 fallow fields and the 6 remnants as seeds were only recovered from those fields. The Mann-Whitney test is a non-parametric test that compares medians of two unmatched samples. It stipulates that two independent groups are homogeneous and they have the same distribution. Furthermore, the Mann Whitney U test is suitable for counts or diversity indexes (Nachar 2008).

3.4.2 Species composition, aboveground vegetation structure and classification

This study determined structure based on growth forms of woody plants through counts of individuals per growth form (seedling, shrub, trees and coppices) and by identification of species as they were encountered.

A. Species composition in the study area

The Jaccard's similarity index (S_{ij}) was calculated to compare the similarity in species composition, between fallow fields and remnant forest vegetation. Jaccard's index is commonly used for binary data that aims at determining the relationship between species and areas (Real and Vargas 1996).

The S_{ij} index is given by the following formula:

$S_{ij} = A / (A+B+C)$

Where, A: Number of species shared by both fields (fallow and remnants)

B: Number of species unique to fallow fields

C: Number of species unique to remnants (Real and Vargas 1996)

Ij: Similarity between quadrats i and j.

B. Vegetation structure

Vegetation structure is defined as the organisation of individuals that form a stand, vegetation type or plant association (Graz 2004). Although studies by Lykke (1998) have use the Size Class Distribution (SCD) as an indicator of vegetation change, for this study, the primary elements of the structure were limited to the growth forms: seedlings, shrubs, trees, and coppices. Although counts of individuals per growth form were determined for each woody species during data collection, analysis only compared growth forms between Fallow fields and remnant forest vegetation, regardless of species. Accordingly, the proportions of each growth form were computed, expressed as a percentage, and graphed. A Chi-square test of association was used to test for any relationship between vegetation structure and fields' type (fallow fields and remnant forest vegetation).

C. Classification and ordination

Sequential sorting of relevés on the basis of species composition, distribution and abundance allows similar relevés and species to be placed next to each other, thus defining different community types (Chytry *et al.* 2002, Kent and Coker 2003).
This study performed a cluster analysis in PC-Ord, as one of the steps used in vegetation classification (Romesburg 2004).

i. Vegetation classification

The vegetation classification was derived from data matrix containing counts of individual woody plants and the type of species. The data matrix were generated from the raw data using Pivot tables in Microsoft Excel, which was than imported into PC-Ord for further analysis. As an initial data cleaning and preparation process in PC-Ord, rare species and outlier fields were removed from the matrix prior to classification and ordination, reducing the data to 44 fields and 33 species. The modified matrix was then used as the basis for classification and ordination. Additionally, these data were explored for the need to transform. The data of this study showed a high variability between species as indicated by the Coefficient of Variance (CV) columns >100, thus all the species data were log transformed using log(x+1), with base-10.

Classification was based on the Sorensen distance measure and flexible beta linkage of -0.025 option (McCune and Mefford 2011). The option of adding the group variable to the second matrix were also used as well as “write all higher-level groupings”. In order to get clusters that make sense, the test was run using 3, 4, 5 and 6 clusters.

Further analysis on Multi-response Permutation Procedure (MRPP) was performed to establish the differences in species composition between the best groups (De Cauwer, 2014). An MRPP was performed on the different clusters and averages were worked out to find clusters with low test statistics (T), which describes the separation between the groups, and high chance-corrected within group agreement (A) (Aerts *et al.* 2011). The groups are regarded to be more homogenous than expected by chance if 1>A>0 (McCune and Mefford 2011). Following MRPP, an Indicator Species Analysis (ISA) was performed on a different number of clusters to compare the p values and Indicator values under the Monte Carlo test. For this analysis, data from 44 fields and 33 species from both the fallow fields and the remnants were used. The different clusters tested under the ISA, 5 clusters indicated groupings of woody species that made sense as indicated by the low mean p value, high number of indicator species and high mean indicator values.

ii. Non-Metric Multidimensional Scaling (NMS) ordination

This study used the NMS ordination in PC-Ord 6, to investigate indirect gradient influencing species distribution (McCune and Mefford 2011). Ordination results were correlated to environmental data obtained from the Harmonized World Soil Database (HWSD) and other environmental data obtained from the field. The environmental data consisted of the geographical coordinates, distance from the river, altitude, slope, years of fallowing and age of fields since cultivation, and the top soil data (sand, pH, organic carbon, cation-exchange, base saturation). The ISA derived classes were similar to the groupings of the NMS in Ordination. The environmental variables were correlated with scores of ordination axes using a Spearman's rank-order correlation test. The correlation between vegetation and environmental variables is one of the most fundamental questions contributing to the understanding of plant species composition and structure in a particular habitat, landscape and region (Mucina 1997).

3.4.3 Seed viability

The Tetrazolium Chloride Test (TZ test) results on the viability of the seed recovered from the seed soil bank were calculated using viability percentage for each species using the formula:

$$V_{sp} = \frac{nv_{sp}}{N_{sp}} \times 100$$

With V_{sp} the viability percent of species *sp*, nv_{sp} the number of viable seed of species *sp*, and N_{sp} the total number of seed of species *sp* tested (Ellis *et al.* 1985).

4. RESULTS

4.1 Species diversity of the aboveground vegetation

A total of 58 woody species from 20 families were recorded across all abandoned agricultural fields, including the remnants. The Fabaceae family dominated the woody plants recorded, with 44% of the total individuals recorded, followed by the Combretaceae family with 41%.

4.1.1 Effect of duration of fallow on species diversity

A Nonlinear Mixed-Effect Model (NLME) analysis showed that fallow had no effect (p=0.444) on species diversity of the woody plants on the fallow fields (Figure 11).

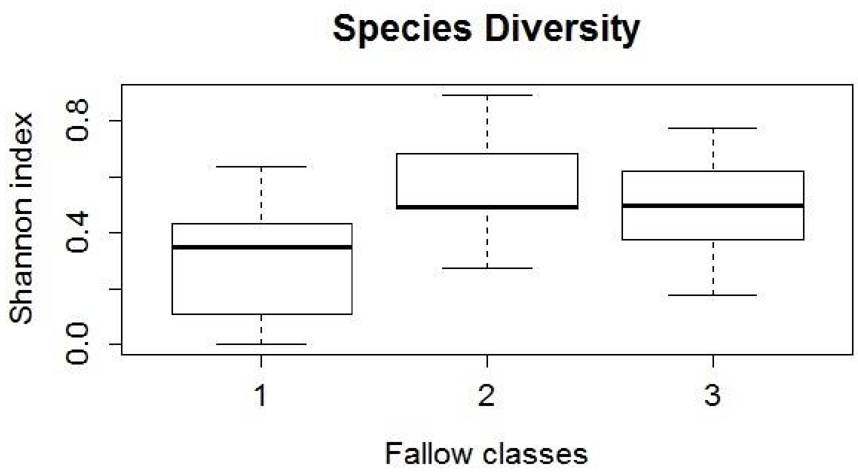

Figure 11: Comparison of species diversity of the aboveground woody plants among the three classes of fallow (1= 1-2 years of fallow (n=15), 2 = 3-4 years of fallow (n=6) and 3 = >/= 5years of fallow (n =12), where n = number of fields.

4.1.2 Effect of ploughing methods on species diversity

Species diversity of woody plants was significantly different (Mann-Whitney test, p=0.037) when different cultivation methods were used (Figure 12).

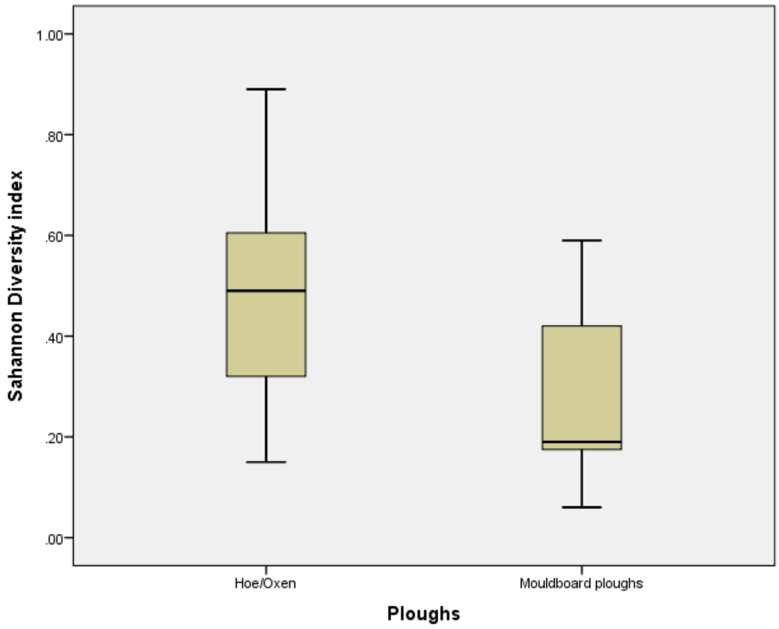

Figure 12: The ploughing methods used in the agricultural fields in relation to woody plant species diversity. Category 1 = fields ploughed with hoes, oxen, oxen/hoes (n=23) and 2 = fields ploughed with mouldboard ploughs on tractors (n=7), where n = number of fields.

4.2 Species diversity between fallow fields and remnant forest vegetation

The Mann-Whitney analysis revealed a significant difference (p=0.001) between the species diversity of the vegetation on the fallow fields and remnant forest vegetation (Figure 13).

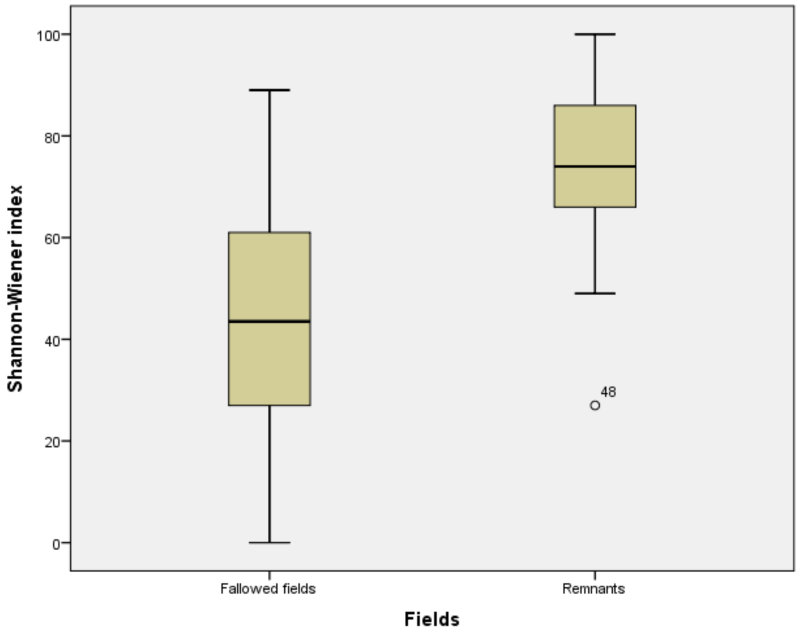

Figure 13: Comparison of species diversity of the aboveground vegetation on fallow fields (n = 46) and Remnant forest vegetation (n = 13), where n = number of fields.

