

**CHARCOAL PRODUCTION AS A MANAGEMENT TOOL AGAINST BUSH  
ENCROACHMENT: VEGETATION DYNAMICS**

**By  
NGATURUE DON MUROUA  
(2011072739)**

**Mini-dissertation (MOB791) submitted in the partial fulfilment of the  
requirement for the degree**

**MAGISTER IN ENVIRONMENTAL MANAGEMENT**

**In the Faculty of Natural and Agricultural Sciences  
Centre for Environmental Management  
University of the Free State  
Bloemfontein**

**November 2013**

**Supervisor: Mr Matti Nghikembua**

I, **Ngaturue Don Muroua, 2011072739**, declare that this dissertation is my own work, that it has not been submitted for any other degree, at the UFS or any other University or any other higher education institution, and that all resources that I have used or quoted are indicated in the text and acknowledged in the list of references.

**Name:** Ngaturue Don Muroua

**Signature:** \_\_\_\_\_

**Date:** 14 May 2014

## **ABSTRACT**

Bush encroachment has become a worldwide phenomenon and a concern for the world's arid and semiarid biomes. Savannas are turning into shrublands and thickets as evident in Namibia. This change in vegetation communities has direct consequences on the functioning of ecosystems and on services delivered by these systems. In Namibia, millions of hectares (ha) of arable land have been invaded by native bush species which vary in densities and structures. This affected area represents 32% of Namibia's terrestrial territory, and about 57% of Namibia's productive arable land. The agricultural (red meat) sector has been experiencing an economic loss of at least N\$ 1 billion annually.

Historically, drivers of bush encroachment *inter alia* include overstocking by grazer, suppression of fires, reduced browsers populations and climate variability. Different methods have been used to try to control the spread of encroaching bushes. Methods used to try and combat bush encroachment includes biological means, the use of chemicals and mechanical means. Most of these methods proved to be inefficient to farming.

Charcoal production since the 1990's, has created an incentive for farmers to remove excess bushes by producing charcoal as a by-product from rangeland rehabilitation. This process is believed to be more selective, environmental friendly and a cost-effective way of combating bush encroachment.

This study was therefore conducted to measure vegetation structure, plant density and composition, species diversity and evenness in response to the charcoal production on farm Pierre, situated in Outjo District, Namibia.

Systematic sampling methods were used to collect data in 400m<sup>2</sup> plots and 1m<sup>2</sup> quadrats along transects placed in a representative Treatment area and Control area.

The study results showed that bush thinning through charcoal production has led to the improvement of vegetation species diversity, veld ecological condition and facilitated a better grass biomass production. The tree density in the Treatment area was reduced by 51.4% and the grass density was 100% more than in the Control area. The veld ecological condition in the Treatment area, based on grass population dynamics was 168% more than in the Control area. The study also found that there was also a moderately strong negative correlation between tree density and grass density.

To ensure that bush thinning for charcoal production remains a sustainable tool for bush encroachment control, key issues such as the reduction in unselective harvesting of large trees and improving on aftercare following bush harvesting need to be addressed by all stakeholders, especially the charcoal producer. This can be done through voluntary means or by developing policies that give incentive's to aftercare treatment and to selective harvesting of problem trees.

**Keywords:** Bush encroachment, biodiversity, charcoal production, vegetation dynamics, rangeland rehabilitation.

## **ACKNOWLEDGEMENT**

Without the support from Mr. W. Groenewaldt the owner of farm Pierre, this study will have not taken place. His support and time spent with the researcher is highly appreciated.

Sincere gratitude is also extended to Ms. M. Kemp and Mr. C. Hartz for their comments and input into the study.

Consulting Services Africa (CSA), my employer, is highly thanked for their support and financial contribution towards this study. Without their support and financial assistance, this study will have not been realised.

Last but not the least, sincere appreciation is extended to Mr. M. Nghikembua for his role as a Supervisor to me. His time and inputs into this study is very much appreciated.

## TABLE OF CONTENTS

<b>Declaration</b>	<b>i</b>
<b>Abstract</b>	<b>ii</b>
<b>Acknowledgements</b>	<b>iii</b>
<b>List of Tables</b>	<b>viii</b>
<b>List of Figures</b>	<b>viii</b>
<b>Chapter 1: Introduction</b>	<b>1</b>
1.1 Bush encroachment background	1
1.1.1 History of bush encroachment	1
1.1.2 Bush encroachment drivers	2
1.1.3 Impacts of bush encroachment	3
1.2 Charcoal industry	4
1.3 Research motivation	4
1.3.1 Rationale of the research	4
1.3.2 Research questions	5
1.3.3 Research objectives	5
1.3.4 Layout of Chapters	6
<b>Chapter 2: Literature review</b>	<b>8</b>
2.1 History of bush encroachment: A thorny problem	8
2.2 Bush encroachment drivers	9
2.2.1 Climate variability and CO <sub>2</sub> emission levels	11
2.2.2 Poor grazing practices	13
2.2.3 A lack or misuse of fire	14
2.2.4 Reduced browsing pressure	15
2.3 Impacts of bush encroachment	16
2.3.1 Impact on rangeland degradation and livelihoods	17
2.3.2 Impact on biodiversity and ecosystem functions and services	19
2.3.3 Impact on groundwater resources	20
2.4 Strategies used to control bush encroachment	21

2.4.1	Use of fire	21
2.4.2	Use of browsers	22
2.4.3	Chemical control	23
2.4.4	Mechanical clearing	23
2.4.5	Charcoal Industry	24
<b>Chapter 3: Description of the study area</b>		<b>27</b>
3.1	Location of Farm Pierre	27
3.2	Climate and Topography	27
3.3	Geology and Hydrogeology	30
3.4	Soils	31
3.5	Fauna	32
3.6	Flora	33
<b>Chapter 4: Research methodology</b>		<b>35</b>
4.1	Introduction	35
4.2	Research design	36
4.2.1	Process description	36
4.2.2	Assumptions	39
4.3	Tools and materials	39
4.4	Data analysis	41
4.4.1	Vegetation density	41
4.4.2	Shannon Diversity Index	42
4.4.3	Species Evenness	42
4.4.4	Tree height structure composition	43
4.4.5	Ecological value of grass species	43
4.4.6	Correlation and Correlation Coefficient Analysis	45
<b>Chapter 5: Results</b>		<b>47</b>
5.1	Tree density	47
5.2	Tree height classes/structure	48
5.3	Tree species richness, diversity and species composition	50

5.4	Grass density	52
5.5	Grass species richness, diversity and species composition	53
5.6	Grass ecological values	55
5.7	Correlation and Correlation Coefficient Analysis	55
<b>Chapter 6: Discussions</b>		<b>57</b>
6.1	Tree population dynamics	57
6.1.1	Tree density	57
6.1.2	Tree height classes/structure	57
6.1.3	Tree species richness, evenness, diversity and species composition	58
6.2	Grass population dynamics	59
6.2.1	Grass density	59
6.2.2	Grass species richness, evenness, diversity and species composition	60
6.2.3	Grass ecological values	60
6.3	Correlation and Correlation Coefficient analysis	61
6.3.1	Bush density vs. grass density	61
6.3.2	Bush density vs. grass species diversity	62
6.3.3	Bush density vs. grass species evenness	62
6.3.4	Bush density vs. grass species richness	62
6.3.5	Bush density vs. grass grazing, -ecosystem, and -successional values	63
6.3.6	Bush density vs. grass perenniality and -biomass values	63
6.4	Charcoal industry policy implications for bush encroachment management	64
<b>Chapter 7: Conclusions and Recommendations</b>		<b>65</b>
<b>List of References</b>		<b>67</b>

## List of Tables

Table 4.4a:	An example of a formatted excel sheet used to calculate evenness	42
Table 4.4b:	Scores used to calculate value of grasses in the different quadrats	43
Table 5.6:	Grass ecological value scores in both areas	55
Table 5.7:	Results of the Correlation Coefficient and p-values of the paired variables	56

## List of Figures

Figure 3.1:	Location of Farm Pierre (study site) in Namibia	27
Figure 3.2a:	Average annual rainfall in mm	28
Figure 3.2b:	Average annual water deficit	28
Figure 3.2c:	Topography on Farm Pierre	29
Figure 3.3a:	Namibian geology	30
Figure 3.3b:	Groundwater resources in Namibia	31
Figure 3.4:	Dominant soils in Namibia	32
Figure 3.6a:	Namibian biomes	34
Figure 3.6b:	Namibian vegetation types	34
Figure 4.2a:	Transects (in red lines) layout and locations on the farm	37
Figure 4.2b:	Plots and quadrats layout along a transect	37
Figure 4.3a:	A 1 m <sup>2</sup> quadrat used for grass sampling	39
Figure 4.3b:	A marked pole use to determine tree height	40
Figure 5.1a:	Treatment area: Tree density	47
Figure 5.1b:	Control area: Tree density	47
Figure 5.2a:	Treatment area: Tree height classes distribution	48
Figure 5.2b:	Treatment area: Tree height classes composition	48
Figure 5.2c:	Control area: Tree height classes distribution	49
Figure 5.2d:	Control area: Tree height classes composition	49
Figure 5.3a:	Treatment area: Tree species evenness	50

Figure 5.3b: Treatment area: Tree species composition	51
Figure 5.3c: Control area: Tree species evenness	51
Figure 5.3d: Control area: Tree species composition	51
Figure 5.4a: Treatment area: Grass density	52
Figure 5.4b: Control area: Grass density	52
Figure 5.5a: Treatment area: Grass species evenness	53
Figure 5.5b: Treatment area: Grass species composition	54
Figure 5.5c: Control area: Grass species evenness	54
Figure 5.5d: Control area: Grass species composition	54
Figure 6.2a: Treatment area grass cover	59
Figure 6.2b: Control area grass cover	59

# Chapter 1: Introduction

## 1.1 Bush encroachment background

Bush encroachment is a form of land degradation which constitutes the invasion and thickening of prolific undesired woody plant species in a savanna or grassland. This invasion results in an imbalance of the natural grass:bush ratio, thereby decreasing the rangeland biomass diversity, quality and productivity.

### 1.1.1 History of bush encroachment

Internationally, the problem of land degradation resulting from bush encroachment and overgrazing has been increasing both in terms of total land area and severity of degradation (Gillson *et al.*, 2012). Bush encroachment has become a common phenomenon in the world's arid and semiarid biomes, where grasslands and savannas are turned into shrublands and thickets (Eldridge *et al.*, 2011). The change in vegetation communities has direct consequences on ecosystems' functioning and service delivery. In Namibia, bush encroachment is most common in the central part of the country.

In Namibia, bush encroachment has had a serious impact on the country's biodiversity and its agricultural (red meat) sector. As explained by Bester (1999) in De Klerk (2004), about 26 million hectares of arable land have been invaded by native bush species which vary in density between 2 500 to 10 500 bushes per hectare. The affected area represents 32% of Namibia's terrestrial territory and about 57% of Namibia's productive arable land, excluding desert and arid areas. The common culprits of this phenomenon according to De Klerk (2004) are: *Acacia mellifera* (Black thorn), *Acacia erubescens* (Blue thorn), *Acacia reficiens* (False-umbrella thorn), *Dichrostachys cineria* (Sickle bush), *Terminalia prunoides* (Purple-pod terminalia), *Terminalia sericea* (Silver-leave terminalia) and *Colophospermum mopane*. The woody species invasion is not easily noticed as it is a gradual process where an increase in bush thickening takes place over a long period and in different

phases. The type of species to invade a particular area in Namibia depends on climatic conditions, soil types and the historical distribution of invading woody species.

### 1.1.2 Bush encroachment drivers

The debates continue on the causes of bush encroachment. What is certain is that, there are different drivers determining the rate of open savannas transformation towards homogenous and dense vegetation. These drivers can be classified into two main categories, namely physical and socio-economic drivers. Physical drivers are those such as grazing and rainfall, while socio-economic drivers include policies and legislations. Brown & Havstad (2004) believes that, it is very important to understand that these drivers can act independently at different scales or in isolation. Therefore the comprehension of such interaction is crucial in determining the most effective and sustainable approach to successfully responding to bush encroachment.

This study thus, aims to collect data and carry out analysis on the vegetation on the farm Pierre, in areas both where vegetation harvesting took place to produce charcoal and where no harvesting took place, the control sites. Based on the study results, some conclusions will be drawn regarding the interrelationships between the bush thinning and rangeland recovery. The findings will assess and evaluate the impact charcoal production has on rangeland productivity in terms of vegetation species diversity, density and structure. It is expected that the areas where bush harvesting took place for charcoal production will have a better vegetation species diversity, grass density and woody plant species structure. Hence, the bush-harvested areas is expected to support both higher biodiversity and income generating activities, such as livestock farming, game and tourism related enterprises.

### 1.1.3 Impacts of bush encroachment

De Klerk (2004), reported that already in the 1970's, a variety of methods were being employed by farmers to combat bush encroachment: biological means (i.e. using goats), chemical treatment, bulldozing of bushes, root ploughs, and manual cutting of bushes using axes and pangas. Most of these methods, however, were found to be uneconomical or counter-productive for farmers because they were overly labour intensive, required heavy and expensive machinery, disturbed top soils, or required aircraft.

As a result of bush encroachment, the agricultural (red meat) sector has been losing at least N\$ 700 million annually (De Klerk, 2004). This economic loss has increased to N\$ 1.6 billion per year and beef production has been reduced by 50% (Christian, 2010).

In communal or tribal land, bush encroachment has resulted in a decrease in livestock numbers per household, thus exposing families to greater food insecurity and reduced household income, and ultimately lowering their living standards. Furthermore, bush encroachment has made rangelands across Namibia more vulnerable to the negative impacts of drought and climate variability.

Bush encroachment is a form of land degradation. Bush encroachment is not only seen as a form of land degradation but also as a serious form of desertification (Eldridge *et al.*, 2011). Most of Namibian biodiversity, especially game and plants, is found outside state protected areas (Marker *et al.*, 1995). Therefore, if charcoal production is a cost-effective and environmentally sustainable strategy to rehabilitate degraded rangelands by removing encroaching species, then incentives for such efforts should be formalized in policies, laws and tax incentives.

## 1.2 Charcoal industry

Since the 1990's, charcoal production has served as a viable method for rangeland rehabilitation. Charcoal production is believed to be a more selective, environmental friendly, and cost-effective way of controlling bush encroachment than other methods. Namibia alone produces about 100 000 metric tons of charcoal annually, and generated an approximate annual income of N\$ 75 - 100 million in 2004 (Diekman & Muduva, 2010).

## 1.3 Research Motivation

### 1.3.1 Rationale of the research

Already in the 1970's, De Klerk (2004) described bush encroachment as a widespread problem in Namibia, and identified the methods such as biological means, chemicals use, bulldozing of bushes, root ploughs, and manual cutting of bushes as techniques that had been employed by farmers to combat the problem. These methods, however, proved to be unviable and environmentally unsound, and therefore never became popular amongst Namibian farmers.

Charcoal production, on the other hand, has become a popular method of addressing bush encroachment because it can be a viable enterprise as well as environmentally beneficial. The charcoal industry has become increasingly important for the agricultural sector and the national economy.

Scholes & Archer (1997) and Scholes (2009) are of the opinion that bush encroachment is irreversible within several decades. But charcoal production in Namibia could prove Scholes & Archer (1997) and Scholes (2009) wrong.

Understanding the effects of bush encroachment control methods and the respective responses on woody species is important for the management of savanna ecosystems.

This study will demonstrate how charcoal production is being used to address bush encroachment challenges.

The study will answer the following questions:

- a) Has charcoal production increased rangeland productivity in terms of improved grazing quality,
- b) Has charcoal production facilitated the recovery of savanna vegetation structure on the farm Pierre, and
- c) Has vegetation biodiversity and species richness improved due to charcoal production?

In particular, this study aims to measure the vegetation height classes, plant density and composition, species diversity and evenness in response to the charcoal production that has occurred on farm Pierre.

### 1.3.2 Research questions

Has charcoal production contributed to the recovery of rangeland condition in terms of increased grass productivity and vegetation diversity?

### 1.3.3 Research objectives

The following are the research objectives:

- a) To determine and compare woody and grass species composition, density, evenness, richness and diversity in areas where the vegetation was harvested for charcoal production and in areas not affected by charcoal production,
- b) To determine and compare trees height classes in areas where the vegetation was harvested for charcoal production and in areas not affected by charcoal production,

- c) Statistically determine the significance of differences in results between areas where vegetation was harvested for charcoal production and in areas not affected by charcoal production and
- d) From the study findings, provide recommendation on policy implications for the promotion of charcoal production as a cost-effective strategic tool for the management and rehabilitation bush encroached rangelands (if charcoal production proved to be beneficial towards rangeland rehabilitation).

#### 1.3.4 Layout of Chapters

This report has started with Chapter 1, introducing bush encroachment not only as a Namibian challenge but also as a global challenge. Chapter 1 also looked at the history and the drivers of bush encroachment. It further explains the impact of bush encroachment and efforts used to control it.

Chapter 2 presents detailed literature reviews on the topic, from the history of bush encroachment, its drivers, impacts on rangeland and biodiversity, methods and strategies used to control bush encroachment and also discusses the charcoal industry. Chapter 2 also discusses the views of different authors and information gaps.

Chapter 3 provides a description of the study area to give the reader a clear understanding of the study site. This information will help to put the study results, findings and discussions into perspective.

Chapter 4 presents in detail the methodology used during the data collection and analysis, while Chapter 5 presents the results of the data collected, and Chapter 6 discusses the results in relation to the impact of bush thinning and the relationship between grass density, species evenness, richness, composition and diversity. Chapter 6 also discusses the impact of bush density and the relationship between grass ecological values.

Chapter 7 presents final remarks and recommendations on the use of charcoal production as a tool that can be used to improve rangeland condition.

## Chapter 2: Literature review

### 2.1 History of bush encroachment: A thorny problem

The agricultural sector in Namibia has been identified as a strategic sector in Namibia's Fourth National Development Plan (NPC, 2012). Hence the Namibian Government has committed itself to investing in this sector and aims to achieve an average of 4% annual growth rate (NPC, 2012). According to the NCCI (2013), the agricultural sector contributed about 7% to the Namibian GDP. Of this, 76% is generated from livestock farming, mainly cattle, goats and sheep (NPC, 2012). The largest contributor is the commercial farming area that contributes 70% of the 76% (NPC, 2012). This statistic appears to indicate that the communal farming areas do not contribute significantly to the agricultural sector, even though 48% (over 1 million) of Namibians derive their livelihoods from subsistence agriculture (NPC, 2012). It is therefore clear that agriculture is very important for livelihoods in both commercial and communal farming areas livelihoods, as well as for the country's GDP. Hence, the pervasive problem of bush encroachment clearly impacts negatively on the broader Namibian society, both directly and indirectly.

