NAMIBIA UNIVERSITY
OF SCIENCE AND TECHNOLOGY

ASSESSMENT OF VEGETATION DIVERSITY, STRUCTURE, COVER AND THE INFLUENCE OF FIRE ALONG THE RAINFALL GRADIENT IN THE KALAHARI, EAST OF NAMIBIA USING LONG-TERM DATA

By

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DECLARATION

I, Emma Laili Kaunapawa Shidolo, declare hereby that the work contained in the thesis entitled Assessment of vegetation diversity, structure, cover and the influence of fire along the rainfall gradient in the Kalahari, east of Namibia using long-term data is a true reflection of my own original research 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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ABSTRACT

Change in climatic condition has a considerable potential to cause change in vegetation structure and functioning of ecosystems. Savanna ecosystems in southern Africa are threatened by reduced rainfalls and wet seasons, coupled with frequent and extended periods of drought. The Kalahari landscape has been described as vulnerable to global climate change. Widespread remobilisation of dune fields are predicted over the next 50 to 80 years. However, there is a lack of long-term research done using empirical data to understand the dynamics of vegetation under this circumstances over a longer period of time. Therefore, the objective of this study is to assess if there was change in species diversity, richness, cover and structure of vegetation over the years within four selected permanent observatory sites located along the Kalahari basin. This is as well to determine the influence of fire and rainfall regime on vegetation.

Vegetation patterns of woody plant and grasses was assessed on four permanently established observatory site along the north south rainfall gradient, east of Namibia. A total of 368 plots found in typical Kalahari sandy soil were sampled using a Braun blanquet method between 2001 and 2016, each plot was 1000 m2. The changes in woody and grass cover was assessed using 95th percentile trend-lines and driving factors were determined by ordinations using the Non-metric multidimensional Scaling.

The one-way ANOVA revealed a significant changes in the decreasing Shannon-Wiener diversity index and species richness along the study area and within specific sample sites over the years. These changes were corresponding to the decreasing rainfall patterns recorded. Furthermore, there was a strong shifting movement observed in the arid vegetation distribution which was advancing further up the north-eastern region, despite it being recognised as an open woodland savanna area due to high rainfall. The shrub vegetation for both broad-leafed and fine-leafed was increasing over the years through the study area, which caused a decrease in grass cover due to high shrub-grass competition for resources. Reduced cover could make the unconsolidated Kalahari top soil highly vulnerable to soil erosion by either wind or water. Consequently, this could trigger remobilization of dune and altering of the landscape. Eventhough long-term monitoring of vegetation in Namibia is a fairly recent concept, the results of this research advocates the importance of such studies as ways of providing us with

information for conservation and planning purposes in response to threats caused by climate change.

Key words: Fire, Species richness, Rainfall, Kalahari basin, Vegetation

DEDICATION

This thesis is dedicated to my loving family, your encouragement and support is what kept me working hard. More especially I would like to dedicate this thesis to my grandmother. kuku Emma Laili, I thank God for keeping you with us, that you may see us achieve our dreams.

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ABBREVIATIONS AND ACRONYMS

asl.	Above sea level
Ave.	Average
BIOTA	Biodiversity Transect Analysis in Africa
FAO	Food and Agriculture Organization
GCM	General Climate Model
GCMs	General Circulation Models
GPS	Global Positioning System
IDH	Intermediate Disturbance Hypothesis
IUCN	International Union for Conservation of Nature
LDC	Livestock Demonstration Centre
AR	Annual Rainfall
mnths	months
MWAF	Ministry of Agriculture Water and Forestry
NASA	National Aeronautics and Space Administration
NMS	Non-metric Multidimensional Scaling
NW	North West
PFA	Plant Functional Attributes
SASSCAL	Southern Africa Science Service Center for Climate Change and Adaptive Land-use Management
spp.	Species
RS	Research Station
WAMIS	Wide Area Monitoring Information System
WIND	National Herbarium of Namibia

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CHAPTER 1

INTRODUCTION

1.1 General introduction

Savanna ecosystems cover about 20% of the world's vegetated land, close to 40% of Africa's land and is the most dominating biome in the sub-Saharan region (Scheiter, 2008; Goldammer & De Ronde, 2004). Savanna are characterized by sparsely distributed trees and shrubs coexisting with extensive areas of grasslands in varying degrees (Wang, 2001; Jürgens *et al*., 2012, Moyo, 2013; Maurin *et al*., 2014; Sankaran *et al*., 2004, Scholes and Archer, 1997), this definition will be adapted for this study. The origin of savannas can be dated to over 32 million years ago from the Oligocene period and currently found spread across the world in a wide range climatic conditions (Sankaran *et al*., 2005; Moyo, 2013; Maurin *et al*., 2014).

The vegetation structure and composition and productivity of any ecosystem is determined by the availability of resources, competition for these resources amongst plant species as well as by disturbances. Moisture availability (resource) and fire (disturbance) are some of the key factors that drives and shape savanna ecosystem (Kraaij and Ward, 2006; Scholes and Archer, 1997; Moyo, 2013). The availability of moisture, positively affects the photosynthetic production, biomass production, plant growth and plant composition (Moyo, 2013). In southern African savanna, dynamics of vegetation are associated to strong shifts between and the wet and dry seasons (Wiegand, 2006). Areas with high precipitation often tend to have more biomass and species richness compared to those with less precipitation. High plant biomass production especially for grasses and herbs due to good rainfall make an area prone to fire events later during the dry periods.

A fire regime, which refers to the frequency, intensity and time of burning affects the biomass, structure and plant composition in varying degrees (Trollope, 2003; Trollope *et al*., 2002). Increase in fire frequency and intensity can cause a reduction in woody plant biomass and suppress the growth of shrubs into trees (Shoopala, 2008). This decreases the competition of resources between the woody and herbaceous plants therefore, allowing for an increase in grass cover, hence the use of fire as a rangeland management practice (le Roux, 2011). High fire frequency reduces or eliminates the presence of fire sensitive plant species, consequently creating a unique and uniform species composition within the area.

Other key factors defining savannas are soil nutrients and herbivory (Mukaru, 2011; Morkel, 2013). The complex interaction of these four factors determines the temporal and spatial ratio of coexisting woody and herbaceous plants (Christiansen, 2014; Scholes & Archer, 1997).

Thornbush and woodland savanna are two of the five distinct biomes in Namibia and occupy the largest overall area of about 65% of the land (Jürgens, 2010; Mendelsohn & el Obeid, 2005; Okitsu, 2005). The two savanna biomes are largely located within the Kalahari basin in the north to eastern part of the country. Characterised by the wet and dry seasons, the climate of the Kalahari is classified as semi-arid with average summer rainfall ranging from 350 mm – 600 mm per annum, varying along parts of the basin. In Namibia specifically, rainfall decreases from the north and north-eastern regions towards the south and south-western region.

Savanna ecosystems are important for the direct and indirect benefits they provide such as environmental regulation, supporting of biodiversity through providing food and habitat as well as providing social and economic benefits for humans (Scheiter, 2008; Shoopala, 2008). Particularly people in communities that are highly dependent on their natural resources. Thornbush and woodland savanna in the north-east provide wood for construction materials, fuel, furniture production, grazing and browsing fodder and medicinal plants. However, increasing exaggerated change in climatic conditions and increased intensity in land use pose a great threat to the productivity of this savanna and the biodiversity that exist and depend on these ecosystems. There is thus a need to monitor the status of vegetation both in structure and composition over a period of time.

Emphasis on long-term monitoring of biodiversity is a fairly recent practice. However, it has been ongoing in other parts of the world for over 150 years (Broodryk, 2010). Long-term monitoring refers to examining and detecting of changes occurring over a long period of time (Broodryk, 2010). For vegetation this is done to evaluate the succession status of the communities as a result of past conditions (Pickett, 1989). This allows us to increase our understanding of vegetation dynamics in response to the complex spatial and temporal dynamics of environmental condition and human influence (Broodryk, 2010; Hamandawana, 2007; Britz & Ward, 2007; Wiegand & Jeltsch, 2000).

Most of the studies done in the two Kalahari biomes have been short-termed (Katjiua & Ward, 2012; Hamandawana, 2007). They report results of immediate vegetation response to disturbance and species list rather than vegetation trends (Burke & Strohbach, 2000). Without the necessary data over a time period, it is difficult to measure the extend and severity of vegetation change. For this purpose, permanent observatories were established along a climatic gradient under the BIOTA southern Africa project to do long-term monitoring of biodiversity (Jürgens *et al*., 2012).

The Biodiversity Transect Analysis in Africa (BIOTA) project was initiated in 1999, focusing on long-term monitoring of biodiversity using a multidisciplinary approach, with the aim to conceptualize strategies for sustainable rangeland management (Jürgens *et al*., 2010; Kangombe, 2010). The southern Africa BIOTA north - south transect has 35 permanently marked and standardized monitoring sites (observatories) that runs from Cape Town in South Africa to the Kavango west region in the north-east of Namibia (Figure 1). The observatories are placed along a climatic gradient from high winter rainfall at Cape Town to moderate summer rainfall in the Kavango west. At some points along the transect, two observatories were established close each other and used to determine and monitor the influence of land-use (Strohbach, 2013; Jeltsch *et al*., 2010; Kangombe, 2010; Pröpper *et al*., 2010).

Figure 1: The southern Africa BIOTA transect with location of the different observatories (Source: Jürgens *et al.*, 2010)

1.2 Statement of the problem

Although 193 parties of the Convention on Biodiversity including Namibia have agreed to the conservation of biodiversity, this task still remains a challenge (Kangombe, 2010, Jürgens *et al*. 2010). Lack of research to understand the evolution and dynamics of biodiversity in Namibia, is the biggest obstacle in achieving conservation goals. Thornbush and woodland savannas are the largest biomes in Namibia (Mendelsohn & el Obeid, 2005), and the main source of livelihood for rural communities in north-eastern regions. The productivity and functioning of these two biomes is however facing tremendous pressure from exaggerated climatic conditions and increased land use (Haarmeyer *et al*., 2010) in the area.

A majority of southern Africa is threatened by a decrease in rainfall (Hamandawana, 2008; Hamandawana, 2007; Steenkamp & Bosch, 1995). In Namibia rainfall seasons in the north-east are becoming short and with increased variability (Kangombe, 2010). In addition there are evidence of increasing atmospheric temperature (Mapaure, 2013; Midgley, *et al*., 2005) that will increase the evaporation, as a result reducing moisture available to plants (David *et al*., 2005). The Kalahari landscape has been described as especially vulnerable to global climate change. General Climate Model (GCM) simulations predict wide-spread re-mobilisation of dune fields in the Kalahari over the next 50 to 80 years (David *et al*., 2005), which includes the thornbush and woodland savannas in the north and eastern part of Namibia. Dune movements will mainly be attributed to the loss of vegetation cover due to reduced soil moisture.

Although fire is a natural event in savanna ecosystems, the frequency of uncontrolled fires has increased in the north eastern region over the year due to human activities (le Roux, 2011). Adversely destroying grazing fields, thatching grass, woodlands and habitat. General Circulation Simulation Models (GCMs) for Namibia suggest that climatic change and increase in fire frequency would cause arid vegetation increase cover by 20% toward the north-east by the year 2050. Both models foretell devastating outcomes that could put immense limitations on the present use of these savanna ecosystems. This study was done to evaluate the status of vegetation within four permanent observatories namely: Mile 46, Mutompo, Sonop and Sandveld located in the Kalahari basin, north-east Namibia. Outcomes of the study provide information that can be used to influence decision making and amending policies concerning rangeland management as well as creating adaptive vegetation management plans within the area.

1.3 Objectives, Research questions and Hypothesis

The specific objectives were:

i. To compare the species diversity and species richness within study sites over the years.

ii. To assess the vegetation cover structure and composition within the study sites over the years and along the study area.

iii. To assess the impact of rainfall and fire occurrence on vegetation.

The study aims to answer the following questions

i. Is there a difference in the species diversity, species richness within the study sites over the years?

ii. What vegetation trends occurred within the various study sites and along the study area over the years in terms of cover, structure and composition?

iii. What influence does rainfall and fire occurrence have on vegetation within the study area?

The working hypothesis for the study was:

Null hypothesis

i. Suggest that the ongoing change in rainfall pattern and fire frequency does not have an impact on the nature of vegetation within the various observatory sites being investigated.

Alternative hypothesis

i. Mile 46, Mutompo and Sonop observatories will have a greater change in the nature of vegetation, compared to the Sandveld observatory. Vegetation communities found in semi-arid savanna ecosystems are high dependant and influenced by the amount of rainfall they receiver, hence they will experience greater vegetation change in the case of changing rainfall pattern. However vegetation communities in arid savanna ecosystem have evolved under highly fluctuating rainfall condition, therefore they will be more stable and experience slow vegetation change. Fire frequency further intensify the impact of ongoing rainfall patterns.

CHAPTER 2

POTENTIAL FACTORS INFLUENCING CHANGE IN VEGETATION

2.1 Environmental abiotic factors

2.1.1 Climatic change

Climate change is a natural process, however the fast rate at which the world is experiencing it today is mainly a result of anthropogenic activities (Ruppel & Ruppel-Schlichting, 2013). There is a strong relation between climatic conditions, structure and functioning of ecosystems, thus is a major concern as humans depend on the services provided by these ecosystems (Pröpper *et al*., 2010; Stringer *et al*., 2009; Galvin *et al*., 2004; Scholes *et al*., 2004). Savanna ecosystems are expected to change due to modified rainfall patterns (Baudena *et al*., 2014). In Namibia changes on rainfall have been observed, annual rainfall has been decreasing over the years, nonetheless incidences of heavy rainfall has been recorded in the northern parts of the country causing floods (Barnes *et al*., 2012; Kangombe, 2010; DRFN/CSAG, 2010; Reid *et al*., 2008; Marsh & Seely, 1992). Drought years are a natural part of Namibia's climatic pattern, but they have become more frequent and more devastating over the recent years as rainfall seasons are becoming shorter and temperatures increasing causing faster rate of evaporation (Ashcroft, 2014; Barnes *et al*., 2012; Kangombe, 2010; Mendelsohn *et al*., 2002). Therefore decreasing the soil moisture available to plants and becomes a hindrance to the growth and survival of vegetation.

Weather conditions experienced today correspond with simulated scenarios using General Circulation Models (GCMs) (Mapaure, 2013). In an assessment study by Midgley *et al*. (2005), the impact of climate change on Namibia's vegetation, will bring about a significant change to the vegetation structure and species richness in 2050 and 2080. Vegetation cover and net primary productivity will be significantly reduced (Mapaure, 2013; Shoopala, 2008; Midgley *et al*., 2005; De Klerk, 2004). The arid vegetation is estimated to increase cover by about 20% towards the north-east and eastern region of the country (Adjorlolo *et al*., 2012; Thornton *et al*., 2009; De Klerk, 2004; Briggs & Knapp, 2001; Thomas *et al*., 2000; Randall, 1983).

To measure the significance of these impact by climate change about 40% of the 800 plant species used in the study for GCMs are anticipated to become critically endangered or extinct in Namibia by 2080 (Midgley *et al*., 2005). Similar simulation models have been done in other parts of the world, a study in the United States of America (USA) showed that about 40% of distribution area of coniferous forest in the USA could be replaced by savanna vegetation structure as an outcome of change in climatic conditions (Gibbens *et al.*, 2005; Bachelet *et al*., 2001).

Moisture is an important component for the survival of vegetation. In a study by Baudena *et al*. (2015) strong correlation was observed between tree cover and annual rainfall in arid African savannas receiving a mean annual precipitation of 650 mm or less per year. This also applies for vegetation in general (Angassa, 2016), in reality the plants don't necessarily depend on rainfall but rather on soil moisture. Soil moisture refers to the amount of water between the pores of soil particles that is available for take up by plants (Angassa, 2016). The relationship between the two is that in the absence of other environmental condition, rainfall and soil moisture are positively correlated.

2.1.2 Fire

Fire is recognized as one of the key factors maintaining and shaping the African savanna ecosystems in forest supporting climatic conditions areas (Bond *et al*., 2005; Maurin *et al*., 2014, van der Wall, 2005; Du Toit, 1995, le Roux, 2011, Bond and Midgley, 2003). Naturally southern African savanna experience a fire incident every 1 or 3 years depending on build-up of fuel (Mannheimer & Curtis, 2009; Mendelsohn & el Obeid, 2005). In the Kalahari most of the fire events occur during the dry winter months between April and October. The distinct wet-dry seasons of semi-arid savanna ecosystem produce rhythmic environmental conditions that favours fire events to occur (Pricope & Binford, 2012; Scholes & Walker, 1993; Le Roux & Morris, 1977). The rainy season promotes fuel growth and the dry season creates conducive condition for burning (Shoopala, 2008; Sheuyange *et al*., 2005; Goldammer & De Ronde, 2004).

This regime has been occurring over thousands of years within the savanna ecosystem therefore, and would be expected for vegetation to have adapted survival mechanism towards this disturbance (Shoopala, 2008; Goldammer & De Ronde, 2004; Scholes & Walker, 1993). Subsequent to change in climatic conditions and the influence of human activities, the fire regime in the north and eastern parts of the country could change (Angassa, 2016; le Roux, 2011; Strohbach & Petersen, 2007). Numerous studies have been done to try and understand the influence of various fire properties on vegetation, however very few have been done in the fire prone north eastern region of Namibia.

According to Scholes & Walker (1993), fire regime is defined as a description of fire type, its intensity, seasonal occurrence and frequency. The intensity of fire is influenced by fuel load. Fine fuel load such as grass and herbs dry out very easily and have good aeration (Scholes & Walker, 1993), they burn rapidly with low intensity, a scenario common in grasslands (Goldammer & De Ronde, 2004). Coarse fuel loads such as thick branches and logs dry slowly. They burn for longer periods and with high heat intensity, this are the type of fires common in thornbush and woodland savannahs (Goldammer & De Ronde, 2004; Trollope, 1978). The occurrence and intensity of fire is also influenced by the climatic conditions, high rainfall and high relative humidity can prevent or reduce the heat intensity of fire.

Effects of fire frequency on species richness and diversity

Fire occurrence is regarded as a disturbance in vegetation ecology (Krebs, 1994). It reduces plant species diversity, by removing fire-intolerant species. At the same time, like herbivory, it also increases species diversity by creating open niches for colonizing (Shoopala, 2008). According to the Intermediate Disturbance Hypothesis (IDH) (Tanner *et al*., 1996; Connell *et al*., 1984; Grime, 1984; Grime, 1979), it is assumed that species diversity will be highest at moderate disturbance frequency. This means few individuals of existing species are lost as a result of either disturbance, interspecific or intraspecific competition, while creating space for new species.

A study by Roxburgh *et al*. (2004) found that the IDH is not just about occupying open niche by new species but is also influenced by the response of species to occurring disturbances. This findings were supported by an assessment done by Peterson & Reich (2007), which found that a biennial fire only increased richness for herbaceous plants while it decreased richness of woody plants.

Effect of fire frequency on vegetation cover, structure and composition

High fire frequency causes an increase in herbaceous plant biomass by increasing sunlight reaching the understory and increasing soil fertility (Goldammer & De Ronde, 2004; Scholes & Archer, 1997). High fire frequency stunt the growth of woody shrubs (De Klerk, 2004; Snyman, 2002; Tainton, 1984; Trollope & Tainton, 1986), but promotes the growth of trees due to low fire intensity as frequent fire reduce fuel load. Shoopala (2008) observed a similar trend in the Hamoye state forest. High abundance of tall trees and little abundance of shrub vegetation were found in high fire frequency zones (Pricope & Binford, 2012) and (Ashcroft *et al*., 2011) also got similar findings.

The season in which the fire occurs has an influence on how plants respond. Herbaceous plants were found to increase their biomass if fire occurs just before the rainy season, whereas the biomass of woody plant was reduced in a similar period (Hudak *et al*., 2004; Dublin *et al*., 1990). In other studies the exposure of *Themeda triandra* to fire in autumn reduced its biomass more than in comparison to burning in winter and spring, whereas *Tristachya leucothrix* responded in the opposite manner (Goldammer & De Ronde, 2004; Bond & Van Wilgen, 1996). Woody plant species such as *Pterocarpus angolensis* grew thick insulating bark and keeps underground carbohydrate storage systems that allow it to survive and coppice after the fire (Shoopala, 2008; Graz, 2004; Krebs, 1994). Encroaching species of *Acacia mellifera*, *Dichrostachys cinerea* and *Terminalia prunoides* are very sensitive to fire, for this reason they are either absent or have very low abundance in fire prone areas (O'Connor *et al*., 2014; Pricope & Binford, 2012; Christian *et al*., 2010; De Klerk, 2004; Pratt & Knight, 1970).