4.3 Soil seed bank

A total of 221 seeds of woody plants were collected from the 59 fields under study including remnants. A total of 19 species from 6 families were recorded from the soil seed bank in both the fallow fields and the remnants. Combretaceae dominated the number of seeds recovered from the soil bank with 45%, followed by Fabaceae at 30%, while the Rhamnaceae family was the least represented with 0.5%.

4.3.1 Species diversity of the soil seed bank

A mixed effect model analysis (NLME) shows that the duration of fallowing had no effect on species diversity of the soil seed bank of woody plants on the fallow fields (p=0.591) (Figure 14).

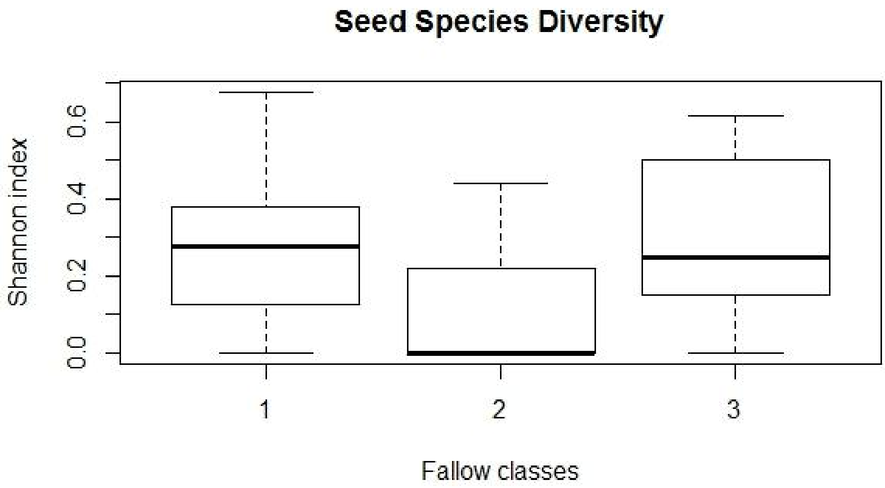

Figure 14: Comparison of species diversity of the soil seed bank woody plants among the three classes of fallow (1= 1-2 years of fallow (n=8), 2 = 3-4 years of fallow (n=4) and 3 = >/= 5years of fallow (n =10), where n = number of fields.

4.3.2 Seed densities among fallow fields (Agricultural fields)

A Nonlinear Mixed-Effect Model (NLME) analysis showed that fallowing had no effect (p=0.565) on seed densities of the woody plants on the fallow fields (Figure 15).

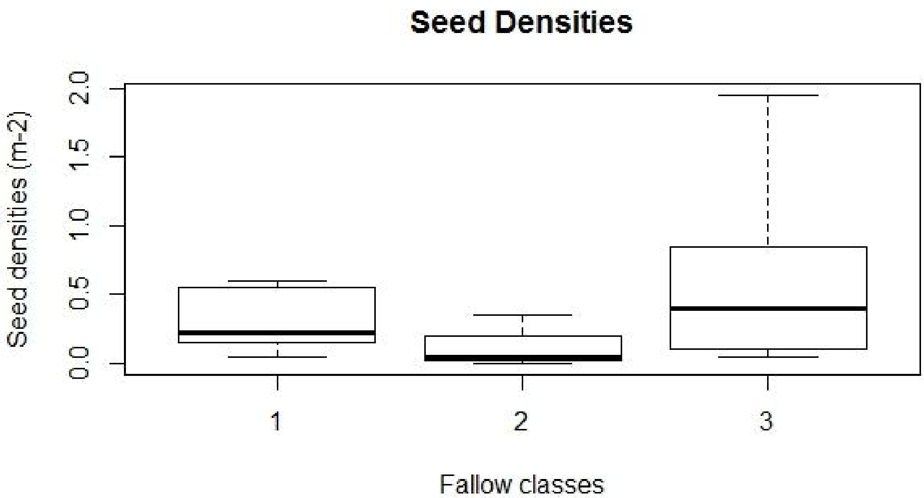

Figure 15: Comparison of seed density of the soil seed bank woody plants among the three classes of fallow (1= 1-2 years of fallow (n=8), 2 = 3-4 years of fallow (n=4) and 3 = >/= 5years of fallow (n =10), where n = number of fields.

4.3.3 Species diversity of soil seed bank compared between fallow fields and remnants

The Mann-Whitney analysis revealed no significant difference (p=0.767) in the species diversity of woody plants represented in the soil seed bank of fallow fields and remnant forest vegetation (Figure 16).

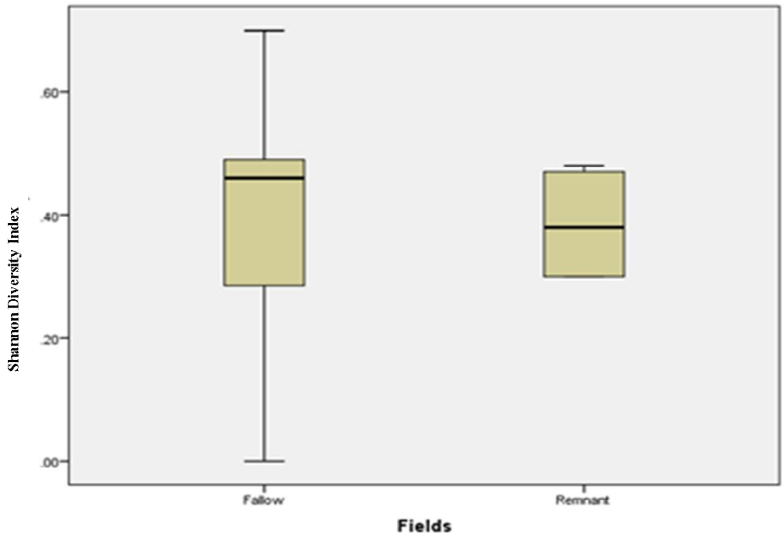

Figure 16: Comparison of species diversity of the soil seed bank woody plants on fallow fields with 14 seeds (n = 23) and Remnant forest vegetation with 11 seeds (n = 6), where n = number of fields.

4.4 Species composition in the study area

A: species composition of the aboveground vegetation

A total of 26 species were common to both the remnants and the fallow fields, while 21 species only occurred on the fallow fields. The remnants only had two species that were not occurring on the fallow fields. Species composition per growth form and type of field is indicated in figure 17. The remnants recorded higher proportions in the seedling category, with *Combretum collinum* and *Bauhinia petersiana* scoring 25% and 26% seedlings respectively. The fallow fields were dominated by *Acacia erioloba* with a proportion of 20% followed by *Combretum collinum* and *Baphia massaiensis* with 10% and 9% respectively. In the coppicing category, *Baikiaea plurijuga and Baphia massaiensis* recorded 20% each for the remnants, while C*ombretum collinum* and *Baphia massaiensis* scored 20% and 22%

respectively in the fallow fields. The shrub category was dominated by *Baphia massaiensis* which recorded 20% in the fallow fields and 17% in the remnants, while *Baikiaea plurijuga* was the leading shrub species, recording proportions of 9% and 10% respectively on fallow and the Remnant forest vegetation.

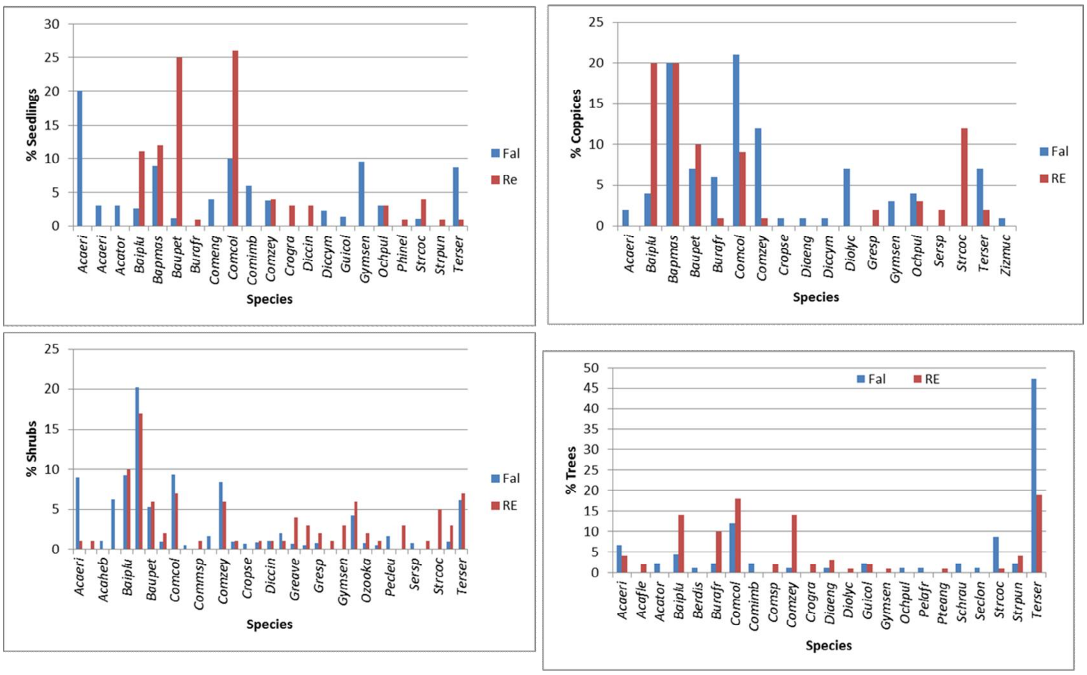

Figure 17: The species (acronyms on page viii to xi) recorded per growth form, with the Y axis representing the percentage of woody plants calculated per fallow fields (AF) or Remnant forest vegetation (RE).

The Jaccard's similarity index revealed 51% similarity in species composition between the fallow fields and remnant. The presence and absence of species as recorded from the fallow fields and remnant forest vegetation are indicated in Appendix B.

B: Species composition of the soil seed bank

The species composition of woody plants from the soil seed bank showed that there were 14 species recorded from the fallow fields compared to 6 species recorded from the remnants (Figure 18). About 6 species were common to both the Remnant forest vegetation and the fallow fields, while 8 species were only recorded from the fallow fields.