The impact of bush encroachment on the Namibian economy and people cannot be understated. Twenty-six million hectares of arable land has been invaded by native bush species (Bester, 1999 in De Klerk, 2004). This immense, affected area represents 32% of Namibia's terrestrial territory, and about 57% of Namibia's productive arable land. Bush encroachment is a form of desertification and has been identified by the United Nations Convention to Combat Desertification (UNCCD) as a serious problem in Africa (Hoffman & Darkoh, 2003).

Bush encroachment has been experienced as a seriously challenging problem in southern Africa since the mid-1900. Moleele *et al.* (2002) agree that since the early 1970s in South Africa and Botswana, bush encroachment has been observed and revealed changes in vegetation cover and types. These changes in vegetation types

were towards homogenous thornvelds which Moleele *et al.* (2002) attributed to both natural and human activities.

Archer *et al.* (1995) pointed out that at least 50 years ago, evidence were found suggesting that the world savannas were transforming as a result of bush encroachment. Scholes & Archer (1997) described bush encroachment as a process where palatable grasses and herbs growth is suppressed by unpalatable woody species. These woody species are not browsed successfully by livestock and continue to dominate the grasses and herbs since livestock selectively graze and browse more palatable vegetation. This process leads to the reduction in biodiversity and in carrying capacity for livestock and threatens many farming communities in both communal and commercial land.

## 2.2 Bush encroachment drivers

A healthy and productive ecosystem according to Odada *et al.* (2009) depends on how people interact with their environment and how natural process determined by the climate and other natural cycles interact with anthropogenic processes and products. A healthy ecosystem is vital for its services rendered to the society and people. These services come in many different forms such as carbon sequestration, food, water resources, waste management, biodiversity and recreation. Due to diverse factors, both natural and anthropogenic, ecosystem services are changing in quality and quantity.

In Namibia, at least 26 million hectares of savanna habitats are encroached by native species (De Klerk, 2004), while Trollope *et al.* (1989) estimated that in South Africa, 13 million hectares of savannas were affected by thorn bush encroachment. However, with the current challenges emanating from bush encroachment, scientists are still not in agreement about bush encroachment drivers and their dynamics.

There are different drivers that lead to bush encroachment. Debates about these drivers continue, and will continue on into the future. Brown & Havstad (2004)

defined agents that transform the savannas' biological communities as drivers. These drivers determine the transformation of savannas through asserting pressure on how farmers manage their rangeland, i.e. markets or tax laws which either give incentives or penalize certain farming activities. Other drivers such as stocking rates, weather and climate have a physical and direct impact on the transformation of savannas. Brown & Havstad (2004) also believes that, it is very important to understand that these drivers can act independently at different scales or in isolation.

Ward (2005) disagreed with the Walter's two-layer model which identifies grazing pressure as the sole cause of bush encroachment. Ward (2005) explained that this phenomenon is even common in under-grazed rangelands and in single soil layers. In Namibia, farmers are made to believe that the removal of natural veld fires and overgrazing by domestic livestock has largely contributed to bush encroachment.

According to Ward (2005), the most important factor in *Acacia mellifera* proliferation was high rainfall frequency and not rainfall amount. This suggests that, even without heavy and continuous grazing, the savanna will tend to transform towards a thicket. Hence, bush encroachment, as explained by Ward (2005), could be part of a natural process even in the absence of overstocking and exclusion of fires as reported by (Wigley *et al.*, 2009 and Moleele *et al.*, 2002).

Observations in Namibia's rangelands suggest that domestic livestock has led to rangeland degradation by altering vegetation compositions that resulted into reduced grass biomass and increased woody biomass. Supporting this observation is Hoffman & Ashwell (2001), that in Southern Africa, overgrazing is considered to be the most important cause of rangeland degradation. Overgrazing not only decreases palatable perennial plants, but favours the less palatable, undesirable vegetation. The reduction in perennial grasses species reduces ground cover can result in more runoff that exposes soils to erosion and gully formations, further reducing rangeland productivity.

Is bush encroachment a man-made or natural phenomenon? Wiegand *et al.* (2005) have hypothesised the latter. Hypothetically, bush encroachment forms part of the savannas patch-dynamics seen in semi-arid and arid environments and are important ecological systems (Wiegand *et al.*, 2005). If this is true, then bush encroachment is a natural and an integral part of savanna vegetation dynamics. But, how big should these encroached patches be, to ensure high system productivity and services delivery? In Namibia, these encroached patches can stretch over many kilometres covering entire farming units and creating unproductive homogenous habitats for both farming and biodiversity conservation. At the landscape scale, these affected savannas cannot be seen to be stable and natural, especially at the current rangeland/farming units (farms and villages size) as proposed by (Britz & Ward, 2007).

Buitenwerf *et al.* (2011) suggested that vegetation cover in savannas is regulated by various scale-dependent variables such climate and herbivory. The driving forces behind the change in savannas' vegetation cover and structure remains a contentious subject. In southern Africa, this change is attributed to anthropogenic activities such as CO<sub>2</sub> emissions, a lack or misuse of fire, reduced browsing pressure, poor grazing practices, especially overstocking of cattle (Moleele *et al.*, 2002) and climate variability.

### 2.2.1 Climate variability and CO<sub>2</sub> emission levels

Gillson *et al.* (2012) is of the opinion that climate and atmospheric changes has direct impact on the land-cover shift. This interaction though is not well understood, but at such scale-dependent relationships could be significant. Wigley *et al.* (2009) also supports Gillson *et al.* (2012) opinion that climate is one of the drivers of vegetation directional shift towards bush encroachment.

According to Ward (2005), the most important factor in *Acacia mellifera* proliferation was high rainfall frequency and not rainfall amount. This view is shared by Wigley *et al.* (2009) who indicated that the communal farmers suggested that in years of

above rainfall followed by a drought, major recruitment of woody species occurred. Understanding the scale-dependency of drivers can answer why this is the case. Above average raining season is associated with higher frequency of rainfall over a longer period. This situation produces more soil moisture for seedling and a longer growing season that allows the seedlings to grow better. On the other hand, higher herbaceous biomass directly and indirectly protects the seedlings from browsing further allowing seedlings to establish.

Angassa & Oba (2007) concluded that shift in vegetation cover from an open savanna to a bush encroached is also likely controlled by stochastic rainfall more than by overgrazing alone. Suggesting overgrazing alone will not necessarily lead to a directional vegetation change from an open savanna to a thick vegetated state of a savanna. It is therefore important to note that land-use practice alone is not the driving force of bush encroachment.

Although not extensively research and understood, CO<sub>2</sub> levels in the atmosphere is identified as a key driver of bush encroachment. Wigley *et al.* (2009) concluded in their research that trees were more responsive to increased CO<sub>2</sub> than herbaceous species. Pointing out that there could be a positive correlation between increased CO<sub>2</sub> and the rate of bush encroachment. Wigley *et al.* (2009) recorded bush encroachment events in areas heavily grazed in private, and lightly grazed communal land and conservation areas. Hence suggesting that the atmospheric CO<sub>2</sub> levels were the likely reason for the increase in woody species density across all land uses.

Sithole & Murewi (2009) are explaining that the variability in the climate and climate change in southern Africa is associated with decreasing rainfall and thus will lead to decrease in water resources, biological diversity and increased rangeland degradation. In semi-arid ecosystems, droughts will be one of the key factors to cause the conversion of open habitats into woodlands (Dalle *et al.*, 2006). This factor and other explained above do play a vital in the rate of bush encroachment in southern Africa and in Namibia.

### 2.2.2 Poor grazing practices

Farming is an important land use and a vital livelihood strategy for both households and broader economy in southern Africa. The ever increasing populations of the world will continue to put pressure on the limited rangelands available for farming activities.

Land use practices according to Wigley *et al.* (2009) and unsustainable land use practices Darkoh (2009) will lead to habitat and land degradation in the semi-arid area of southern Africa. This degradation can alter the functioning and structure of savanna ecosystems, thereby influencing the type of ecosystem services available to support livelihoods activities.

Poor grazing practices include both undergrazing and overgrazing. Overgrazing is believed to occur when continuous heavy grazing is practiced. This sustained grazing pressure according to Eldrige *et al.* (2011) decreases the aboveground grass biomass. The reduction in stem and leaf biomass, also contribute to the grasses root system reduction, leading to decreased competition between grasses and woody plants, through an increased resource availability for the woody species establishment and more shrub recruitment (Eldrige *et al.*, 2011 and Coetzee *et al.*, 2007). The reduced grass biomass is understood to reduced fire frequency and intensity thus further allowing woody species seedlings and saplings to establish.

Past overstocking by mainly cattle is said to be the main contributing factor of overgrazing in commercial land (Wigley *et al.*, 2009). These high stocking rates were the major cause of encroachment as explained by Eldrige *et al.* (2011). Eldrige *et al.* (2011), Tefera and Mlambo (2010), and Wigley *et al.* (2009) agree that this change in plants composition from open balances savanna to thickets resulted in exclusion of natural fires that allowed woody plants to successfully recruit into bigger size classes thereby escaping the fire trap.

As explained earlier, changes to livestock stocking rates have been blamed for influencing bush encroachment rate. Higher stocking rates of grazers contributed to overutilization on grass and led to exclusion of natural fires. While Wigley *et al.* (2009) and Boulant *et al.* (2009) argued that low stocking rates of browsers allowed woody plant species such as the *Acacia* species to proliferate causing their encroachment.

Unsustainable grazing pressure does not only cause land degradation through bush encroachment but also genetic erosion of plants communities (Bennani *et al.*, 2010). Tefera *et al.* (2008) concluded that grazing pressure is one of the major attributing factors that promotes bush to encroach an area.

### 2.2.3 A lack or misuse of fire

The functions and structure of many savanna ecosystems are determined by fire regimes (O'Reilly *et al.*, 2006). The effect of fire on savanna vegetation is determined amongst other aspects, by frequency and intensity. Fire is one of those global ecological factors determining species composition, structure and distribution of vegetation across ecosystems and landscapes. Other important factors influencing vegetation types at landscape level are climate and soils (Hassan *et al.*, 2007).

In Namibia both natural and man-made fires have been part of the landscape. Hunters and gatherers have been using fire for hunting game and pastoralists have used fires to stimulate out of season grasses' growth.

Angassa and Oba (2008) and Dalle *et al.* (2006) found that the official ban and suppression of fire has led to an estimated 52% increase in bush encroachment in some of Ethiopia's rangelands. While Wigley *et al.* (2009) found that cool burning and fire exclusion also led to major escape events for tree seedlings and consequently accelerating woody species colonisation.

Fire frequency and intensity not only affect native species but also exotic species. Watson *et al.* (2009) believe that exotic shrubs also controlled by same fire types as those used to control or manage native bush encroaching species. According to Watson *et al.* (2009) low-frequent fires and cold fires sites recorded more encroaching of woody plants species. Buitenwerf *et al.* (2011) on the other hand concluded that fire only damage trees above-ground thus inducing stem dieback above-ground and that trees were rarely killed by fires. Buitenwerf *et al.* (2011) failed to differentiate between hot and cold fires and this could be why he concluded that fires only affect vegetation structure and not vegetation density.

Buitenwerf *et al.* (2011) argument demonstrates the complexity of vegetation studies. Hot fires have been observed by this author to “kill” trees, especially those problematic shrubs. These shrubs are in-reach of the fire flames and their stems are not so big that fires cannot “kill” them. It is true that fires will not be able to “kill” many trees (>80%). The definition of tree killing is debatable. But the real impact of a hot fire is less debatable. Fires do reduce the above-ground tree stem density, thus opening up rangelands. Better grass cover and a heterogenic vegetation structure are experienced after hot fires.

Zida *et al.* (2008) concludes that fire intensity and severity can boost or suppress seedling recruitment. Zida *et al.* (2008) also cautioned that post fire rangelands are drought prone and further land degradation risk can be high. Therefore the timing to use fire as a management tool needs to be well thought through.

#### 2.2.4 Reduced browsing pressure

Very little is known in the literature on how browsers control the spread of bush encroachment. From observation bush encroached areas are very hard to rehabilitate through the use of high stocking rates of browser. Therefore the direct impact of browse on established encroachment is very limited.

Browsers thus are best in controlling bush encroachment by controlling the recruitment of woody species through browsing on the seedlings and saplings. High density browsers can achieve such an impact.

Van der Waal *et al.* (2011) suggested that tree seedlings and saplings are outcompeted in veld under fertile conditions. Van der Waal *et al.* (2011) concluded that, it is why tree recruitment in kraals is low. This view cannot be left unchallenged. In kraals, not only is the fertilizing agents very high, but also urea. Urea can change the pH of the soil, buy lowering it and thus can inhibit recruitment of many other plants species. From observation, there are only a few plants species that grows in the kraals.

It is also important to note that some of the large browsers such as elephants can distribute seeds through their dung. Elephants are effective in reducing the density of trees but not shrubs. In areas where bush encroached is well established, elephants create a homogenous vegetation structure, mainly accessed by the mega herbivores only.

As concluded by Roques *et al.* (2001), browsing impact on bush encroachment was most effective in the earlier stages of woody plants establishment. Roques *et al.* (2001) also suggested that, grazing impact on bush encroachment was much more important than browsing pressure. This conclusion was made due to fact that grazing pressure affects herbaceous plant biomass that influences natural veld fire frequency and severity.

### 2.3 Impacts of bush encroachment

Bush encroachment impact on the environment and society can be very detrimental. There are no positive impacts that can overwhelm negative impacts. Positive impacts of bush encroachment arguably are increase in browsing animal species such as kudu and generating new income generating activities such as charcoal production. But these positive impacts will not overweigh negative impacts such as loss of

biodiversity (Parr *et al.*, 2012), rangeland degradation, reduced ecological carrying capacity (Lange *et al.*, 1997), loss of net farming income, injuries to livestock and wildlife due to thickets prickling.

### 2.3.1 Impact on rangeland degradation and livelihoods

The rangeland condition describes the state of rangelands ability to produce forage that will support sustained optimal production of livestock. Such condition affects the rangeland resilience to land degradation (Trollope *et al.*, 1990) in (Tefera *et al.*, 2007).

It is difficult to comprehend the impact of bush encroachment on rangeland and livelihoods. This is due to the interaction of anthropogenic and natural drivers of bush encroachment (Fasona & Omojola, 2009).

Bush encroachment in savannas and grasslands has been a serious worry for many years for land managers. Bush encroachment has been long seen as a threat against grass biomass output and livestock handling, therefore threatening the sustainability of all farming types, from pastoral to commercial livestock farming (Wigley *et al.*, 2009).

Degraded rangeland is incapable of optimally supporting ecosystems that are healthy and able to produce adequate products and provide efficient services to sustain livelihoods and economies. Apart from shrinking natural resource on the land, Fasona & Omojola (2009) are of the opinion that the degradation of land also diminishes the resilience and ability of the land to withstand stochastic environmental disturbances.

Secondary impacts in areas affected by bush encroachment can be experienced. Such impacts can include secondary invasion of alien species in this already weakened land.

Bush encroachment as described earlier generate different benefits and consequences. Below is a list adopted from (Wigley *et al.*, 2009).

Bush encroachment pros and cons:

- a) Increase in woody biomass produces more building materials,
- b) Increase in woody biomass produces more fencing materials,
- c) Increase in woody biomass produces more firewood resources,
- d) Increase in woody biomass produces more browse for browsers at the expense of grazers,
- e) Increase in woody biomass produces less grass for grazers,
- f) Increase in woody biomass lead to loss of biodiversity,
- g) Increase in woody biomass create poor visibility for game viewing,
- h) Increase in woody biomass lead to loss of grass layer and exclusion of fire and
- i) Increase in woody biomass increases the threat of invasion by opportunistic alien invaders.

The pros and cons identified above, impact the different land uses differently. Therefore the control and management strategies will also differ. Bush encroachment in communal land tends to generate mix feelings. Due to human population increase in communal land, woody species provided much needed building materials and heat energy resources, browse for goats and also cattle (author's own observations). Goat rearing has become more important in communal areas since it is relatively less energy intensive and requires less capital investment. Poorer households are able to farm with goats with ease. In both commercial and communal land, bush encroachment has been seen as a form of land degradation. Bush encroachment has reduced farming income and carrying capacities. Charcoal production is a benefit from bush encroachment but will be unable to outweigh the cost of reduced carrying capacity for cattle farming.

### 2.3.2 Impact on biodiversity and ecosystem functions and services

Conservation of biodiversity is a major concern for conservation institutions such as line Governmental Ministries and conservation organisations. Hence, savanna habitats transformation into homogenous thickets is a concern to achieving conservation goals in formal and in informal conservation areas such as commercial land conservancies.

Savannas are characterised by their tree-grass interaction. This tree-grass balance and their respective climate governed savannas functions, which intern influence fauna production and shapes their assemblages (Van der Waal *et al.*, 2011). Thus, a change in the tree-grass composition is bound to impact the savanna ecosystem characteristics and functionality.

Sirami & Monadjem (2012) and Eldridge *et al.* (2011) came to the same conclusion that significant decrease in species richness was associated with shrub cover increase. Eldridge *et al.* (2011) also found increase in plot scale species extinction correlating with decrease of grass cover, as a result of increase in shrub cover. Shrub or bush cover increase has been associated with different adverse environmental conditions such as homogenous vegetation structures, impenetrable thickets, restricted access to rangeland, poor veld fertility and underutilised rangeland.

The adverse environmental conditions created by bush encroachment can lead to creation of new unproductive biomes or may cause biome shifts from open savannas to closed savannas or thickets. Altering the functions and biodiversity of the original landscapes thereby reducing the productivity and economic benefits from rangelands (Buitenwerf *et al.*, 2011). Taking cognisance that savannas account for about 40% of the terrestrial land surface Field *et al.* (1998) in Throop & Archer (2008), stated that the transformation of savannas could be detrimental to the global ecosystems, especially those directly affected by the bush encroachment.