2.2 Resources utilization

2.2.1 Land use

Land use is the biggest cause of biodiversity loss in southern Africa (Pröpper *et al*., 2010). In the north-east, large areas of vegetation have been cleared for agricultural purposes, posing as the biggest threat to biodiversity in the area (Propper *et al*., 2010). The size of land cleared in the Kavango regions increased from 26 140 ha in 1943 to 94 550 ha 1996 (Propper *et al*., 2010). The continuous increase in human population puts increasing pressure to expand agricultural and livestock production, and therefore increases area of land use change (Mendelsohn & el

Obeid, 2005; Propper *et al*., 2010). A survey in Alex Muranda LDC observed clear difference in vegetation structure between areas inside and outside of the LDC (Strohbach & Petersen, 2007). The shrub cover of the *Pterocarpus angolensis-Guibourtia coleosperma* woodland and Acacietea vegetation types were low outside the LDC and increased towards the western part inside the LDC (Strohbach & Petersen, 2007). Other paired observatories established are the Ogongo - Omano goNdjamba & Gellap Ost – Nabaos. Each pair is found on a vegetation habitat type, but each observatory having a different land-use. These paired observatories have been observed to show a difference in species richness over the years (Schmiedel *et al*., 2010). The intensity or change of land use has also been reported to backtrack or enhance ecological processes such as succession status and altering foraging quality of the vegetation. This can occur by changing the ratio of plant life forms (structure) or species cover.

Four observatories were selected for this study. Mile 46, Sonop and Sandveld observatories are all found on fenced off state owned farms. The Mile 46 observatory is situated on Alex Muranda Livestock Development Centre and was established in 1980 as a demonstration farm for livestock breeding of the Sanga cattle (Haarmeyer *et al*., 2010). Adjacent to Mile 46 is the Mutompo observatory, located in the same woodland, but on communal land. The surrounding communities of Epingiro and Mutompo utilize these communal woodlands for activities such as crop field and communal grazing for their livestock, both small (goats) and large (cattle) (Haarmeyer *et al*., 2010; Pröpper *et al*., 2010). For this reason, the observatory is also used to assess the impact of land-use within the dry woodlands of Okavango (Strohbach & Petersen, 2007). Both Mile 46 and Mutompo observatories are situated in a fire prone area and experience frequent fire events. Alex Muranda LDC has fire breaks along its borders, this enables evaluations on fire exclusion in the Mile 46 observatory, compared to the Mutompo observatory which has no fire control mechanism (Haarmeyer *et al*., 2010).

Sonop Research Station like Alex Muranda LDC has breeding programmes for the Nguni and Sanga cattle breeds. The centre is also used to conduct trails for game management on behalf of the Ministry of Environment and Tourism, hence the presence of giraffe, eland, kudus and warthogs in the research centre (Haarmeyer *et al*., 2010; personal obs. Shidolo E., 2015). In addition to monitoring of climate change impact, the Sonop observatory is used as a control plot to assess the vegetation recovery progress of adjacent sites that were cleared (Haarmeyer *et al*., 2010). The stocks of cattle from Alex Muranda and Sonop are both used for recruitment into cattle populations of small-scale and commercial farms. The Sandveld observatory is situated on the Sandveld Research station that was established in the 1960s. In 1984, the centre began to be used as a research station to assess the impact of long-term grazing intensity of cattle on the vegetation (Haarmeyer *et al*., 2010).

Effect of wood harvesting on vegetation cover, structure and composition

Harvesting of trees pose as a threat to the woodland savannas in the Kavango regions (Haarmeyer *et al*., 2010; Pröpper *et al*., 2010; Mendelsohn & el Obeid, 2005). According to Mendelsohn & el Obeid (2005) *Burkea africana*, *Pterocarpus angolensis*, *Baikiaea plurijuga*, *Terminalia sericea* and to a lesser extent *Guibourtia coleosperma* are the most sought after trees for wood harvesting. The harvested wood is used for construction material, fencing posts, fuel and in some case for charcoal production (Chidumayo & Gumbo, 2010; le Roux, 2011). According to Strohbach & Petersen (2007), the abundance of these species is very low in the Alex Muranda LDC, and becomes very rare on the outside of the fence (Propper *et al*., 2010; Strohbach & Petersen, 2007). Unsustainable harvesting of *Baikiaea plurijuga* and *Pterocarpus angolensis* has led to the two being declared “Near Threatened” adapted under the IUCN Red List Categories version 3.1. (2001) (Pröpper *et al*., 2010; Loots, 2005).

Traditionally most of the houses in north-eastern part of Namibia are made out of wood (Chidumayo & Gumbo, 2010; Cunningham, 1993). Research by Cunningham (1993) found that a single palisade fence surrounding the main homestead was made of approximately 7 700 poles in the northern parts of Namibia. About 500 large tree stems and 9000 small sticks were used for fencing, in total a homestead would use on average 21 600 poles (Cunningham, 1993). In Botswana firewood is the main source of fuel used, on average an urban house would use 2 230 kg of firewood per year while a rural house would use 4 820 kg of wood per year (Chidumayo & Gumbo, 2010). Although not at a similar scale fuel wood is still regularly used in the rural communities in Namibia. In the Oshana and Omusati region *Coleophospermum Mopane* is popularly harvested for fire wood due to its dense matter and good coal production (Kangombe, 2010 and Mannheimer & Curtis, 2009)

Hardwood harvesting alters the structure of the vegetation community, promotes transition of woodlands to shrubland savannas (Privette *et al*., 2004; Scholes *et al*., 2002), by reducing the tree cover. In a case of intense harvesting, it reduces the species richness (Hüttich, 2011) and can alter plant composition by changing the microclimate below the canopy. According to Sankaran *et al*., (2005), reduced tree cover triggers an increase in herbaceous cover and species richness due to reduced competition for sunlight. Trees and shrubs do not really have a direct relation, so species richness and composition for shrubs tend to remain unchanged.

Effect of herbivory of vegetation

Herbivores help to shape and maintain the savanna ecosystems (van der Waal, 2005; Du Toit, 1995). They affect vegetation in multiple ways by trampling on plants, altering the soil nutrient content and defoliating plant (Morkel, 2013; Barnes, 2001). The difference in ratio of grazing to browsing animals in the Kalahari is great, in favour of grazers (Chidumayo & Gumbo, 2010). Disturbance by grazing causes change to the herbaceous layer as animals remove and reduce biomass of palatable grasses and herbs (Mukaru, 2009; Todd & Hoffman, 1999). Grazing also leads to an increase in species richness by opening up niches for recruitment (Hanke *et al*., 2014; Morkel, 2013; Wesuls *et al*., 2013), or reduce the richness depending on the intensity (Morkel, 2013; Chistiansen, 2014). Extreme continuous grazing due to poor management, results in perennial grasses being replaced by annual grasses that are less palatable and resistant to grazing (Sweet & Burke, 2006; Reid *et al*., 2004; De Klerk, 2004; Tainton, 1999), (Enkono *et al*., 2013). Preferred grasses like *Panicum maximum* and *Anthephora pubescens* are replaced with less preferred grasses like *Eragrostis pallens* and other *Eragrostis* species, as well as *Aristida* spp (Tainton, 1999).

Browsers reduce biomass of trees and shrubs by defoliating them, where as in other cases like elephant, the whole plant is uprooted (Heilmann *et al*., 2006; de Beer *et al*., 2006). This feeding behaviour of elephants can covert forests and woodlands into open grassland savanna ecosystems and potentially alter the plants composition (Mapaure, 2013; de Beer *et al*., 2006; Cumming *et al*., 1997). Small and medium sized herbivores on the other hand have no immediate effect on the composition, but rather just reduces the cover of woody plants. Herbivory can also cause change in vegetation indirectly by allowing sunlight to reach the ground for herbaceous plant, and increase soil temperature that can promote seed germination

(Gaujour *et al*., 2012; Ford & Grace, 1998). Herbaceous plant tolerant to sunlight begin to grow, while the intolerant herbs die off.

Impact of long-term herbivory, is clearly observed in areas around permanent water points. A study on large herbivores on vegetation at the Waterberg plateau (Mukaru, 2009), showed that plant density, cover, diversity and richness were significantly lower close to the water point where the animals spend most of the time (Fensham *et al*., 2005;). The piosphere was degraded by large herbivores by trampling and over-utilizing the vegetation (Mukaru, 2009 and Puttick *et al*. (2014)). In a study at Fort Beaufort, Puttick *et al*. (2014), observed that similar piosphere effects were observed in areas of human settlement as a result of land use. Once over-utilization of vegetation has occurred, exclusion of herbivores helps for the land to recover, however the reduced land productivity allows encroaching of invasive woody plants (Enkono *et al*., 2013).

CHAPTER 3

MATERIALS AND METHODS

3.1 Overall study area

The study was done on four observatories: Mile 46 (S01), Mutompo (S02), Sonop (S03) and Sandveld (S41) situated in the north-eastern part of Namibia. They belong to the BIOTA Southern Africa transect established under the BIOTA project, the first three (S01, S02 and S03) are part of the transect running from northeast of Namibia to the Cape Peninsula in South Africa, and the fourth observatory (S41) is part of the transect (Figure 1), that runs across Namibia form the west to the east. The study transect runs along the rainfall gradient along the Kalahari basin (Figure 2).

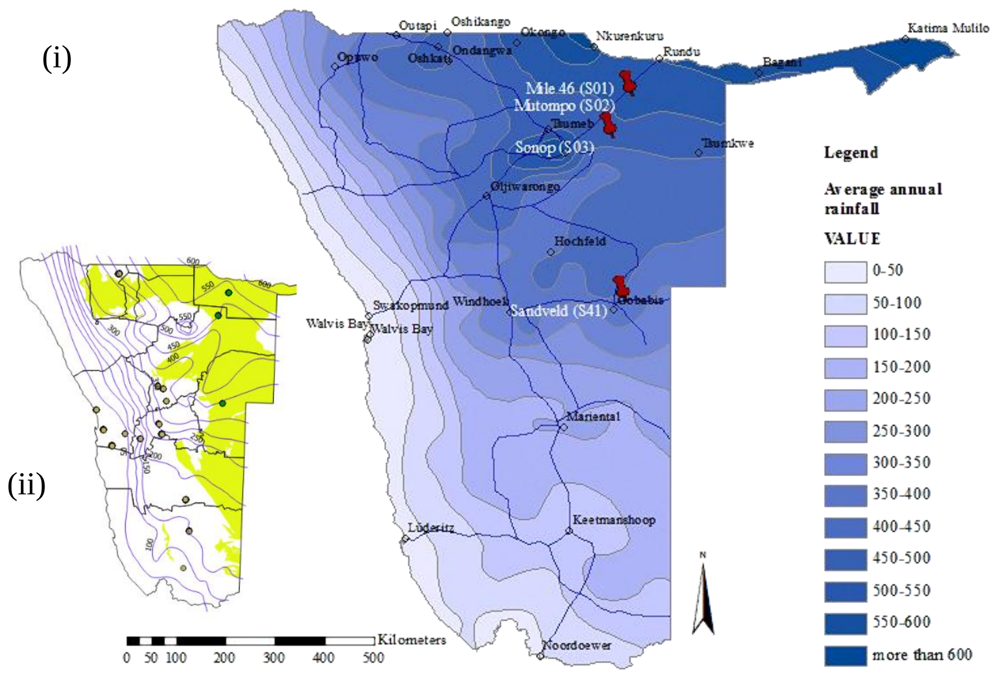

Figure 2: (i) An average annual rainfall of Namibia exhibiting a decline from the north-east to the south-west and physical location of observatories under study, (ii) shows spatial distribution of the Kalahari basin (B. Strohbach, 2016).

3.2 Observatories

3.2.1 Mile 46 and Mutompo observatory

Location and physical environment

Mile 46 and Mutompo are paired observatories situated about 65 km south-west of Rundu in the Kavango west Region. The pair is separated by a fence, on the western side of the fence is the Alex Muranda Livestock Development Centre (LDC), host of the Mile 46 observatory owned by the state under the Ministry of Agriculture, Water and Forestry, operating since 1985. On the eastern side of the fence is communal land which hosts the Mutompo observatory. The Mile 46 observatory lies at 18° 18' 8.05"S; 19° 14'52.20"E (NW corner), while Mutompo observatory lies at 18° 18' 8.03"S; 19° 15'32.19"E (NW corner), both observatories are about 1180 m above sea level (Haarmeyer *et al*., 2010).

Soil and geology

Dune remnants in Mile 46 and Mutompo observatory have an east-west orientation. Although the dune ridges have been subjected to erosion over the years, valleys between dune ridges are still visible, with a height difference of about 10 m and a distance of ± 800 m between ridges.

In Mile 46 the soil is dominated by ferralic Arenosol with association of petric Calcisols, (FAO, 1998; Petersen, 2008), with a depth of more than 2 m. The soil has a pale brown colour as a result of poor accumulation of humus. Above ground is a layer of litter mainly made up of leaves and grass. The soil is acidic with pH of 5 and below, and it becomes more acidic with depth. Content of organic carbon is higher especially in the inter-dunal loamy soil, owed to the accumulation of organic matter (Haarmeyer *et al*., 2010).

In Mutompo the soil type is dominated by ferralic Arenosols with a single profile of stagnic Regosols (FAO, 1998; Petersen, 2008), representing the presence of a pan. Additionally, the dark brown greyish soil colour is an indication of high organic carbon content in the soil, which is much higher than that of Mile 46. The soil is acidic, with an average pH value of 5.6 (Haarmeyer *et al*., 2010)

Climate

According to the findings of the BIOTA project, mean annual rainfall is about 527 mm, with peaks in January/February. Temperature can range from a minimum of -1.8°C in the winter, to a maximum temperature of 43.9°C in summer, with a mean atmospheric temperature of 22.6°C. Because of the high temperatures, mean annual potential evapotranspiration is high about 1340 mm. The prevalence of these conditions results into a high relative humidity of 84%. Occurrence of wind is observed throughout the year, however strong wind occurs between May and August, blowing in the south-easterly direction (Haarmeyer *et al*., 2010).

Vegetation

The two observatories belong to the north-eastern Kalahari woodland savannah (Mendelsohn & el Obeid, 2005). Vegetation in Mile 46 consist of closed woodland, open bushland and thickets. Closely related to the soil patterns, the woodlands consist of trees like *Pterocarpus angolensis*, *Guibourtia coleosperma* and shrubs like *Diplorhynchus condylocarpon*, *Ochna pulchra* and *Strychnos* spp. growing in the deep sandy soil. The *Acacia fleckii-Brachiaria nigropedata* community also found in the deep sand and acts as an ecotone between the woodland and the thickets. Dense stands of *Bauhinia petersiana* and large grass cover of *Schmidtia pappophoroides* and *Digitaria seriata* are observed. In the inter-dunal valley supports *Acacia* thickets comprised of species like *Acacia luederitzii* and *Croton gratissimus* (Haarmeyer *et al*., 2010).

Figure 3: An example of the *Pterocarpus angolensis*-*Guibourtia coleosperma* woodland community in Mile 46 observatory. (Photo: E. Shidolo, 2015)

Vegetation in Mutompo follows a similar pattern as that of Mile 46 vegetation, whereby tree species of *Pterocarpus angolensis, Burkea africana* and *Schinziophyton rautanenii* as well as shrub species of *Ochna pulchra* and *Strychnos* species are found in the deep sands. The open bushland is characterised by *Bauhinia petersiana*, *Acacia fleckii* and high grass cover of *Brachiaria nigropedata*, *Eragrostis rigidor*, *Stipagrostis uniplumis* and *Schmidtia pappophoroides*. The thickets in the inter-dunal valleys are dominated by species like: *Dichrostachys cinerea, Acacia mellifera* and *Mundulea sericea* (Haarmeyer *et al*., 2010; Strohbach & Peterson, 2007). The two observatory sites are classified as part of the Zambesian Baikiaea woodlands ecoregion (Strohbach & Peterson, 2007).

Figure 4: An example of the *Pterocarpus angolensis*-*Guibourtia coleosperma* community in Mutompo. (Photo: E. Shidolo, 2015)

3.2.2 Sonop

Location and physical environment

The Sonop observatory established in 2001 on Sonop Research station is a state owned farm. It is found about 120 km north-east of Grootfontein in the Otjozondjupa region at 19° 04’ 27.42”S; 18° 54’15.72”E (NW corner), and at an altitude of about 1236 m asl.

Soil and geology

Undulating fossil dunes are very obvious in Sonop. The dunes have height difference of about 20m, with an east-west orientation. The soil profiles of Sonop consist of well drained deep sands going down up to more than 2 m. Constituted by a multiple of soil types, the northern part of the observatory is made up of rubic Arenosol moving towards the east-west direction, followed by the haplic Arenosol in the middle and then the haplic Cambisol on the southern border (Petersen, 2008; Kutuahupira *et al*., 2001). In addition, two calcrete pans exist in the southwestern part. The nutrients content in the top soil are low, but micronutrients such as iron, copper and zinc are high. The soil is also acidic, with a mean pH value of 5.3 (Haarmeyer *et al*., 2010).

Climate

Strong rainfall seasons occur between December and March, with a mean annual rainfall of 498 mm. The highest record of 837 mm was observed in 2006 (Haarmeyer *et al*., 2010). A minimum temperature of -1.5°C, and a maximum temperature of 43°C was observed, as well as a mean annual temperature of 23.1°C between 2001 and 2009. Mean annual potential transpiration and maximum mean relative humidity, like Mile 46 is high with 936 mm and 82% respectively. Strong winds occur between June and October, with a south-westerly direction (Haarmeyer *et al*., 2010).

Vegetation

The observatory belong to the north-eastern Kalahari woodland savanna (Mendelsohn & el Obeid, 2005). The observatory has two vegetation units: The *Terminalia sericea-Combretum collinum* community (deep sand vegetation) and the *Acacia mellifera-Eragrostis rigidor* community (thornbush savanna). On the deep sands of the dunes some broad-leaved tree species like *Pterocarpus angolensis* occur, which are dominated by lower trees of *Terminalia sericea* and *Combretum* species. The thornbush savannah in the interdunal slopes is subdivided further into two units: *Acacia luederitzii-Brachiaria deflexa* and *Acacia erioloba-Ozoroa paniculosa* community (Haarmeyer *et al*., 2010).

Figure 5: An example of the *Terminalia sericea-Combretum collinum* community at Sonop observatory, typical vegetation in the deep sands. (Photo by: E. Shidolo, 2015)

3.2.3 Sandveld

Location and physical environment

The observatory is situated on the Sandveld Research station in the Omaheke region north east of Gobabis, at 19° 04' 27.42"S; 18° 54'15.72"E (NW corner), resting at about 1523m asl. The research station was opened in 1968, working with both small and large livestock, and belongs to MAWF.

Soil and geology

A direct translation of the observatory name, Sandveld is located on Kalahari sandy plains. The plains are dominated by two soil types, diagonally from the center towards the south-west is the rubic Arenosol and in the opposite direction towards the north–east is the brunic Arenosol, a typical sandy soil in the area. Several small pans are found on the south western border of the observatory giving prevalence to weak petric Calcisol (Haarmeyer *et al*., 2010).

The texture of the soil is mainly silt and some clay. Presence of clay is associated with high organic matter in the top soil, however organic carbon content and nitrogen decrease with soil depth. Like the other sites the soil is also acidic, with a mean pH of 6.0 (Haarmeyer *et al*., 2010).

Climate

Categorised as semi-arid, Sandveld receives an average rainfall of 404 mm per annum, the highest rainfall of 545 mm was recorded in 2008 (Haarmeyer *et al*., 2010). Temperature can reach a maximum of 40.2°C in the hottest days and a minimum of -6.5°C in cold days. The mean annual potential evapotranspiration is estimated to be around 1369 mm, the highest amongst the four study sites, and a mean relative humidity of 47%. The wind speed is relatively uniform throughout the year, blowing in the south-easterly direction (Haarmeyer *et al*., 2010).

Vegetation

Two vegetation types occur in the observatory, the *Acacia mellifera-Eragrostis trichophora* community and the *Terminalia sericea-Acacia erioloba* community. The *Acacia mellifera-Eragrostis trichophora* unit occurs in the southern part of the observatory, with *Grewia flava*, *Acacia hebeclada* and *A. erioloba* forming a dense shrubland. The second unit is a shrubland characterised by *Terminalia sericea*, *Dichrostachys cinerea* and grasses of *Stipagrostis uniplumis* and *Schmidtia pappophoroides* (Strohbach & Luther-Mosebach, 2010).