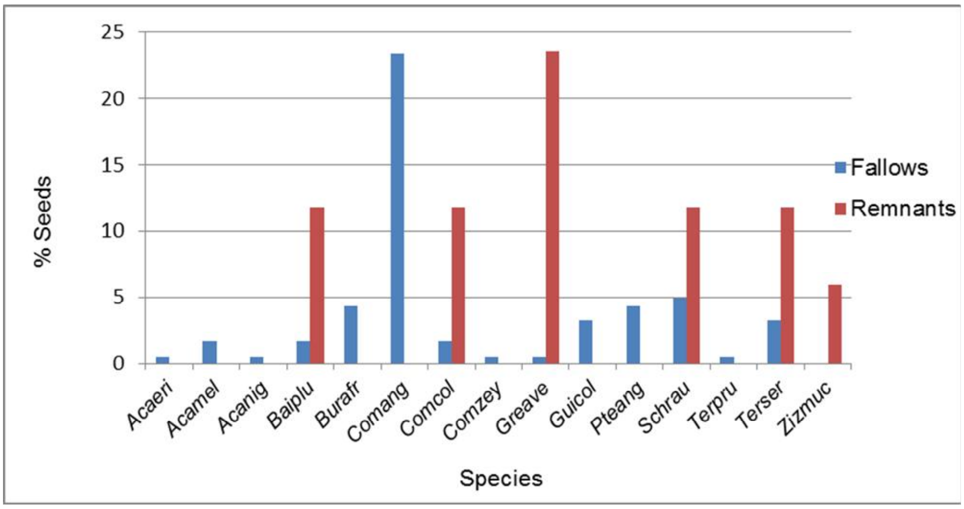

Figure 18: The species (acronyms on page viii to xi) recorded from the soil seed bank, with the Y axis representing the percentage of woody plants calculated per fallow fields (AF) and the Remnant forest vegetation (RE).

Using soil seed bank data, the Jaccard's similarity index revealed 33% similarity in species composition between the fallow fields and remnant forest vegetation. The presence and absence of species as recorded from the fallow fields and remnant forest vegetation are indicated in Appendix B.

4.5 Vegetation structure

This study recorded the number of individuals based on the growth forms such as coppices, seedlings, and shrubs (Appendix C). The study found a significant association between vegetation structure (defined in this study by growth forms) and field type (fallow fields and remnant forest vegetation). This is shown by the Chi-square Test of association ($\chi 2$ = 646.409, df =2, P= 0.000 < 0.05). The fallow fields recorded more individuals per growth form compared to the Remnant forest vegetation (Figure 19).

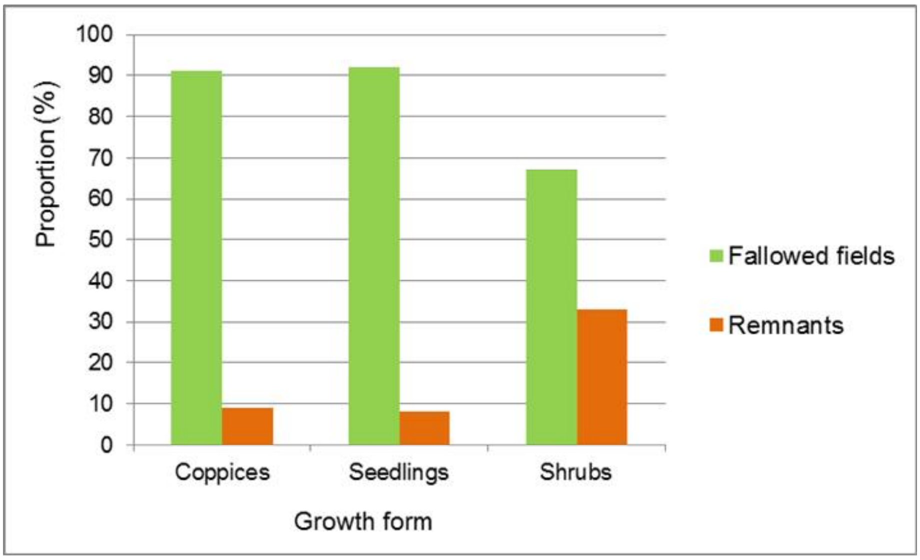

Figure 19: The proportions of the growth forms of the woody plants on fallow fields and remnant forest vegetation.

4.6 Classification and ordination

4.6.1 Vegetation classification

The hierarchical classification separated fields into different divisions. At 30% similarity there were five interpretable associations identified and indicated by the different colours and the phenon line in figure 20.

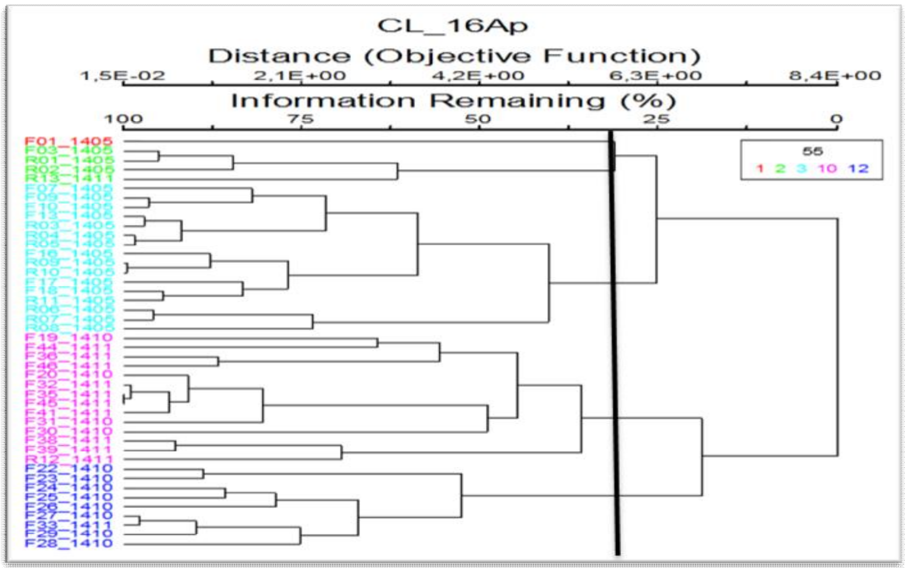

Figure 20: A dendogram with a phenon line drawn at 30% similarity to delimit 5 fields clusters based on species composition of the above ground vegetation on the fallow and remnants surveyed.

The Multi-Response Permutation Procedure (MRPP) results indicated that the five groups provided the most informative number of clusters with more homogeneity within groups than expected by chance (MRPP A = 0.246, T = -21.794).

The Monte Carlo test of the Indicator Species Analysis (ISA) showed that the use of five clusters had a lower mean p value (p=0.008), a higher number of indicator species (43 species) and a higher mean indicator value (IV) (29.6) when compared to six, four and three clusters. However, the ISA could only specify indicator species for four woody plant communities (Table 2), the *Baikiaea plurijuga* - *Strychnos cocculoides*, *Combretum zeyheri* - *Baphia massaiensis*, *Acacia erioloba* - *Diospyros lycioides* and *Acacia tortilis* – *Combretum imberbe* communities. The last group did not show any indicator species and therefore, it was believed to be grouping based on other factors; this group was regarded as an outlier.

Table 2: The Indicator Species Analysis (ISA), from five clusters, showing Indicator Values (IV) and P values. The IV of 100% shows perfect indication and zero means no indication. The *p*-values were calculated from the Monte Carlo Test for each species and only species with high IV and p-values <0.05 are shown.

Woody Plant Communities	**Indicator value (IV)**	**P**
***1. Baikiaea plurijuga - Strychnos cocculoides community* (10 fields)**		
Baikiaea plurijuga	85.20	0.0002
Strychnos cocculoides	41.9	0.0010
Grewia falsistipula	24.5	0.0002
Grewia avellana	21.3	0.0068
***2. Combretum zeyheri - Baphia massaiensis* (17 fields)**		
Combretum zeyheri	80.4	0.0002
Baphia massaiensis	63.1	0.0002
Terminalia sericea	58.5	0.0002
Bauhinia petersiana	52.7	0.0002
Burkea Africana	50.0	0.0002
Ochna pulchra	41.3	0.0004
Combretum collinum	40.3	0.0006
***3. Acacia erioloba - Diospyros lycioides* (4 fields)**		
Acacia erioloba	49.5	0.0002
Diospyros lycioides	18.5	0.0056
Gymnosporia senegalensis	13.6	0.0130
***4. Acacia tortilis – Combretum imberbe* (11 fields)**		
Acacia tortilis	96.5	0.0002
Combretum imberbe	35.5	0.0010
Combretum engleri	34.6	0.0006
Hyphaene petersiana	33.3	0.0010
Acacia hebeclada	27.5	0.0022

4.6.2 Non-metric Multidimensional Scaling (NMS) ordination

The result of the Non-metric Multidimensional Scaling (NMS) shows that the best solutions were explained by two axis (two dimensional). The NMS partitioned the five communities along the two axes which are similar to the groupings in table 2. Axis one contributed 74% to the variation of the communities obtained from the NMS, while axis two contributed 12% to the total variation. The results show that three communities were aligned along the first gradient (axis 1). The blue polygon is similar to the *Acacia tortilis – Combretum imberbe* community from table 2 (consisting 9 fallow fields), while the purple polygon from the NMS is similar to the *Acacia erioloba - Diospyros lycioides* community from table 2 and consists of 13 fallow fields. The NMS isolated one field which were regarded as an outlier. The results also indicated two communities along axis 2: The light blue polygon were found to be similar to the *Combretum zeyheri - Baphia massaiensis community* consisted of 10 fallow fields and 3 Remnant forest vegetation and the green polygon represented an outlier community based on other factors (Figure 21). The remnants were mostly grouped along the communities along axis 2. The polygons indicate some woody plant communities corresponding to the cluster analysis and the indicator species analysis.