Bush encroachment was identified by Sirami *et al.* (2009) as being a major impact on bird diversity in open landscapes. Bush encroachment not only negatively impact on bird diversity but also on mammals' diversity. Antelope species such as the springbok have completely disappeared in areas where bush encroachment is severe. Generally speaking, the Namibian savannas support more grazers than browsers. Therefore bush proliferation will reduce mammals' diversity in a long-term if left unchecked. Mammals are a very important component of the Namibian savannas and form a web of complicated food chains on which livelihoods and the economy depend on.

### 2.3.3 Impact on groundwater resources

Namibia is the driest country south of the Sahara Desert. The rainfall is scarce and unpredictable. All the perennial rivers forms national boundaries and hence groundwater resources are pivotal to Namibians existence. According to Christian (2010), over 80% of Namibia's economic productivity relies solely on groundwater.

Trees in general use far more water than grasses. Therefore it is expected that a bush encroached area will lose much more water from the soil than an open savanna. Christian (2010) estimated that a 5,000ha farm loses about 12 million m<sup>3</sup> water through transpiration of bush encroacher species. While a 5,000ha farm where bush has been thinned to optimum level will save about 6 million m<sup>3</sup>. With an area of 26 million ha rangeland affected by bush encroachment (De Klerk, 2004), at least 31 trillion m<sup>3</sup> of water loss through transpiration can be saved if bush is thinned.

With the current extensive bush encroachment problem in Namibia, coupled with the anticipated climate change impact, Namibia's water resources will put on tremendous pressure in the future. Addressing bush encroachment could free-up some of these scarce resources.

## 2.4 Strategies used to control bush encroachment

In order to implement the best possible control strategy for the specific bush encroacher, managers need to understand that an increase in woody plant species abundance is influenced by two processes; First by a vegetative growth through existing biomass and secondly by an increase in density through reproduction (Smit, 2004).

Depending on how bush encroachment control tools and strategies are used, these tools and strategies can impact the species abundance processes simultaneously or separately. The most efficient bush control tool and strategy should be the one that aim to manage both the vegetative and reproduction processes simultaneously and should be able to be deployed in different seasons.

A combination of control strategies and tools are likely to be most efficient. Different tools and strategies have been used over the years to manage bush encroachment. These methods inter alia include the use of fire, browsers, chemical control and mechanical clearing.

### 2.4.1 Use of fire

Fire is an important tool for bush control and has been part of the savanna system. Natural fires are ecological process that impact on the savannas ecosystem processes and also influence functions and service delivery of savannas. The frequency and intensity of fires determine their effectiveness on bush proliferation control.

Due to erratic and low rainfall patterns in Sub-Sahara semi-arid regions, natural fires have been suppressed in the effort to protect grazing. In Namibia, good rainfall is not guaranteed nor is it easy to predict. Since the end of pastoralist, the formation of communal and commercial farming land made it necessary for farmers to avoid and to stop veld fires. The suppression of fires whether natural or man-made was voluntarily and/or legislatively controlled.

The voluntary and legislatively guided fire suppression over many years is believed to have promoted the proliferation of bush encroachment (Dalle *et al.*, 2006). Fire, according to Angassa & Oba (2008) suppresses woody plants growth by killing and reducing their density. This suppression can be over a short-term especially when the woody plants were only destroyed above-ground.

There are several reasons why this method is not widely used. Mostert *et al.* (1971) identified absence of suitable fire breaks as a limiting factor in the use of this method. Large track farming land has been ruined by uncontrolled fires that were initially aimed at controlling bush proliferation. This destruction led to further loss of valuable woody and herbaceous biomass (Mostert *et al.*, 1971). Uncontrolled fires not only affect the rangeland quality but also farmers' income. Farmers who have triggered uncontrolled fires have faced litigation from neighbours who sued them in the effort to recover lost grazing land and property.

Other limiting factors not allowing this seemingly natural process is the nature of bush encroachment. Bush encroachment limit grass and other herbaceous growth. By limiting grass and other herbaceous growth, there is seldom enough biomass to provide fuel for a hot fire needed to at least kill the woody species at above-ground and to reduce the density of problem bush.

#### 2.4.2 Use of browsers

The use of browsers such as goats were found to be very limiting and almost no literature looked at this methods. Using browsers only at a stage when bush encroachment is a problem does not generate sufficient impact on the biomass and density of encroaching bushes. Herbivory in savannas is important in complementing other natural process to maintain the tree-grass balance (Van der Waal *et al.*, 2011).

As conclude by Angassa & Oba (2008), herbivory alone is not enough to control bush encroachment. Angassa & Oba (2008) further indicated that herbivory was only partially effective in controlling seedlings recruitment.

Herbivory combined with other control tools and strategies such as fire and tree cutting was the most effective way of bush control (Angassa & Oba, 2008).

#### 2.4.3 Chemical control

Different chemicals are available in the market to control bush encroachment. Some of these chemicals are species specific, some can be applied directly to the plant, while others are soil-applied.

As explained by Trollope *et al.* (1989), these arboricides that are used to kill problem bushes, prevent plant growth by inhibiting photosynthesis. This method is one the most expensive method and many farmers are financially unable to use it. But it can be a very effecting way of bush control. A large track of affected land can easily be treated within a very short period, especially when aerial application is used. But costs of treatment are very high.

There are also strict controls on how these arboricides are used for both livestock and human safety, and environmental pollution concerns.

#### 2.4.4 Mechanical clearing

Mechanical clearing involves the physical removal of problem individuals or physically damaging problem plants to kill and remove them. The method can include cutting, stem-ringing and uprooting. These bush control techniques require a lot of labour when cutting is involved and heavy machinery when uprooting is implemented.

Not all mechanical clearing are effective as mentioned by Dalle *et al.* (2006), that some efforts do not yield significant impact on improving the condition of the rangeland. Methods such cutting are labour intensive and take a long time before an adequate size area is rehabilitated. While techniques such as bulldozing are effective in removing bush but lead to extensive soil disturbances leading to soil erosion and other relating land degradation symptoms.

After the physical removal or killing of bushes, the dead woody plants are left to rot and this might years. Large pile of dead plant materials lie around, creating macro habitats for invasion of alien species. These mechanical control methods are very expensive and leaving the dead plants materials to rot away is a big challenge. Therefore many farmers have started to use the waste plants materials to produce charcoal to supplement the land restoration efforts and also to generate some extra income for the farm/household.

#### 2.4.5 Charcoal Industry

Since the 1990's, charcoal production has become an incentive for farmers to remove excess woody plants biomass by producing charcoal as a by-product of bush thinning. Charcoal production is believed to be more selective, environmental friendly and a cost-effective way of managing bush encroachment. Namibia alone produces about 100 000 metric tons of charcoal annually and generated between N\$ 75 to 100 million in 2004 (Diekman & Muduva, 2010).

Unlike in other parts of Africa, charcoal production in Namibia is not just an economic activity but a sustainable way of rangeland rehabilitation. In some parts of Africa, e.g. Kenya, charcoal production is leading to woodland depletion (Kituyi, 2004). In the Democratic Republic of Congo and Malawi, charcoal production is also a serious threat to woodland and forests.

##### a) Charcoal industry impact on bush encroachment control

It is understood that charcoal production is a by-product of rangeland rehabilitation and that biodiversity improvement is a spin-off of bush clearing. Limited studies exist in Namibia that can qualify and quantify the impact of charcoal production on the spread of bush encroachment and on biodiversity conservation.

More studies will be needed to be conducted in different parts of the country to development a good data base that can be used to generate a clear understanding

on how charcoal production is complementing efforts to control bush encroachment, to conserve and improve biodiversity in Namibia. This study is just a very small part of this attempt.

Diekman & Muduva (2010) found that there are about 230 charcoal producers who employ about 4,800 charcoal workers. Over 6,200 commercial farms are affected by bush encroachment. While about 3.5% are involved in the charcoal production. Average commercial farms are 5,000 ha in size (NPC, 2006). Therefore only 1.15 million ha of the 26 million ha are being rehabilitated through charcoal production.

#### b) Charcoal industry policy implications for bush encroachment management

In the current free market economy, it will be complicated if government subsidise the charcoal industry. Currently it appears that the sector is growing and is profitable under the current labour and trade conditions.

There are different policy and legislative framework addressing the need to control bush encroachment as a national priority (De Klerk, 2004). These are address in the:

- a) National Agricultural Policy and Strategy,
- b) Namibia Forest Development Policy,
- c) Forestry Act,
- d) Soil Conservation Act,
- e) Environmental Management Act,
- f) Poverty Reduction Strategy,
- g) National Strategy for the sustainable use of biomass energy resources,
- h) Key Issues Paper for the Biomass Energy Conservation Strategy,
- i) White Paper on Energy Policy,
- j) National Rangeland Management Policy and
- k) Incentives Schemes for Invader Bush Management – a cost and benefits analysis (2009).

The list above is comprehensive and a lot of issues are discussed and strategies recommended. Bush encroachment is identified as a national challenge, but yet, individual farmers are left to look into the thorny issues themselves. Thus only looking at short-term benefits and not looking into total eradication of bush encroachment.

Biomass policies in Namibia should be seen and recognized to enhance supply to environmental friendly markets, provide market incentives and also look into poverty reduction objectives (Zulu & Richardson, 2012). This recommendation from Zulu & Richardson (2012) will facilitate a sustainable effort towards bush encroachment control from the central government to charcoal worker, therefore reducing conflicting needs and goals in the charcoal industry.

## Chapter 3: Description of the study area

### 3.1 Location of Farm Pierre

The research was conducted on farm Pierre, (S -19,727742°;E 16,583342°) located in Outjo District, Kunene Region (Figure 3.1). The surface area of the farm is about 3,400 hectares and is 1,372 m above sea level (Google earth, 2013). Livestock farming has been the main agricultural activity on this farm for over 50 years.



Figure 3.1: Location of Farm Pierre (study site) in Namibia

### 3.2 Climate and Topography

Outjo area, just as the rest of Namibia falls within the Subtropical High Pressure Zone, this zone is known for its massive dry air (Mendelsohn *et al.*, 2003). Namibia is

the driest country in Sub-Sahara Africa due to the Botswana Anticyclone and the South Atlantic Anticyclone presence (Mendelsohn *et al.*, 2003). In winter, the Botswana Anticyclone has the most effective impact on the climate by feeding dry air over Namibia (Mendelsohn *et al.*, 2003). Mendelsohn *et al.* (2003) also stated that this anticyclone obstructs the flow of moist air from the north, while the South Atlantic Anticyclone from the south-west blow cold and dry air into the coast.

Due to this climatic conditions explained above, the Outjo area annual average rainfall is 400 mm (Figure 3.2a). Most of this rainfall occurs in summer, most noticeably between January and March. Very little rainfall occurs during winter. The study area has an annual water deficit of 1,701 mm to 1,9000 mm (Figure 3.2b). Therefore, water resources management in the study area and in Namibia in general is of critical importance. Any over extraction by industry, agricultural practices and plants can create water scarcity and stress within the region.

In summer, maximum temperatures during the hottest months can range between 34°C to 36°C and in winter average minimum temperatures during the coldest months can range between 4°C to 6°C (Mendelsohn *et al.*, 2003).

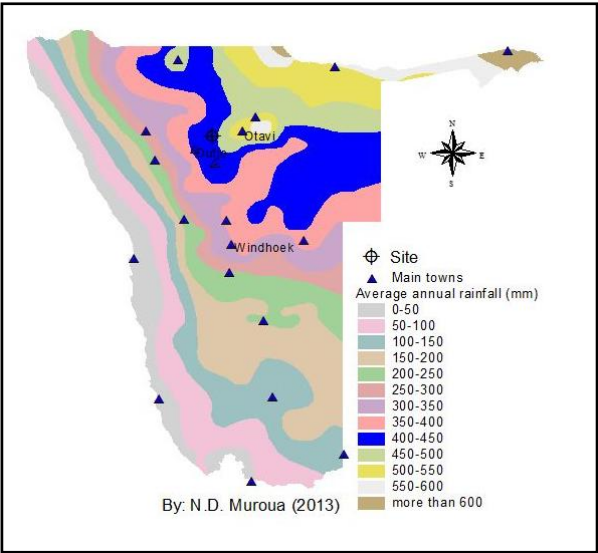


Figure 3.2a: Average annual rainfall in mm

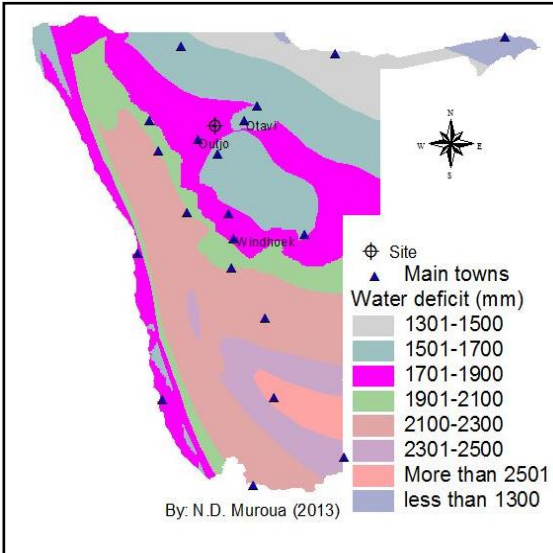


Figure 3.2b: Average annual water deficit

The topography in the study area is generally flat with a few scattered hills in the south-west and eastern parts of the farm, Figure 3.2c. The highest peak is 1,458 m above sea level and only about 80 m in height (Google earth, 2013).

Not taking into account the hills, Google earth (2013) images shows that on the northern farm boundary, from west to east, the landscape rises from 1,333 m to 1,374 m above sea level. Just 41 m over 6 km from west to east. The western boundary elevation change is similar to that of the northern boundary. While the southern and eastern boundaries are also similar in elevation change from 1,374 m above sea level to 1,390 m above sea level (Google earth, 2013).

As the results of described topography, there no major hydrological features on the farm. Rainfall runoff does occur but the drainage is such that runoff is not collecting on the farm in large quantities. The main water collecting point is borrow pit used for the construction and maintenance of the gravel road C 39. Runoff from the few hills is not significant and has not created large water bodies, just small streams.



Figure 3.2c: Topography on Farm Pierre (white line = farm boundary; yellow line = C 39 road)

### 3.3 Geology and Hydrogeology

The geology of the area within the immediate vicinity of the study site is dominated by the Kalahari and Namib Sands sequence (Mendelsohn *et al.*, 2003). The succession of the Kalahari and Namib Sands according to Mendelsohn *et al.* (2003) was underlain by the Kalahari Group about 1 to 70 million years ago. According to Christelis & Struckmeier (2001), the Kalahari Group in the study site is characterised by the Limestone and dolomite rock types (Figure 3.3a).

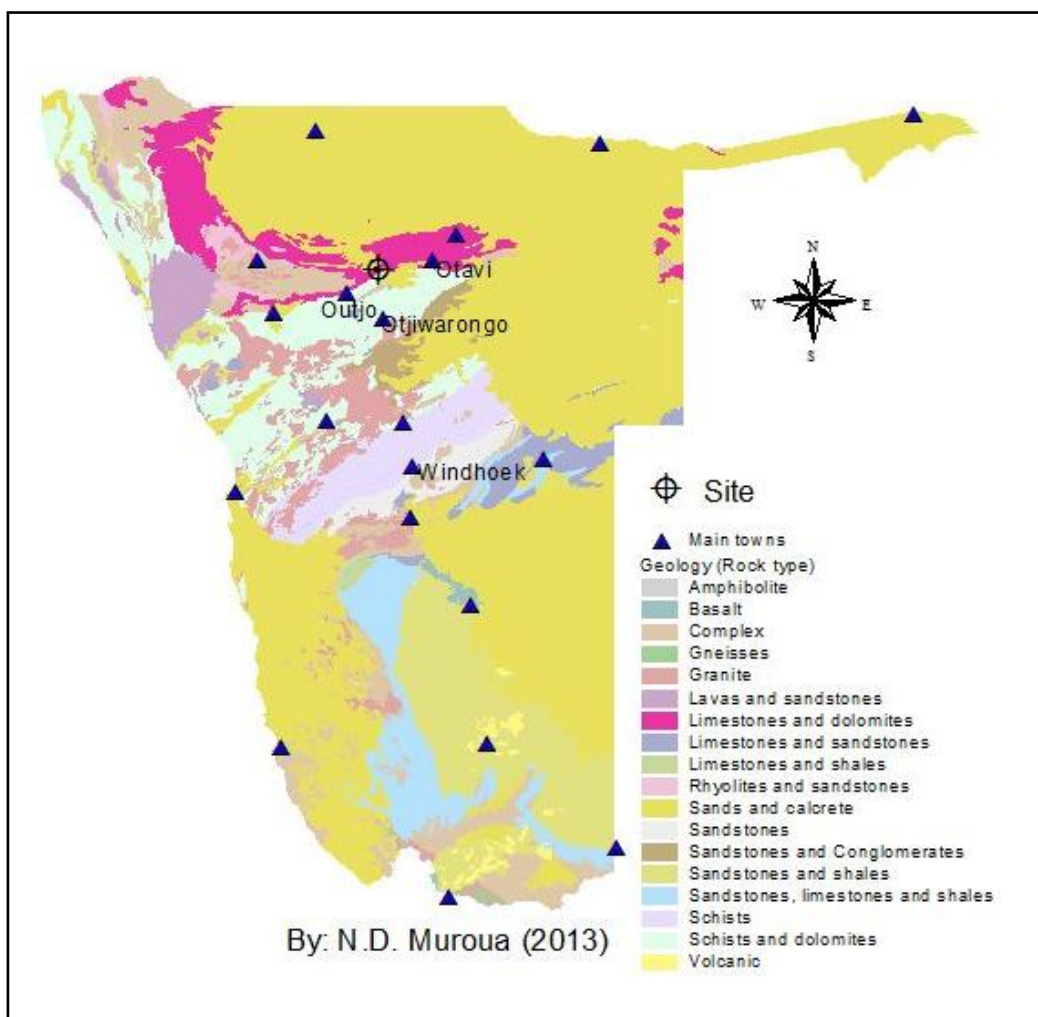


Figure 3.3a: Namibian geology

Christelis & Struckmeier (2001), indicated that the study area falls within the Otavi Mountain Land Hydrogeological Region. This Region according to Mendelsohn *et al.*; (2003) is characterised by Productive Fractured/Porous Aquifers (Figure 3.3b). Some of aquifers in this region form Karstveld due to the limestone and dolomite that dissolve and form large caverns.