Figure 6: An example of the *Terminalia sericea-Acacia erioloba* community, found in the Sandveld observatory. (Photo by: E, Shidolo, 2015)

3.3 Data collection

Each BIOTA observatory has an area of 1 km^2 (1000 m x 1000 m), with boundaries oriented towards the northern direction. Each observatory was further divided into one hundred 1-hectare plots of equivalent to 100 m x100 m. All 100 plots were given location identification using the GPS, and physically marked off by putting a metal pole in the north western corner. To ensure good representation of the vegetation community, the twenty priority sampling plots were selected at random from the various habitats within the observatory using the basic d'Hondt divisor method (Jürgens *et al.*, 2010). To accommodate research of other discipline the hectare plot was divided into two parts, the vegetation sampling in the northern part of the plot, and the zoological sampling in the southern part (Figure 7).

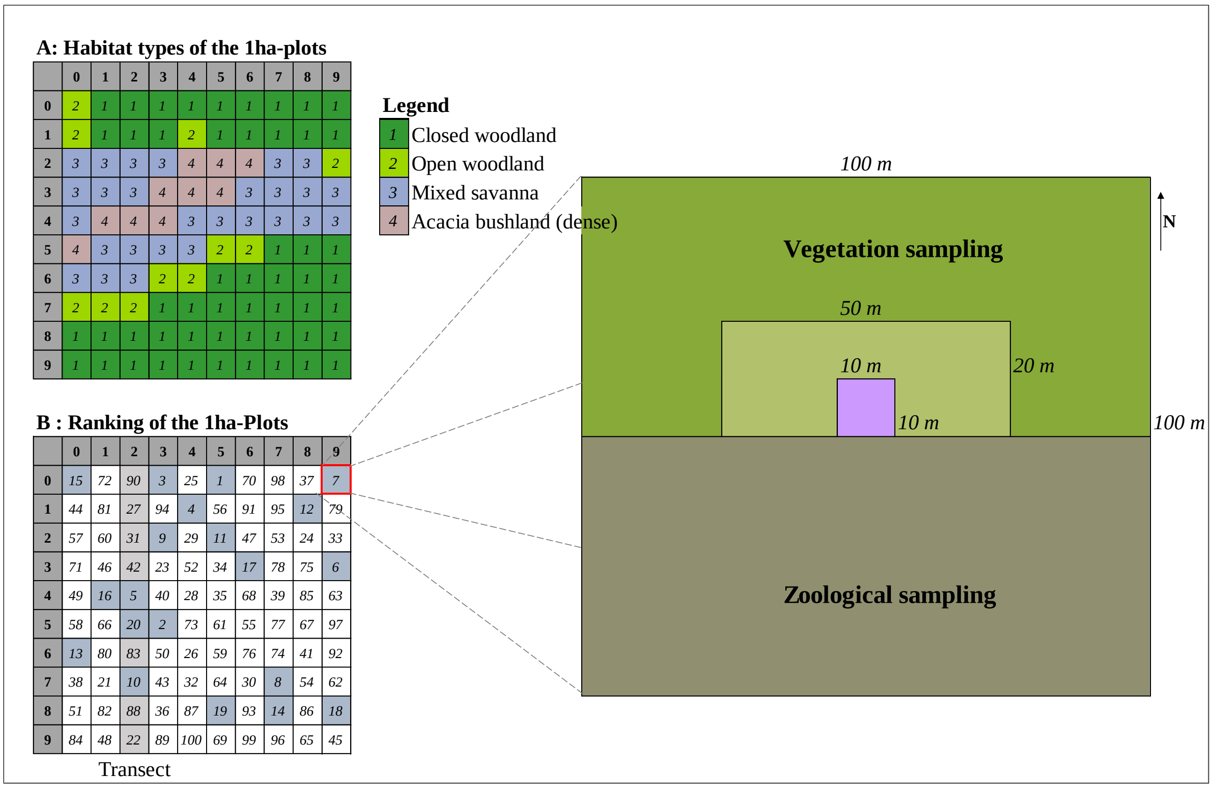

Figure 7: A schematic layout showing an example of a BIOTA observatory in southern Africa and arrangement of different sampling areas within the hectare plot, diagram A shows the borders of various habitats and B shows the placement of random sample hectare plots representing the different habitats (E. Shidolo, 2016). See actual observatory maps in Appendix 1. Not to scale.

3.3.1 Vegetation data compilation

Physiological processes of a plant are a response to the change in the environment (Bartels & Salamini, 2001; Villagra *et al.*, 2010). Vegetation in Namibia is very dependent on the rainfall (Mendelsohn & el Obeid, 2005; Mendelsohn *et al*., 2002), annual plants only appear when a certain amount of rain has been received. Because of this fact vegetation data was collected during the course of the rainy season between the months of February and April, from 2002 to 2015. During this period, most annual plants such as herbs and grasses grow and produce inflorescence, which makes it easy for fast identification and increasing the chances of encountering most species (Kangombe, 2010). The Braun-Blanquet sampling method was used to collect the vegetation data, standard sample plots of 20m x 50m were used, adapted from Vegetation Survey project of Namibia (Strohbach, 2001). The standard plot size was determined in a manner that; the size was small enough to work with, but could be used in various biomes and still give true representation of the vegetation.

At the sampling site, a 20 m x 50 m plot used, was demarcated using two 50 m and two 20 m measuring tape, attaching them to permanent marker (metal poles) in the corners (Jürgens *et al*., 2010). The person conducting the survey walked through the plot recording of all the plant species present on a vegetation data sheet (Appendix 2). The Namibian taxonomy checklist by Klaasen and Kwembeya (2013), together with field guides were used to name species, hence the use of *Acacia* instead of *Vachellia*/*Senegalia.* Once all the species were recorded, a rough estimate of ground cover was given to each species and at different height classes for the trees and shrubs species, and growth form for the herbs, expressed in percentage. Tree classes consist of high trees (>10 m), small trees (5-10 m) and low trees (2-5 m), while shrubs are grouped as small shrub (0.5-1 m) and low shrub (<0,5 m). For use in this study all trees categories were combined, and so were the shrub categories. Due to soil heterogeneity within the observatories, it was found appropriate to only use plots located on typical Kalahari sandy soils for comparison of vegetation along the study area. Eleven plots were selected at Mile 46, 10 plots at Mutompo, with 12 and 11 repetitions between 2002 and 2015 respectively. Nine plots were selected for observatory Sonop, with 9 repetitions between 2002 and 2015. Similarly at Sandveld observatory, 9 plots were 5 repetitions of data capturing done between 2005 and 2013.

Field guide books were used to identify unknown plant species however, if the surveyor could not identify a certain plant, a provisional name was assigned. A specimen was collected, pressed and dried or in a case of a rare species, a photo was taken for later identification at the National Herbarium of Namibia. Accompanying the specimen, detailed notes of features of the specimen, the location and general environmental information were taken while in the field to help with identification. After identification was done and the correct names were incorporated, data was entered into a database using the TurboVeg 2.0 software (Hennekens & Schaminée, 2001). Vegetation data collected by past surveyors was also downloaded from the data base and incorporated. In addition to the vegetation data, information about the habitat was also recorded. These included the slope, landscape type, edaphic features and disturbances.

3.3.2 Fire data compilation

Records of fire events in the observatories were very limited, however notes were made during the process of assessment as to whether there was a fire within the plot between the previous field assessment and the next. Furthermore, the data from the notes was verified using shape-files of Namibia's active and burned area from NASA (https://firms.modaps.eosdis.nasa.gov.download) and WAMIS (https://fire.uni-freiburg.de/iffn/iffn.html) websites, with the help of experts in the field. With the use of field notes, presence of fire was assigned specifically to plots that were burned.

3.3.3 Climate data compilation

Climatic data was downloaded from BIOTA (www.biota-africa.org) and SASSCAL weathernet (www.sasscalweathernet.org) websites. Mile 46 and Mutompo share one weather station placed on Alex Muranda RS (about 6 km south of the observatory) whilst, Sonop and Sandveld each has its own weather station. Relative humidity, air temperature, solar radiation, precipitation, wind speed and wind direction were recorded by the weather stations, however, for this study, precipitation was the main focus. Physiological processes of a plant are a response to the change in the environment, for example plants are expected to have more leaves, change structure and seeds to germinate after an increase in available moisture over a period of time.

Annual plants are short lived and within the study area they often only grow after some rain (Mendelsohn & el Obeid, 2005). In order to understand the influence of rainfall on both annual and perennial plants, annual rainfalls and a mean rainfalls of 3 months preceding sampling were used in the study. Example: A mean of October, November and December rainfall was used on samples done before mid-January. While a mean of November, December and January rainfall was used on samples done after mid-January.

3.4 Data manipulation and analysis

3.4.1 Plant species diversity and species richness

The species diversity for each observatory over the years was calculated using the Shannon Wiener diversity index (H') (Shannon &Weaver, 1949) using the RStudio software (RStudio Team, 2015).

$$H' = -\sum_{i=1}^{s} p_i \ln(p_i)$$

Where 's' is the number of species or species richness, 'pi' stands for the number of individuals of species divided by the total number of samples and 'ln' is the natural logarithm.

Once the species diversity and species richness for each year was calculated in RStudio, using the "vegan" package, the Shapiro-Wilke test was used to test for normality and a one-way ANOVA tests were done in Statistical Package for Social Sciences (SPSS 23) test for significant difference in diversity and richness in observatories over the years. In addition the influence of environmental factors on species diversity and species richness were determined using NMS ordination in PC-Ord 6.0 (McCune & Mefford, 2011). An autopilot was initially applied to determine the appropriate number of dimensions that interpreted the best results. A hundred runs on real data with 500 iteration, using the Sorensen distance measure were used for ordination.

3.4.2 Vegetation cover, structure and composition

A 90th percentile of vegetation cover estimate in various plant functional attributes was used to create trend lines within scatter plots to illustrated vegetation cover patterns in the individual observatories over the years. The 90th percentile was found appropriate to use as the 95th and 99th percentile values resulted into maximum vegetation cover estimate values which is influenced by the author of the data.

The density of plants in different PFA groups such as life form (grasses, shrub and trees), leaf sizes (fine and broad leafed plant) and life cycle period (annual and perennials) are highly influenced by environmental factors (Strohbach & Kutuahuripa, 2014). Classification into PFA was done based on categories by Gillison & Carpenter (1997) adapted from Strohbach & Kutuahuripa (2014). Herbs were not used in this study due to uncertainty in species identification, leading to observer bias. Detailed grouping of species is presented in Appendix 5. Therefore to demonstrate what vegetation trends occurring in individual observatories and in the overall study area, non-metric multidimensional scaling ordinations were done using PC-Ord 6.0 (McCune & Mefford, 2011). Weighed variables of various functional attributes and relevés vegetation data were used to illustrate relationships between PFA and ordination scores of relevés. Vector lines were used to determine the behaviour of vegetation change within observatories.

3.4.3 Influence of rainfall and fire occurrence on vegetation.

To determine the influence of rainfall and fire occurrence on vegetation NMS ordinations were done. All ordinations were run on Sorensen (Bray-Curtis) distance measure (Mather, 1976; Kruskal, 1964). Initial testing NMS analysis was done on slow and thorough autopilot to determine the appropriate number of dimensions (with less than 20% stress value) and starting configuration for the rest of the ordination analysis. Two-dimensions were identified as the best fitting and with the greatest variance. The number of iterations were kept at default of 500 and 100 runs were done with real data.

CHAPTER 4

RESULTS

4.1 Species diversity and species richness

The NMS ordination result showed that 87.6% of variation between the various relevés, whereby Axis 1 explained 57.9% of the variation and Axis 2 explained 29.7%

There was a strong positive correlation of mean monthly rainfall (that refers to the 3 months rainfall) and fire occurrence Axis 2. Plant species richness and species diversity (H') were highly influenced by rainfall, both were positively correlated on Axis 2. Annual rainfall is the main driving variable on Axis 1 with a positive correlation. The NMS ordination revealed that the mean monthly rainfall and presence of fire had stronger influence on species richness and species diversity compared to the actual annual rainfall. As a result clear distinct clusters of the observatories were formed in the ordination. According to the species richness and species diversity gradient Mile 46, Mutompo had higher species richness and diversity followed by Sonop and Sandveld at the lower end of the gradient. The biplot also show a shift of relevés from Mile 46, Mutompo and Sonop moving down the gradient on Axis 2 (Figure 8).

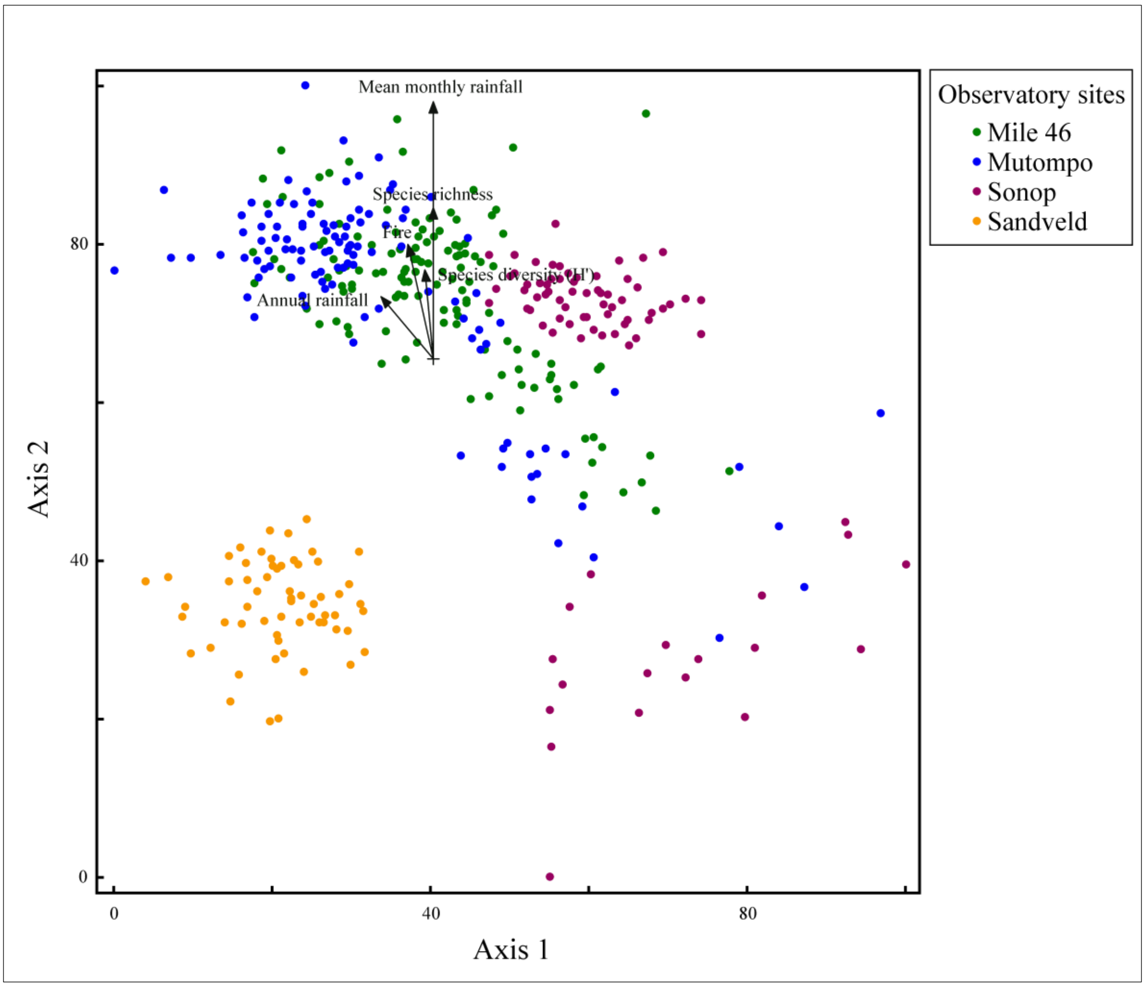

Figure 8: NMS ordination biplot showing the species richness and species diversity gradient and the influence of environmental variables on vegetation in the different observatory sites as well as for the study area in whole.

All the four observatories had a significant difference in species diversity between the years, Mile 46 ($F_{(11,120)}$=8.55), Mutompo ($F_{(10,99)}$=3.74), Sonop ($F_{(8,72)}$=10.15) and Sandveld ($F_{(5,54)}$=20.58) at a p-value less than 0.05. The highest mean species diversity (H') was observed in the Mile 46 observatory, then followed by the Sonop observatory. Species richness was also significantly different between the years on all the observatories, Mile 46 ($F_{(11,120)}$=9.16), Mutompo ($F_{(10,99)}$=4.16), Sonop ($F_{(8,72)}$=12.63) and Sandveld ($F_{(5,54)}$=21.87) at a p-value less than 0.05. Similar to species diversity, Mile 46 and Sonop observatories had the highest species richness. Species richness and diversity were both observed decreasing over the years in all the observatories (Figure 9).

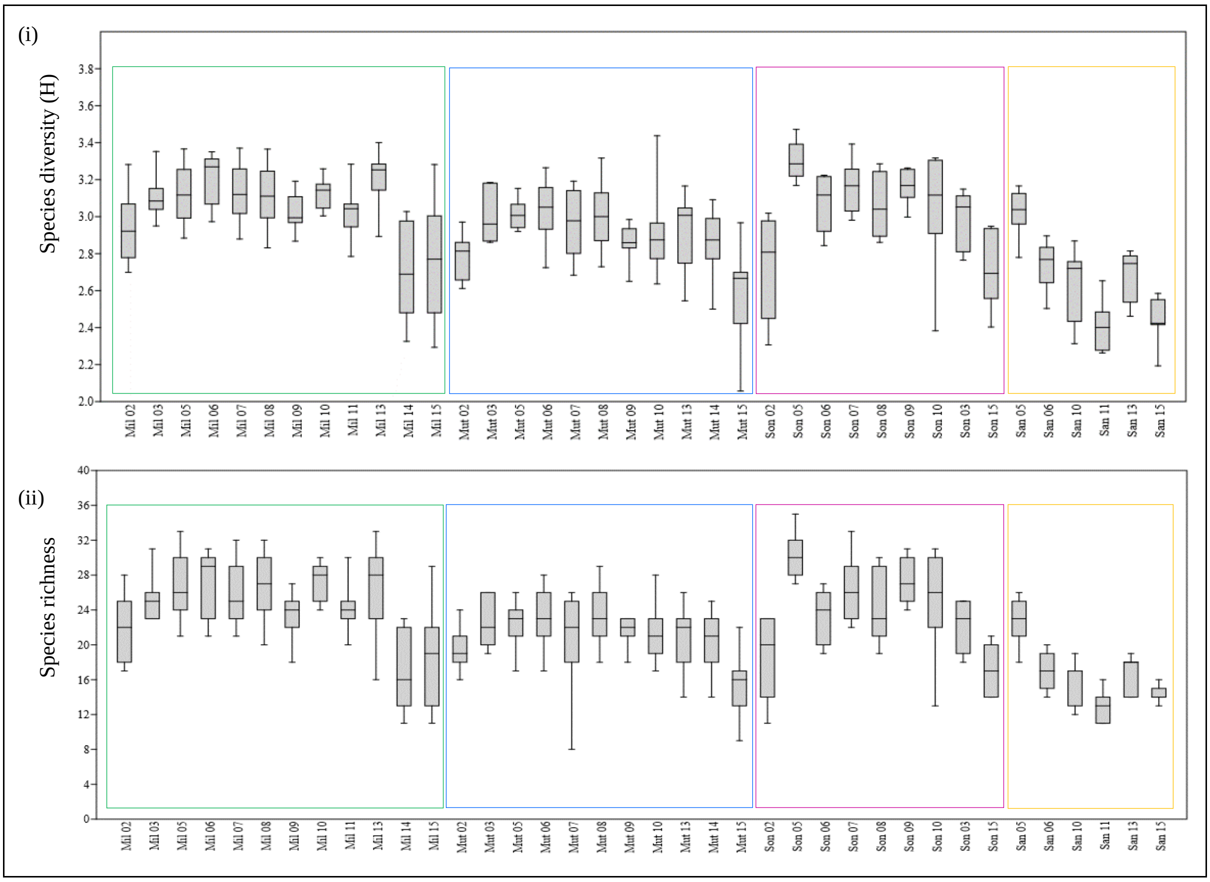

Figure 9: (i) Box and whisker plots comparing the Shannon Wiener diversity index (H') between the years in the different observatory sites and (ii) box and whisker plots comparing the species richness between the years within each observatory site.

4.2 Vegetation cover, structure and composition

NMS ordination revealed a total of 87.6% of variation between the various relevés, whereby 57.9% of the variation was explained on Axis 1 and 29.7% of variation was explained on Axis 2. There was a positive correlation of shrub cover on the Axis 1 whereas vegetation cover for tree and grass cover had a negative correlation on the same axis. On Axis 2 relevés were divided according to leaf size abundance cover, the broad leafed plants had a positive correlation, while fine leafed plants had a negative correlation along Axis 2.