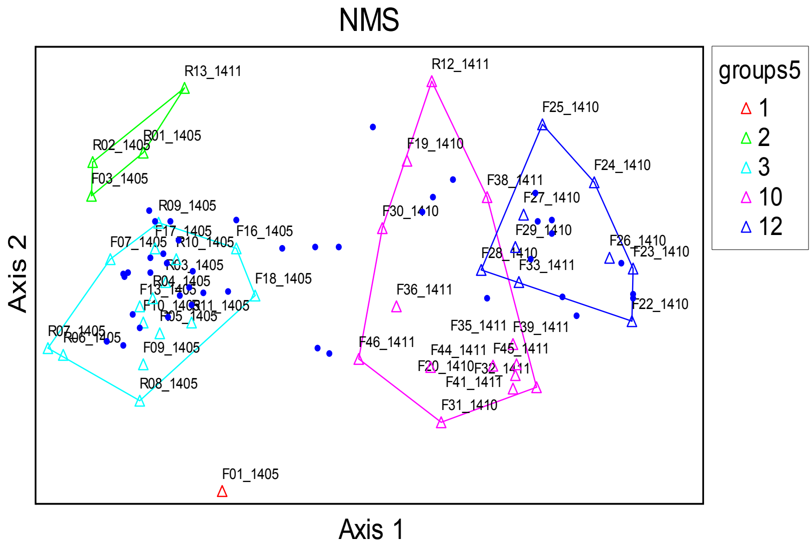

Figure 21: The four groups and an outlier partitioned during the non-metric multidimensional scaling (NMS) from all fields combined. Where F= fallow fields and where R = Remnant. The woody plant communities along the two axes are identified by different polygons which are similar to those found by ISA analysis in table 2

Further analysis of Spearman's rank-order correlation was used to correlate the scores from the ordination axis and the environmental data. The Spearman's rank-order correlation showed that axis one largely had an influence on the woody plant communities. The results show that there is a correlation between the woody plant communities and the soil factors. The organic carbon of the top soil contributed 77% to the woody plant associations, followed by the cat-ion exchange capacity which contributed 68% as well as the slope contributing 65% to the associations. The distance from the Kavango river also contributed -0.898 (Table 3). The value is negative as it indicates the distance away from the river.

Table 3: The environmental data, the scores of the ordination axes correlated to the Spearman's rank-order correlation test. Environmental data consisted of top soil characteristics: Potential Hydrogen (pH), Organic carbons (OC), Cat-ion Exchange (CEC) capacity, Base Saturation (BS) as well as distance from the river, altitude, slope, fallow periods and age of field since the start of crop cultivation. The month when data was collected was also added to the table.

	ALTITUDE	*SLOPE*	*SAND_TOP*	*PH_TOPSO*	*OC_TOPSO*	*CEC_TOPS*	*BS_TOPSO*	*KAVANGO*	*FALLOW*	*AGE OF F*	Month of collection	Axis 1	Axis 2
ALTITUDE	1,00											-0,64	0,09
SLOPE	-0,49	1,00										**0,65**	0,08
SAND_TOP	0,71	-0,64	1,00									-0,69	0,03
PH_TOPSO	0,56	-0,70	0,34	1,00								-0,63	-0,10
OC_TOPSO	-0,77	0,75	-0,97	-0,57	1,00							**0,77**	0,00
CEC_TOPS	-0,70	0,64	-1,00	-0,33	0,96	1,00						**0,68**	-0,03
BS_TOPSO	0,78	-0,80	0,91	0,70	-0,99	-0,91	1,00					-0,80	-0,02
KAVANGO	0,66	-0,73	0,75	0,64	-0,83	-0,74	0,85	1,00				-0,86	0,22
FALLOW	0,48	-0,37	0,45	0,37	-0,50	-0,45	0,51	0,55	1,00			-0,58	0,09
AGE OF F	0,45	-0,39	0,44	0,36	-0,48	-0,44	0,49	0,54	0,99	1,00		-0,56	0,10
Month of collection	-0,60	0,74	-0,65	-0,59	0,73	0,65	-0,76	-0,83	-0,47	-0,47	1,00	**0,90**	0,03

4.7 Seed viability

The TZ test results indicated that 55% out of 221 seeds recovered from the agricultural fields did not show any stains indicating dead seeds. The results also showed that 45% of the seeds tested stained red indicating that the seeds were viable (Figure 22).

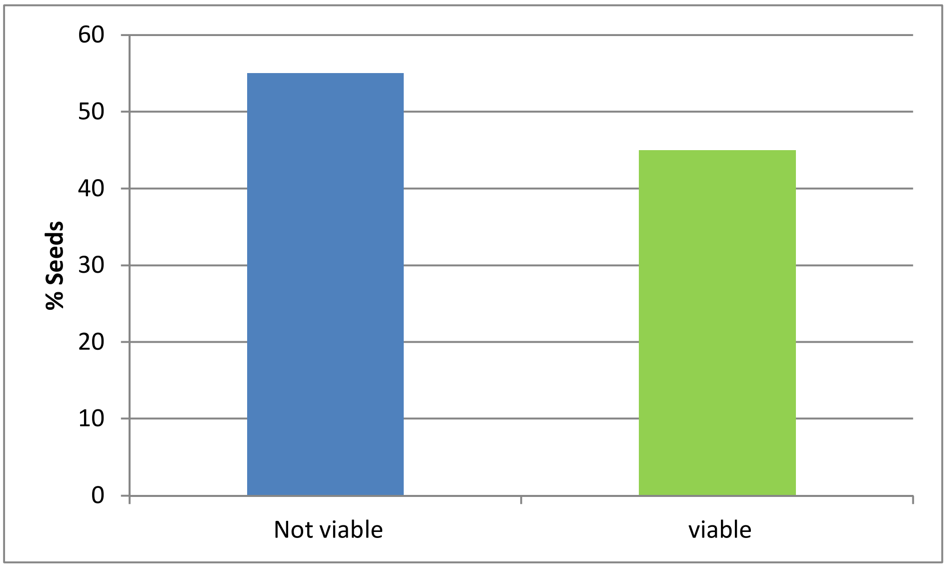

Figure 22: The proportions of seeds and how they performed under the Tetrazolium Chloride Test. Not viable = Seeds that did not respond to the test, and Viable = Seeds that have stained red, hence viable. The graph shows all 221 seeds collected from both the fallow fields and remnant forest vegetation.

4.8 Regeneration of timber species

The results have shown low proportions of the species mostly used for timber in Kavango regions compared to other woody plant species (Figure 23). The graph indicates that *Baikiaea plurijuga* recorded better percentages in all categories compared to *Burkea africana* and *Guibourtia coleosperma.* The *Pterocarpus angolensis* was only represented in the seed category.

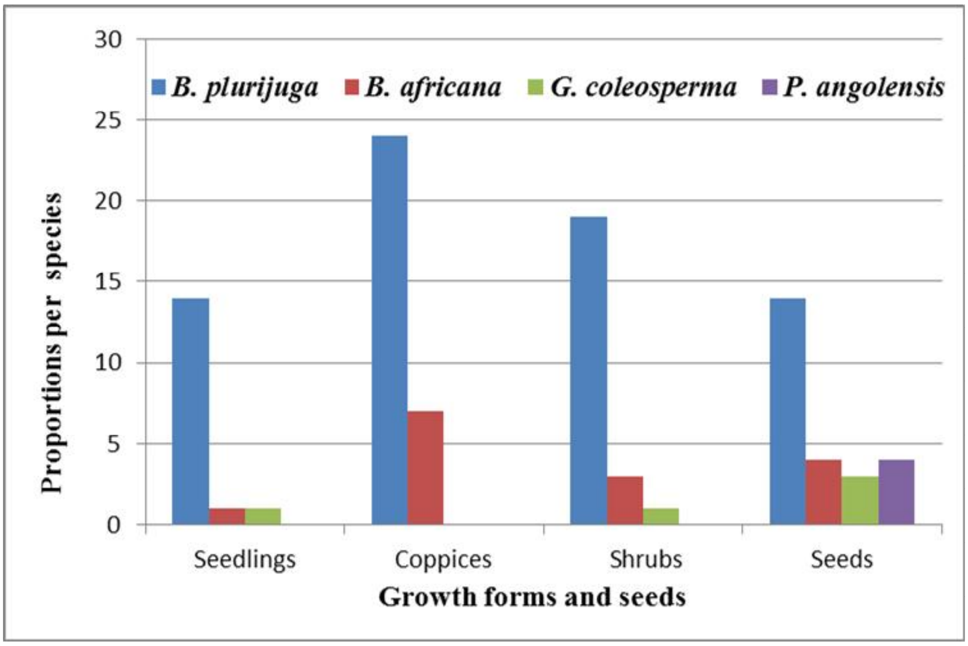

Figure 23: The proportions of the timber species recorded per growth forms aboveground and the seeds recovered from the soil seed bank on all fallow fields and remnant forest vegetation. The bars represent the timber species: *Pterocarpus angolensis, Baikiaea plurijuga, Burkea africana* and *Guibourtia coleosperma.*

5. Discussion

5.1 Species diversity of the aboveground Vegetation

5.1.1 Effect of duration of fallow on species diversity

The results of this study showed that the duration of fallowing has no effect on species diversity of aboveground woody plants (Figure 11) in the Mashare Constituency, Kavango East Region. This could be a consequence of the duration of the fallow period (1 to 25 years) which was probably not long enough for the differences in species diversity to occur. This may mean that cultivation created a more or less homogenous microenvironment which attracted similar types of species. Benayas *et al.* (2007a), found homogenous vegetation on large agricultural areas that were abandoned at the same time. This could also explain the results of no differences found in species diversity amongst fallow fields.

5.1.2 Effect of ploughing methods on species diversity

The results of this study have also shown that woody plant species diversity of the aboveground vegetation was significantly different (Figure 12) when different ploughing methods were used (p=0.039). Fields that were ploughed using traditional methods (hoes and ploughs drawn by oxen) showed high species diversity compared to the modern technique of ploughing using mouldboard ploughs on tractors. This shows that the traditional methods of ploughing have a low impact on the soils as observed on the fields surveyed ([1]Mrs. Kandjimi, November 2014, personal communication). Additionally, this could also be a reflection of the species diversity of the old soil seed banks that germinated. The results confirmed the findings of Cramer *et al.* (2008) who demonstrated that the soil seedbanks were maintained when fields were previously cultivated using traditional methods. Thus, species diversity is promoted when moderate disturbances occurred in an area, as supported by the Intermediate Disturbance Hypothesis (Fenner and Thompson 2005).

On the other hand, the mould board ploughs are known to destroy the soil structure as soils are completely turned upside down. This could have reduced the species diversity as plants are completely destroyed by exposing the underground parts of the plants (roots). Cramer

[1] Mrs. M. Kandjimi, Communal Farmer, Tyeye Village, Mashare Constituency, Kavango East Region

et al. (2008) also found that the use of modern ploughing implements (e.g. mouldboard ploughs) completely disturbed the soil structure, organic matter content and soil nutrients, which affects the regeneration of plants. Similar studies by Hibsher *et al.* (2013) also found that mouldboard ploughs affected the distribution of seeds in the soil which resulted in low regeneration by seeds and vegetative regrowth of plants. Therefore ploughing methods affect species diversity of fallow fields.