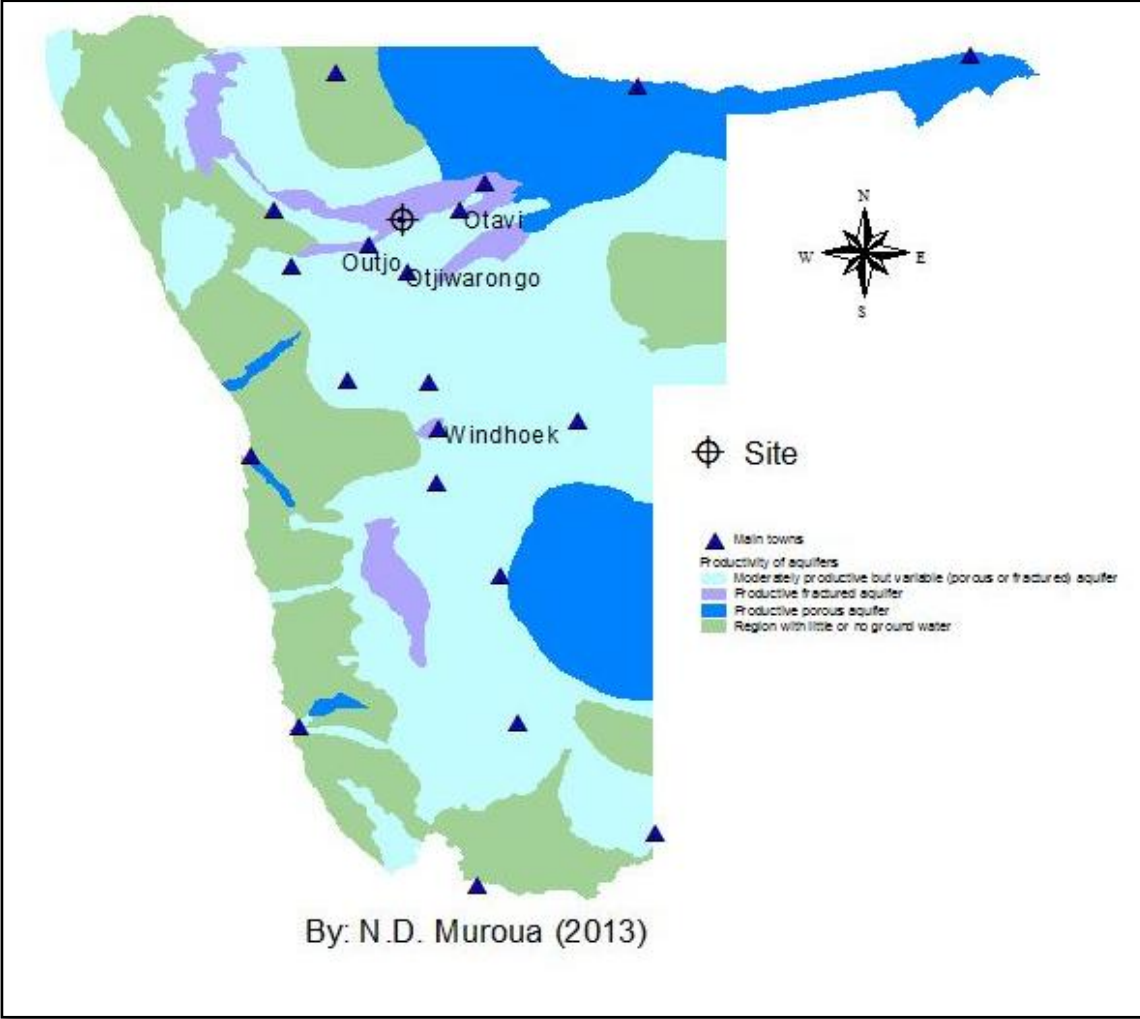


Figure 3.3b: Groundwater resources in Namibia

### 3.4 Soils

The dominant soil group is the Leptosols for the northern part of the farm and Rock outcrops in the southern parts of the farm (Digital Atlas of Namibia, 2013 and Mendelsohn *et al.*, 2003). See Figure 3.4.

The type of Leptosols found in the study site is the Mollic Leptosols. The Mollic soils according to Mendelsohn *et al.* (2003) have a good surface structure. Mendelsohn *et al.* (2003) further concludes that Leptosols are some of the shallowest soils as little as 30 cm deep due to the presence of hard bedrock near the ground surface.

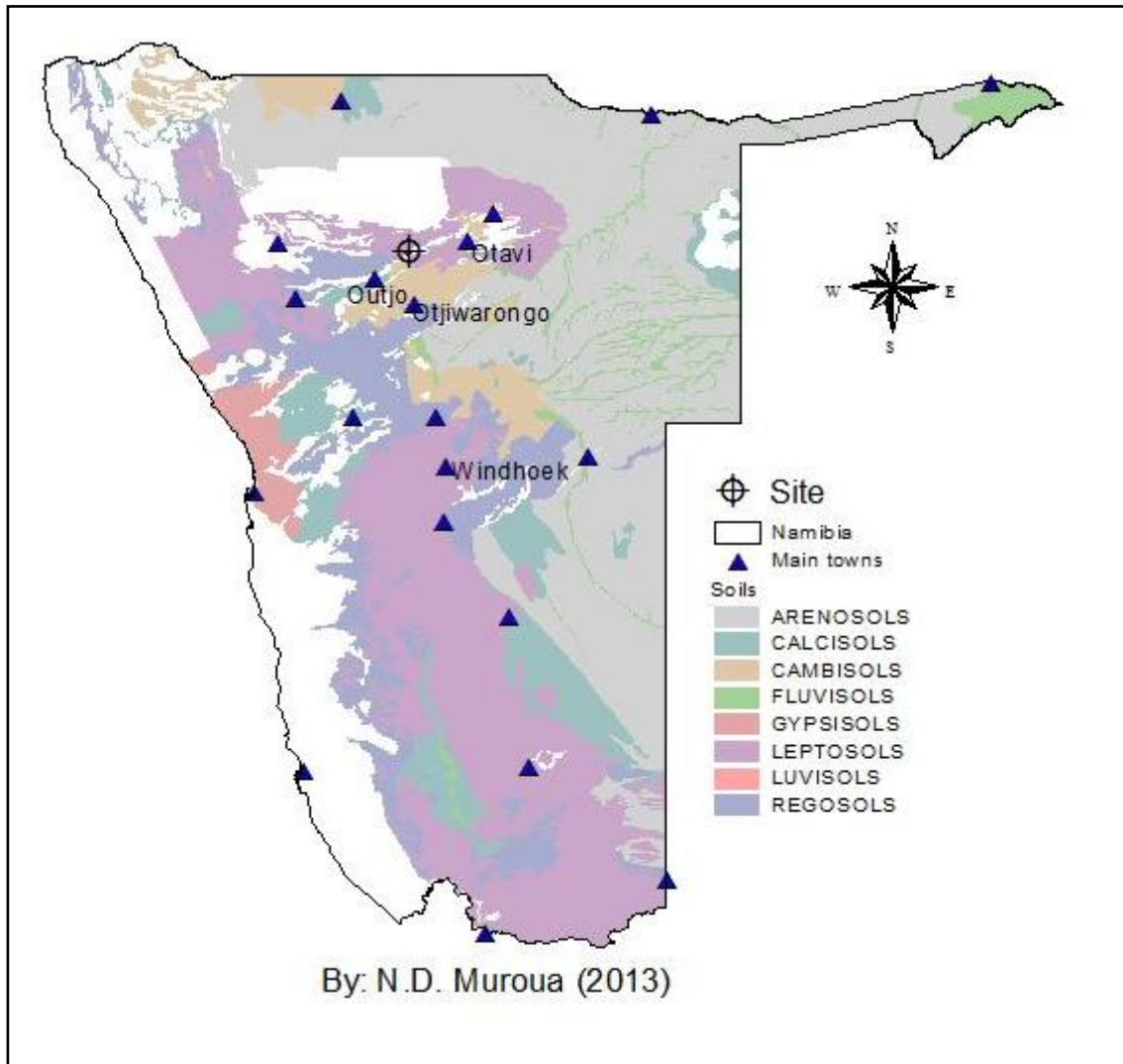


Figure 3.4: Dominant soils in Namibia

### 3.5 Fauna

During the data collection period, little evidence of large mammal (wildlife) were observed in the study site. The most common mammals' signs were dung and pellets from livestock. Cattle and goats were also seen on site. Signs of presence of small mammals such as mice and rats was also observed. From farm workers informal

discussions, it can be concluded that wildlife species such warthog, kudu, steenbok, oryx and leopard are common on the farm.

Some reptiles were encountered on the site at the time of study. This included a few snakes and lizards. Birds were seen on site and were very common, especially in the treatment area.

No amphibians were observed at the time of study and further observation showed that the habitat did not support a significant existence of amphibians. There is no aquatic habitat and hence no possibility of existence of fish species and other large aquatic organisms. Insects presence was observed and included common flies, grasshoppers, butterflies, spiders and ants.

### 3.6 Flora

The study area/site falls within the Tree and Shrub Savanna Biome (Digital Atlas of Namibia, 2013), also see Figure 3.6a. The dominant woody plants species are *Acacia reficiens* (False-umbrella thorn), *Dichrostachys cineria* (Sickle bush), *Terminalia prunoides* (Purple-pod terminalia), *Colophospermum mopane* (Mopane tree), *Combretum apiculatum* (Red bushwillow) and *Comiphora* species. This vegetation type support more than 500 different plants species (Digital Atlas of Namibia, 2013).

The vegetation type of the area is characterised by the dominating *Colophospermum mopane*, and hence falls under the Mopane Savanna (Figure 3.6b).

The farm is mainly encroached by *Colophospermum mopane* at a density of 4,000 trees per hectare (De Klerk, 2004). Key encroaching species observed other than *Colophospermum mopane* during the study are:

- a) *Dichrostachys cinerea* and
- b) *Acacia mellifera*.

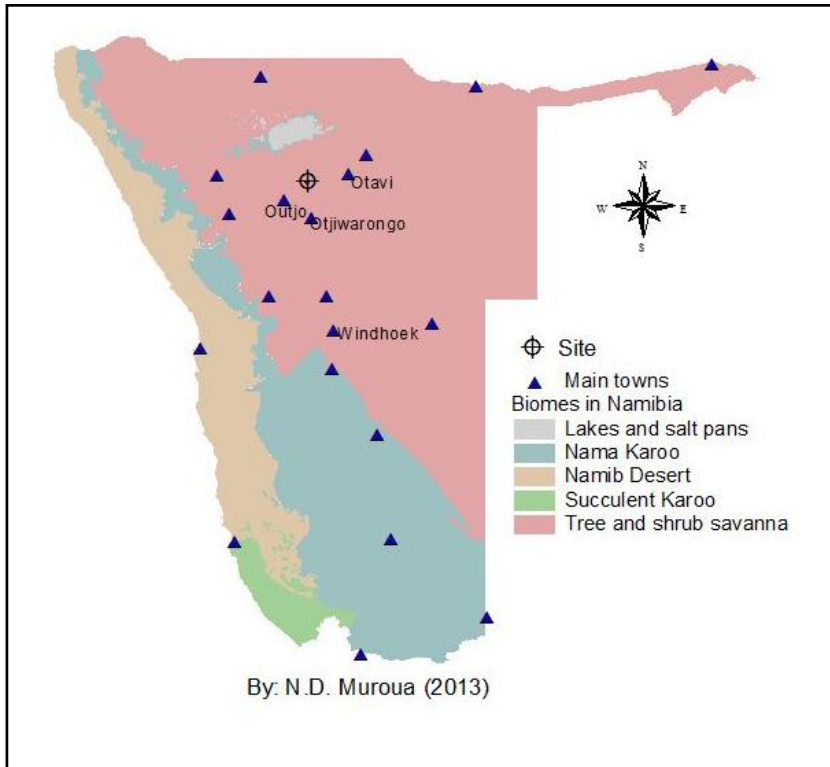


Figure 3.6a: Namibian biomes

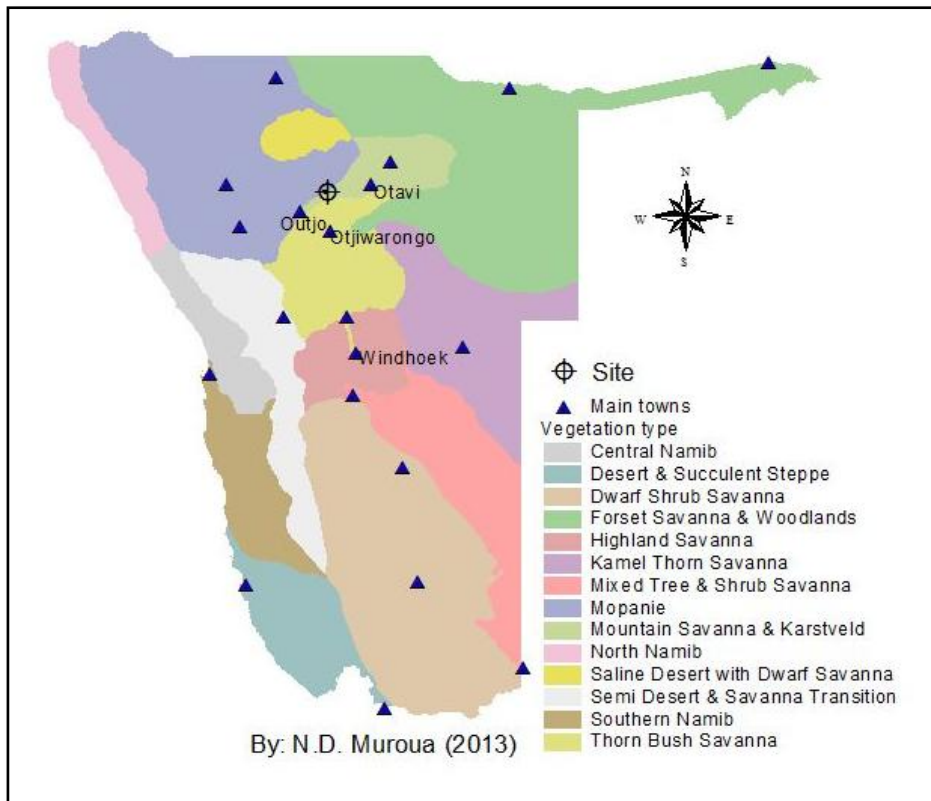


Figure 3.6b: Namibian vegetation types

## **Chapter 4: Research methodology**

### **4.1 Introduction**

Studying the response of arid and semi-arid rangeland ecosystems to herbivory can be difficult. Heterogeneity in precipitation in arid and semi-arid rangeland ecosystems is one of the most important drivers of rangeland response to grazing regimes, especially in Namibia. The latter will also apply to rangeland response to bush thinning or clearing. Ecologists have a difficult task of determining the most important drivers of ecosystem change in arid and semi-arid rangelands (Smet & Ward, 2005). This caution from Smet & Ward (2005) was taken very seriously when selecting study sites and also when identifying different variables that could influence the response of the study sites to bush thinning through charcoal production.

This study focused on assessing the vegetation dynamics between areas where bush have been harvested (treatment site) for charcoal production and between areas not harvested (control sites) for charcoal production. The sites that were selected for this research have similar attributes and same variables. Key differences between the selected sites are only the type of bush thinning management implemented to reduce the bush density. Hence variables such as soil types, vegetation type, topography, geology, geomorphology, land use, waterpoints distribution, and rainfall are very similar between the treatment site and the control site.

The study was planned to be conducted at the end of the growing season, towards the end of March 2013. During this time of the year, plants have reached seasonal maturity and can easily be identified. But due to factors beyond the author's control, the study was conducted during the second week of May 2013. By this time, plants identification was difficult, especially taking into account that Namibia has experienced one of the driest summers in years.

## 4.2 Research design

### 4.2.1 Process description

A systematic sampling method was used for this study. Proportionate and representative plots were set up in the treatment and control sites for sampling purposes. The 20 m × 50 m (Whittaker) plot size was planned to be used as it is believed to be widely used for assessment of savannas and woodlands (Dovie *et al.* (2008), and Kalema & Witkowski (2012). During sampling and methodology trials, prior to the actual study, it was found that the Whittaker plot size was too big to be used, especially in the control site. Thus as recommended by Hardy *et al.* (1999) that the sample area can be decreased if the woody vegetation density is high, the size of the plots were reduced to 20 m x 20 m. These plots were set-up along a transect and at least 50 m from any road, fence, watering and feeding points or any other unnatural disturbances to avoid variables such as fence-line and roadside effects on data to be collected.

Two transects were determined in the treatment area and in the control area, see Figure 4.2a. The location of the transects were determined by considering the homogeneity of the area for the respective treatment site and control site. The location of the transects were also determined by the areas ability to accommodate at least ten 20 m × 20 m plots, spaced 80 m apart. Hence, 20 plots were sampled for the entire treatment area and 20 plots for the entire control area. In total, 40 plots were sampled over the whole study area. Within each plot, a 1 m<sup>2</sup> quadrat was placed in the center, see Figure 4.2b.