A major vegetation gradient was observed in the steep change from broad leafed plants to fine leafed plants. Increase in broad leafed plant cover was observed moving toward the Mile 46, Mutompo and Sonop observatories, which are associated with higher annual rainfall as well as high mean monthly rainfall as seen in Figure 8 (Appendix 3). Towards the opposite end, the fine leafed vegetation was dominating with increasing cover towards the Sandveld observatory south of the study area The Sandveld observatory was distinctly isolated due to dominance of fine leafed plants, the observatory is associated with low annual rainfall as well as low mean monthly rainfall as seen in Figure 8 & Figure 10a. The ordination generally revealed increasing tree cover towards the Mile 46 and Mutompo observatory, increasing shrub cover towards the Sonop observatory, while grass cover was increasing in the opposite direction of increasing shrub cover.

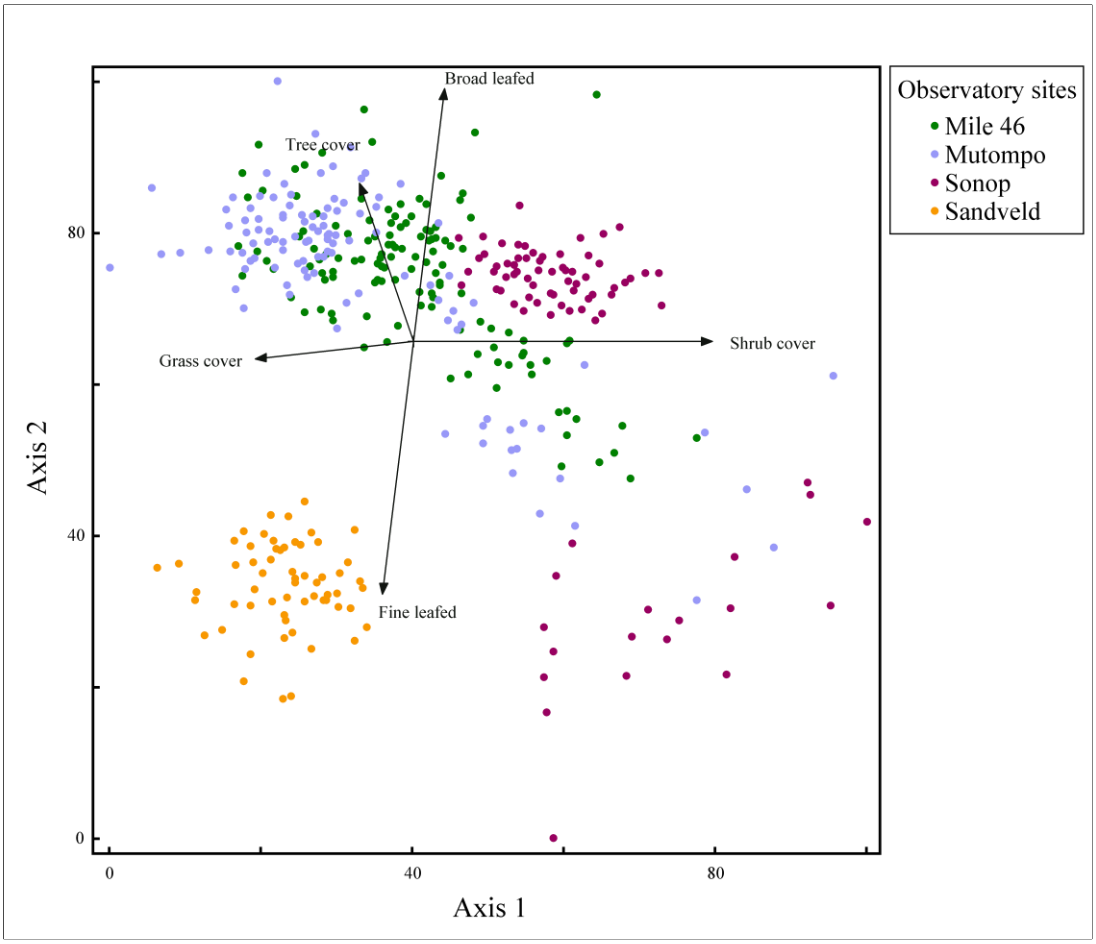

Figure 10a: NMS ordination biplot showing life form and leaf size gradients observed throughout the study area.

Ordination results also showed a shift in vegetation character for some plots indicated by vectors (Figure 10b). Some plots in Mile 46 and Mutompo observatories are shifting towards similar vegetation description as that of Sonop observatory releves, and some plots in the Sonop observatory are shifting towards similar vegetation description as that of Sandveld observatory. However, The vegetation in Sandveld observatory plots appears to be rather stable (Figure 10b).

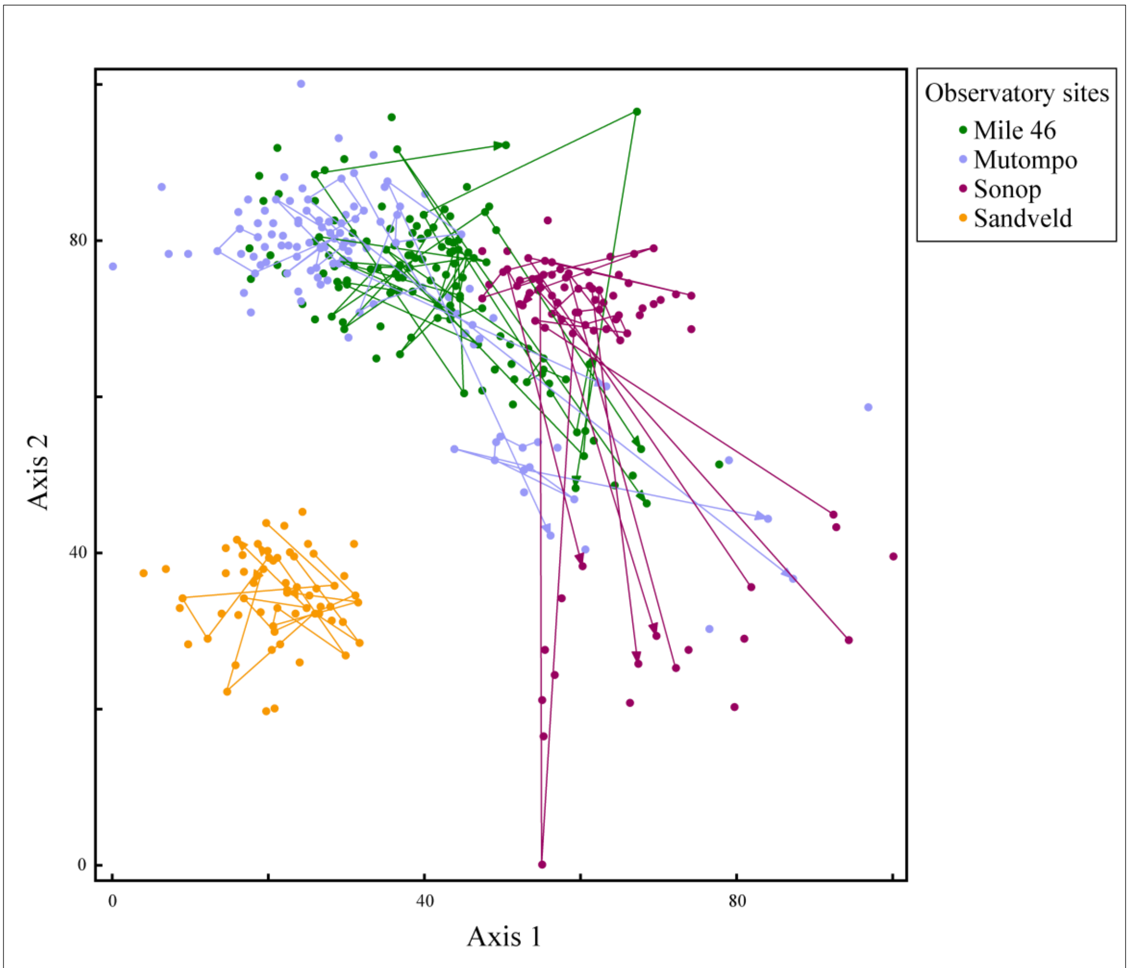

Figure 10b: NMS ordination biplot showing vectors indicate the shifting direction of vegetation in the various observatories.

Trend lines (Figure 11a) for all the observatories showed a decrease in annual rainfall, total vegetation cover and grass cover, with Sonop and Sandveld experiencing a steep reduction in annual rainfall. The mean monthly rainfall in all the observatories was decreasing over the years seen in Figure 11b. The decrease in cover positively correlates to the decrease in tree, shrubs and grass cover. However, fine leafed plants cover slightly increased in the two northern observatories (Figure 11b), more in Mutompo than in Mile 46 observatory as well as at Sandveld.

In Sonop, the total vegetation cover started decreasing in 2008 and is ongoing. This is found to be positively correlated to the decrease in tree, shrub (specifically the fine leafed woody) and grass (Figure 11 a & b Sonop). Despite the steady decrease in trees and shrubs cover at Sonop observatory, overall the broad leafed plant cover has actually been increasing slightly over the years.

Decrease in total vegetation cover in Sandveld is very slow and has been observed ongoing since the observatory was established, however in 2011 cover started to increase again. Total vegetation cover positively correlated to the increase of fine and broad leafed plant cover increase (Figure 11a & b Sandveld).

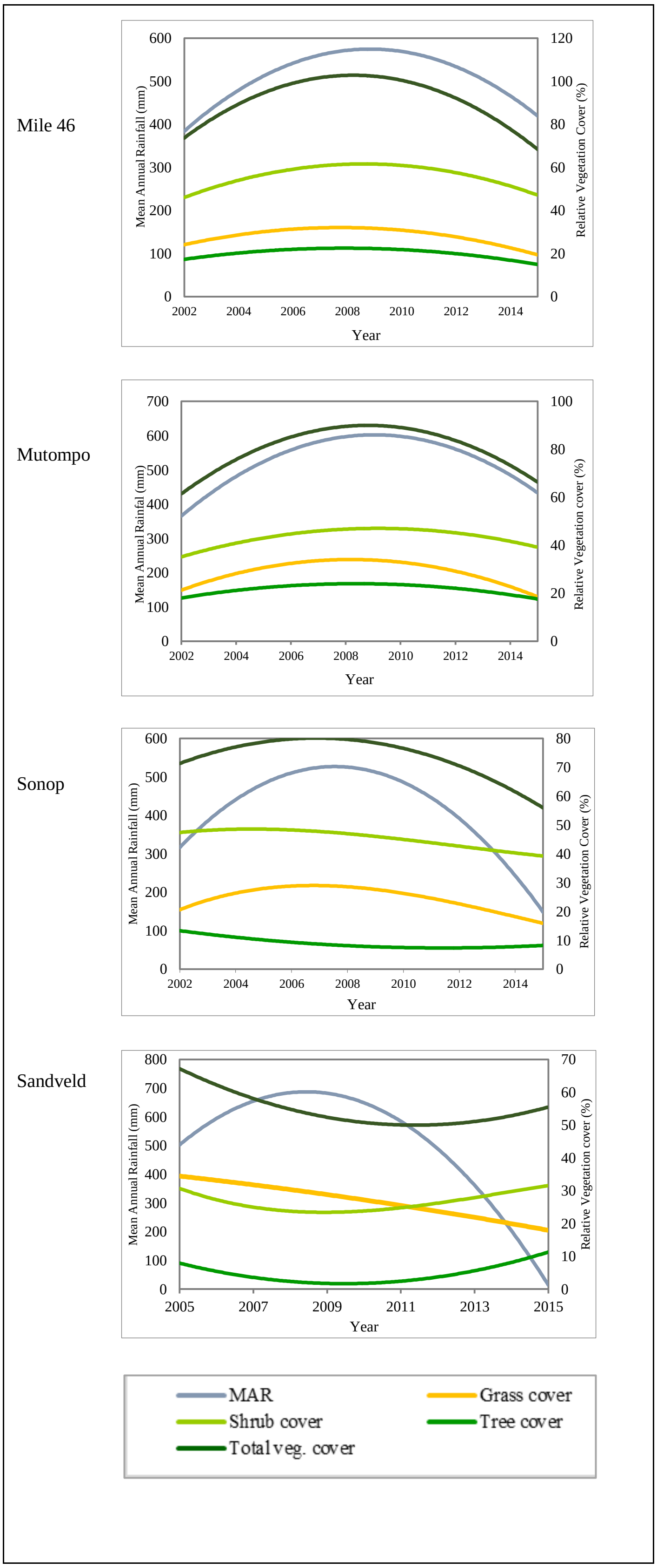

Figure 11a: Trendline plots lines of rainfall (mm) and vegetation cover (%) of plant life form in individual observatories (Mile 46, Mutompo, Sonop & Sandveld) over the study period (2002 - 2015).

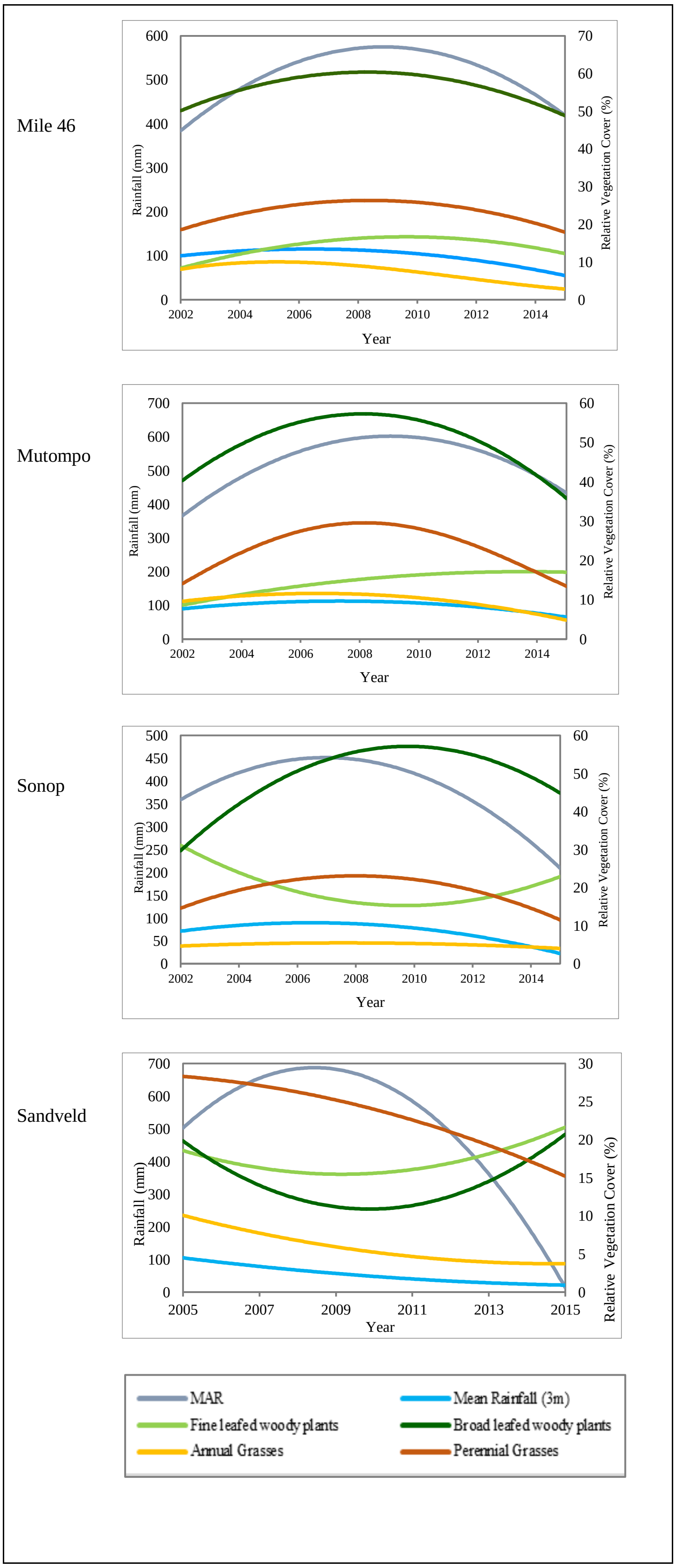

Figure 11b: Trendline plots of rainfall (mm) and vegetation cover (%) of various plant functional attributes (leaf size and life cycle period) in individual observatories (Mile 46, Mutompo, Sonop & Sandveld) over the study period (2002 - 2015).

The NMS ordination in Figure 12 depicted a strong positive correlation of annual rainfall gradient along Axis 1. The gradient captured a variation of 57.9% within the vegetation communities in the study area. Other factors on Axis 2 explained 29.7% of the variation were observed. The biplot gives clear proof of a rainfall gradient along the study area. The Sandveld observatory receives the least amount of annual rainfall which then increases by a small margin as you move towards the Sonop observatory up north. Further north, rainfall increases slightly more at the Mile 46 and Mutompo observatory area. Vegetation at Mile 46 and Mutompo observatories is more influenced and dependent on high annual rainfall in comparison to those found in the Sonop and Sandveld observatories. Therefore the rainfall gradient on Axis 1 was used in the next couple of figures to determine the relationship of annual rainfall on selected species.

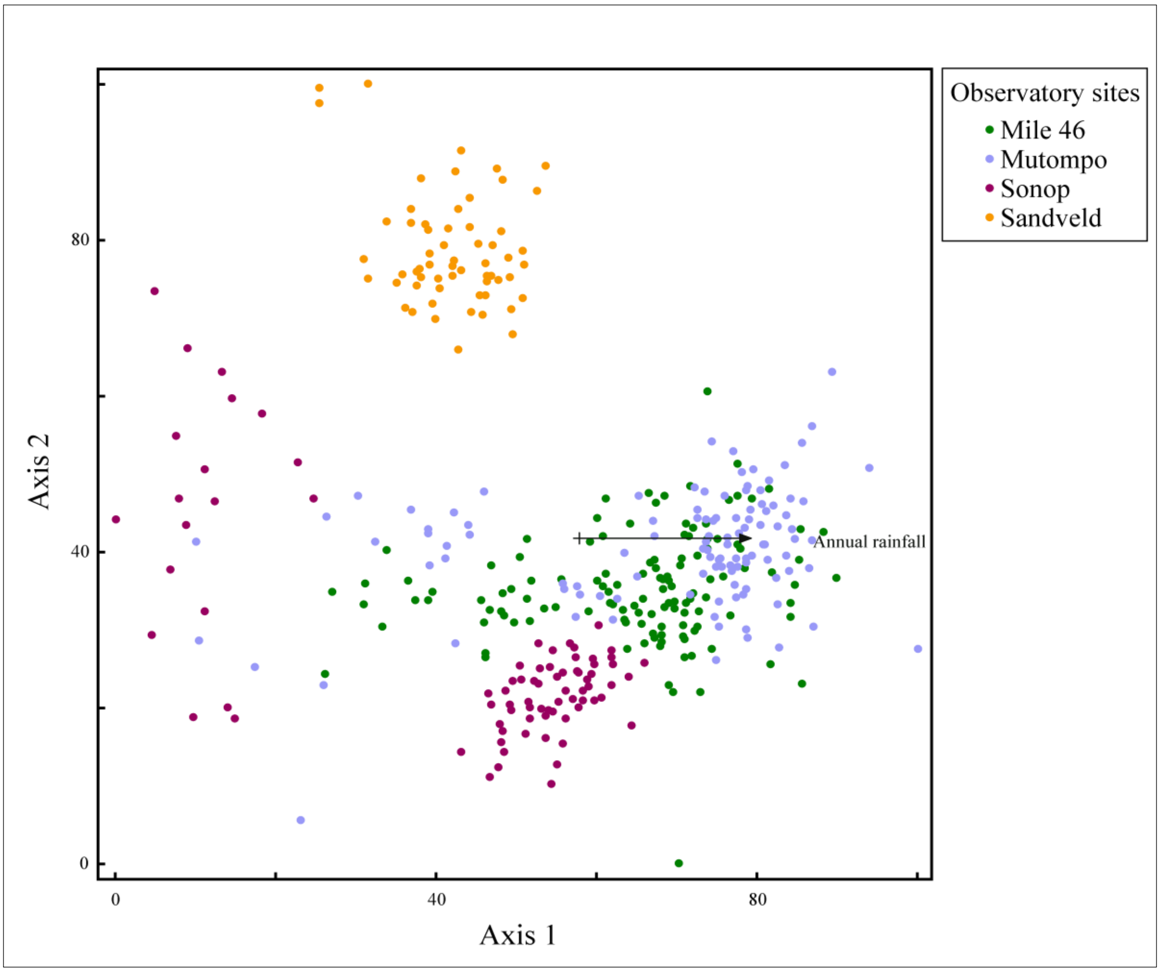

Figure 12: NMS biplot showing the influence of annual rainfall on vegetation in the different observatories and along the study area.