5.2 Species diversity between fallow fields and remnant forest vegetation

The result of this study found significant differences (p=0.001) in species diversity of woody plants between fallow fields and remnant forest vegetation (Figure 13). The Remnant forest vegetation showed more species diversity when compared to the fallow fields. This could be because the remnants comprised of matured trees and shrubs that can serve as seed sources and provide nursing grounds for seedlings to germinate and establish. Van Uytvanck (2009) also found that areas with intact vegetation were better off in protecting juvenile trees, hence allowing the establishment and growth of the tree species. Other reasons could be that Remnant forest vegetation provide different niches that attract different species. This argument supports the findings of Benayas *et al*. (2007), who stated that landscape heterogeneity favours species diversity. Similarly other studies have found that the intact vegetation of the remnants fields not only attracted seed dispersers but also facilitates woodland regeneration under the tree canopies (Cramer *et al*. 2008, Tambara *et al*. 2012).

On the other hand, the repeated disturbance exerted on fallow fields, initially by clearing and subsequently crop cultivation could have reduced the species diversity of woody plants. These findings are supported by Cramer *et al*. (2008) who found out that some species were lost as a result of intolerance to the disturbances on the agricultural fields. Other studies by Collins *et al*. (1995) also found that repeated disturbances led to a reduction in species richness as the habitat structures were changed. Therefore agricultural activities were found to have caused the loss of biodiversity and reduced the abundance of adopted species (Benayas *et al*. 2007). The low species diversity of woody plants on fallow fields may have also resulted from low dispersal rates to the fields. Hooper *et al*. (2005) found that the dispersal of large seeded species to fallow fields was challenged by a lack of vectors to disperse the seeds. They found that the dominating vectors found were mostly birds, ants / termites and rodents that usually carry tiny seeds. This was further supported by Stelli (2011) who found that species diversity on fallow fields was influenced by dispersal. This means that there are less seeds of woody plants that are expected on the fallow fields compared to the Remnant forest vegetation. The other reason could be ineffective seed sources, as only few and similarly matured plants were found on fallow fields. Various researchers have shown that isolated trees are ineffective as seed sources for the regeneration of completely disturbed areas (Alelign *et al*. 2007, Eilu and Obua 2007). However, it is important to note that other influential factors such as inter-specific interactions with surrounding vegetation, environmental modification and seed bank, and the availability of resources may have affected the vegetation recovery on fallow fields (Cramer *et al*. 2008, Tambara *et al*. 2012).

5.3 Soil seed bank

5.3.1 Species diversity of the soil seed bank

As with the aboveground vegetation, the duration of fallowing did not show significant effects on the species diversity of the seeds recovered from the soil seed bank of fallow fields (Figure 14). This means that the species diversity did not change significantly, regardless of the last time of cultivation (or age of fallow). This could be attributed to the duration of time (1 year to 25 years) these fields were fallow. Other studies found significant differences in species diversity of the soil seed bank after a time period of 53 years of fallowing in Ethiopia.

Another reason could be that since fallow fields were subjected to disturbances, they attracted species that tolerated disturbances; hence the species were similar. Therefore the nature and degree of disturbances influences the number of species and the density of soil seed banks (Mengistu *et al.* 2005a). It is also expected that most woody species on fallow fields will regenerate from seedlings and coppices and not necessarily from a persistent soil seed bank (Parker 1989).

5.3.2 Seed density among fallow fields

The study also showed that the duration of fallowing had no effect on seed densities of the woody plants on the fallow fields (Figure 15). The number of seeds that occurred on the fallow fields was not affected by the time of fallowing. Similarly, studies by Lemenih and Teketay (2006) also found no pattern in woody plant density related to cultivation periods. Only few seeds (221) were recovered from 4600 m^2 samples from fallow fields. In Ethiopia, Mengistu *et al.* (2005) found 973 seeds on 3. 825 ha of the degraded area, which was lower than in the soil seed bank of the remnants. Disturbance on the fallow fields which include field clearing, cultivation and weeding could have led to the reduction of individuals from the soil bank. This corroborates the findings by Mengistu *et al.* (2005), who found that disturbances at sites over many years lead to low seed density of the soil bank. Additionally, the topsoil in which most of the seeds are stored was also eroded. This study found a low representation of woody plants which are currently overexploited for timber: *Pterocarpus angolensis*, *Baikiaea plujirjuga*, *Burkea africana* and *Guibourtia coleosperma* (Figure 23). This could be as result of over utilization which has reduced the number of plants that can produce sufficient amounts of seeds. Other studies also found that seed depositions of native woody plants into the fallow fields decreased with fallow ages (Finegan and Nasi 2004, Lemenih and Teketay 2006).

Namibia has been receiving less than average rains during the past years (SASSCAL Weather Net 2017) and it could be that an insufficient amount of seeds was produced over the years. The situation could have been worsened by the lack of seed dispersers of woody plants to fallow fields. In addition, it could be that the soil seed bank has been exhausted through seed germination and thus no plant establishment as a result of land clearing and ploughing. Similarly, Stelli (2011) found that seed density of the soil seed bank was influenced by the availability of trees, seeds, and microsite characteristics.

5.3.3 Species diversity of soil seed bank compared between fallow fields and remnants

There was no significant difference in the species diversity of woody plants of the soil seed bank when fallow fields and remnant forest vegetation were compared (Figure 16). However, there were different species that were only recovered from the fallow fields. The reason could be because the Remnant forest vegetation are regarded as common land,

and as a result resources were exploited through the selection of species for fire wood and poles or wood curving. In addition, further damages that are caused by livestock through browsing could have eliminated individuals that could be sources of seed rains in the proximity of fallow fields. On the other hand, fallow fields seed recovery was dominated by pioneer species such as the *Combretum* species and the *Grewia* species. The seeds could have come from distant areas as it is dispersed through wind (*Compretum* spp.) and animal/human dispersal (*Grewia* spp.) to the fallow fields. This could explain the differences found in the woody species regenerating when remnant and fallow fields were compared. It is worth noting that vegetation on the land cleared for agriculture not only depends on the soil seed bank aid and seed rains from the surrounding vegetation but also on pre-existing seedlings and shoots sprouting from stumps of woody species for plant recruitment (Ehrensperger *et al.* 2013c). However, the sample size of Remnant forest vegetation (n = 6) could have been too small for effective comparison with fallow fields (n = 23).

5.4 Species composition of the aboveground vegetation and the soil seed Bank.

5.4.1 Species composition of the aboveground vegetation

The Jaccard Index of Similarity showed a 51% similarity (Figure 17) in the aboveground species composition of woody plants between the fallow fields (AF) and Remnant forest vegetation (RE). This implies that only about half of the species are common to both fallow fields and remnant forest vegetation. There were more species recorded for the fallow fields than the Remnant forest vegetation. Species that only occurred on the remnants included early successional species *Dichapetalum cymosum, Senna occidentalis, Sesamum spp., Pechuel-loeschea leubnittziae, Tribulus terrestris, Acrotome inflata* and *Datura innoxia*. These are species that colonize and invade areas that are heavily disturbed and create a good environment for pioneers' species to grow. Pioneer species recorded included the *Acacia spp., Croton spp., the Combretum spp., Boscia albitrunca, Erythrophleum africanum, Peltophorum africanum,* and *Ziziphus mucronata.* The occurrence of these species on the fallow fields could be as a result of the microclimates presented on the fallow fields. The openness of fallow fields tends to allow enough light and other resources as well as less competition. Some of the species do not do well if they have to compete for resources, making the fallow fields favourable to such species to grow. This was confirmed by Benayas *et al.* (2007b), that fallowing tends to promote species that are adapted to open spaces. Abandoned fields tend to favour the population and diversity of species characteristics of woody vegetation, namely shrub land and forest. This study found that clearing of land for agriculture leads to the decrease of important species for timber such as *Pterocarpus angolensis, Baikiaea plurijuga, Burkea africana* and *Guibourtia coleosperma.*

5.4.2 Species composition of the Soil seed bank

The results of the soils seed bank showed 33% similarity (Figure 18) in species composition of the woody plants when compared between the fallow fields (AF) and Remnant forest vegetation (RE). This means that 67% of the seeds were not common to all fields. This result shows that the soil seeds bank still comprised of seeds of the original vegetation of the Kavango woodland as indicated by species such as *Pterocarpus angolensis*, *Burkea africana* and *Guibourtia coleosperma*. These could show seeds that have been dispersed a long time ago as some species were not represented on the Remnant forest vegetation. Teketay (1998) found that variations in seeds recovery from a soil seed bank reflected the differences of species, for example how long seeds persist in the soil, the mode of dispersal, as well as seed predation. Although there are more native species that were not recovered, it is expected because seed losses could have occurred as a result of cultivation practices and predation by small mammals. Similarly, Lemenih and Teketay (2006) found that soil seed banks of native woody species were exhausted of seeds as a result of land preparation, cultivation, and successive weeding. Other species included the *Acacia* spp., *Grewia* spp. *Combretum* spp., and the *Terminalia prunioides*. Most of these species are consumed by animals and they might have been dispersed on fallow fields through droppings. Livestock or small stock walk long distances in search of grazing grounds; hence the seeds of those species might have been dispersed from distant areas. Grewia fruits are also consumed by rural people; as such it is brought to their homesteads, hence their occurrence on fallow fields. Seeds of the Combretum species and the *Terminalia prunioides* are wind dispersed; as such it can dispersed to far distant areas from the parent tree and this might be the reason it was recovered from fallow fields. The findings of the soil seed bank correlates to the aboveground woody species composition that were only regenerating on fallow fields and not on Remnant forest vegetation. Similarly, Lemenih and Teketay (2006) found that apart from the seeds that remained from the original forest before crop cultivation, seed rains also came from adjacent natural forests or from the selectively preserved on-farm trees. However, Van Uytvanck (2009) found that the lack of deposition of seeds on fallow fields occurred as a result of the deficiency of attractive sites for rodents to hide seeds as well as resting trees for birds where they defecate consumed seeds.

5.5 Vegetation structure

The Chi-square Test of association (Figure 19) revealed an association between growth form and type of field (P= 0.000). The Remnant forest vegetation recorded a lower number of individuals per growth form (Appendix B1) compared to the fallow fields. The Remnant forest vegetation could indicate a diminishing regeneration ability of the fields as a less number of coppices and seedlings were recorded. The reasons could be because of the high competition experienced by seedlings as the Remnant forest vegetation consist of more vegetation, hence the ability to grow and get established is minimal. Although from a different environment, Christensen (1977) found that canopy closure and competition from more vigorous understory species resulted in high mortalities in small size classes. Other reasons could be that juveniles suffer from other disturbances such as fire burns and browsing as remnants are continuously grazed. As long as the farmers continue to compete for grazing and wood on the common land, regeneration of woody plants will remain low.