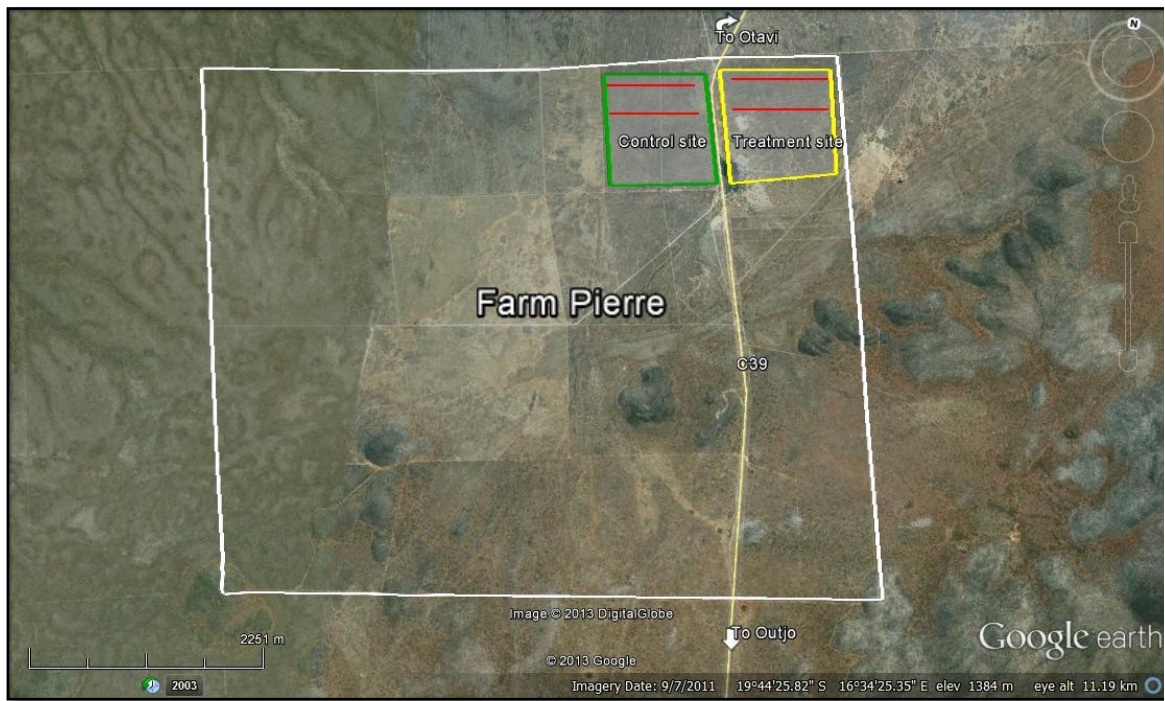


Figure 4.2a: Transects (in red lines) layout and locations on the farm

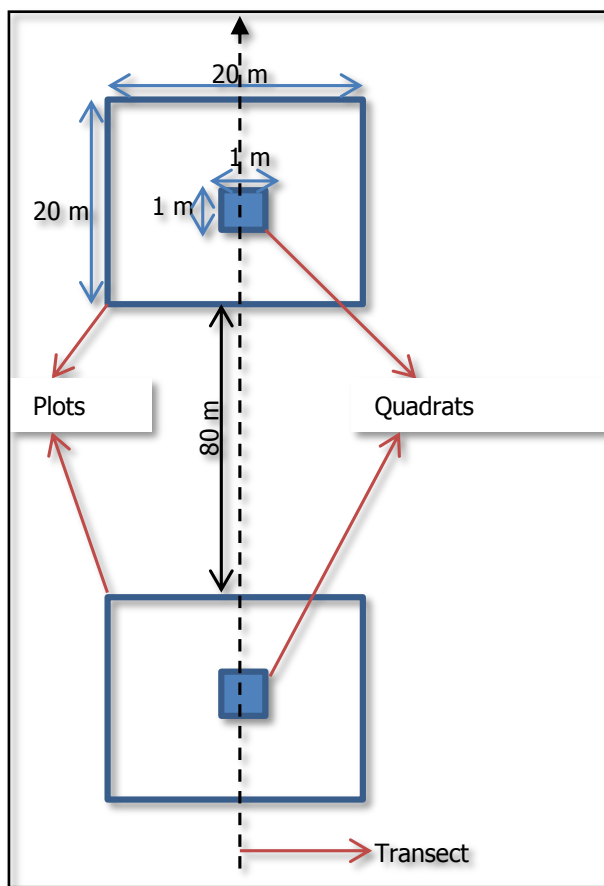


Figure 4.2b: Plots and quadrats layout along a transect

Within each plot, individual woody plants were identified, counted and their height was also recorded. Woody plant species height classes were divided into; >0.0 m - 0.5 m, 0.6 m - 1.0 m, 1.1 m – 1.5 m, 1.6 m - 2.0 m, 2.1 m - 2.5 m, >2.6 m - 3.0 m, and >3.0 m. A marked pipe with corresponding height classes was used for this classification. Woody species density, diversity, composition, species evenness and height structure was determined from data collected from these plots.

**NB:** Please note that only the woody species usually harvest for charcoal were recorded. Species such as the *Commiphora species*, *Grewia species*, *Croton species*, *Maroela species* and *Albizia species* were not recorded and considered in the analysis.

Within each quadrat, individual grasses were counted and their species determined. Mulch cover in each quadrat was determined by estimating the percentage (%) area covered by mulch. From this collected data, grass species diversity, density, composition and species evenness was determined. The ecological values (grazing value, ecosystem value, perenniality, succession value and biomass value) of grass species were also determined by using the grass guides and summarised according to treatment and control areas.

A data collection sheet for each transect was developed and used for data recording during data collection. Plant species identification was done in the field using plants identification guides. Voucher species were collected and identified at the camp.

The purpose of this methodology was aimed at testing the impact of bush thinning through charcoal production on the vegetation density, species diversity, evenness and composition, grass biomass production and on the woody vegetation structure.

## 4.2.2 Assumptions

The following assumptions were applied to this study:

- a) The control sites represent the charcoal land use sites pre-treatment (before bush harvesting for charcoal production).
- b) The month of April represent the end of the growing season, hence the likelihood of finding new plant species beyond April is negligible.
- c) All the other variables such as soil types, vegetation type, topography, geology, geomorphology, land use, waterpoints distribution and rainfall are similar between the treatment and the control sites.
- d) The treatment (charcoal production) is the only major variable between treatment site and control site.

## 4.3 Tools and materials

To establish the 20 m x 20 m plots, a 20 m rope was use to mark out each plot's length and width. The 1 m<sup>2</sup> quadrat was made from a 4 m long plastic PV (15mm) pipe that was folded to make the 1 m<sup>2</sup> quadrat, see Figure 4.3a.



Figure 4.3a: A 1 m<sup>2</sup> quadrat used for grass sampling

A 4 m long plastic PV (50mm) pipe was marked according to the required woody plants height classes, see Figure 4.3b. This pipe was used to measure and determine the woody plants height. The plastic pipe were used due to their light weight.



Figure 4.3b: A marked pole use to determine tree height

Grass and tree guides were not only used to identify trees and grasses, but also to categorise each grass species according to their local corresponding ecological values, such as in grazing value, ecosystem value, perenniality, succession value and biomass value.

## 4.4 Data analysis

Different statistical analysis was carried out in agreement with Huston (1994) and Oindo (2002) who are of the opinion that a single statistic is not enough to adequately describe the biodiversity.

### 4.4.1 Vegetation density

The vegetation density was calculated for each plot (for trees) and each quadrat (for grasses).

#### **Tree density**

The following formula was used for tree density:

Density per plot = Total trees counted x 25 e.g.

Density per plot = 37 x 25

= 925 trees per ha

The value 25 was used to convert m<sup>2</sup> into hectares (ha). This is because each plot of 400 m<sup>2</sup> is 0.04 ha, meaning the plots area can be divided 25 times into one hectare.

#### **Grass density**

The following formula was used for grass density:

Density per quadrat = Total grasses counted x 10 000 e.g.

Density per quadrat = 23 x 10 000

= 230 000 grasses per ha

The value 10 000 was used to convert m<sup>2</sup> into hectares (ha). This is because each quadrat of 1 m<sup>2</sup> is 0.0001 ha, meaning the plots area can be divided 10 000 times into one hectare.

#### 4.4.2 Shannon Diversity Index

The Shannon Diversity Index was used to calculate and measure the woody plants and grass species diversity in the study sites. The Shannon Index combines both species richness and relative population densities. The author therefore trusted that this Index will produce a more balance assessment when considering that both species richness and relative densities are important in determining the Diversity Index.

The following formula was used to determine both the tree and grass diversity:

$$\text{Shannon's } H' = -\sum p_i \ln p_i$$

#### 4.4.3 Species Evenness

The woody plants and grass species evenness was calculated and measured by using the Excel formula sheet provided by the Center for Environmental Management, University of the Free State (UFS), see Table 4.4a.

**Table 4.4a: An example of a formatted excel sheet used to calculate evenness**

Species	Total Recorded	s	xs	ln(xs)	Difference	Difference^2
A. pubescens	3	1	3	1.0986	-1.7417	3.033371042
A. schinzii	31	2	31	3.4340	0.5937	0.352500304
A. adscensionis	109	3	109	4.6913	1.8511	3.426489902
B. insculpta	10	4	10	2.3026	-0.5377	0.289104892
B. radicans	20	5	20	2.9957	0.1555	0.024168567
B. nigropedata	16	6	16	2.7726	-0.0677	0.004580734
C. ciliaris	11	7	11	2.3979	-0.4424	0.195695262
E. cenchroides	13	8	13	2.5649	-0.2753	0.075801371
E. echinocloidea	15	9	15	2.7081	-0.1322	0.017482034
E. rigidior	15	10	15	2.7081	-0.1322	0.017482034
H. contortus	17	11	17	2.8332	-0.0071	4.97942E-05
H. melanocarpus	24	12	24	3.1781	0.3378	0.114098021
M. repens	54	13	54	3.9890	1.1487	1.319544318
M. caffra	65	14	65	4.1744	1.3341	1.779869305
S. ioclados	3	15	3	1.0986	-1.7417	3.033371042
S. uniplumis	13	16	13	2.5649	-0.2753	0.075801371
T. racemosus	16	17	16	2.7726	-0.0677	0.004580734
	435					
			Total	2.8403	Total	13.76399073
					Total/S	0.809646513
					arctan	0.680595347
					1-(2/pi)*arctan	0.566719545

#### 4.4.4 Tree height classes/structure composition

To determine the tree height structure, the trees were divided into 7 height classes, namely; a) >0 m - 0.5 m, b) 0.6 m -1.0 m, c) 1.1 m – 1.5 m, d) 1.6 m -2.0 m, e) 2.1 m -2.5 m, f) 2.6 m - 3.0 m and g) >3.0 m.

All the trees were counted and each individual measured and recorded into the corresponding height class. The tree height composition in each area, being the treatment or the control sites, was calculated by totalling (adding) all recorded trees in each site and dividing the specific height class into the total number of trees counted. This yielded the composition of each height class in a percentage.

#### 4.4.5 Ecological value of grass species

Table 4.4b below shows the different scores used in the specific ecological categories to determine the respective ecological scores. This was achieved by multiplying the total number of specific species in each quadrat with the corresponding score. The Grazing Value for example is therefore, the sum of all species scores in all quadrats in the particular site. This method was applied to all Value Calculations.

Table 4.4b: Scores used to calculate value of grasses in the different quadrats.

<b>Grazing Value</b>	<b>Ecosystem Value</b>	<b>Succession Value</b>	<b>Perenniality Value</b>	<b>Biomass Value</b>
High = 3	Decreaser = 6	Climax = 3	Perennial tuft = 6	Perennial tuft = 6
Average = 2	Increaser I = 3	Subclimax = 2	Weak perennial = 3	Weak perennial = 3
Low = 1	Increaser II = 2	Pioneer = 1	Annual = 1	Annual = 1
	Increaser III = 2			

How the Ecological Values were determined:

- a) Grazing Value: The ranking from High to Low was adopted from Muller (2007) and Van Oudsthoorn (1999). The ranking is based on the palatability of each species taking into account; a) leaf production, b) nutritional value, c) and chemical composition. Thus the score of 3, 2 and 1 was given to the Highest, Average and Lowest values respectively.

- b) Ecosystem Value: Hardy *et al.* (1999), Muller (2007) and Van Oudsthoorn (1999), explained that:
- i. Decreaser species, are those grass species which are dominant in a good veld condition, but decreases when the veld is overgrazed or under-utilised. These species are much more valuable and hence were given a score of 6.
  - ii. Increaser I species, are those species not dominant in a good veld condition, but increases in abundance when the veld is under-utilised. A score of 3 was given to these species since they denote veld degradation and not as valuable as the Decreaser species.
  - iii. Increaser II species, are those species not dominant in a good veld condition, but increases in abundance when the veld is over-utilised. A score of 2 was given to these species since they denote veld degradation due to overgrazing.
  - iv. Increaser III species, are those species not dominant in a good veld condition, but increases in abundance when the veld is selectively grazed. A score of 2 was given to these species since they denote veld degradation due to overgrazing.
- c) Succession Value: The ranking from Climax to Pioneer was adopted from Muller (2007) and Van Oudsthoorn (1999). The ranking is based on the successional phase each species reach its competitive advantage over the other. Therefore the score of 3, 2 and 1 was given to the Climax, Subclimax and Pioneer rankings respectively.
- d) Perenniality Value: The value for Perenniality was adopted from Muller (2007) and Van Oudsthoorn (1999). The value is based on how long of each species live and also each species life cycle. Hence Perennial Tuft species were classified as those species that live for more than 5 growing seasons, the Weak Perennials as those species that live between 2 to 5 growing season, while the Annual species are those only survive 1 growing season. Therefore

the score of 6, 3 and 1 was given to the Perennial Tuft, Weak Perennial and Annual rankings respectively.

- e) Biomass Value: The Biomass score is the same as the Perenniality rankings, assuming that, in general Perennial Tuft produce more biomass than the Weak Perennial, and that the Annual species produces less biomass than the other two higher rankings

#### 4.4.6 Correlation and Correlation Coefficient Analysis

The relationship between variables was investigated. To accomplish this, sample data were paired, bivariate data where different variables were measured on individual basis. The correlation, through the use of scatter diagram was used to determine the strength of the relationship between selected variables.

The Correlation Coefficient was used to calculate the exact value to the relationship between the paired variables. Where the value  $r = 1$  indicate a perfect positive correlation, the  $r = 0$  indicate no correlation and the value  $r = -1$  indicate a perfect negative correlation.

The formula used to calculate the Correlation Coefficient is:

$$r = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2} \sqrt{\sum_i (y_i - \bar{y})^2}}$$

The MoonStats<sup>©</sup> statistical software was used to create the scatter diagram and also to confirm the Correlation Coefficient value, which the measure of how two variables are linearly associated (Clewer & Scarishbrick, 2001). The MoonStats<sup>©</sup> statistical software according to Welman *et al.* (2012), uses the Spearman rank-order correlation.

The MoonStats<sup>©</sup> statistical software also use the Pearson product-moment correlation to present the relationship strength between two continuous variables. The Pearson product-moment correlation is best suitable for use in correlation analysis when it can be assumed that the variables are roughly normally distributed. The MoonStats<sup>©</sup> statistical software was also used to determine the statistical significance (p-value) of the correlation between selected variables.

The different variables were paired as follows:

- a) Bush density vs. grass density
- b) Bush density vs. grass species diversity
- c) Bush density vs. grass species evenness
- d) Bush density vs. grass species richness
- e) Bush density vs. grass grazing value
- f) Bush density vs. grass ecosystem value
- g) Bush density vs. grass successional value
- h) Bush density vs. grass perenniality value
- i) Bush density vs. grass biomass value

# Chapter 5: Results

## 5.1 Tree density

From studying Figure 5.1a and Figure 5.1b, the Treatment area as expected has the lowest tree density. The average tree density per plot in the Treatment area is 923 trees per hectare, while in the Control area the average tree density is almost double, 1795 per hectare. The least dense plot was Plot 4 with 250 trees per hectare, in the Treatment area, while Plot 15 was the most densely populated with 1625 trees per hectare. The Control area lowest density was 1225 trees per hectare in Plot 2, while the highest density in this area was 2225 trees per hectare, in Plot 10.

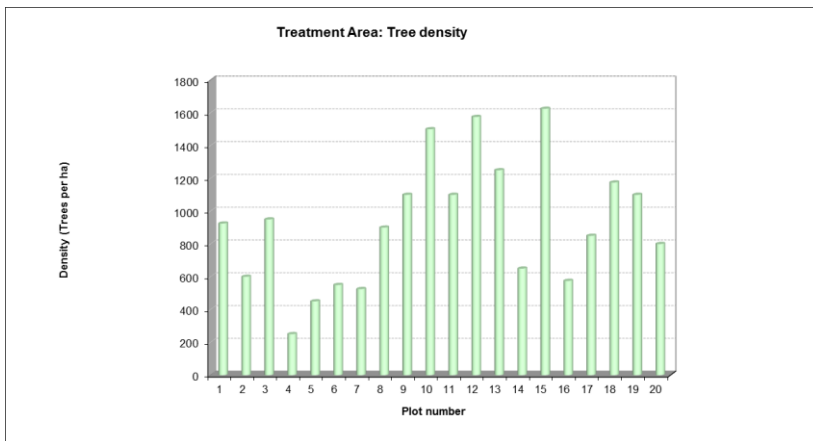


Figure 5.1a: Treatment area: Tree density

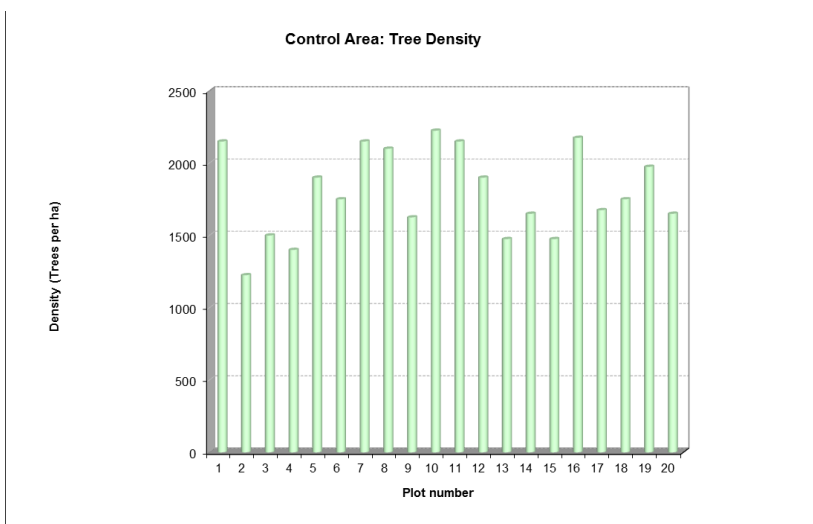


Figure 5.1b: Control area: Tree density

5.2 Tree height classes/structure

The height classes between the Treatment area and the Control area were very distinct. In the Treatment area, the most dominant height classes are the first 4 classes, falling between >0.0 m to 2.0 m (Figure 5.2a), making up 81% (Figure 5.2b) of the structure. While height classes 5 to 7, falling between 2.1 to >3m were the least common, representing only 19%.