Annual rainfall increases roughly by a difference of 200 mm from the lowest to the highest end on the rainfall gradient on NMS ordination Axis 1. All the selected grass species were observed at all the observatory sites sampled. *Aristida stipitata* cover increased exponentially along an increasing rainfall gradient. Whereas, *Eragrostis rigidor* cover had a negative response to increasing annual rainfall. *Schmidtia pappophoroides* and *Stipagrostis uniplumis* had an increasing grass cover with a positive relationship with increasing annual rainfall. However, further increase in annual rainfall over the 450mm/yr resulted in decreased cover for the two species. *Stipagrostis uniplumis* had a steep decline in cover, while, *S. pappophoroides* had a more steady decrease in cover.

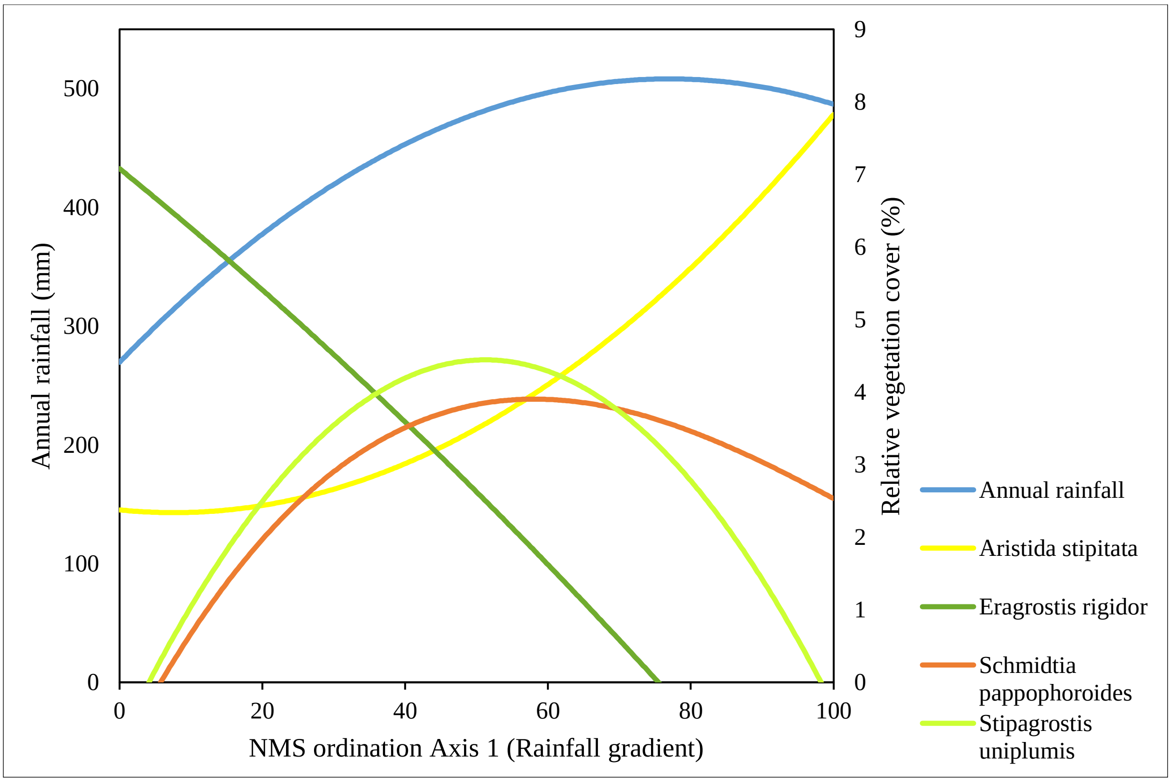

Figure 13: The response of selected perennial grass species (*Aristida stipitata*, *Eragrostis rigidor*, *Schmidtia pappophoroides* and *Stipagrostis uniplumis*) in terms of vegetative cover (%) to an increasing rainfall (mm/yr) gradient.

Acacia erioloba was observed at all the observatory sites sampled, with the highest tree and shrub cover recorded at observatory Sandveld. As depicted (Figure 14) the vegetative cover of both the *Acacia erioloba* trees and shrub greatly declined against an increase in annual rainfall along Axis 1 in the referred NMS ordinations (Figure 12).

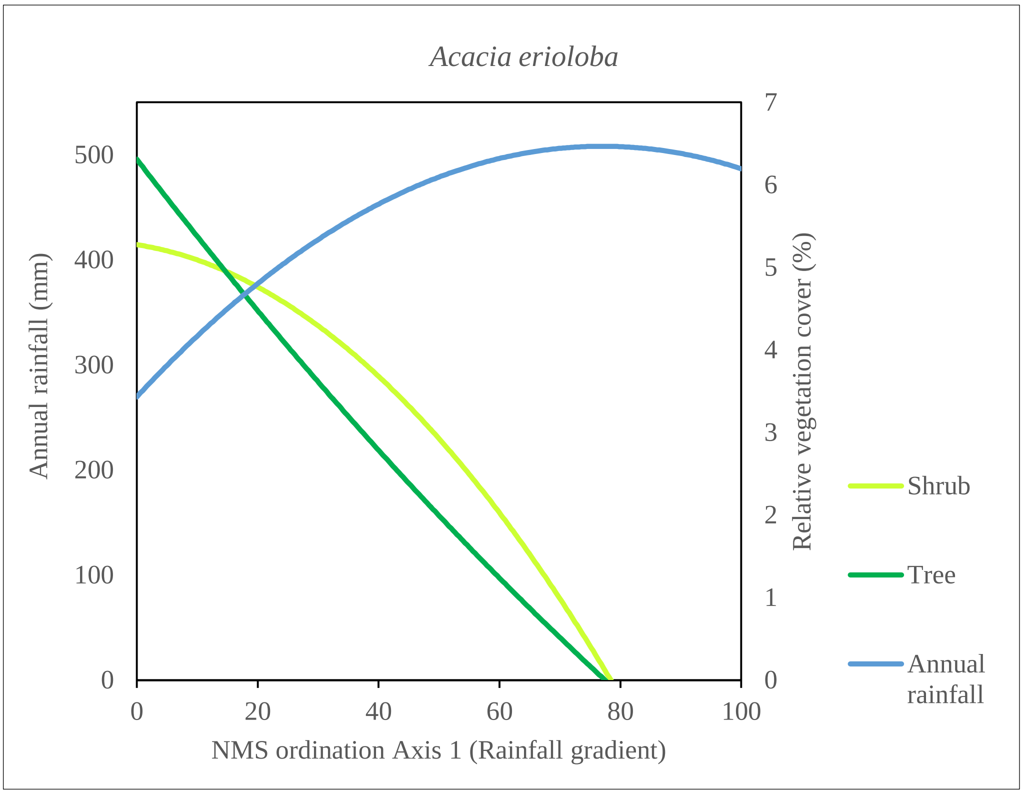

Figure 14: The respond of *Acacia erioloba* (Tree and Shrub) in terms of vegetative cover (%) to an increasing rainfall (mm/yr) gradient.

Acacia mellifera was also observed from all the observatory sites, the highest cover was recorded at the Sandveld observatory. As shown (Figure 15) both the tree and shrub cover of *Acacia mellifera* had a negative relationship with an increasing annual rainfall gradient observed on Axis 1 of the NMS ordination. Comparing the tree and shrub cover, it appears that *Acacia mellifera* shrubs were dominating by almost double the tree cover along the rainfall gradient, with an exception of high rainfall area where the *Acacia mellifera* tree cover was higher.

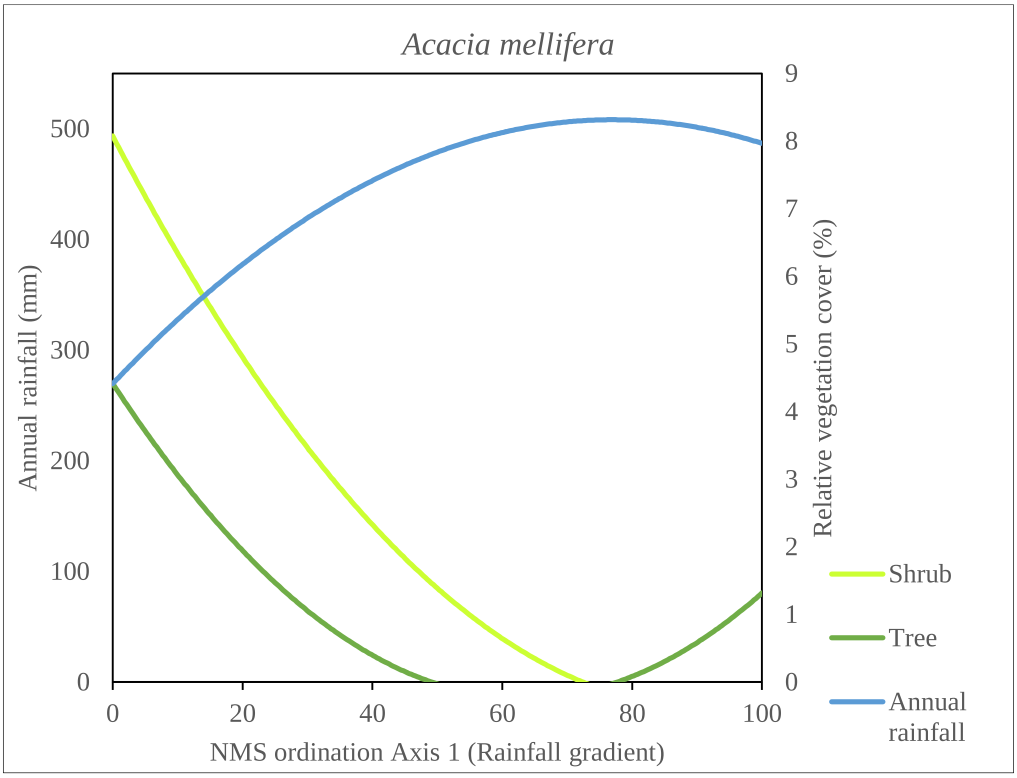

Figure 15: The respond of *Acacia mellifera* (Tree and Shrub) in terms of vegetative cover (%) to an increasing rainfall (mm/yr) gradient.

Terminalia sericea was a common species and observed in all the observatory sites sampled, the response of the trees and shrubs of this species to an increasing rainfall gradient was however different (Figure 16). Tree cover for *Terminalia sericea* was low at Sandveld which lies at the lower ends of the rainfall gradient. The tree cover however increased immensely as annual rainfall was increased toward the northern part of the study area where Mile 46 and Mutompo observatories were located (Figure 12). Similarly shrub cover for *T. sericea* was also recorded increasing as the annual rainfall increased. However, over the 450mm/yr rainfall, shrub cover of *T. sericea* began to decline.

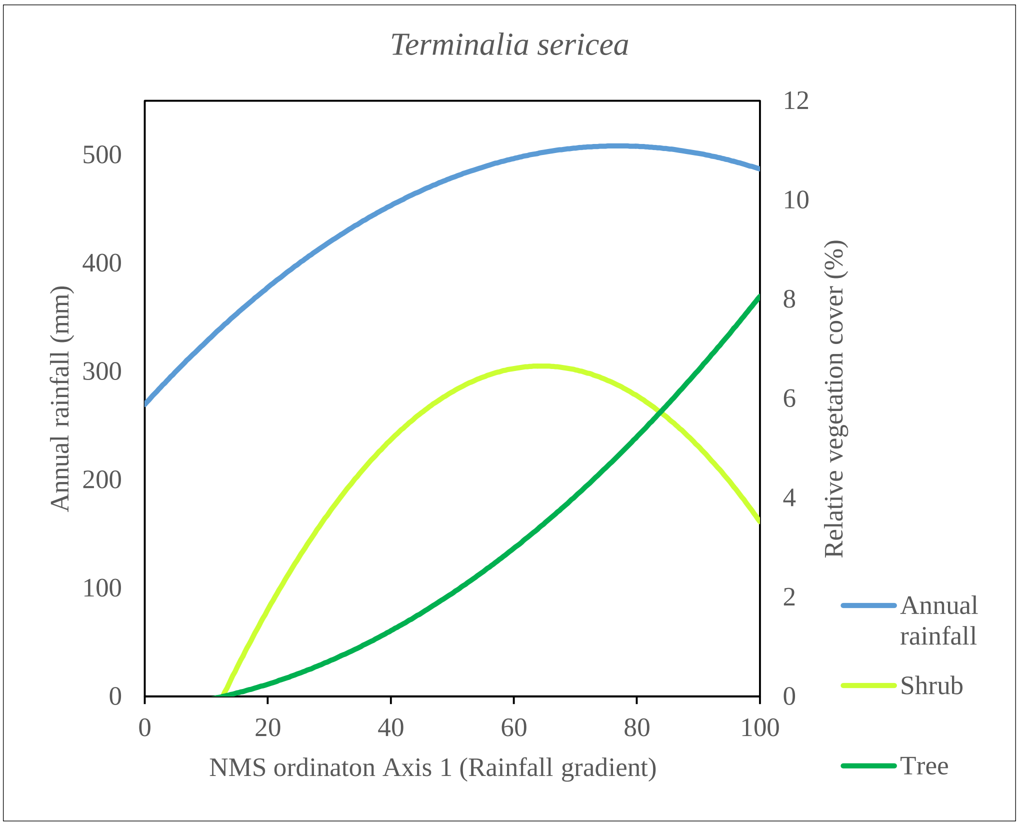

Figure 16: The respond of *Terminalia sericea* (Tree and Shrub) in terms of vegetative cover (%) to an increasing rainfall (mm/yr) gradient.

Burkea africana was observed in all the observatories with an exception of Sandveld observatory. Both the tree and shrub cover of *Burkea africana* had a positive correlation with increasing annual rainfall gradient along Axis 1 of the NMS ordination (Figure17). At high end of annual rainfall tree cover becomes more dominating in terms of vegetative cover with two folds higher than shrub cover.

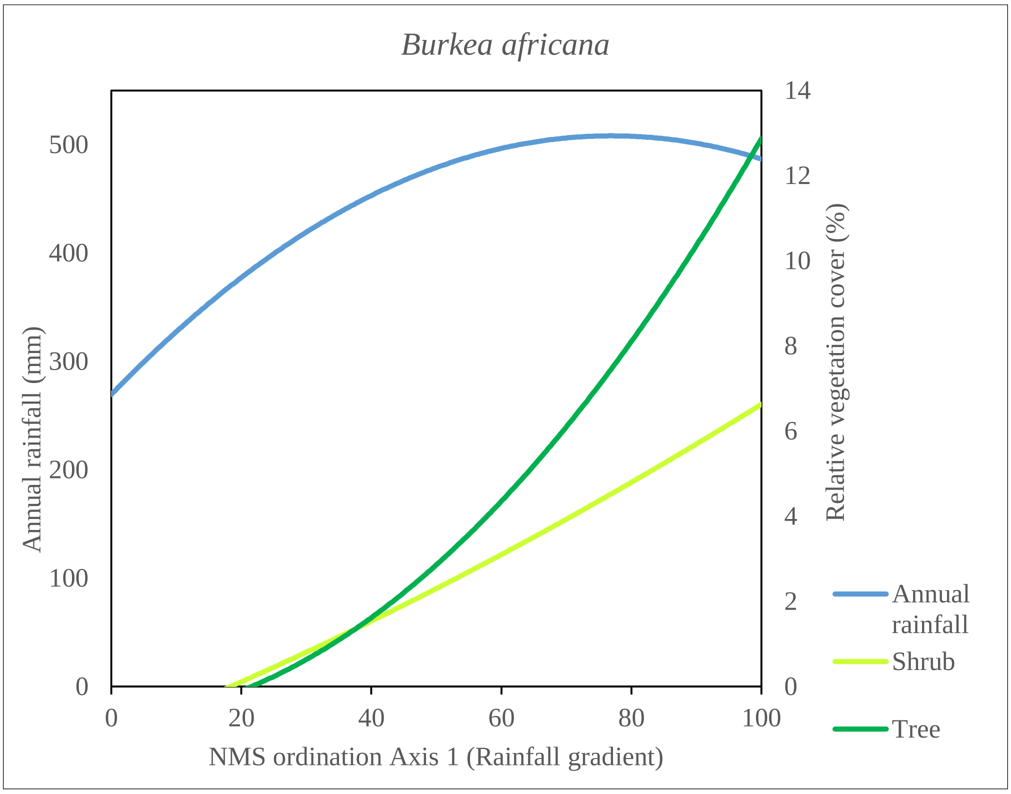

Figure 17: The respond of *Burkea africana* (Tree and Shrub) in terms of vegetative cover (%) to an increasing rainfall (mm/yr) gradient.

Pterocarpus angolensis was observed in all the observatories with an exception of Sandveld observatory. Both the trees and shrub cover of *Pterocarpus angolensis* had a positive correlation with increasing annual rainfall gradient along Axis 1 of the NMS ordination (Figure18). At the high end of annual rainfall where Mile 46 and Mutompo observatory are place (Figure 12), tree cover became more dominating in terms of vegetative cover with almost two folds higher than shrub cover.

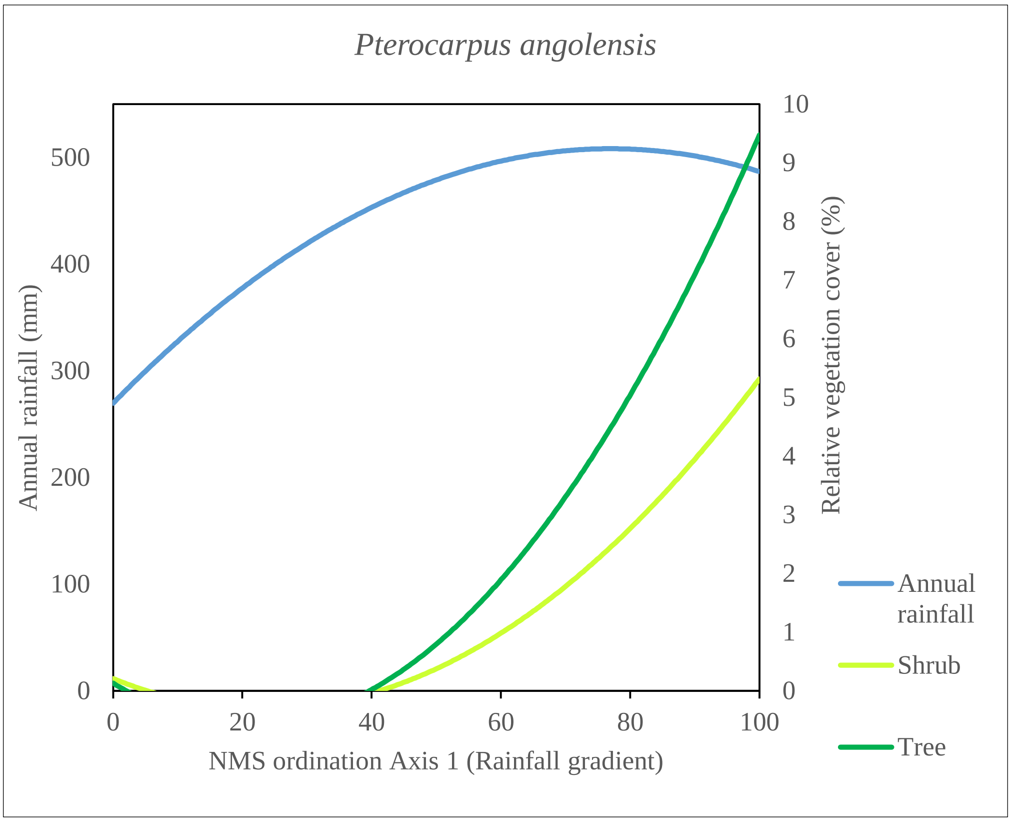

Figure 18: The respond of *Pterocarpus angolensis* (Tree and Shrub) in terms of vegetative cover (%) to an increasing rainfall (mm/yr) gradient.

CHAPTER 5

DISCUSSION

5.1 Species richness and species diversity

In general spatial heterogeneity of vegetation is often brought about by environmental gradients. The establishment of species in an area is dependent on the ability of the environment to provide resource for growth, survival and reproduction (Krebs, 1994). Seed germination is strongly influenced by moisture availability and the length of time that moisture is available (Joubert *et al*., 2013 and Rothauge, 2011). In savanna ecosystems, species richness is linked to rainfall, increasing rainfall gradient is positively related to increasing species richness (White *et al*, 2010; Okitsu, 2005). Similar results were found for this study. Mile 46 and Mutompo observatories are situated in a region that receives an average rainfall of 550 mm/yr, while Sandveld receives an average rainfall of 400 mm/yr (Haarmeyer *et al*., 2010). In the opposite direction the rainfall variability decreases moving from observatory Sandveld towards Mile 46 and Mutompo observatories. Ordination results (Figure 8) showed that species richness was increasing as you move from Sandveld towards Mile 46 and Mutompo observatories.