The fallow fields had more individuals per growth form and it could be attributed to the new niches created, favouring seedling growth of some species. Benayas *et al.* (2007) found that abandoned agricultural land provides open spaces under secondary succession which are colonized by pioneer vegetation. This study also found more coppices on fallow fields which could have resulted from continuous harvesting for firewood and browsed by livestock forcing plants to remain shrubby (Personal observation 2014). Research by Graz (2004) confirmed that the modification of the natural environment through resource extraction, grazing by domestic animals, and fire may favour some type of growth forms over another. Although the fallow fields recorded high numbers per growth form, the establishment of those individuals depends on the continuous fallowing of such fields and the environmental factors. This study could not establish when owners will return to their fallowed fields for further cultivation.

5.6 Vegetation classification and ordination

5.6.1 Vegetation classification

The results of the classification separated fields into five interpretable associations (Figure 20). A few of the Remnant forest vegetation were found grouped together in the *Baikiaea plurijuga* - *Strychnos cocculoides* community but most Remnant forest vegetation occurred mixed with the fallow fields. There was also one group comprising of fallow fields only. This could be because of the similar vegetation occurring in the Kavango regions.

An Indicator Species Analysis (ISA) performed on several clusters shows that 5 clusters indicated the best groupings of woody species which led to the following communities: the *Baikiaea plurijuga* - *Strychnos cocculoides*, *Combretum zeyheri* - *Baphia massaiensis*, *Acacia erioloba* - *Diospyros lycioides* and *Acacia tortilis* – *Combretum imberbe* community.

The *Baikiaea plurijuga* species was a key indicator species for the *Baikiaea plurijuga* - *Strychnos coculoides* association (Table 3) that were found to regenerate around the agricultural fields of the Mashare constituency. Similar findings by Kabajani (2016b) also recorded high seedling density of *Baikiaea plurijuga* in the Mashare area. *Baikiaea plurijuga* is fire sensitive and does not do well in fire prone areas, as a result the plant establishes itself closer to the agricultural fields where the occurrences of fire frequencies are less (De Cauwer *et al.* 2016b). This association belongs to the open *Baikiaea-Burkea* woodland which is characterized by fire tolerant species and species adapted to browsing (De Cauwer 2013b, Revermann and Finckh 2013).

The second plant association found by this study is the *Combretum zeyheri* - *Baphia massaiensis* (Table 3) associated with species such as *Terminalia sericea, Bauhinia petersiana* and *Burkea africana*. Similar to the findings by Strohbach (2013b), this shrub community occurred on the sandy soils and formed a transition between the depressions, dry riverbeds and dune valleys. Studies by Strohbach and Petersen (2007) found *Bauhinia petersiana* variants which comprised of similar shrub species found in this association. These shrub species are mostly browsed by livestock and they have led to an encroached state of the woodland that have resulted from continued grazing and protection from frequent fires (Strohbach and Petersen 2007).

This study also identified associations of the old flood plains (Omurambas) which is the *Acacia erioloba* - *Diospyros lycioides* community*,* associated with species such as *Gymnosporia senegalensis* and *Securidaca longepedunculata* (Table 3). Studies by De Cauwer *et al.* (2016b) found similar species that occur on the dry riverbeds and are referred to as slope communities. Strohbach and Petersen (2007) described the same community as *Acacia erioloba* variant and the authors stated that shrub species such as *Securidaca longepedunculata* have a low occurrence in this community. This study also found low occurrence of *Securidaca longepedunculata* in this community. As indicated by various studies, the *Acacia erioloba* prefers substrates that are shallower with high clay content and they are regarded to be more loamy when compared to other woodlands (Strohbach and Petersen 2007, Gröngröft, Luther-Mosebach, Landschreiber, and Eschenbach 2013). The old flood plains are used for subsistence agriculture, grazing/browsing and the collection of firewood, as such the woody plant species are adapted to browsing (Gröngröft *et al.* 2013, Revermann and Finckh 2013).

The last association found by this study (Table 3) is the *Acacia tortilis* – *Combretum imberbe,* which is associated with species such as *Combretum engleri* and *Hyphaena petersiana*. According to Mannheimer and Curtis (2009), *Acacia tortilis,* which is an indicator species for this group, grows on a variety of soils but prefers sandy loam soils. Studies by Tambara *et al.* (2012) found that *Acacia tortilis* is an early successional species with invasive qualities. The ability of this species to grow anywhere probably explains its abundance in the Mashare area. This association forms part of the old flood plains which are mostly used for subsistence agriculture and grazing. Similarly, Strohbach (2013a) found an association of *Acacia tortilis* - *Hyphaene petersiana* community. The author further found that this association was occasionally occurring on the fringes along flood plains with somewhat higher salinity or as a transition zone to the *Terminalia sericea* - *Combretum imberbe* association. Similarly this study found the *Hyphaena petersiana* as one of the species that grows on old flood plains associated with high saline content.

This study has indicated that fallowing allows the regeneration of woody plants and this was also confirmed in Zimbabwe by Tambara *et al.* (2012). However, the representations of woody species that are under threat from exploitation such as *Pterocarpus angolensis, Baikiaea plurijuga, Burkea africana* and *Guibourtia coleosperma* (Figure 23), were very low, indicating a regeneration problem. This may mean that farmers need to be engaged in assisted regeneration of valuable tree species so that such species can be reintroduced back onto the farmers' fields.

5.6.2 Non-metric Multidimensional Scaling (NMS) ordination

The study showed strong woody vegetation – environment relationship for the Mashare area. Species were grouped into distinct communities and much of the variation in species composition was explained along the first ordination axis. The ordination results of this study confirmed the three woody plant communities obtained from the ISA analysis: *Acacia tortilis – Combretum imberbe, Acacia erioloba - Diospyros lycioides* and *Combretum zeyheri - Baphia massaiensis.* The woody vegetation was associated based on the distance from the Okavango River and the soil. The woody plant communities such as *Acacia tortilis – Combretum imberbe and* Acacia *erioloba - Diospyros lycioides* were found in close proximity to the river and these comprised of species that grow in the depressions and the dry river beds (Figure 21). The *Combretum zeyheri - Baphia massaiensis* community were found to form a transition between the depressions, dry riverbeds and dune valleys. This study found that woody plant communities were grouping based on the top soil properties such as organic carbons, cat ion exchange, as well as the slope. Tambara *et al.* (2012) similarly found significant differences in tree species diversity in Zimbabwe as a result of soil types. Therefore this study found that woody vegetation composition and structure vary with soil type as confirmed by the associations delimited along the environmental gradient.

5.7 Seed viability of the soil bank

The study also determined the ability of the recovered seeds of woody plants to germinate, which is expected to contribute to the recovery of the woodlands after fallowing. The results of this study showed that 45% of the woody plant seeds tested were viable (Figure 22). This shows that most seeds recovered did not show the ability to germinate. A large number of *Combretum engleri* seeds recorded did not respond to the Tetrazolium Chloride Test. The trees were fruiting at the time of data collection; hence some seeds were newly dispersed. It is also known that some plant species increase the chance of survival by producing large volumes of seeds but the seeds have a short life span, which could be the case with the *Combretum engleri* seeds. Studies by Lemenih and Teketay (2006) found that isolated trees found in cultivated fields may produce infertile seeds as a result of the distance between the trees for the successful fertilisation process to occur. Trees can be monoecious or dioecious resulting in producing infertile seeds e.g. *Sclerocarya birrea* in the northen part of Namibia. The authors also found that the age of the trees plays a big role in seed production as older trees were found to produce unproductive seeds. Similarly, the fields were surrounded by old trees and this could also have contributed to the high number of seeds turning out not to be viable. Lots of individuals were also recorded from the *Grewia* species of which some did not show germination capability. Most seeds that were recovered appeared old, meaning that the seeds were dead. Studies by Lemenih and Teketay (2006) found low rates (5.7%) of viable seeds of woody plants after seven years of cultivation.

Although the viability test showed that some seeds may germinate, the seedlings might not grow to tree heights without assistance. Research by Pathak (2015) found that relying on nature to recover important tree species took many years compared to assisted recovery of vegetation. Therefore, assisted regeneration in the Kavango east region, through direct seeding and planting of important woody plants of concern may lead to the recovery of the woody species in a short period of time.

5.8 Conclusion

This study found that the woody species diversity of the aboveground vegetation and the soil seed bank on fallow fields of the Mashare Constituency were not affected by the duration of fallowing. However, ploughing methods affected species diversity of the fallow fields and the traditional methods were found to favour species diversity. This may have resulted from the minimal impact the traditional methods have on plants and the soil structure. The remnant forest vegetation plots were found to be more diverse than the fallow fields and this could be due to the different microsites and the diversely matured woody plants that can facilitate the growth of other plants.

The seed density of woody species of the soil seed bank of ffallow fields was also not affected by the duration of fallowing. In addition, there were also no significant differences found in woody species diversity when the soil seed bank of remnant and fallow fields were compared. This could be attributed to low seed production over the last couple of years as a result of the low rains received in the region.

Furthermore, this study found that woody species composition of the fallow and the remnant forest vegetation were different. The fallow fields comprised of more early successional woody species when compared to the remnant forest vegetation. Fallow fields created good environmental conditions with less competition for more species to colonize, especially those woody plants that tolerate disturbances. Again the soil seed bank results showed that the woody species composition of the fallow fields were different from the remnant forest vegetation and this could have resulted from the old soil seed bank that remained in the soil without germinating, in addition to the species that were dispersed from distant vegetation by animals.

Moreover, the vegetation structure based on the growth forms (seedlings, coppices, and shrubs) was different between the remnant vegetation and fallow fields. Thus, fallow fields support the regeneration of woody plants. The concern remains with the important species that are overexploited for timber, as these species were not prominently showing regeneration ability.

This study found four woody plant associations of which three woody plant communities were further confirmed by the ordination analysis. The associations were grouped based on the distance from the river and top soil characteristics such as organic carbons, cat-ion exchange, as well as the slope. The associations indicated species of the flood plains, dune sand and those that occur in the transition between the dunes and flood plains.
Moreover, most seeds were not viable and this somehow explains the differences found in the species diversity of the aboveground vegetation. Therefore, assisted regeneration of important tree species is highly recommended to ensure survival.