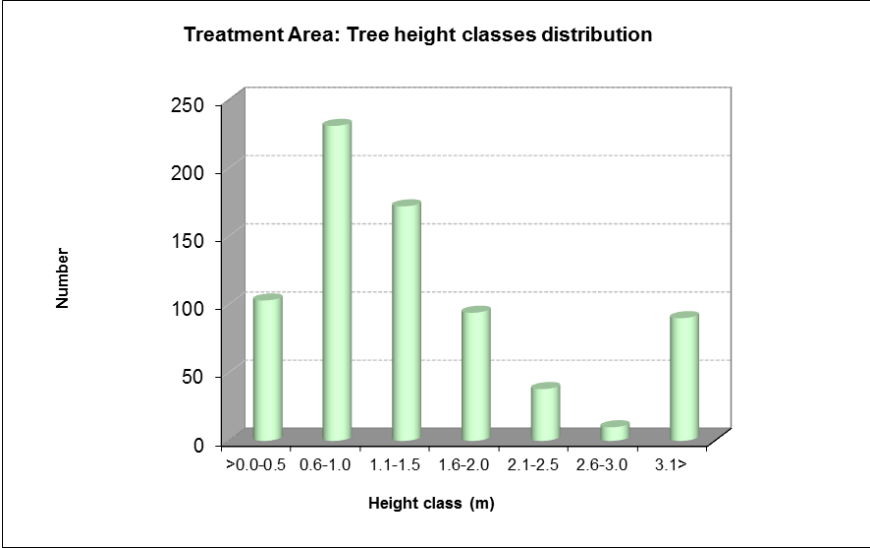


Figure 5.2a: Treatment area: Tree height classes distribution

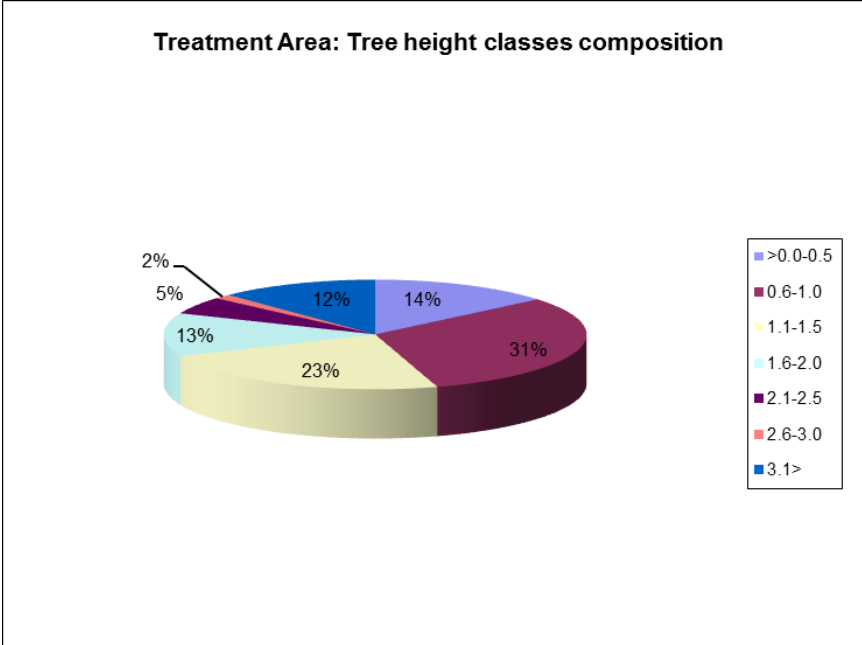


Figure 5.2b: Treatment area: Tree height classes composition

In the Control area, data collected shows that, the most dominant height classes are the last 3 classes, falling between 2.1 m to >3 m (Figure 5.2c), making up 73% (Figure 5.2d) of the structure. While height classes 1 to 4, falling between >0.0 m to 2.0 m are the least common, representing only 27% of the total structure.

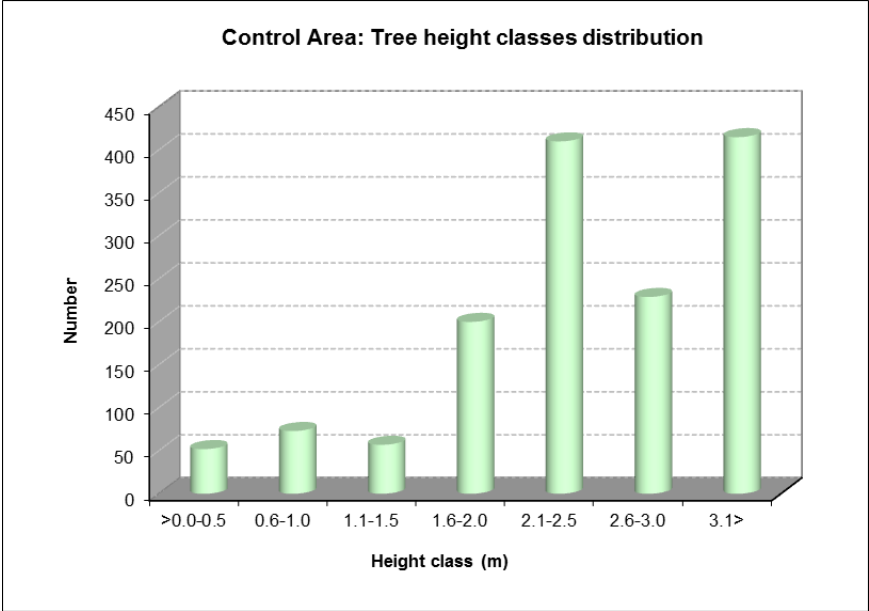


Figure 5.2c: Control area: Tree height classes distribution

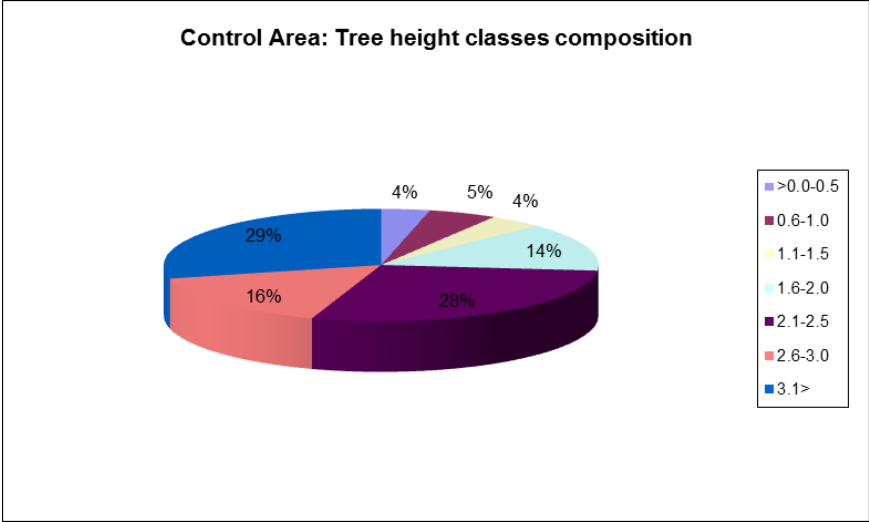


Figure 5.2d: Control area: Tree height classes composition

### 5.3 Tree species richness, diversity and species composition

Ten different woody plant species commonly used for charcoal were recorded in the Treatment area, while only 6 species were found in the Control area (Figure 5.3a and Figure 5.3c).

The determined species evenness in Treatment area was 0.19, while in the Control area this value was lower at, 0.15. Species diversity value of 1.19 was calculated in the Treatment area, lower than the 1.24 in the Control. This was not expected, but these findings are due to the fact the Shannon Diversity Index combines both species richness and relative population densities to compute the diversity value. Studying Figure 5.3b, it can be explained that due to the very high presence of *C. mopane* (59%), the diversity value of the Treatment area is reduced even though there are 10 different species. Hence, a skewed species composition observed in the Treatment area has resulted in a lower diversity index, while a more even species composition as presented in Figure 5.3d, produced a higher diversity index for the Control area.

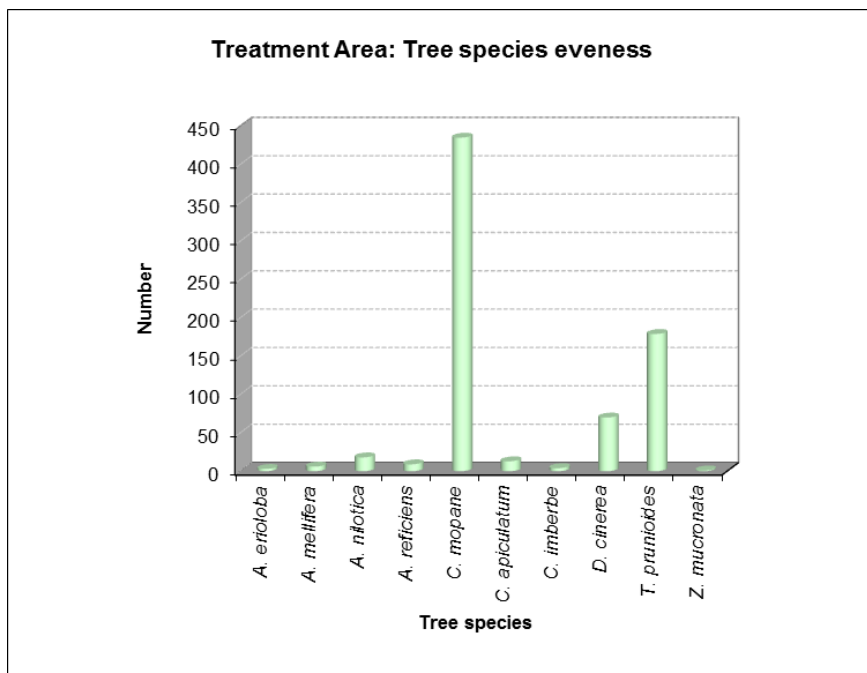


Figure 5.3a: Treatment area: Tree species evenness

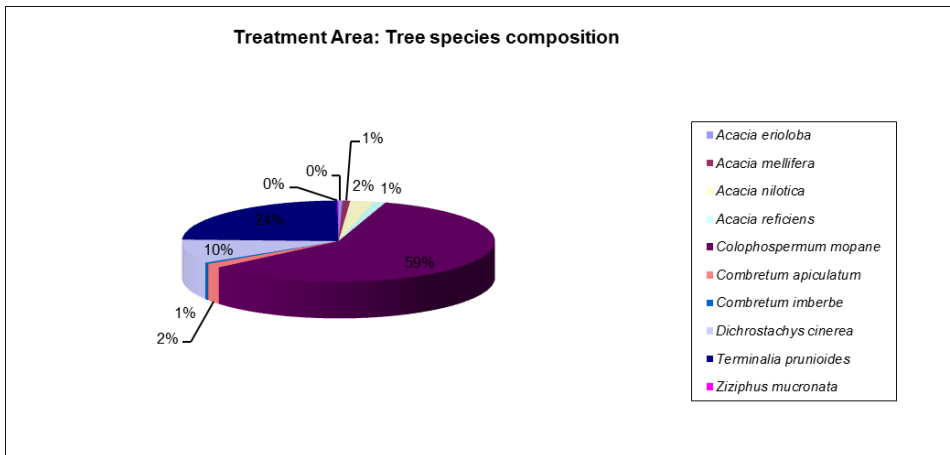


Figure 5.3b: Treatment area: Tree species composition

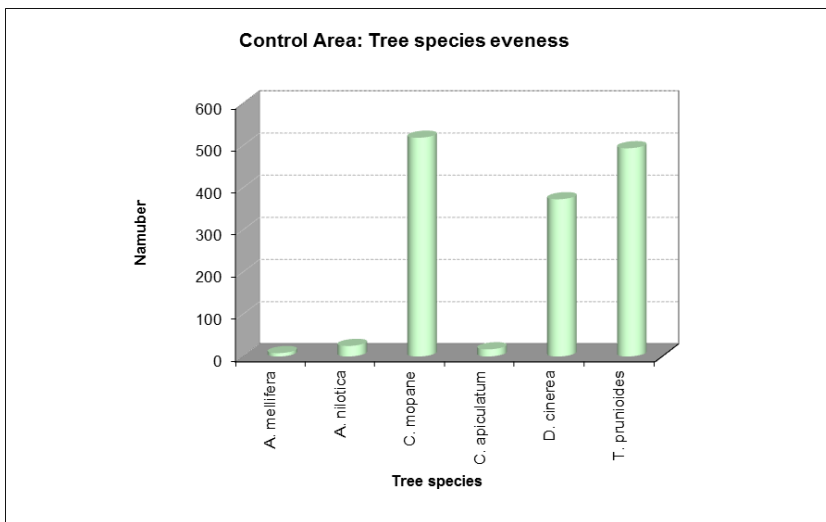


Figure 5.3c: Control area: Tree species evenness

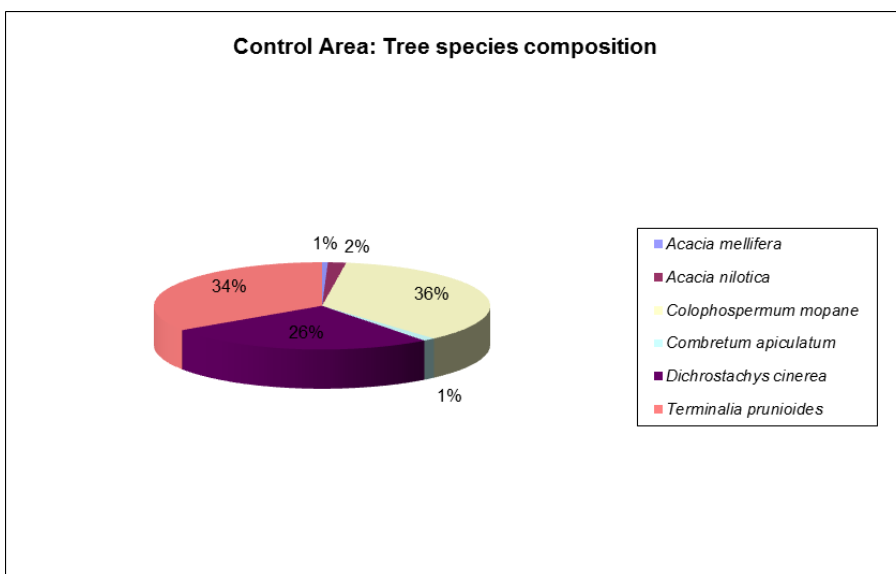


Figure 5.3d: Control area: Tree species composition

## 5.4 Grass density

The grass density as shown in Figure 5.4a and Figure 5.4b revealed that, at the highest end, the density in the Treatment area is almost 3 times that of the Control area. Therefore producing an average density of 217 500 grasses per hectare and 169 000 grasses per hectare in the Treatment and Control areas respectively. The lowest recorded density in the Treatment area was 50 000 grasses per hectare, while the highest was 980 000 grasses per hectare. In contrast the Control area lowest density was 20 000 grasses per hectare and the highest density was 370 000 per hectare. The Treatment area has produced over 100% more grasses than the Control area.

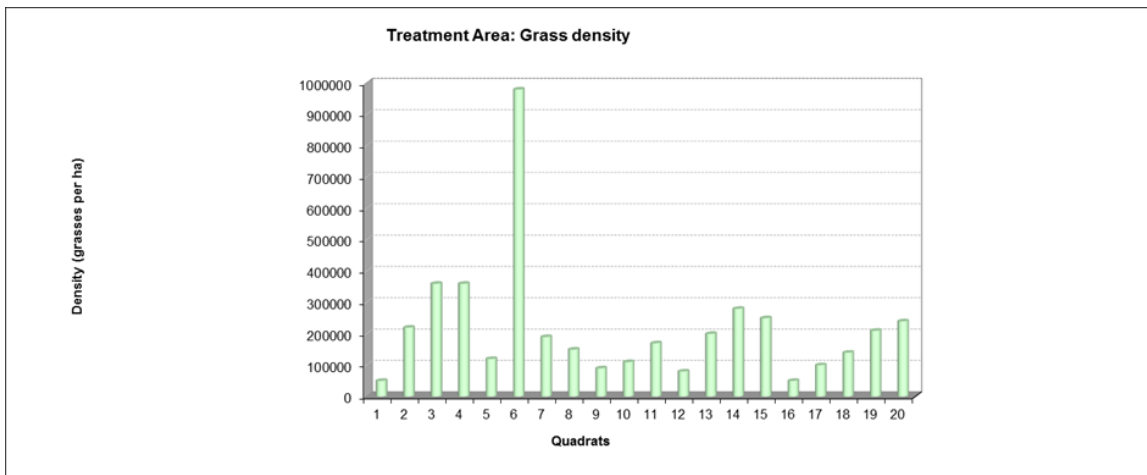


Figure 5.4a: Treatment area: Grass density

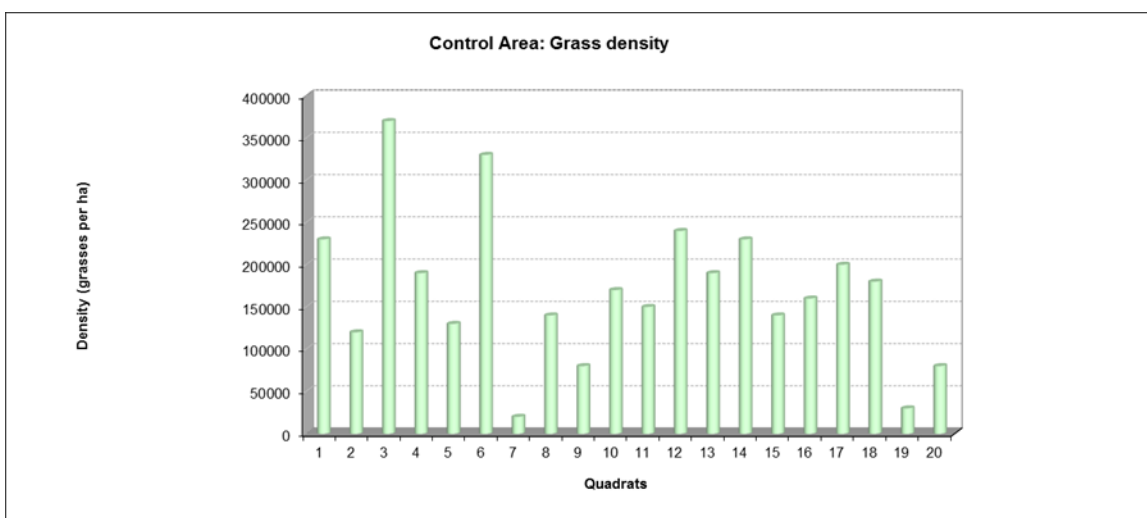


Figure 5.4b: Control area: Grass density

## 5.5 Grass species richness, diversity and species composition

The grass species richness in the Treatment area was higher with 3 species than in the Control area. There were 17 different grass species recorded in the Treatment area as shown in Figure 5.5a, while 14 grass species were recorded in the Control area (Figure 5.5c).