Soil moisture is crucial for germinating and establishment of seedlings and it is positively correlated to rainfall. Seeds of various plant species have different germination moisture threshold (Kangombe, 2010 and Meyer *et al*., 2007), which explains why some plant species only grow in areas of high annual rainfall (Snyman, 2004). Grass species generally have a lower seed germination moisture threshold, this means they require little soil moisture over a short period (Meyer *et al*., 2007) hence they are able to grow in regions of both low and high rainfall. The germination moisture threshold for most woody species however is often higher than that for grass, and thus require to grow in areas with high rainfall. This could explain the absence of *Burkea africana* and *Pterocarpus angolensis* species at Sandveld observatory as results seen in (Figure 17 and Figure 18). The capacity for high rainfall areas to meet the high and low germination moisture threshold makes it possible for these areas to have a higher species richness. The low annual rainfall variability in these areas could also help explain the high species diversity. Despite the general trend, species richness and diversity in the observatories was decreasing. In studies by Higgins *et al*. (2000); O'Connor (1995) and Hoffmann (1996) they found that some woody plants germinates cannot survive drought conditions during the wet season this sequentially strongly affects the species richness and species diversity. Under the current climatic pattern observed and those modelled in other studies, this is a concerning issue in the future if rainfall continues to decrease.

Apart from abiotic factors, biotic factors are also involved in the determination of species richness, composition and species diversity. The interception of solar radiation and rainfall by trees and shrubs create and modify the microclimate under the canopy (Vetaas, 1992; Georgaiadis, 1989). As feedback these factors influence the species richness, composition and species diversity. The open and closed woodland and shrubland at Mile 46, Mutompo and Sonop observatories provide an ideal state for the creation of multiple niches (Haarmeyer *et al*., 2010; Strohbach & Petersen, 2007). New plant species from surrounding area can then colonise these open niches and therefore increase species richness in the area. The ordination plot (Figure 8) suggested a strong influence of rainfall on the sampled vegetation communities. Rainfall is essential for plant growth (Meyer *et al*., 2007), high rainfall yields higher tree and shrub cover as seen in Figure 10a. It also supports the findings of the results (Figure 15, 16, 17, & 18), trees cover of *Terminalia sericea* and *Acacia mellifera* had gradually become dominant over shrub cover in high annual rainfall areas of Mutompo and Mile 46 observatories as opposed to high shrub cover of the same species in low annual rainfall areas of Sandveld observatory. Trees and shrubs create unique microhabitats with microclimates of low sunlight and high humidity of different intensities depending on the tree and shrub height class (Georgaiadis, 1989). That would then be ideal to establishment of other species and therefore increasing the species richness, an example of such species are *Setaria verticillata* and *Eragrostis biflora*. At Sandveld vegetation is described as open shrubland with low tree and shrub density and high grass cover (Haarmeyer *et al*., 2010). The vast grass area in Sandveld results into a large portion of area having a similar microclimate while the few trees and shrubs can only create very little space with a different microclimate in comparison to the other observatories. These scenarios could therefore explain the increasing species richness along the rainfall gradient.

Intermediate disturbance hypothesis (IDH), states that areas that experience moderate disturbances would have higher species richness, while those that experience very high or low disturbance will have low species richness (Roxburgh *et al*., 2004; Shea *et al*., 2004). This IDH concept has been used in numerous studies by Wiegand *et al*. (2006); Schwilk *et al*. (1997), Palmer (1994) and Collins (1992) to explain coexistence in species henceforth its impact on species richness, species diversity and composition. Disturbance creates open habitat and alters the environmental condition. The occurrence of fire in densely vegetated communities' cause foliage kill, that in turn increases sunlight, temperature, humidity, moisture availability and soil nutrients by reducing the vegetation cover of existing plants for new species to colonise. Mile 46 and Mutompo experiences an incident of fire at a 1-2 year interval, Sonop experienced one fire incident, while Sandveld has not been burn since the establishment of the observatories (Appendix 4).

The positive parallel rainfall and fire gradient best explains the species richness gradient observed in the study area. Mile 46 and Mutompo experiences the normal average fire frequency for savanna ecosystems considering the amount the annual rainfall they receive (Scholes & Walter, 1993). It would then be expected that fire would promote and increase in species richness in these observatories, by opening up niches and improving the access of resources like sunlight in the understory environment. Outcomes from a study by Shoopala (2008) in Hamoye, revealed that species richness and diversity were highest in areas that had been burned between 5 to 10 times over a period of 19 years. This translates to a fire interval of 2.5 years in an area that receives a mean annual rainfall of 550 mm. According to this hypothesis Sonop and Sandveld observatories are then not favoured due to the lack or inadequate disturbances and therefore they will yield a lower species richness in comparison to the Mile 46 and Mutompo observatories. This seems to be the case for Sandveld observatory. However, Sonop had the second highest overall mean species richness after Mile 46 as seen in Figure 9.

Sonop RS is situated on a transitional zone between open/closed woodland savanna in the northern part and a closed thornbush savanna in the southern part. On the ordination biplot this is represented as the cluster between the Mile 46, Mutompo observatory and observatory Sandveld. The ordination (Figure 8) also clearly indicates that vegetation on sandy plot at

Sonop are more closely relatable to the vegetation at Mile 46 and Mutompo observatories then to that of Sandveld. At a transitional zone environmental conditions that occur are suitable support vegetation from the two meeting plant communities (Krebs, 1994). Therefore this zone has a higher species richness compared to the species richness of the broad leafed and fine leafed merging plant communities. This transitional zone effect could be potential to the cause and explanation of the high species richness observed in the Sonop observatory. The Sonop observatory can be referred to as an ecotone observatory.

Statistical analysis revealed that all the observatories are experiencing a significant decrease in species richness and species diversity over the years. The decrease in species richness and diversity can be attributed to decreasing mean annual rainfall, which has a huge influence in the growth and survival of woody plant. In addition, mean monthly rainfall also showed a decreasing trend over the years (Figure 11). This had a huge influence on the presence and absence of grass species as well as the vegetation cover, consequently also affecting species diversity negatively. Namibia is experiencing shortness of rainfall season, decreased rainfall and longer periods of drought. These makes it hard to meet the required moisture threshold for some plant species to germinate, grow and reproduce.

Disturbance is another important component of the savanna ecosystem and highly influenceS the species richness and diversity. Fire and herbivory are the two main types of disturbance in in the savanna ecosystem (Baudena *et al*.,2014). The results show that species richness and diversity were increasing in a similar gradients as that of fire. The presences of fire interrupts the unchanged ground environmental conditions by reducing blockage of rain and sunlight by well-established vegetation, allowing more rain and sunlight to reach the ground and cause seed germination (Smit & Rethman, 1999). Through this species richness was also increased. Shoopala (2008), found that species richness was highest in areas with high and medium fire frequency compared to those with low fire frequency.

The results of species richness and diversity in Mile 46, Sonop and Sandveld observatories still continued to decrease over the year despite the fact that all stations make use of rotation grazing management systems. For this reason grazing pressure was not considered as a contributing factor in the observed trends for the three observatory sites (Mile 46, Sonop and Sandveld).

However between the Mile 46 and Mutompo observatory, herbivory could explain some of the difference observed. Mile 46 and Mutompo observatories share the same woodland and are exposed to similar environmental conditions. The two host locations are however placed under different management systems as discussed in chapter 1. According to Pröpper *et al*. (2010) and Strohbach & Petersen (2007) the Mutompo observatory is exposed to higher land use pressure that comes from surrounding settlement communities. Intensive grazing pressure can intensively reduce grass species richness, wood harvesting creates a more open woodland and destroys existing microhabitats. These factors in addition to others such as soil nutrients, could explain why Mutompo observatory has a lower species richness in comparison to Mile 46.

5.2 Vegetation cover, structure and composition

The leaf size of a plant is an adaptation feature that reflects the type of environment in which that plant species has evolved to survive in (Xu *et al*. 2009). It was clearly observed that the rainfall gradient was the main driver of vegetation composition and in turn causing change from the broad leafed plants to fine leafed plants from the northern to the southern parts of study areas as seen in Figure 8 & Figure 10a. A study on communal conservancies by Strohbach (2014) and that by Privette *et al*. (2004) expressed similar result on vegetation along the rainfall gradients. Increase in broad leafed plant cover toward the Mile 46, Mutompo and Sonop observatories, is associated with higher annual rainfall as well as high mean monthly rainfall. The Sandveld observatory is dominant to fine leafed plants such as *Acacia* species (*Acacia erioloba* and *Acacia mellifera*) (Figure 14 & Figure 15), that are associated to arid conditions. The fast infiltration of rain water into the deep Kalahari sand pose a challenge for plants to acquire the necessary moisture required for the plants to survive, and are therefore expected to have mechanisms for adaptation. *Acacia erioloba* plants have deep reaching taproots that enable them to retrieve underground water in the deep sands (Burke, 2006). Meanwhile, the small leafed plants reduce the loss of moisture by having a smaller surface area from which transpiration can occur. This is what makes fine leafed plants more suitable to live and survive in areas of low rainfall such as Sandveld. Broad leaves have a larger surface area that translates into high transpiration (Xu *et al*. 2009). In order to keep up with the water demand, broad leafed plants grow in areas with high rainfall or longer wet seasons.

The ordination (Figure 10a) revealed increasing tree cover gradient towards the Mile 46 and Mutompo. Sankaran *et al*. (2005), did an investigation on factors that determine the abundance of tree cover in African savannas, and found that increase in rainfall resulted into high tree cover, supported by Privette *et al*. (2004) and Smit & Rethman (1999). The results of this study however, suggest that this is not true for all woody plants in general. *Acacia erioloba* both tree and shrub decreased cover against an increase in annual rainfall (Figure 14), this was a similar case to *Acacia mellifera* shrubs. The results suggested that another factor was affecting the two species. According to ordination results the fire frequency gradient was the determinant factor in the increasing tree cover gradient observed, findings by Moyo (2013) concurred with this results. This gave support to the findings of other studies that observed that in arid area, the structure of vegetation in savanna is largely determined by the amount of rainfall. However, high rainfall areas are prone to fire events as they are able to continuously produce adequate fuel load over a short period. These factors are important to maintain the savanna ecosystem (Sankaran *et al.*, 2005; Staver *et al*., 2009; Higgins *et al*., 2000, Bond *et al*., 2005 and Scholes & Archer, 1997).

A higher proportion for tall and medium high of trees in Hamoye were found in medium fire frequency zones (Shoopala, 2008), which in this study would be equivalent to the Mile 46 and Mutompo observatories. High fire frequency reduces cover of young fire sensitive woody plants by trapping them into a fire prone height class (Staver *et al*., 2009; Higgins *et al*., 2000), while fire resistant woody plant continues to grow out of the trap zone and increasing tree cover in fire prone areas. This clearly explains the high tree cover of *Burkea africana* and *Pterocarpus angolensis* in the high rainfall areas Figure 17 & Figure 18 due to the impact of fire events. It is therefore expected for Mile 46 and Mutompo to greater end of the tree cover gradient (Bond & van Wilgen, 1996; Frost and Robertson 1987).

The shrub cover gradient was increasing towards the Sonop observatory. The high rainfall and very low fire frequency in the observatory promotes the growth of woody vegetation cover. A study by Shoopala (2008) and Mapaure (2013) found that zones that had a low fire frequency had higher cover of shrubs greater than compared to high fire frequency zone. Strohbach & Peterson (2007) found similar result at Alex Muranda RS, they observed that in the efforts to prevent fire transferring into the borders of RS by using fire breaking at the border fence, has led to encroachment of the *Bauhinia petersiana – Acacia fleckii* shrubland. In addition, Shoopala (2008) and Mapaure (2013) also observed that shrubs in this area are tall with a height ranging between 1 - 2 m. Staver *et al*. (2009) and Mapaure & Moe (2009) found that woody plants also had a higher growth rate during the fire-free period post a fire event, which supports the results observed in Hamoye. Altogether, all these studies concur with the shrub cover gradient observed along the study area. The young woody plants are vulnerable to fire events as they don't have thick barks and stems to protect meristem from the fire damages (Higgins *et al*., 2000). However, those with root stocks are capable of resprouting (Hodgkinson, 1998), after the fire event causing an increase in shrub cover (Mapaure, 2013; Higgins *et al*., 2000). Plant species like *Burkea africana, Pterocarpus angolensis, Ochna pulchra*, *Terminalia sericea* (Moyo, 2013; Strohbach, 1998) and *Acacia* spp. (Burke, 2013) have the ability to resprout after a fire event (Burke, 2013; Burke, 2006). Hence why they have a high cover with fire prone area (Figure 16, 17, & 18).

Although the Sonop observatory has the necessary environmental condition for high tree cover, the high density of shrub cover due to low fire frequency results into high competition amongst the woody plants as well as between woody plants and grasses for resources. Consequently this reduces the woody plant growth rate (Smith & Goodman, 1986) and grass cover henceforth, a low rate of recruitment of trees in the population.

The grass cover gradient increases towards the Sandveld observatory and in the opposite direction to the increase in rainfall, tree and shrub cover. In savanna ecosystems that receives a mean annual rainfall of about 650 mm or less, rainfall is very influential on the coexistence of woody vegetation and grasses (Accatino *et al*., 2010). The Sandveld observatory at minimum receives 18% less annual rainfall in comparison to the other observatories and has the highest rainfall variability throughout the study area (Mendelsohn & el Obeid, 2005). Due to lower rainfall, moisture availability becomes a limitation for the woody plants in the observatory, hence the low woody cover and density (Figure 11 j). Consequently the low tree and shrub cover allow for more sunlight and rainfall to reach the understory vegetation, causing an increase in grass cover (Scheiter & Higgins, 2009; Scheiter, 2005). This can explain the higher grass cover observed at Sandveld. Scholes & Arche, (1997) state that several studies (Ko & Reich, 1993; Haworth & McPherson, 1995; Návar & Bryan, 1990) observed that tree cover intercept can prevent about 5-50% of rainfall from reaching the underground vegetation. While other studies (Ko & Reich, 1993, Jackson *et al*., 1990; Georgiadis, 1989) revealed that woody vegetation cover can block about 25-90% of sunlight to reach the ground Scholes & Arche, (1997).

As mentioned earlier rainfall is the major influencing factor on vegetation in arid and semi-arid savanna ecosystem. The result of this study suggests that this observation is true for both spatial and temporal gradients whereby, the decrease in annual rainfall and monthly rainfall over the years resulted in decreasing vegetation cover and grass cover. The annual rainfall was the driving factor for woody plants, while the grass cover in this study was strongly influenced by the mean monthly rainfall (Appendix 6) Hüttich (2011); Bucini & Hanan (2007) and Sankaran *et al*. (2005) observed similar results.

Despite the decreasing vegetation cover, the cover of fine leafed plants seems to increase in recent years, more in the Mutompo, Sonop and Sandveld observatories. The fine leafed vegetation is mainly comprised of *Acacia* spp. which have evolved to adapt to harsh environmental conditions with low rainfall (Burke, 2013; Mannheimer & Curtis, 2009). Smit & Rethman (1999) state that following a reduction of tree cover, previously disadvantaged plant species take over and begin to outcompete species that initially occurred in the area. In the face of decreasing annual rainfall, reduced wet seasons and longer period of drought, fine leafed woody plants are at an advantage to outcompete broad leafed plants that are highly dependent on higher rainfall. Fine leafed cover in Mile 46 increase roughly be 5%, while it increased roughly by 8% in Mutompo, despite similar climatic conditions and fire regime. This reveals that other factors are influencing vegetation in the Mutompo observatory. Pröpper *et al* (2010) and Strohbach & Petersen (2007) mentioned that communities in the surrounding make use of the woodland neighbouring to the Mutompo observatory for grazing, timber harvesting, fire wood collecting and other uses. However, these activities are in fact occurring within the Mutompo observatory site (personal. obs. E. Shidolo, 2016) (Appendix 7), in addition to decreasing rainfall and increased frequency of fire events. Therefore, as expected the woody plant cover especially those of broad leafed plants like those mentioned in Chapter 2 was reduced. Thus creating spaced for fine leafed woody species to colonise and increase in cover. Furthermore, reduced grass cover can promote cover of these fine leafed plants through reduced competition for resources with juveniles (Baudena *et al*., 2014).

Cover for woody vegetation at observatory Sonop appears stable but very slowly decreasing despite steep decline in rainfall. In an area between semi-desert grasslands south of the United States and the woodlands north of Mexico that receives an average of 602mm/yr, similar results were observed. The vegetation within the grassland-woodland ecotone was found relatively stable over several centuries (Weltzin & McPherson, 2000). The stability within the observatory appears to be maintained through coexistence interaction of fine leafed vegetation and that of broad leafed vegetation through resource partitioning. Although the vegetation community in Sonop is dominated by broad leafed vegetation, and in years of low rainfall the fine leafed vegetation cover slightly increases.

Both broad leafed and fine leafed woody plants at Sandveld displayed an increase in cover in recent year. Increase in cover of fine leafed vegetation was mainly attributed to an increase in *Acacia* spp. cover particularly *Acacia mellifera* and *Acacia erioloba*, while for *Terminalia sericea* was responsible for increased broad leafed cover (Figure 14, 15 & 16). These species are known to be well adapted to the arid climatic conditions of the Kalahari ecosystem (Burke, 2006). *Acacia mellifera* has shallow but scattering roots that allow it to get water over a large area (Adams, 1967), while *Acacia erioloba* and older *Terminalia sericea* have long taproots that allow the plant to draw water from deep in the soil (Burke, 2006). Therefore, increasing woody cover would cause a decrease in grass cover, competition for water can again explain this results (Figure 11 h). In studies by Nzehengwa (2013; Hipondoka &Versfeld, 2006), mention that *Acacia mellifera* and *Terminalia sericea* shrubs have competitive advantage against the herbaceous layer that includes grasses for water because of the adventurous root systems that they have. Studies by Kraaij & Ward, (2006) and Wiegand *et al*. (2006) found that germinating seeds and seedlings of *Acacia mellifera* are more affected by rainfall than by present grass cover. Therefore, although grass cover is high at observatory Sandveld, the competition between the tree seedling and grasses (Baudena *et al*, 2014) is not sufficient to prevent grow and recruitment into the population.

This could then lead to encroachment by shrubs that will subseqentially lead to loss of grass cover and ranging land. Baudena *et al* (2014) states that competition between the trees and grass has a strong impact on the tree seedlings. High grass cover increases competition for resources with the seedlings of woody vegetation, often seedlings are outcompeted

Even though grass cover requires little moisture for recruitment and growth, the results of the study still showed a decrease in both annuals and perennials (Figure). At Mile 46 and Mutompo this can be attributed to the frequent fire incidents that occur. Le Roux (2011), states that most fire incidents in the Kavango West and East Regions are ground fires. Fire incidents can promote growth in perennial grasses by removing grass moribund in high rainfall areas. It can however have a negative impact to both annuals and perennials under reduced rainfall and wet season, longer drought period and increasing grazing pressure. In a study by Rothauge (2006) the analysis of data revealed that Sandveld RS is slowly experiencing degradation of the rangeland, despite the rotational grazing system that has been put in place (Boys, 2015; Smit, 2003). The 54 grazing camps at Sandveld RS are divided into 3 grazing groups of equal potential of which the grazing groups are utilized at different times of the year, with a resting period of about 16 months (Rothauge, 2006; Smit, 2003). The managed grazing intensity allows for the cattle to be very selective on the species they forage on, often leaving low nutrients and tough perennial grass species such as *Eragrostis rigidor*, *Stipagrostis uniplumis* and *Aristida stipitata*. Over the years these grass accumulate moribund grass due to low grazing intensity and lack of other disturbances like fire (Zimmermann *et al*., 2010). The build-up of dead grass materials prevents the growth of new shoots in perennial grasses, while shading by moribund grass hinder the germination of annual grass seeds by intercepting the sunlight (Zimmermann *et al*., 2010; Gul *et al*., 2014). In addition to the just mention effect, decreasing rainfall was the most obvious cause of reduced grass cover on observatory Sandveld.