5.9 Recommendations

The Ministry of Agriculture, Water, and Forestry (Namibia) together with institutions of higher learning can collaborate and identify farmers that are willing to try assisted regeneration of woody species that are important to them. Furthermore, studies on more fallow fields are recommended to confirm the findings of this study. Moreover, floating or germination of recovered seeds is recommended to test viability of seeds instead of the

Tetrazolium Tests that can be costly. Studies can also include fruiting phenology of the woody plants so that fruiting times can be documented for seed collections.

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7. Appendices

7.1 Appendix A

Appendix A: Species diversity (Shannon-Wiener index) of the aboveground vegetation and the soil seed bank calculated using the Multi-Variate Statistical Package (MVSP). Tables include all data recorded from fallow fields and remnant forest vegetation. The Shannon-Wiener index was calculated from the raw data and was not log transformed.

DIVERSITY INDICIES

Data file - G:\Shan MV Veg.mvs

Analysis begun: 17 March 2017 10:11:04 AM

Analysing 46 variables x 59 cases

Shannon's method			
Log base 10			
Sample	Index	Evenness	Num.Spec.
AF01	0,615	0,879	5
AF02	0,228	0,252	8
AF03	0,497	0,588	7
AF04	0	0	1
AF05	0,221	0,463	3
AF06	****	****	0
AF07	0,488	0,577	7
AF08	0,774	0,717	12
AF09	0,894	0,859	11
AF10	0,683	0,716	9
AF11	0,612	0,642	9
AF12	0,743	0,743	10
AF13	0,497	0,477	11
AF14	0,477	1	3
AF15	0,75	0,786	9
AF16	0,775	0,695	13
AF17	0,653	0,723	8
AF18	0,484	0,464	11
AF19	0,489	0,812	4
AF20	0,174	0,577	2
AF21	0,398	0,471	7
AF22	0,346	0,574	4
AF23	0,592	0,701	7
AF24	0,49	0,63	6
AF25	0,526	0,676	6
AF26	0,63	0,81	6
AF27	0,438	0,918	3

DIVERSITY INDICIES

Seed data

Analysis begun: 20 March 2017 05:10:48 PM

Analysing 20 variables x 36 cases

Shannon's method			
Log base 10			
Sample	Index	Evenness	Num.Spec.
F01_1405	0,477	1	3
F02_1405	0,276	0,918	2
F03_1405	0	0	1
F04_1405	0,477	1	3
F06_1405	0	0	1
F07_1405	0	0	1
F08_1405	0,196	0,65	2
F10_1405	0,415	0,87	3
F11_1405	0,477	1	3
F12_1405	0	0	1
F13_1405	0,477	1	3
F14_1405	0,413	0,865	3
F15_1405	0	0	1
F16_1405	0,301	1	2
F19_1410	0,699	1	5
F20_1410	0,501	0,832	4
F21_1410	0,319	0,67	3
F22_1410	0,262	0,549	3
F23_1410	0,633	0,905	5
F24_1410	0,587	0,84	5
F25_1410	0,29	0,964	2
F26_1410	0,477	1	3
F28_1410	0,658	0,942	5
F31_1410	0	0	1
F32_1411	0	0	1
F33_1411	0,276	0,918	2
F34_1411	0,678	0,97	5
F36_1411	0	0	1

AF28	0,366	0,471	6
AF29	0,579	0,744	6
AF30	0,285	0,598	3
AF31	0,273	0,573	3
AF32	0,244	0,811	2
AF33	0,293	0,486	4
AF34	0,426	0,61	5
AF35	0,06	0,201	2
AF36	0,684	0,88	6
AF37	0,759	0,796	9
AF38	0,147	0,21	5
AF39	0,397	0,66	4
AF40	0,398	0,569	5
AF41	0,175	0,367	3
AF42	0,136	0,226	4
AF43	0,364	0,431	7
AF44	0,361	0,517	5
AF45	0,186	0,619	2
AF46	0,349	0,5	5
R 1	0,488	0,541	8
R 10	0,868	0,868	10
R 11	0,748	0,828	8
R 12	0,719	0,924	6
R 13	1,003	0,875	14
R 2	0,274	0,391	5
R 3	0,687	0,687	10
R 4	0,737	0,817	8
R 5	0,833	0,873	9
R 6	0,655	0,775	7
R 7	0,859	0,859	10
R 8	0,613	0,679	8
R 9	0,855	0,821	11

F38_1411	0,458	0,96	3
R01_1405	0	0	1
R02_1405	0,301	1	2
R07_1405	0	0	1
R08_1405	0,301	1	2
R11_1405	0	0	1
R12_1411	0,477	1	3
R13_1411	0,458	0,96	3

7.2 Appendix B

Appendix B1: Species composition of woody plants aboveground as recorded from the fallow fields and remnant forest vegetation. Where 1 = species present in the field and where 0 = species absent from the field.

Species	Fallow	Remnant
Acacia erioloba	1	1
Acacia erubescens	1	0
Acacia fleckii	1	1
Acacia hebeclada	1	0
Acacia karoo	1	0
Acacia mellifera	1	0
Acacia tortilis	1	0
Baikiaea plurijuga	1	1
Baphia massaiensis	1	1
Bauhinia petersiana	1	1
Berchemia discolor	1	0
Boscia albitrunca	1	0
Burkea africana	1	1
Combretum engleri	1	0
Combretum collinum	1	1
Combretum imberbe	1	0
Combretum zeyheri	1	1
Croton gratissimus	1	1
Croton pseudopulchellus	1	0
Datura inoxia	1	0
Dialium engleranum	1	1
Dichrostachys cinerea	1	1
Dichapetalum cymosum	1	0
Diospyros lycioides	1	1
Erythrophleum africanum	1	0
Grewia avellana	1	1
Grewia bicolor	1	1
Grewia falsistipula	1	1
Guibourtia coleosperma	1	1
Gymnosporia senegalensis	1	1
Hyphaene petersiana	1	0
Ochna pulchra	1	1
Ozoroa okavangoensis	1	1
Ozoroa schinzii	1	1
Pechuel-loeschea leubnittziae	1	0
Peltophorum africanum	1	0
Philonoptera nelsii	1	1

Piliostigma thonningii	1	0
Pseudolachnostylis dekindtii	1	0
Pterocarpus angolensis	0	1
Schinziophyton rautanenii	1	0
Sclerocarya birrea	1	0
Securidaca longepedunculata	1	1
Searsia tenuinervis	1	1
Strychnos cocculoides	1	1
Terminalia prunioides	1	1
Swartzia madagascariensis	0	1
Terminalia sericea	1	1
Ximenia amricanum	1	1
Ziziphus mucronata	1	0

Appendix B2: Species composition of the seeds of woody plants as recorded from the soil seed bank on fallow fields and remnant forest vegetation. Where 1 = species present in the field and where 0 = species absent from the fields.

Species	Fallow	Remnants
Acacia erioloba	1	0
Acacia mellifera	1	0
Acacia nigrescens	1	0
Baikiaea plurijuga	1	1
Burkea africana	1	0
Combretum engleri	1	0
Combretum collinum	1	1
Combretum zeyheri	1	0
Grewia avellana	1	1
Guibourtia coleosperma	1	0
Pterocarpus angolensis	1	0
Schinziophyton rautanenii	1	1
Terminalia prunioides	1	0
Terminalia sericea	1	1
Ziziphus mucronata	0	1

7.3 Appendix C

Appendix C: The number of individual woody plants recorded per field and per growth form (coppices, seedlings, shrubs, trees). Where AF = fallow fields and where RE = Remnant forest vegetation.

Fields	**Coppices**	**Seedlings**	**Shrubs**	**Trees**	**Grand Total**
AF01	4	8	4	1	17
AF02	19	77	22	2	120

AF03	7	114	49	12	182
AF04			3	3	6
AF05			12	2	14
AF06					
AF07	98	362	26	1	487
AF08	207	69	26		302
AF09	25	47	8		80
AF10	38	90	107	1	236
AF11	48	47	75	3	173
AF12	9	19	47	2	77
AF13	12	160	130	1	303
AF14			3		3
AF15	4	31	99		134
AF16	13	30	54	2	99
AF17	27	78	96		201
AF18	16	82	85		183
AF19	50	73	12		135
AF20		57	12		69
AF21		140		1	141
AF22		240	2	2	244
AF23	1	169	31		201
AF24		136	30		166
AF25		16	12		28
AF26		99	11		110
AF27		31	10		41
AF28		89	33	1	123
AF29		67	1		68
AF30		17	16		33
AF31		62	17		79
AF32		7	6		13
AF33		29	1		30
AF34		49	21		70
AF35		11	22	1	34
AF36	17	22	25		64
AF37	39	81	19	2	141
AF38	2	370			372
AF39	18	41	1		60
AF40	5	88	1	5	99
AF41		45		1	46
AF42		295	6	43	344
AF43	1	118	13	2	134
AF44		60	7	1	68
AF45		26		1	27
AF46	11	28	11	1	51
RE01	9	97	14	1	121

RE02	10	6	49	8	73
RE03	31	83	68	13	195
RE04	9	12	67	5	93
RE05		6	59	15	80
RE06	1	15	26	20	62
RE07	3	7	42	12	64
RE08		11	50	7	68
RE09		35	42	5	82
RE10		9	37	14	60
RE11	6	24	34	5	69
RE12		3	36	7	46
RE13		3	58	9	70
Grand Total	**740**	**3991**	**1748**	**212**	**6691**

7.4 Appendix D

Appendix D: Seed guide for the Master's Thesis in Natural Resource Management

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Namibian University of Science and Technology 2015

Contents of content

7.4.1. Introduction

The seed phase is the most important stage in the life cycle of higher plants with respect to its survival (Finch-Savage and Leubner-Metzger 2006). The seed is the structure, in which a usually fully developed plant embryo is dispersed. The seed enables the embryo to survive the period between seed maturation and seedling establishment (Koornneef *et al.* 2002). Therefore the function of the seeds is to ensure the initiation of the next generation. Additionally, seeds are the results of sexual reproduction in flowering plants that involve the production of male and female gametes.

During seed collections, for the MSc. in Natural Resource Management a seed guide was developed to assist students to identify the seeds, their dormancy state and where possible how to treat them before germination. The list only consists of species that were collected from Mashare constituency but it is not exhaustive. Seed dormancy is an important state most seeds undergo hence it will be discussed in the following paragraphs.

7.4.2 Seed dormancy

The seeds of most plants are able to survive extended periods of conditions because it becomes dormant before it germinates. The core action of the growth potential of the embryo and the restraints caused by the surrounding tissues determines the ability of seeds to be dormant and to germinate (Koornneef *et al*., 2002). Seed dormancy is define as the incapacity of a viable seed to germinate under favourable conditions (Baskin and Baskin 1998). Therefore seed dormancy prevents immediate/early germination on the parent plant (Murdoch and Ellis 2000) as well as at times when the chance of the survival of the plant to maturity is poor. There are seed types without dormancy which are termed non-dormant.