The determined species evenness in Treatment area was 0.57, while in the Control area this value was lower at, 0.32. Species diversity value of 2.44 was calculated in the Treatment area, higher than the 1.73 in the Control. This evenness and diversity values are as expected. Studying the Figure 5.5a and Figure 5.5b, it is clear that higher grass densities and an even grass species composition will produce a better evenness and diversity index. The contrary will be true when Figure 5.5c and Figure 5.5d, representing the Control area yielded a lower score in both the grass species even and diversity index.

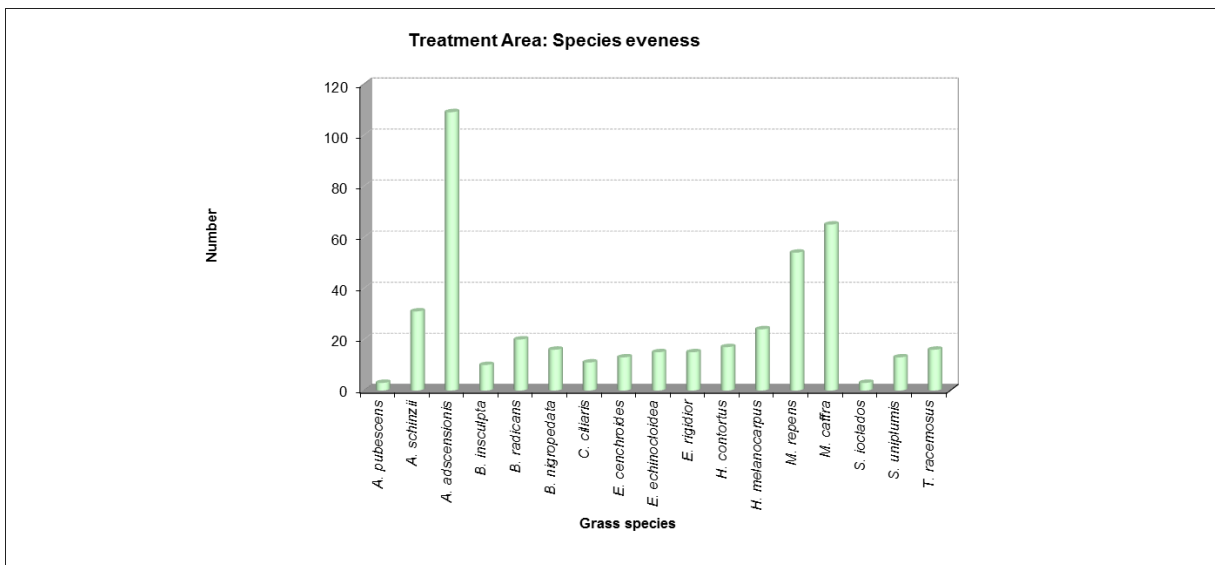


Figure 5.5a: Treatment area: Grass species evenness

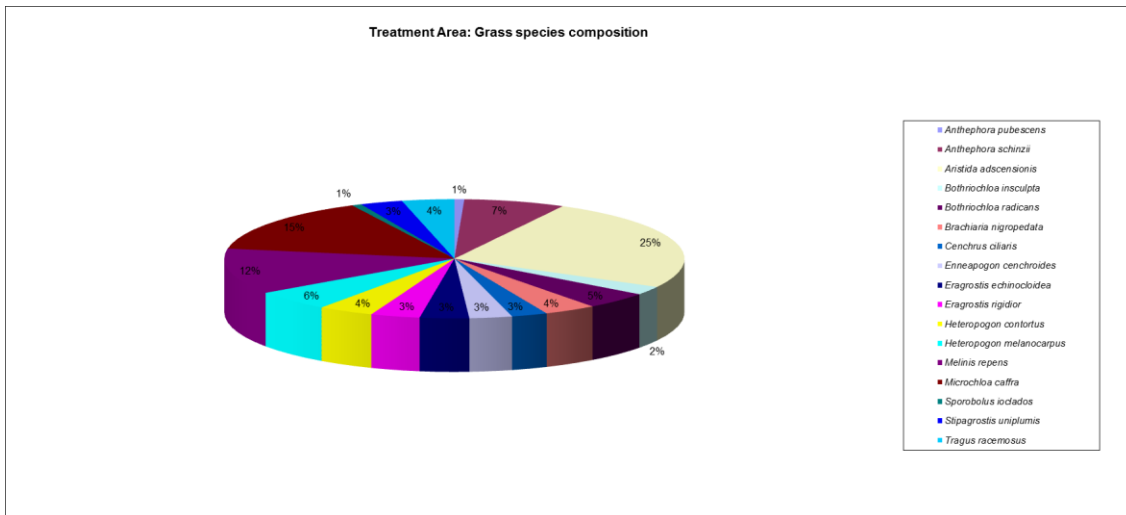


Figure 5.5b: Treatment area: Grass species composition

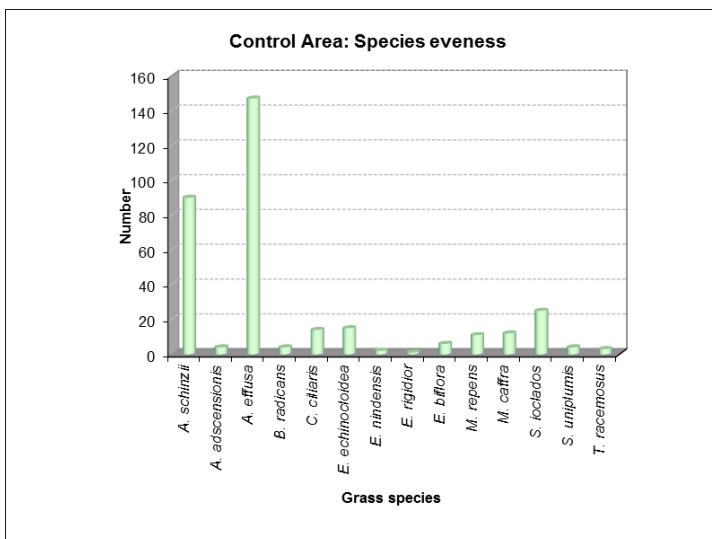


Figure 5.5c: Control area: Grass species evenness

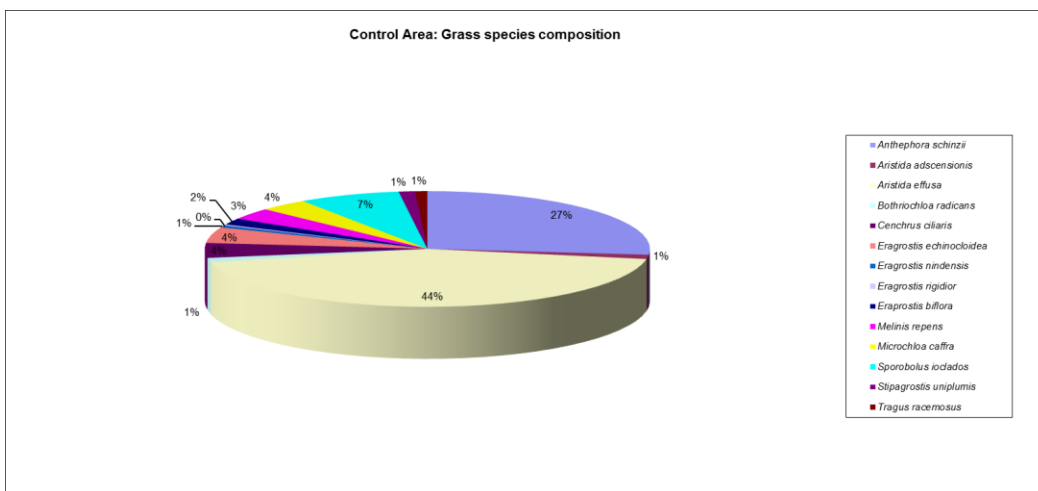


Figure 5.5d: Control area: Grass species composition

## 5.6 Grass ecological values

The results from the analysis and calculations done for the different grass ecological values, presented in Table 5.6, clearly indicate that the Treatment area has a better grazing, ecosystem, successional, perennality and biomass scores. The average ecological score for the Treatment area is 938.4, while the Control area has a much lower score of 557. Hence the overall ecological score for the Treatment area is about 168% more than yielded in the Control area.

Table 5.6: Grass ecological value scores in both areas

	<b>Grazing</b>	<b>Ecosystem</b>	<b>Succession</b>	<b>Perennality</b>	<b>Biomass</b>
<b>Treatment area</b>	625	990	679	1199	1199
<b>Control area</b>	417	732	428	604	604

## 5.7 Correlation and Correlation Coefficient (r) Analysis

Nine correlation and Correlation Coefficient analysis were conducted. The Correlation Coefficient analysis and the p-value (for statistical significance, 95% confidence limit) are presented for all the 9 correlations carried during this study. Table 5.7 present these results from the Correlation Coefficient and p-values of the paired variables. See next page.

All the correlations were found to be statistically insignificant. Moderate to moderately strong negative correlations between bush density and grass density was found in both the Treatment area and Control area respectively. The results also show that bush density negatively impacted on the grass species diversity, this can be concluded from the moderately strong negative correlation coefficient of -0.3 in the Control. Table 5.7 also shows that bush density is negatively affecting grass species richness, grazing value, ecosystem value, successional value, perennality and biomass production.

Table 5.7: Results of the Correlation Coefficient and p-values of the paired variables

		Treatment area	Control area
<b>Bush density vs. grass biomass value</b>	p-value	0.340	0.156
	r	0.23	-0.33
<b>Bush density vs. grass perenniality</b>	p-value	0.340	0.156
	r	0.23	-0.33
<b>Bush density vs. grass successional value</b>	p-value	0.613	0.192
	r	-0.12	-0.30
<b>Bush density vs. grass ecosystem value</b>	p-value	0.401	0.165
	r	-0.20	-0.32
<b>Bush density vs. grass grazing value</b>	p-value	0.804	0.230
	r	-0.06	-0.28
<b>Bush density vs. grass species richness</b>	p-value	0.989	0.105
	r	-0.00	-0.00
<b>Bush density vs. grass species evenness</b>	p-value	0.691	0.904
	r	0.09	0.03
<b>Bush density vs. grass species diversity</b>	p-value	0.433	0.197
	r	0.19	-0.30
<b>Bush density vs. grass density</b>	p-value	0.180	0.391
	r	-0.31	-0.20

## Chapter 6: Discussions

### 6.1 Tree population dynamics

#### 6.1.1 Tree density

There is a marked difference between tree density in the Treatment area and in the Control area. The average tree density in the Treatment area was 923/ha while in the Control area 1795/ha density was recorded. This clearly demonstrate that the bush harvesting for charcoal production has reduced the density of trees by 872/ha or 51.4%. Therefore, for the purpose of bush control, charcoal production do lead to a more open rangeland, even after 5 years of thinning.

Dalle *et al.* (2006) suggested that a 2500/ha woody plants density is the lowest margin for bush encroachment. Clearly on Farm Pierre, this lower bush encroachment margin as suggested by Dalle *et al.* (2006) is more than the highest density of the tree density on the farm. Can bush encroachment in the study area be considered to be very low based on Dalle *et al.* (2006) suggestion? The answer should be no. Because the productivity of the rangeland in the study area has been reduced and its ecological value lowered by the current level of bush encroachment at a bush density of 1795/ha.

#### 6.1.2 Tree height classes/structure

The tree height classes between the two areas are contrasting in nature. This also clearly demonstrates the impact of the treatment on the study area. Where larger trees are selectively harvested for their potential to produce more charcoal. Hence fewer large trees were recorded in the Treatment area compared to the Control area. Angassa and Oba (2008) stated that bush thinning may stimulate regeneration of vegetation through seedlings recruitment and coppicing. The statement from Angassa and Oba (2008) can be linked to the study results. There are evidents that

the Treatment area's trees have responded to thinning. Due to reduced tree density, more seedlings are germinating in the Treatment area than in the Control area.

As a result of reduced competition for space, light, water and nutrients, the density of encroacher woody plants in the Treatment area is expected to increase at a faster rate than in the Control area, where competition for space, light, water and nutrients remains very high. This is evident in the percentage of the first height class composition, in the treatment area this class represent 14% and 4% in the Treatment and Control areas respectively.

Bush thinning for charcoal production appears to have resulted in a skewed height class distribution. The Control area height class distribution represents a healthier trees' structure. Where adult trees or larger trees have not been harvested for charcoal production, hence their higher density in the Control site. Selective harvesting as claimed by charcoal producers is therefore not fully implemented during tree thinning for charcoal production. The poor implementation of selective harvesting can be due to lack of oversight and the economic incentive created by producing more charcoal from larger trees. This attitude characterize that economic incentives to charcoal production is higher than that of ecosystem and rangeland rehabilitation.

### 6.1.3 Tree species richness, evenness, diversity and species composition

Rehabilitation of rangeland usually leads to improve species richness, diversity and composition. Theoretically, the Treatment area should have better values for these characteristics.

The Treatment area recorded more woody plants species, therefore higher species richness and evenness. With a very small margin, the Control area scored a higher species diversity index and also recorded a much better species composition, consequently mimicking a healthier rangeland.

These findings cannot be necessarily linked to bush thinning for charcoal production. Earlier it was indicated that this practice was not selective, and it can be fairly assumed that all charcoal producing woody plants were harvested for charcoal production. The presence of these trees in both the Treatment area and Control area is due to natural environmental conditions and not necessarily due to charcoal production.

## 6.2 Grass population dynamics

### 6.2.1 Grass density

There are good indications that bush harvesting for charcoal production has led to better grass biomass and density. Looking at Figure 5.4a and Figure 5.4b (page 60), the average grass density in the Treatment area was almost double that of the Control area. Surely, this is a clear result of bush thinning. Figure 6.2a and Figure 6.2b below demonstrate these results too.



Figure 6.2a: Treatment area grass cover



Figure 6.2b: Control area grass cover

Bush thinning reduced the competition between trees and grasses. This allowed grasses to establish at a better rate than that of grasses growth in the Control area. In the Control area, grasses are competing with themselves and also with the trees. This competition for space, light, water and nutrients is very intense and limit both the tree and grass growth.

### 6.2.2 Grass species richness, evenness, diversity and species composition

Smit & Rethman (1999) explained that grass colonization of bare ground improve by the level of increased tree thinning. Muller (2007) and Van Oudsthoorn (1999) agree with Smit & Rethman (1999) who also stated that annual grasses are the dominant colonizers of bare ground or poor soil. Progressively more species will establish themselves as the soil improve, thereby improving species richness, evenness, diversity and species composition.

The Control area in this study represents a poor or bare ground, while the Treatment area represented an improved ground and soil. As explained by Muller (2007), Van Oudsthoorn (1999) above and Smit *et al.* (1999), their findings also similar to this study's results. Bush thinning appears to have led to improved grazing by improving soil and ground conditions. This improved conditions produced 17 different grass species compared to 14 in the Control area. The Treatment area also produced much better species evenness and diversity. As to be expected in a better condition rangeland, the species composition distribution is good in the Treatment area, compared to the poor soil and ground conditions in the Control area that produced a much skewed species composition distribution. Where two species made out over 70% of the total species found in the Control area.

### 6.2.3 Grass ecological values

This study has produced conclusive results that showed that bush thinning for charcoal production can be used as a tool to improve rangeland conditions. The overall ecological value score for the Treatment area was 168% higher than in the Control area. This result implies that bush thinning create a conducive environment that facilitate rangeland recovery.

Most notably, one of a key rangeland condition indicator the grass biomass production, was clearly very high (199% higher) in the Treatment area. Further justifying bush harvesting for charcoal production.

Presented earlier were Muller (2007), Van Oudsthoorn (1999) and Smit & Rethman (1999) who stated that annual grasses are the dominant colonizers of bare ground or poor soil. The Control area due to very high woody plants density has a poor ground and soil conditions. Poor soils are characterised by grass species that have poor grazing value. Grass species such as *A. schinzii* and *A. effusa* who are annuals have a poor leaf production and are representing 71% of the total grass biomass in the Control area. Therefore contributing minimal to the overall grass biomass and carrying capacity of the rangeland.

The Treatment area due to thinning has a balance composition of grass species. Good perennial-tuft species such as *A. pubescens* and *C. ciliaris* make up a small percentage of the of the total grass biomass. The Treatment area is still improving towards a more climax succession stage. Looking at the grass species composition between the two sites, the Treatment area is in a much better stage in terms of level of rangeland conditions and resilience.

### 6.3 Correlation and Correlation Coefficient analysis

\*Please note that, all the Correlation Coefficient analysis results were found to be statistically insignificant.

#### 6.3.1 Bush density vs. grass density

Dalle *et al.* (2006) concluded that there is a negative correlation between herbaceous biomass and woody plants. This conclusion from Dalle *et al.* (2006) is also very true to this study findings.

Both in the Treatment area and in the Control area, the correlation between tree density and grass density was found to be negative. With the correlation in the Treatment area producing a stronger negative correlation. The negative correlation is due to the factors explained earlier, that are to do competition between the

herbaceous and woody plants. A balance between the two plant communities creates a savanna while the dominance of one creates a woodland or a grassland.

### 6.3.2 Bush density vs. grass species diversity

As expected in the Treatment area, the correlation paired variables produced a positive relationship. Where low bush density facilitated higher grass species diversity. Due to lower bush density, the diversity of grass improves as the veld condition continues to regenerate. The Control area as a results of poor soils and extreme competition for space, water, light and nutrients between the plant populations, produced a negative correlation.

These findings again demonstrate the impact of bush thinning and also supports the views that bush thinning contribute to better grass species diversity.

### 6.3.3 Bush density vs. grass species evenness

In both the Treatment and Control area, the correlation was positive, but very weak, especially in the Control area. Due to the tree-grass interrelationship, the more the tree density the poorer the species evenness is expected.

The correlation in the Control area is very weak, indeed close to zero value or no correlation. Bush thinning appears not to greatly impact on the grasses species evenness. Hence thinning will not necessarily produce a better grass species evenness. Other environmental factors such as soil type, rainfall, topography, grazing pressure and lithology can also impact the grasses distribution and density. Grass species evenness appears not to be a good indicator for rangeland condition.

### 6.3.4 Bush density vs. grass species richness

There is no correlation between the bush density and grass species richness in the Treatment area, while in the Control area there is a negative correlation. The

Treatment area findings illustrate that the veld condition is in transformation and not stable. This correlation is expected to change as the veld condition improves with time.