GCMs by Midgley *et al*. (2010), suggested that the arid vegetation cover will increase towards the north-eastern region of Namibia. Furthermore, GCM by Thomas *et al*. (2006) predicted a loss in vegetation cover particularly the grass and herb cover. It raises concern that the results of this study are following these predicted trends. The general trend over the study found high grass cover was associated with low tree and shrub cover (Higgins *et al*., 2000; Archer, 1995), which is supported by the concept of resources partitioning described in other studies (Meyer *et al*, 2007; Scholes & Archer, 1997). However, contrary to this concept grass cover in Mile 46, Mutompo and Sonop observatories continued to decrease despite the decreasing woody plants cover. Thus, stressing the strong dependency of vegetation on rainfall in these three observatories, to maintain the structure and species diversity, White *et al*. (2010) support this findings. Based on evidence, change in rainfall pattern was the main driving factor causing a shift in the nature of vegetation in the Mile 46, Mutompo and Sonop observatory towards the nature of vegetation observed in the Sandveld observatory. Vegetation in the Sandveld observatory appeared to be stable in the ordination (Figure 10), such results could mean that existing vegetation on the observatory are already adapted to low rainfall and therefore resistant to prevailing climatic conditions. Baudena *et al* (2014) states that the interaction between water and vegetation is linked to vegetation resilience to climatic conditions in that ecosystem.

CHAPTER 6

CONCLUSIONS

The study found that species diversity and species richness gradient within the study area were increasing from the south (Sandveld observatory) towards the northern parts (Mile 46 and Mutompo observatory) of the study area. There's a lot more plant species occurring in Alex Muranda RS in comparison to the Sandveld RS. Generally, this trend is seen as an outcome of moisture availability. In addition to the number of species, the high species diversity in the northern part of the study area is an indication of high species evenness. That can be used as an indication of vegetation community that gives equal opportunities for a majority of plant species to coexist within the community. Species richness and species diversity over the years in all the observatories were found to have a significant difference with an overall decreasing trend. Such trend outcomes within an observatory site could be viewed as an indication and a warning sign of land degradation occurring within the Kalahari area studied.

The influence of rainfall and fire on species richness and composition were observed to have strong influence on vegetation throughout the study area. An area that receives a great amount of rainfall is able to support the establishment and survival for a larger number of plant species in comparison to areas with less rainfall. Additionally, rainfall facilitates other ecological activities such as fire that further promotes the increase of species richness and improves evenness and species diversity. Therefore, further reduction of rainfall within the study area over the years will result in either loss of species or more plant species becoming endangered. In extreme situation of reduced rainfall, we can expect loss of cover and live woody vegetation. Subsequently converting woodland and shrubland into grassland leading to reduced or loss of land productivity and ecosystem services.

Although the Kalahari is generally vulnerable to climate change, it is the broad leafed vegetation communities that are more vulnerable compared to the fine leafed vegetation communities, due to high dependence on the high rainfall with low variation. This means that continuous reduction in rainfall over the years will result in the replacement of broad leafed vegetation communities by fine leafed vegetation. Vegetation cover overall will be reduced due to the loss of trees and shrubs, that will result into increase in grass cover. According to the results it appears as if the shift in vegetation has already started to occur within the study area. However, ordination result showed rather a stable vegetation community at Sandveld. This indicates that in face of reduced rainfall, these fine leafed vegetation communities are more resistant and persistent to change and would require less conservation efforts in comparison to the broad leafed vegetation communities. Actually some species such as *Acacia mellifera* and *Terminalia sericea* are well adapted and thrive even during drought periods. A combination of fine and broad leafed vegetation communities in the Sonop observatory creates more stable vegetation community that is able to withstand climatic variation, and perhaps could provide a solution to salvage the broad leafed vegetation community in times of ongoing climate change.

The study showed that Mutompo has a lower vegetation cover despite it shares the same woodland with Mile 46. In addition, it has an increasing fine leafed vegetation cover while fine leafed vegetation cover at Mile 46 is decreasing with rainfall reduction. This suggests that other factors, not rainfall and fire, are influencing vegetation in Mutompo. On the other hand it could also be an indication of the effectiveness of the fire barrier, separating the two observatories.

Grass cover in observatories is low except for Sandveld observatory due to the tree/shrub to grass competition. However in the presence of increasing fine leafed cover grass cover in further and greatly reduced. This means that under climate change where woodland savanna will be dominated by fine leafed vegetation, grazing capacity in such area will be reduced immensely through reduced grass cover.

The high cover of *Aristida stipitata* at the high end of the rainfall gradient could be explained in two scenarios: an indication of a subclimax vegetation community or as an indication of degraded land. The presence of good grazing values, grasses of *Schmidtia pappophoroides* support that high cover of *Aristida stipitata,* is rather an indication of a subclimax vegetation community. The steep decline in *Stipagrostis uniplumis* towards increasing annual rainfall gradient suggests the other factor associated with high rainfall like fire occurrence, is negatively affecting the growth and survival of other species in a negative way. Another possible explanation could be the association of plant species with each other for growth and survival.

The impact of rainfall and fire influence the growth and survival of one species at different life stages. Due to this, there is a difference in cover between trees and shrubs of a single plant species sometime observed. Fire for intense promotes a high tree cover of fire resistance species and a low shrub cover.

Results of the study verified the alternative hypothesis of the study. A continuous reduction of rainfall and wet seasons has the potential to eventually alter woodland savannas into thornbush and grassland savannas. In the northern part of the study area this would mean decreasing cover of broad leafed woody plants and permanent loss of tropical plant species. Meanwhile woody plants adapted to arid conditions and grass cover would increase. In the southern part of the study area, further decrease in rainfall could result into dwarf shrub and further reduced grass cover.

Although this is considered as a long-term vegetation study, the period of data collected was still inadequate to fully make conclusion of the trends observed. I therefore encourage a continual data collection from these observatories. In addition, data collection process in the observatories could also be improve to increase the accuracy of the estimates. This can be done by designating a specific observatory to one particular researcher as a way to reduce biased data collection. Another method which is currently being put on trial is the use of a drone pictures. Pictures from the drone could be used to help give more realistic cover estimates.

As a part of to fully understand the influence and impact of fire, it is necessary to look at all aspect of fire regime such as the frequency, intensity, fire return interval. For this study this was not possible due to unavailability of some of the information. It is therefore encouraged that personnel at the various research stations to record such information.

The findings of the study advocate for appointment of a management body consisting of people from communities living in the area that will help monitor and manage the use of woodland resources on communal land. Due to deteriorating rainfall conditions, controlled burning of camps would have a negative impact on the vegetation. However, to enhance productivity of the rangeland at Sonop RS, perhaps strategic debushing could be recommended, in order to increase the grass cover. At Sandveld RS, increasing grazing period within camps will increase disturbance through trampling by cattle that will reduces and remove the accumulating grass moribund. This will then promote grass growth and increase rangeland productivity.

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APPENDICES

Appendix 1: A table with a list of coordinates of the 20 priority monitory plots for Mile 46, Mutompo, Sonop and Sandveld and a schematic model showing their position on the observatory plots. The red block shows the top ten priority plots and the orange blocks shows the 11th -20th priority plots.

Mile 46 Observatory

		Centre Point	
Plot #	Ranking #	Latitude (S)	Longitude (E)
5	**1**	18°18'8.05"	19°15'9.26"
53	**2**	18°18'24.49"	19°15'2.44"
3	**3**	18°18'8.05"	19°15'2.44"
14	**4**	18°18'11.34"	19°15'5.84"
42	**5**	18°18'21.2"	19°14'59.02"
39	**6**	18°18'17.91"	19°15'22.9"
9	**7**	18°18'8.05"	19°15'22.9"
77	**8**	18°18'31.07"	19°15'16.08"
23	**9**	18°18'14.63"	19°15'2.44"
72	**10**	18°18'30.9"	19°14'59.02"
25	**11**	18°18'14.63"	19°15'9.26"
18	**12**	18°18'11.34"	19°15'19.48"
60	**13**	18°18'27.78"	19°14'52.2"
87	**14**	18°18'34.36"	19°15'16.08"
0	**15**	18°18'8.05"	19°14'52.2"
41	**16**	18°18'21.2"	19°14'55.62"
36	**17**	18°18'17.91"	19°15'12.66"
89	**18**	18°18'34.36"	19°15'22.9"
85	**19**	18°18'34.36"	19°15'9.26"
52	**20**	18°18'24.4"	19°14'59.02"

Fig.1 : Ranking of the 1ha-Plots

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	*15*	*72*	*90*	*3*	*25*	*1*	*70*	*98*	*37*	*7*
1	*44*	*81*	*27*	*94*	*4*	*56*	*91*	*95*	*12*	*79*
2	*57*	*60*	*31*	*9*	*29*	*11*	*47*	*53*	*24*	*33*
3	*71*	*46*	*42*	*23*	*52*	*34*	*17*	*78*	*75*	*6*
4	*49*	*16*	*5*	*40*	*28*	*35*	*68*	*39*	*85*	*63*
5	*58*	*66*	*20*	*2*	*73*	*61*	*55*	*77*	*67*	*97*
6	*13*	*80*	*83*	*50*	*26*	*59*	*76*	*74*	*41*	*92*
7	*38*	*21*	*10*	*43*	*32*	*64*	*30*	*8*	*54*	*62*
8	*51*	*82*	*88*	*36*	*87*	*19*	*93*	*14*	*86*	*18*
9	*84*	*48*	*22*	*89*	*100*	*69*	*99*	*96*	*65*	*45*

Fig.2 : Habitat types of the 1ha-plots (Hab)

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	*2*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*
1	*2*	*1*	*1*	*1*	*2*	*1*	*1*	*1*	*1*	*1*
2	*3*	*3*	*3*	*3*	*4*	*4*	*4*	*3*	*3*	*2*
3	*3*	*3*	*3*	*4*	*4*	*4*	*3*	*3*	*3*	*3*
4	*3*	*4*	*4*	*4*	*3*	*3*	*3*	*3*	*3*	*3*
5	*4*	*3*	*3*	*3*	*3*	*2*	*2*	*1*	*1*	*1*
6	*3*	*3*	*3*	*2*	*2*	*1*	*1*	*1*	*1*	*1*
7	*2*	*2*	*2*	*1*	*1*	*1*	*1*	*1*	*1*	*1*
8	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*
9	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*

1	Closed woodland
2	Open woodland
3	Mixed savanna
4	Acacia bushland (dense)

Mutompo Observatory

		Center Point	
Plot #	Ranking #	Latitude (S)	Longitude (E)
6	**1**	18°18'7.7"	19°15'52.1"
93	**2**	18°18'36.9"	19°15'42"
76	**3**	18°18'30.6"	19°15'52.1"
52	**4**	18°18'24"	19°15'38.5"
15	**5**	18°18'11"	19°15'48.9"
17	**6**	18°18'11"	19°15'55.7"
41	**7**	18°18'20.8"	19°15'35.1"
59	**8**	18°18'24"	19°16'2.5"
44	**9**	18°18'20.8"	19°15'45.5"
55	**10**	18°18'24"	19°15'48.9"
32	**11**	18°18'17.81"	19°15'38.95"
24	**12**	18°18'14.3"	19°15'45.5"
47	**13**	18°18'21.07"	19°15'55.85"
63	**14**	18°18'27.59"	19°15'42.33"
89	**15**	18°18'34.11"	19°16'2.61"
72	**16**	18°18'30.85"	19°15'38.95"
40	**17**	18°18'21.07"	19°15'32.19"
69	**18**	18°18'27.59"	19°16'2.61"
64	**19**	18°18'27.4"	19°15'45.5"
53	**20**	18°18'24.33"	19°15'42.33"

Fig.1 : Ranking of the 1ha-Plots

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	*49*	*78*	*92*	*30*	*79*	*59*	*1*	*84*	*71*	*62*
1	*99*	*39*	*82*	*72*	*32*	*5*	*86*	*6*	*83*	*53*
2	*64*	*47*	*21*	*67*	*12*	*66*	*81*	*97*	*100*	*94*
3	*85*	*73*	*11*	*89*	*90*	*80*	*43*	*55*	*57*	*75*
4	*17*	*7*	*44*	*56*	*9*	*29*	*61*	*13*	*34*	*48*
5	*63*	*50*	*4*	*20*	*25*	*10*	*58*	*54*	*28*	*8*
6	*37*	*27*	*31*	*14*	*19*	*35*	*41*	*46*	*38*	*18*
7	*60*	*98*	*16*	*33*	*76*	*52*	*3*	*23*	*40*	*65*
8	*96*	*36*	*77*	*26*	*88*	*68*	*93*	*42*	*74*	*15*
9	*70*	*69*	*87*	*2*	*24*	*91*	*51*	*22*	*45*	*95*

Fig.2 : Habitat types of the 1ha-Plots (Hab)

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*
1	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*
2	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*
3	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*
4	*3*	*3*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*
5	*4*	*4*	*4*	*4*	*4*	*4*	*4*	*4*	*5*	*5*
6	*3*	*3*	*4*	*4*	*2*	*4*	*4*	*4*	*5*	*5*
7	*1*	*1*	*1*	*1*	*1*	*2*	*2*	*2*	*2*	*2*
8	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*
9	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*

1	Closed woodland
2	Open woodland
3	Mixed savanna
4	Thicket
5	Acacia woodland

Ranking at Sonop Research Station

		Centre Point	
Plot #	Ranking #	Latitude (S)	Longitude (E)
15	**1**	19°04'30.67"	18°54'32.86"
42	**2**	19°04'40.42"	18°54'22.58"
52	**3**	19°04'43.67"	18°54'22.58"
71	**4**	19°04'50.17"	18°54'19.0"
72	**5**	19°04'50.17"	18°54'22.58"
21	**6**	19°04'33.92"	18°54'19.0"
95	**7**	19°04'56.67"	18°54'32.86"
31	**8**	19°04'37.17"	18°54'19.0"
0	**9**	19°04'27.42"	18°54'15.72"
69	**10**	19°04'46.92"	18°54'46.58"
84	**11**	19°04'53.42"	18°54'29.44"
77	**12**	19°04'50.17"	18°54'39.72"
56	**13**	19°04'43.67"	18°54'36.3"
11	**14**	19°04'30.67"	18°54'19.0"
96	**15**	19°04'56.67"	18°54'36.3"
51	**16**	19°04'43.67"	18°54'19.0"
89	**17**	19°04'53.42"	18°54'46.58"
73	**18**	19°04'50.17"	18°54'26.0"
49	**19**	19°04'40.42"	18°54'46.58"
25	**20**	19°04'33.92"	18°54'32.86"

Fig.1 : Ranking of the 1ha-areas

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	*9*	*61*	*84*	*77*	*47*	*100*	*64*	*86*	*44*	*88*
1	*98*	*14*	*31*	*96*	*92*	*1*	*69*	*94*	*21*	*35*
2	*56*	*6*	*52*	*99*	*40*	*20*	*97*	*81*	*27*	*95*
3	*60*	*8*	*71*	*34*	*80*	*93*	*75*	*28*	*90*	*73*
4	*79*	*55*	*2*	*39*	*24*	*91*	*89*	*66*	*87*	*19*
5	*85*	*16*	*3*	*62*	*42*	*50*	*13*	*54*	*45*	*83*
6	*67*	*59*	*26*	*49*	*29*	*36*	*68*	*74*	*23*	*10*
7	*76*	*4*	*5*	*18*	*38*	*72*	*78*	*12*	*53*	*46*
8	*70*	*51*	*43*	*33*	*11*	*58*	*37*	*63*	*30*	*17*
9	*65*	*57*	*32*	*41*	*48*	*7*	*15*	*22*	*25*	*82*

Fig.2 : Habitat types of the 1ha-areas (Hab)

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*
1	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*
2	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*
3	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*1*	*1*
4	*3*	*3*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*
5	*3*	*3*	*3*	*3*	*3*	*2*	*2*	*2*	*2*	*2*
6	*4*	*4*	*4*	*3*	*3*	*3*	*3*	*3*	*3*	*3*
7	*5*	*5*	*4*	*4*	*4*	*4*	*4*	*4*	*4*	*4*
8	*5*	*5*	*5*	*4*	*5*	*5*	*5*	*5*	*5*	*5*
9	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*5*	*5*

1	Dense *Terminalia sericea - Combretum* shrubland
2	*Terminalia sericea-Baphia massiensis* shrubland
3	Open *Acacia* bushland
4	*Acacia* thicket
5	Open distrubed *Acacia* bushland
6	Open *Acacia* bushland

Sandveld Observatory

		Centre Point	
Plot #	Ranking #	Latitude (S)	Longitude (E)
23	**1**	22°02'43.1"	19°08'13.0"
71	**2**	22°02'59.3"	19°08'06.0"
37	**3**	22°02'46.3"	19°08'27.0"
12	**4**	22°02'39.8"	19°08'09.5"
85	**5**	22°03'02.6"	19°08'20.0"
89	**6**	22°03'02.6"	19°08'33.9"
36	**7**	22°02'46.3"	19°08'23.5"
11	**8**	22°02'39.8"	19°08'06.0"
83	**9**	22°03'02.6"	19°08'13.0"
46	**10**	22°02'49.6"	19°08'23.5"
75	**11**	22°02'59.3"	19°08'20.0"
55	**12**	22°02'52.8"	19°08'20.0"
99	**13**	22°03'06.5"	19°08'34.1"
54	**14**	22°02'52.8"	19°08'16.5"
42	**15**	22°02'49.6"	19°08'09.5"
7	**16**	22°02'36.6"	19°08'27.0"
48	**17**	22°02'49.6"	19°08'30.4"
41	**18**	22°02'49.6"	19°08'06.0"
3	**19**	22°02'36.6"	19°08'13.0"
95	**20**	22°03'05.8"	19°08'20.0"

Fig.1 : Ranking of the 1ha-plots

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	*97*	*38*	*81*	*19*	*88*	*64*	*22*	*16*	*55*	*58*
1	*74*	*8*	*4*	*93*	*35*	*56*	*65*	*66*	*57*	*99*
2	*24*	*21*	*29*	*1*	*77*	*76*	*68*	*37*	*53*	*43*
3	*41*	*95*	*31*	*48*	*50*	*54*	*7*	*3*	*47*	*91*
4	*85*	*18*	*15*	*69*	*44*	*83*	*10*	*61*	*17*	*79*
5	*87*	*89*	*73*	*23*	*14*	*12*	*52*	*26*	*33*	*28*
6	*63*	*71*	*67*	*60*	*34*	*80*	*45*	*100*	*62*	*32*
7	*72*	*2*	*92*	*49*	*51*	*11*	*94*	*98*	*96*	*39*
8	*70*	*42*	*82*	*9*	*25*	*5*	*78*	*86*	*84*	*6*
9	*75*	*90*	*36*	*30*	*46*	*20*	*59*	*40*	*27*	*13*

Fig.2 : Habitat types of the 1ha-plots (Hab)

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	*2*	*1*	*1*	*3*	*3*	*3*	*3*	*3*	*3*	*3*
1	*1*	*1*	*1*	*1*	*1*	*2*	*2*	*1*	*1*	*1*
2	*1*	*1*	*1*	*1*	*1*	*2*	*2*	*2*	*2*	*2*
3	*1*	*1*	*1*	*1*	*1*	*1*	*2*	*2*	*2*	*1*
4	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*2*	*1*
5	*1*	*1*	*2*	*2*	*2*	*4*	*4*	*4*	*4*	*2*
6	*1*	*1*	*3*	*2*	*2*	*3*	*3*	*3*	*3*	*3*
7	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*
8	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*4*
9	*3*	*3*	*3*	*3*	*4*	*4*	*4*	*4*	*5*	*5*

1	*Terminalia sericea* bushland
2	*Acacia erioloba* bushland
3	*Acacia erioloba - Acacia mellifera* bushland
4	*Grewia flava - Tarchonathus camphorathus* bushland
5	*Acaia mellifera* shrubland

Appendix 2: Vegetation data collection form adapted from the standardized raw data collection form of the vegetation survey in Namibia.