In the woodlands dormancy is treated by livestock through ingestion. The digestive system of the animals serves as an aid in breaking the dormancy through seed scarification of some species (Cowling *et al.* 1997). Seeds of legume species such as the *Acacia* species, *Baphia massaiensis, and Bauhinia petersiana* are mostly grazed by cattle. Such seeds contain hard seed coat showing physical dormancy, which is treated by the animal digestive system. The digestive system contains microorganisms that triggers microbial fermentations and digestive enzymes (Venier *et al.* 2012). As results these processes alter seed coats promoting mechanical or chemical scarification increasing germination probability. Seed death can also occurs as the microbial fermentations and digestive enzymes can damage the embryo (Fenner and Thompson 2005). However the effect of seed passages through a digestive tract of herbivores depends on the permeability of the seed coat (Venier *et al.* 2012). Therefore seed survival after ingestion by herbivores has been related to seed mass, shape, and coat thickness.

Baskin and Baskin (2004) distinguished four types of dormancies:

1) Physiological dormancy

Seeds undergo physiological inhibiting mechanisms of germination the embryo is fully developed but dormant (Baskin and Baskin 1989). The seed first has to after-ripen passing through a series of conditional dormancy before it becomes non-dormant. This type of dormancy is very common (Baskin and Baskin 2004). When unfavourable environmental conditions are experienced by seeds in this category it goes into secondary dormancy (Baskin and Baskin 1998).

2) Physical dormancy

Seeds contain impermeable seed coat or pericarps, as results of the seed coat preventing imbibition by water even though the embryo is fully developed and non-dormant (Baskin & Baskin, 1998).. The embryos are fully developed and non-dormant (Baskin and Baskin 1989). Therefore the embryo remains dry till the seed coat is broken (Baskin and Baskin 2004). The hard seed coat of species with physical dormancy germinate in late spring, summer and autumn can become permeable with the aid of high temperature and high fluctuations of temperature. In the same way low winter temperature soften seed coats of species germinating in early spring (Baskin and Baskin 1998). Also with elevated temperatures the seeds are able to detect when the environment is suitable for growth (Baskin and Baskin 1998).

3) Morphological dormancy

Seeds that portrays this type contains undeveloped embryos in terms of size, but has developed cotyledons and hypocotyl-radical (Differentiated). Embryos need time to grow and germinate (Baskin and Baskin 2004). As soon as the embryo development is complete and seeds are dispersed germination is likely to occur if requirements are met (Baskin and Baskin 1989). Seeds in this category need light for embryo growth and such seeds only stay in the soil for few months (Baskin and Baskin 1998). That is why when the environment is stable, dormancy only occurs as a result of haphazard local disturbances (Fenner and Thompson 2005).

4) Morphophysiological dormancy

The seed embryos are underdeveloped (size) and they also have physiological dormancy. Seeds need to be treated with warm and cold stratification or make use of GA to break dormancy (Baskin and Baskin 2004).

5) Combinational dormancy

The seeds contains both Physical and Physiological dormancy, which means seeds contain impermeable seed coats and dormant embryos. The seeds need to after ripen as well as seed coats needs to be treated (sand paper, nicking and pricking). The order on how treatment should be done is species specific (Baskin and Baskin 2004). Seeds in this category need cold temperatures to overcome embryo dormancy (Baskin and Baskin 1998).

7.4.3 The list of species, the dormancy and possible treatments

1. **Family**: Arecaceae **Species***:* *Hyphaene petersiana,* **Dormancy**: Morphophysiological, **Seed treatment**: Seeds need after-ripening and Scarification.

2. **Family**: Anacardiaceae **Species**: *Ozoroa okavangensis*
Dormancy: Physiological dormancy **Seed treatment**: Moist pre-chill or preheat or dry after-ripening (FAO 1994).

3. **Family**: Anacardiaceae **Species**: *Sclerocarya birrae*
Dormancy: Physical and Physiological dormancy **Seed treatment**: First treat the Physical dormancy and then subject seeds to cold stratification for few weeks for seeds to after ripen. Good results obtained from seven to eight months old seeds (Von Teichman *et al.* 1986).

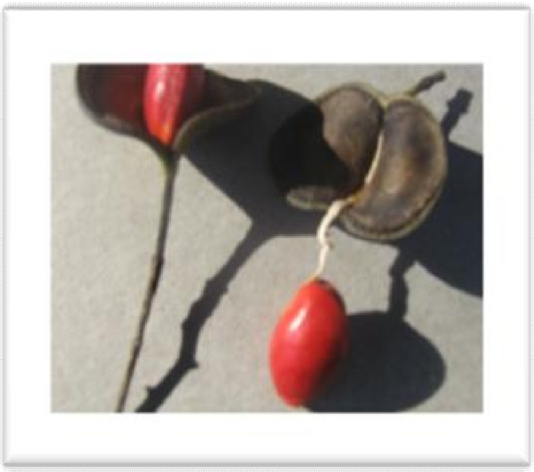
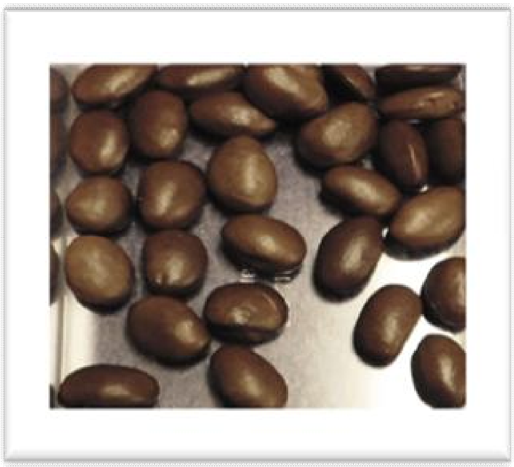
4. **Family**: Anacardiaceae **Species***: Searsia tenuinervis*
Dormancy: Combinational Dormancy **Seed treatment**: Seeds need after ripening. Heating create blisters which further creates a slit for water to penetrate (Baskin and Baskin 2004).

5. **Family**: Caesalpinioideae **Species***: Baikiaea plurijuga*
Dormancy: Combinational Dormancy **Seed treatment**: Seeds sown directly in containers produced germination rates of 80-90% (Joker and Jepsen 2003). According to Joker (2003) pre-treatment by soaking the *B. plurijuga* seeds in 80°C hot water for 2 minutes is recommended. The author also found 80-90% germination rates in harvested seeds of 7-25 days. It is important that

seedlings are transplanted one or two weeks after germination as the tap root grow faster (Joker 2003).


6. **Family**: Caesalpinioideae **Species**: *Bauhinia petersiana* **Dormancy**: Physical **Seed treatment**: Scarification by nicking, sand paper and pricking

7. **Family**: Caesalpinioideae **Species**: *Guibourtia coleosperma* **Dormancy**: Physical No dormancy mechanism **Seed treatment**: Seeds can germinate without treatment (Moses 2012b). Studies by Haita (2015) found 83% germination rate for *G. coleosperma* seeds soaked in warm water. Studies by De Cauwer and Younan (2015) found that time for germination were reduced by surface sterilization and other treatments.

8. **Family**: Caesalpinioideae **Species**: *Burkea africana* **Dormancy**: Physical, **Seed treatment**: Scarification or chemical treatment


10. **Family**: Chrysobalanaceae **Species**: *Parinari curatellifolia* **Dormancy**: Physical and Physiological **Seed treatment**: Pre-treatment by using hot water or sulphuric acid provide good results. Seeds may still take up to 6

months to germinate. Germination rates of 34% were obtained after complete removal of seed coats and storage of 60 days (Maharaj and Glen 2008)

Top Tropicals.com

11. **Family**: Combretaceae **Species**: *Terminalia sericea* **Dormancy**: Physical **Seed treatment**: Nicking and soaking in cold water for 12 h resulted in 51% germination. Gibberellic acid (GA3) resulted in 67% germination rates (Amri 2011)

12. **Family**: Combretaceae **Species**: *Combretum collinum* **Dormancy**:

Physiological **Seed treatment**: Mechanical scarification with sand paper is recommended. Germination of 85% were recorded at temperatures of 15 - 35°C using sand (Matthews and Powell 2006).

13. **Family**: Combretaceae **Species***: Combretum zeyheri* **Dormancy**: Physiological dormancy **Seed treatment**: Mechanical scarification can be done using sand paper**.** Germination 85% recorded at temperatures of 15 - 35°C using sand (ISTA 2005)

14. **Family**: Euphorbiaceae **Species***: Schinziophyton rautanenii* ''Manketti'

Dormancy: Physical and physiological **Seed treatment**: Studies by Graz (2002) recommended the moist pre-chill or hot pre-heat treatments before germination. Pricking combined with soaking were also found to improve germination (De Cauwer and Younan 2015). Graz (2003) found that seedlings S. *rautanenii* grow faster under conditions of light or moderate shade.

15. **Family**: Fabaceae **Species**: *Baphia massaiensis* **Dormancy**: Physical

Seed treatment: Pricking, nicking or scarification and soaking were found to improve germination (De Cauwer and Younan 2015)

.

16. **Family**: Fabaceae **Species***: Pterocarpus angolensis* 'Kiaat' **Dormancy**: Slight physical dormancy **Seed treatment**: According to Joker (20002) seeds

of *P. angolensis* can germinate without treatment but germination is improved by scarification. Nicking seeds were found to improve germination (De Cauwer and Younan 2015). Also soaking of seeds in cold water or in Gibberellic acids promoted germination (Chisha-Kamusu *et al*. 2007). Germination in pots using sand is recommended (Joker 2000).

17. **Family**: Tiliaceae **Species**: *Grewia avallana* **Dormancy**: Physiological **Seed treatment**: Heat scarification: constant heat exposure at

40°C for 4-6 weeks (Sohail *et al*. 2015).

18. **Family**: Tiliaceae **Species**: *Grewia bicolor* **Dormancy**: Physiological **Seed treatment**: Cold or heat scarification is recommended. Constant heat exposure at 40°C for 4-6 weeks yielded 70% germination rates (Sohail *et al*. 2015)

19. **Family**: Strychnaceae **Species**: *Strychnos cocculoides* **Dormancy**:

Physiological **Seed treatment**: Seed can be treated with fire or soaking in water to break dormancy. Studies by Williams *et al.* (2006) obtained 80% germination rates on freshly harvested seeds. Heita (2015) found that soaking *S. cocculoides* in Hydrochloric Acid yielded no germination, hence the specific chemical treatment is not recommended.

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