Vegetation Data

Observer:	Number:	Computer No:	
Landscape:	Date:	Altitude:	
Locality:	Region:	GPS reading: ° ' " S ° ' " E	
	District:		
	Owner:	Accurancy of GPS: (Schwarzeneck)	
		Estimation from 1:50 000 map	General estimate

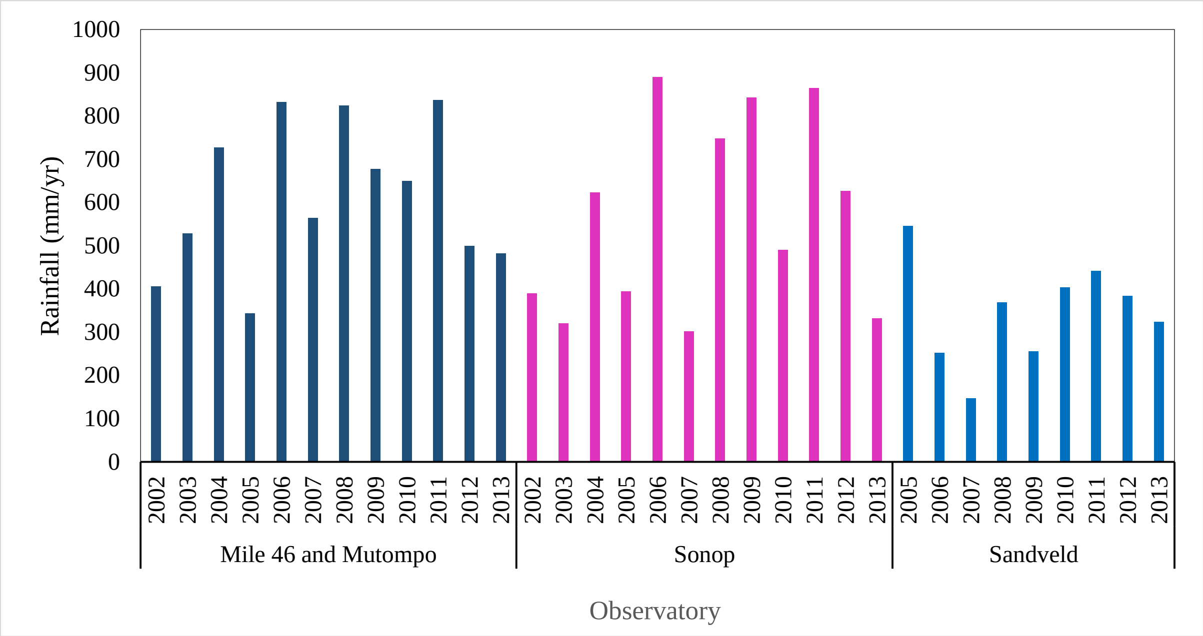
Vegetation Structure:

Total	Trees	Shrubs >1m	Trees and Shrubs	Shrubs <1m	Grasses	Herbs
Average height						
Total cover						
Vegetation Structure						
Th: High tree >20m Tt: Tall tree10-20m Ts: Small tree 5-10m Tl: Low tree 2-5m Sh: High shrubs 2-5m St: Tall Shurb 1-2m Ss: Small shrub 0.5-1m Sl: Low shrub						

Species composition

Coll. No.	Species	Abundance by growth form									
		Tl		T2	T3	S1		S2		Hl	
		Th	Tt	Ts	Tl	Sh	St	Ss	Sl	G	H
	Total cover:										

Appendix 3: Annual rainfall measurements over the years in the four observatories



Appendix 4: Table showing absences and occurrence of fire events within the four observatories over the study period.

Years	**Mile 46**	**Mutompo**	**Sonop**	**Sandveld**
2002-2003	--	--	--	--
2003-2004	--	--	--	--
2004-2005	√	√	--	--
2005-2006	√	--	--	--
2006-2007	--	√	--	--
2007-2008	√	√	--	--
2008-2009	--	--	--	--
2009-2010	√	√	--	--
2010-2011	--	--	--	--
2011-2012	--	--	--	--
2012-2013	√	√	√	--
2013-2014	--	--	--	--
2014-2015	--	--	--	--

Appendix 5: Table showing the maximum cover value for each species in the different observatories, as well as clustering of each species in terms of layer (tree, shrub and grass), life cycle period (annual and perennial plants) and leaf sizes.

Species	**layer**	**Life cycle Period**	**Leaf size**	**Mile 46**	**Mutompo**	**Sonop**	**Sandveld**
Acacia ataxacantha	s	p	no	5	2	6	
Acacia ataxacantha	t	p	no	2			
Acacia erioloba	s	p	mi	5	8	6	5
Acacia erioloba	t	p	mi	6	4	8	6
Acacia fleckii	s	p	no	6	5	6	2
Acacia fleckii	t	p	no	2	4	4	
Acacia hebeclada	s	p	mi			6	7
Acacia hebeclada	t	p	mi			4	
Acacia luederitzii	s	p	mi	4	2	8	
Acacia luederitzii	t	p	mi	2	2	6	
Acacia mellifera	s	p	mi		2	8	6
Acacia mellifera	t	p	mi			6	4
Acacia reficiens	s	p	mi	2		4	
Acacia reficiens	t	p	mi			2	
Acacia species	s	p	mi			2	
Andropogon gayanus	g	p	mi			2	
Anthephora pubescens	g	p	mi			2	
Aristida adscensionis	g	a	mi	2	2	2	
Aristida congesta	g	p	mi	6	4	2	8
Aristida effusa	g	a	mi			2	2
Aristida engleri	g	p	mi			2	
Aristida hordeacea	g	a	me		2		
Aristida meridionalis	g	p	mi	2	4	5	8

Aristida pilgeri	g	p	mi	2	2	2	
Aristida rhiniochloa	g	a	mi			2	2
Aristida scabrivalvis	g	a	mi			2	
Aristida stipitata	g	p	mi	6	7	6	5
Aristida stipoides	g	a	mi		6	2	
Asparagus aspergillus	s	p	pi			2	
Asparagus bechuanicus	s	p	pi			2	
Asparagus cooperi	s	p	pi	2	2	4	2
Asparagus denudatus	s	p	pi			4	
Asparagus exuvialis	s	p	pi	2		2	
Asparagus nelsii	s	p	pi	7	4	4	4
Asparagus suaveolens	s	p	pi	2		4	2
Asparagus virgatus	s	p	pi	2		2	
Asystasia welwitschii	s	p	no			2	
Baikiaea plurijuga	s	p	no	2	2	2	
Baikiaea plurijuga	t	p	no	2	2	4	
Baissea wulfhorstii	s	p	no	2		5	
Baphia massaiensis	s	p	no	9	9	9	
Barleria kaloxytona	s	p	mi			2	
Bauhinia petersiana	s	p	me	9	8	6	
Boscia albitrunca	s	p	mi		2	2	
Boscia albitrunca	t	p	mi			4	
Brachiaria brizantha	g	p	me			2	
Brachiaria deflexa	g	a	mi		2	2	
Brachiaria nigropedata	g	p	mi	5	3	2	2
Burkea africana	s	p	no	7	8	6	
Burkea africana	t	p	no	9	9	7	
Catophractes alexandri	s	p	mi			4	
Cenchrus ciliaris	g	p	mi			2	

Chloris virgata	g	a	mi	2		2	
Clerodendrum dekindtii	s	p	mi	2	2	2	
Combretum apiculatum	s	p	no	3		2	
Combretum collinum	s	p	no	9	8	8	
Combretum collinum	t	p	no	8	5	7	
Combretum engleri	s	p	mi	6	2	5	
Combretum hereroense	s	p	mi	4	2	4	
Combretum imberbe	t	p	mi	2			
Combretum psidioides	s	p	mi	8	6	6	
Combretum psidioides	t	p	mi	5	4	2	
Combretum zeyheri	s	p	no	6	9	2	
Combretum zeyheri	t	p	no	4	3		
Commiphora africana	s	p	no	4	2	4	2
Commiphora angolensis	s	p	mi	6	2	9	
Commiphora edulis	s	p	mi			4	
Commiphora glandulosa	s	p	mi	2		2	
Commiphora tenuipetiolata	s	p	no			2	
Croton gratissimus	s	p	no	5	6	6	
Cryptolepis oblongifolia	s	p	no	2	2		
Cymbopogon caesius	g	p	mi			2	2
Cynodon dactylon	g	p	na			2	
Dactyloctenium giganteum	g	a	mi	2			
Dialium engleranum	s	p	mi	2	3		
Dialium engleranum	t	p	mi		2		
Diascia engleri	s	p	na	2			
Dichapetalum rhodesicum	s	p	no		2		
Dichrostachys cinerea	s	p	mi	7	7	4	7
Dichrostachys cinerea	t	p	mi	2	3		
Digitaria gayana	g	a	mi		2		

Digitaria milanjiana	g	p	mi	2			
Digitaria seriata	g	p	na	6	5	5	2
Diospyros chamaethamnus	s	p	mi	4	2		
Diospyros lycioides	s	p	mi				2
Dipcadi longifolium	s	p	me	2			2
Diplorhynchus condylocarpon	s	p	no	6	4		
Diplorhynchus condylocarpon	t	p	no		2		
Ehretia rigida	s	p	mi			2	2
Elephantorrhiza elephantina	s	p	me				2
Elephantorrhiza suffruticosa	s	p	me				2
Elionurus tripsacoides	g	p	mi	2	2		
Enneapogon cenchroides	g	a	mi			2	2
Eragrostis biflora	g	a	mi			2	2
Eragrostis cimicina	g	a	mi	2			
Eragrostis cylindriflora	g	a	mi	2	4		
Eragrostis dinteri	g	a	mi	5	5	2	
Eragrostis echinochloidea	g	p	mi			2	
Eragrostis jeffreysii	g	p	mi	2	2	4	4
Eragrostis lehmanniana	g	p	mi	4	5	5	2
Eragrostis nindensis	g	p	na	2			2
Eragrostis pallens	g	p	mi	6	6	4	7
Eragrostis porosa	g	a	mi				2
Eragrostis rigidior	g	p	mi	6	5	7	8
Eragrostis rotifer	g	a	mi			4	
Eragrostis trichophora	g	a	mi		2	2	
Grewia avellana	s	p	pl	6	4		
Grewia bicolor	s	p	no		2	2	
Grewia falcistipula	s	p	no	2	3	2	
Grewia flava	s	p	no	4	4	4	6

Grewia flavescens	s	p	no	5	2	6	
Grewia olukondae	s	p	no	4	4	5	
Grewia retinervis	s	p	mi	5	4	4	
Grewia villosa	s	p	me	2	4		
Guibourtia coleosperma	s	p	no	5	4		
Guibourtia coleosperma	t	p	no	6	7		
Gymnosporia senegalensis	s	p	mi	2			
Heteropogon contortus	g	p	mi	5	2	2	
Hippocratea parvifolia	s	p	no	4	2	4	
Hyperthelia dissoluta	g	p	mi	5	4		
Lannea gossweileri	s	p	no	4	5		
Lannea zastrowiana	s	p	mi	3	4		
Lantana angolensis	s	p	mi	2			
Maytenus senegalensis	s	p	mi	4	2	4	
Melinis repens s. grandiflora	g	a	mi	7	8	4	4
Melinis repens s. repens	g	p	mi	6	6	4	4
Mundulea sericea	s	p	no			9	
Ochna cinnabarina	s	p	mi	2			
Ochna pulchra	s	p	no	7	7	6	
Ochna pulchra	t	p	no	4	4	2	
Ozoroa crassinervia	s	p	mi	2	2	2	
Ozoroa paniculosa	s	p	no	4	4	2	4
Ozoroa schinzii	s	p	no	4	4	4	
Panicum coloratum	g	p	mi				2
Panicum kalaharense	g	p	mi	5	2	3	
Panicum maximum	g	p	mi	4	2	4	
Peltophorum africanum	s	p	me	2	4	4	
Peltophorum africanum	t	p	me	3	2		
Perotis leptopus	g	a	na	4	2		

Perotis patens	g	a	mi	4	2	5	
Perotis vaginata	g	a	mi	2	3		
Philenoptera nelsii	s	p	me	5	4	5	
Philenoptera nelsii	t	p	me	5	2	5	
Pogonarthria fleckii	g	a	mi	2	5	2	4
Pogonarthria leiarthra	g	a	mi	6	4		
Pogonarthria squarrosa	g	p	mi	2	4	4	5
Psydrax livida	s	p	mi	2		8	
Pterocarpus angolensis	s	p	ma	4	4		
Pterocarpus angolensis	t	p	ma	8	8	3	
Rhigozum brevispinosum	s	p	mi			4	2
Rhus tenuinervis	s	p	no	6	4	4	2
Rhus tenuinervis	t	p	no	2			
Schinziophyton rautanenii	s	p	ma	4			
Schinziophyton rautanenii	t	p	ma	3			
Schizachyrium exile	g	a	mi		2		
Schmidtia pappophoroides	g	p	mi	6	7	2	6
Securidaca longepedunculata	s	p	mi	3	2		
Securidaca longepedunculata	t	p	mi	2	2		
Setaria pumila	g	a	mi		2		
Setaria verticillata	g	a	mi				2
Sporobolus fimbriatus	g	p	mi	2	2	4	
Stipagrostis uniplumis	g	p	mi	5	6	5	7
Strychnos cocculoides	s	p	mi	4	4		
Strychnos cocculoides	t	p	mi	2	2		
Strychnos pungens	s	p	mi	4	4	4	
Strychnos pungens	t	p	mi	2	2		
Tarchonanthus camphoratus	s	p	no				6
Terminalia sericea	s	p	no	8	7	9	8

Terminalia sericea	t	p	no	6	9	5	6
Tragus berteronianus	g	p	mi			2	2
Tricholaena monachne	g	a	mi	6	6	5	2
Triraphis purpurea	g	a	mi				2
Triraphis ramosissima	g	p	mi				2
Triraphis schinzii	g	p	mi	2	2	4	2
Urochloa brachyura	g	a	mi	4	5	4	4
Ximenia americana	s	p	mi	5	6		
Ximenia caffra	s	p	mi	2	2	2	
Ziziphus mucronata	s	p	mi	2	2	4	4

Codes:

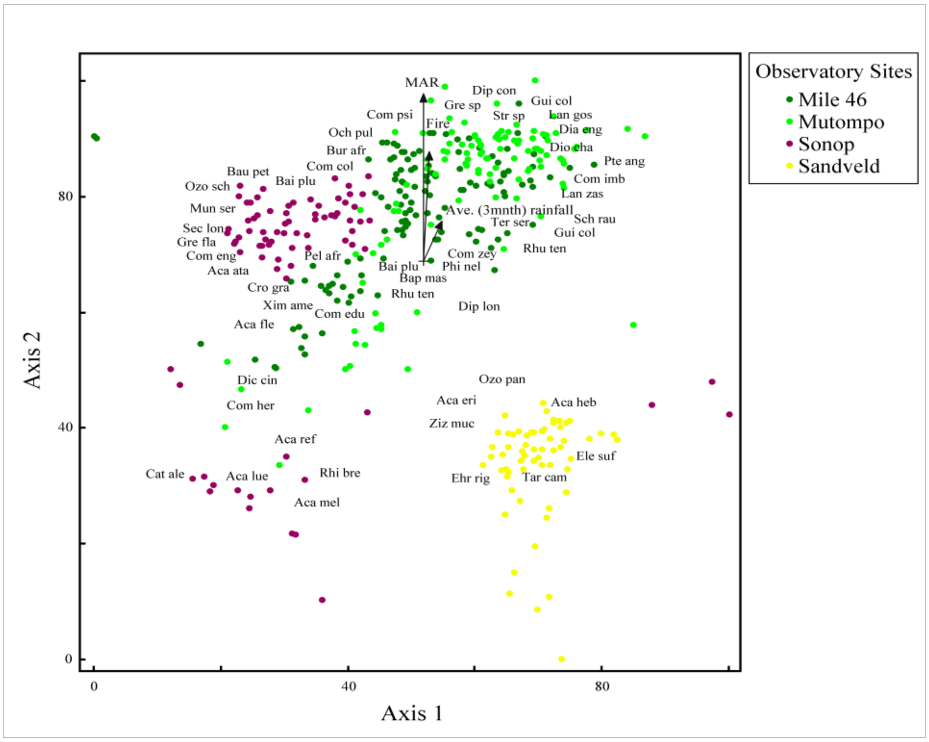
Leaf size			(mm^2)
	picophyll	pi	<2
Fine leaved	leptohyll	le	2-25
	nanophyll	na	25-225
	microphyll	mi	225-2025
Broad leaved	notophyll	no	2025-4500
	mesophyll	me	4500-18200
	platyphyll	pl	18200-36400
	macrophyll	ma	36400-18 x10^4
	megaphyll	mg	>18 x 10^4

Plant form layer	
Tree	t
Shrub	s
Grass	g

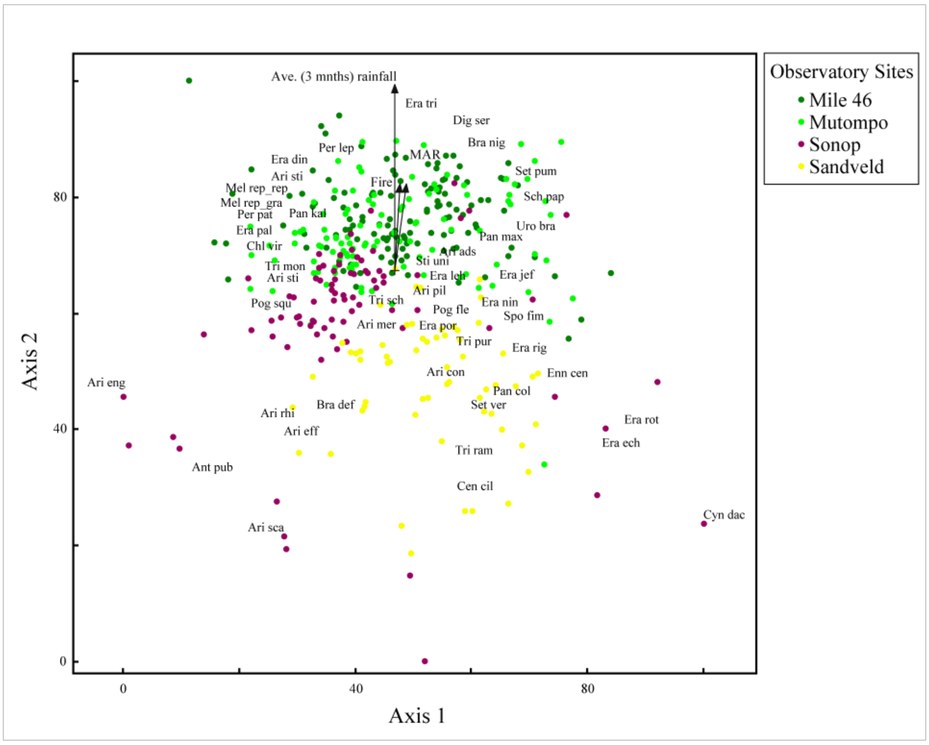
Life cycle period	
Perennial	p
Annual	a

Appendix 6: NMS ordination biplot graph showing (a) woody species composition laid with environmental variables gradients (Annual rainfall, Mean monthly rainfall and fire occurrence), (b) grass species composition overlaid with environmental variables gradients (Annual rainfall, Mean monthly rainfall and fire occurrence).

(a)



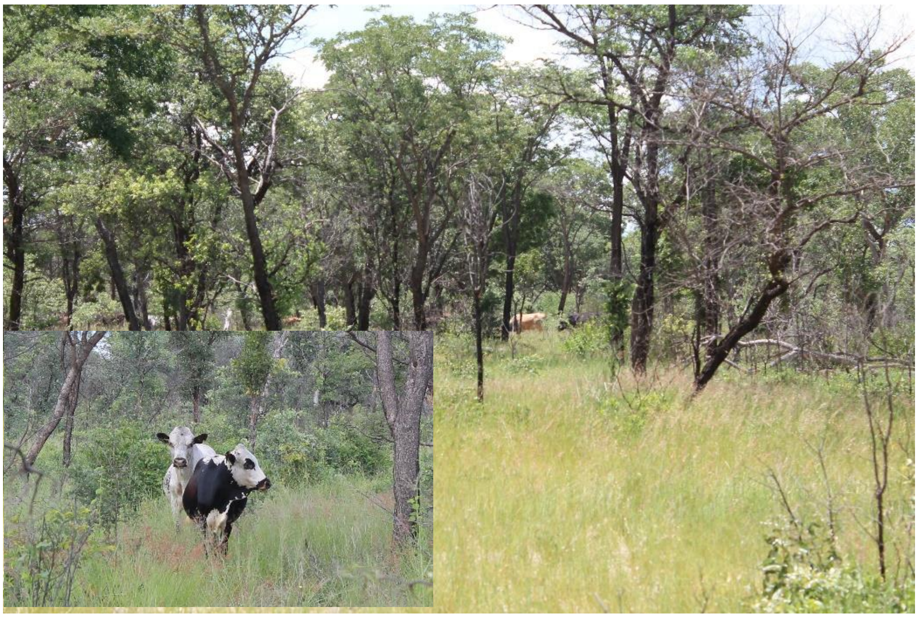
(b)



Appendix 7: Picture (a) showing woody stems of *Terminalia sericea* that were recently harvested in the Mutompo observatory. This were found in a plot approximately 100 m north-east of priority plot 6, (b) shows herded cattle grazing within the Mutompo observatory.

(a)

(b)



Appendix 8: Images of (a) *Combretum collinum*, (b) *Terminalia sericea* and (c) *Guibourtia coleosperma* resprouting after a fire event and wood harvesting within the Mile 46 and Mutompo observatories.

(a)

(b)

(c)