The finding in the Control area indicates the impact of bush encroachment on the grass species richness. This correlation is moderately strong and clearly indicates the expected negative relationship. But unstable and disturbed veld can also produce more species of pioneer status.

Species richness alone is not a good indicator of veld condition, since even a poor veld can support a variety of species. The Treatment area's species richness produced only 3 species more than in the Control area.

#### 6.3.5 Bush density vs. grass grazing, -ecosystem, and -successional values

In both the Treatment and Control areas, the correlation between bush density vs. grass grazing, -ecosystem, and -successional value is negative. A stronger negative correlation is always found in the Control area. Highlighting the negative impact of bush encroachment on grass grazing value, ecosystem value and successional value.

The Treatment area has transformed from a pioneer veld to an improved sub-climax veld and is continuing to transit this condition to a more climax state. This state of transition is producing mixed correlation and not as expected.

#### 6.3.6 Bush density vs. grass perenniality and -biomass values

The correlation between bush density vs. grass perenniality value and -biomass value in the Treatment area produced a moderate positive relationship while in the Control area a moderately strong negative relationship is yielded.

The finding describes how the bush thinning has improved grass perenniality composition and also how bush thinning improves grass biomass production. These

ecological values of grasses are key indicators of veld condition. Improving veld grasses perenniality and biomass are objectives of every farmer and many farmers rangeland management is gear towards achieving good veld conditions for both livestock and game farming.

#### 6.4 Charcoal industry policy implications for bush encroachment management

The current policy framework for bush encroachment management is adequate. Charcoal production is a tool that can be sustainably used to control bush encroachment in Namibia. Not only is the environment benefiting from charcoal production but economic benefits are also realised. Making bush encroachment management an affordable operation.

Lack of enforceable guidelines to promote best practices in the industry will continue to encourage unselective bush thinning as observed in the study. Therefore charcoal producers should be encouraged to comply with local policies and subjected to third party environmental audits such as the Forest Stewardship Council (FSC). This can be done by adopting a policy that requires all charcoal producers to become compliant to the Forest Stewardship Council standards.

To encourage compliance to the Forest Stewardship Council, will require adherence to certain socio-economic and environmental principles that promote sustainable development. This compliance can be enforced through regular inspections by the Forest Stewardship Council officials, associates or consultants. Cost for compliance audit, monitoring and enforcement is therefore not carried by the government but by the sector.

## Chapter 7: Conclusions and Recommendations

Bush encroachment has become a common phenomenon in the world's arid and semiarid biomes. Where grasslands and savannas are turned into shrublands and thickets (Eldridge *et al.*, 2011). This change in vegetation communities have direct consequences on ecosystems functioning and services delivery.

Changes in the ecosystem functions and services due to bush encroachment has resulted into reduced productivity of rangeland and also negatively impacted on the biodiversity of the rangeland. There are many drivers of bush encroachment. These drivers are can be anthropogenic activities such as CO<sub>2</sub> emissions, a lack or misuse of fire, reduced browsing pressure, poor grazing practices, especially overstocking of cattle and natural stochastic events such as climate variability.

There are different methods of bush encroachment control. Many of these methods are no easy to implement and are expensive. A combination of control strategies and tools are likely to be most efficient. Different tools and strategies have been used over the years to manage bush encroachment. These methods inter alia include the use of fire, browsers, chemical control and mechanical clearing.

Bush thinning for charcoal production in Namibia has generated a lot of interest amongst farmers affected by bush encroachment. Therefore, charcoal production has been appreciated as one of the tools available to farmers to redress bush encroachment and its impact of the rangeland, while at the same time generating income and creating the much needed employment from off-farm activities.

Results from this study have showed that indeed bush thinning for charcoal production has:

- a) Increased rangeland productivity in terms of better grazing quality,
- b) Facilitated the recovery of savanna vegetation structure on the farm and
- c) Improved vegetation biodiversity, richness and grass biomass production.

The current charcoal sector seems to be working just fine, to both the benefit of the environment and people. Extensive interventions are not needed from the government to control the sector.

Key relevant issues to be address in the future are:

- a) Unselective harvesting of large trees: This can be done by adopting a policy that requires all charcoal producers to become compliance to the Forest Stewardship Council standards and values.
- b) Post harvesting bush control: Here the government can take a lead role in providing subsidies to farmers to use arboricides or introduce a fire program to support the control coppicing and seedlings recruitment in treated sites.
- c) It appears that in Namibia, there is a lack of documentation on the quantification of limits of bush encroachment levels, that can be used to identify when an area is considered bush encroached and at what degree. Hence, more long-term studies are needed to look into this issue.

## List of References

- Angassa, A. & Oba, G. 2008. Bush encroachment control demonstrations in southern Ethiopia: 1. Woody species survival strategies with implications for herder land management. *African Journal of Ecology*. 47:63-76.
- Angassa, A. & Oba, G. 2007. Effects of management and time on mechanisms of bush encroachment in southern Ethiopia. *African Journal of Ecology*. 46:186-196.
- Archer, S.R., Schimel, D.S. & Holland, E.A. 1995. Mechanisms of shrubland expansion - land-use, climate or CO<sub>2</sub>? *Climatic Change*. 29:91-99.
- Bennani, K., Alami, I.T., Bendaou, N., Saidi, N., Gaboun, F. & Al Faiz, C. 2010. Conservation and multivariate analysis utility in characterization of ecogeographical relationships of *Trifolium* and *Lotus* species. *African Journal of Ecology*. 49:1-9.
- Boulant, N., Garnier, A., Curt, T. & Lepart, J. 2009. Disentangling the effects of land use, shrub cover and climate on the invasion speed of native and introduced pines in grasslands. *A Journal of Conservation Biogeography*. 15:1047-1059.
- Britz, M.L. & Ward, D. 2007. Dynamics of woody vegetation in a semi-arid savanna, with a focus on bush encroachment. *African Journal of Range & Forage Science*. 24(3):131-140.
- Brown, J.R. & Havstad, K.M. 2004. Monitoring to detect change on rangelands: physical, social and economic/policy drivers. *African Journal of Range & Forage Science*. 21(2):115-121.
- Buitenwerf, R., Bond, W.J., Stevens, N. & Trollope, W.S.W. 2012. Increased tree densities in South African savannas: >50 years of data suggests CO<sub>2</sub> as a driver. *Global Change Biology*. 18:675-684.
- Christelis, G. & Struckmeier, W. 2001. Groundwater in Namibia: an explanation to the hydrogeology map. John Meinert Printing. Windhoek.
- Christian, C. 2010. *Groundwater Resources in Namibia: a Desk Top Study*. Namibia Agricultural Union. Windhoek.
- Coetzee, B.W.T., Tincani, L., Wodu, Z. & Mwasi, S.M. 2007. Overgrazing and bush encroachment by *Tarchonanthus camphoratus* in a semi-arid Savanna. *African Journal of Ecology*. 46:449-451.

- Dalle, G. Maass, B.L. & Isselstein, J. 2006. Encroachment of woody plants and its impact on pastoral livestock production in the Borana lowlands, southern Oromia, Ethiopia. *African Journal of Ecology*. 44:237-246.
- Darkoh, M.B.K. 2009. An overview of environmental issues in Southern Africa. *African Journal of Ecology*. 47:93-98.
- De Klerk, J.N. 2004. *Bush encroachment in Namibia*. John Meinert Printing. Windhoek.
- Diekman, U. & Muduva, T. 2010. *Namibia Black Gold? Charcoal production, practices and implications*. John Meinert Printing. Windhoek.
- Digital Atlas of Namibia*. 2013 [Online image]. Available from: <[http://www.uni-koeln.de/sfb389/e/e1/download/atlas\\_namibia/main\\_namibia\\_atlas.html](http://www.uni-koeln.de/sfb389/e/e1/download/atlas_namibia/main_namibia_atlas.html)>. [Accessed 16 February 2013].
- Dovie, D.B.K., Witkowski, E.T.F. & Shackleton, C.M. 2008. Knowledge of plant resource use based on location, gender and generation. *Applied Geography*. 28(4):311-322.
- Eldridge, D.J., Bowker, M.A., Roger, E., Maestre, F.T., Reynolds, J.F. & Whitford, W.G. 2011. Impacts of shrub encroachment on ecosystem functioning: towards a global synthesis. *Ecology Letters*. 14:709-722.
- Fasona, M. & Omojola, A. 2009. Land cover change and land degradation in parts of the southwest coast of Nigeria. *African Journal of Ecology*. 47:30-38.
- Gillson, L., Midgley, G.F. & Wakeling, J.L. 2012. Exploring the significance of land-cover change in South Africa. *South African Journal Science*. <http://dx.doi.org/10.4102/sajs>.
- Google earth*. 2013 [Online image]. Available from: <<http://www.google.com/earth/index.html>>. AfriGIS (Pty) Ltd. [Accessed 20 February 2013].
- Hardy, M.B., Hurt, C.R. & Bosch, O.J.H. 1999. Veld condition assessment. In: Tainton, N. (ed): *Veld management in South Africa*. University of Natal Press. Pietermaritzburg, pp. 195-216.
- Hassan, S.N., Rusch, G.M., Hytteborn, H., Skarpe, C. & Kikula, I. 2007. Effects of fire on sward structure and grazing in western Serengeti, Tanzania. *African Journal of Ecology*. 46:174-185.

- Hoffman, T. & Ashwell, A. 2001. *Nature divided: land degradation in South Africa*. University of Cape Town Press. Cape Town.
- Hoffman, M.T. & Darkoh, M. 2003. Rangelands as dynamic systems-desertification: patterns and processes in Africa. *African Journal of Range & Forage Science*. 20(2): 101-106.
- Huston, A.H. 1994. Biological diversity: The coexistence of species on changing landscapes. [Onlinebook]. Available from: <[http://books.google.ca/books?id=VA7Ct-SCU1kC&printsec=frontcover&dq=Biological+Diversity.The+Coexistence+of+Species&hl=en&sa=X&ei=iUMrUdW2M5TO4QTTn4HADQ&ved=0CCIQ6AEwAA#](http://books.google.ca/books?id=VA7Ct-SCU1kC&printsec=frontcover&dq=Biological+Diversity.The+Coexistence+of+Species&hl=en&sa=X&ei=iUMrUdW2M5TO4QTTn4HADQ&ved=0CCIQ6AEwAA#>)>. [Accessed 23 February 2013].
- Kalema, V.N. & Witkowski, E.T.F. 2012. Land-use impacts on woody plant density and diversity in an African savanna charcoal production region. *International Journal of Biodiversity Science, Ecosystem Services & Management*. 8(3):231-247.
- Lange, G., Barnes, J.I. & Motinga, D.J. 1997. *Cattle numbers, biomass, productivity, and land degradation in the commercial farming sector of Namibia, 1915 to 1995*. Directorate of Environmental Affairs. Windhoek.
- Kituyi, E. 2004. Towards sustainable production and use of charcoal in Kenya: exploring the potential in life cycle management approach. *Journal of Cleaner Production*. 12:1047-1057.
- Marker, L., Kraus, D., Barnett, D. & Hurlbut, S. 1999. *Cheetah survival on Namibian farmlands*. Solitaire Press. Windhoek.
- Mendelsohn, J., Jarvis, A., Roberts, C. & Robertson, T. 2003. Atlas of Namibia: a portrait of the land and its people. David Philips Publishers. Cape Town.
- Moleele, N.M., Ringrose, S., Matheson, W. & Vanderpost, C. 2002. More woody plants? The status of bush encroachment in Botswana's grazing areas. *Journal of Environmental Management*. 64:3-11.
- Mostert, J.W.C., Roberts, B.R., Heslinga, C.F. & Coetzee, P.G.F. 1971. *Veld management in the O.J.S. region*. Department of Agriculture and Water Supply. Government Printers. Pretoria.
- Muller, M.A.N. 2007. Grasses of Namibia. John Meinert (Pty) Ltd. Windhoek.

*Namibia Chambers of Commerce and Industry (NCCI)*. 2013 [Online data]. Available from: <<http://www.ncci.org.na/NCCI/data/Economy.aspx>>. [Accessed 19 February 2013]. Windhoek.

National Planning Commission (NPC). 2012. Namibia's fourth National Development Plan (NDP4), 2012/13 to 2016/17. Windhoek.

National Planning Commission (NPC). 2006. Joint Report on economics and politics in Namibia. Windhoek. (Unpublished).

Odada, E.O., Ochola, W.O. & Olago, D.O. 2009. Drivers of ecosystem change and their impacts on human well-being in Lake Victoria basin. *African Journal of Ecology*. 47:46-54.

Oindo, B.O. 2002. Body size and measurement of species diversity in large grazing mammals. *African Journal of Ecology*. 40:267-275.

O'Reilly, L., Ogada, D., Palmer, T.M. & Keesing, F. 2006. Effects of fire on bird diversity and abundance in an East African savanna. *African Journal of Ecology*. 44:165-170.

Parr, C.L., Grayand, E.F. & Bond, W. J. 2012. Cascading biodiversity and functional consequences of a global change-induced biome switch. *A Journal of Conservation Biogeography*. 18:493-503.

Roques, K.G., O'Connor, T.G. & Watkinson. A.R. 2001. Dynamics of shrub encroachment in an African savanna: relative influences of fire, herbivory, rainfall and density dependence. *Journal of Applied Ecology*. 38:268-280.

Scholes, R.J. & Archer, S. 1997. Tree-grass interactions in savannas. *Annual Review of Ecology and Systematics*. 28:517-544.

Scholes, R.J. 2009. Syndromes of dry-land degradation in southern Africa. *African Journal of Range & Forage Science*. 26(3):113-125.

Sirami, C. & Monadjem, A. 2012. Changes in bird communities in Swaziland savannas between 1998 and 2008 owing to shrub encroachment. *A Journal of Conservation Biogeography*. 18:390-400.

Sirami, C., Seymour, C., Midgley, G. & Barnard, P. 2009. The impact of shrub encroachment on savanna bird diversity from local to regional scale. *A Journal of Conservation Biogeography*. 15:948-957.

- Sithole, A. & Murewi, C.T.F. 2009. Climate variability and change over southern Africa: impacts and challenges. *African Journal of Ecology*. 47:17-20.
- Smet, M. & Ward, D. 2005. A comparison of the effects of different rangeland management systems on plant species composition, diversity and vegetation structure in a semi-arid savanna. *African Journal of Range & Forage Science*. 22(1):59-71.
- Smit, G.N. 2004. An approach to tree thinning to structure southern African savannas for long-term restoration from bush encroachment. *Journal of Environmental Management*. 71:179-191.
- Smit, G.N., Richter, C.G.F. & Aucamp, A.J. 1999. Bush encroachment: An approach to the understanding and managing the problem. In: Tainton, N. (ed): *Veld management in South Africa*. University of Natal Press. Pietermaritzburg, pp. 246-260.
- Smit, G.N. & Rethman, F.G. 1999. The influence of tree thinning on the establishment of herbaceous plants in a semi-arid savanna of southern Africa. *African Journal of Range and Forage Science*. 16:9-18.
- Tefera, B.S. & Mlambo, V. 2010. Encroachment of *Acacia brevispica* and *Acacia drepanolobium* in Semi-arid rangelands of Ethiopia and their influence on Sub-Canopy Grasses. *Research Journal of Botany*. 5:1-13.
- Tefera, S., Dlamini, B.J. & Dlamini, A.M. 2008. Dynamics of savannas in Swaziland: Encroachment of woody plants in relation to the use and soil classes and indigenous knowledge on plants utilisation. *Research Journal of Botany*. 3:49-64.
- Tefera, S., Dlamini, B.J., Dlamini, A.M. & Mlambo, V. 2007. Current range condition in relation to land management systems in semi-arid savannas of Swaziland. *African Journal of Ecology*. 46:158-167.
- Throop, H.L. & Archer, S.R. 2008. Shrub (*Prosopis velutina*) encroachment in a semidesert grassland: spatial-temporal changes in soil organic carbon and nitrogen pools. *Global Change Biology*. 14:2420-2431.
- Trollope, W.S.W., Hobson, F.O., Danckwertz, J.E. & Van Niekerk, J.P. 1989. Encroachment and control of undesirable plants. In: Danckwertz, J.E. & Teague, W.R. (eds): *Veld management in the eastern Cape*. Department of Agriculture and Water Supply. Government Printers. Pretoria.

- Van der Waal, C., Kool, A., Meijer, S.S., Kohi, E, Heitkonig, I.M.A., De Boer, W.F., Van Langevelde, F., Grant, R.C., Peel, M.J.S., Slotow, R., De Knegt, H.J., Prins, H.H.T. & De Kroon, H. 2011. Large herbivores may alter vegetation structure of semi-arid savannas through soil nutrient mediation. *Oecologia*. 65:1095-1107.
- Van Oudsthoorn, F. 1999. Guide to grasses of Southern Africa. Briza Publications. Pretoria.
- Ward, D. 2005. Do we understand the causes of bush encroachment in African savannas? *African Journal of Range & Forage Science*. 22(2):101–105.
- Watson, P.J., Bradstock, R.A. & Morris, E.C. 2009. Fire frequency influences composition and structure of the shrub layer in an Australian subcoastal temperate grassy woodland. *Austral Ecology*. 34:218-232.
- Welman, Kruger & Mitchel. 2012. Research methodology (3<sup>rd</sup> edition). Oxford University Press. Cape Town.
- Wigley, B.J. Bond, W. J. & Hoffman, M.T. 2009. Bush encroachment under three contrasting land-use practices in a mesic South African savanna. *African Journal of Ecology*. 47:62-70.
- Wiegand, K., Ward, D. & Saltz, D. 2005. Multi-scale patterns in an arid savanna with a single soil layer. *Journal of Vegetation Science*. 16:311-320.
- Wikipedia. 2013 [Online image]. Available from: [http://en.wikipedia.org/wiki/Correlation\\_and\\_dependence](http://en.wikipedia.org/wiki/Correlation_and_dependence). [Accessed 22 December 2013].
- Zida, D., Tigabu, M., Sawadogo, L., Tiveau, D. & Oden, P.C. 2008. Long-term effects of prescribed early fire, grazing and selective tree cutting on seedling populations in the Sudanian savanna of Burkina Faso. *African Journal of Ecology*. 47:97-108.
- Zulu, L.C. & Richardson, R.B. 2012. Charcoal, livelihoods, and poverty reduction: Evidence from sub-Saharan Africa. *Energy for Sustainable Development*. <http://dx.doi.org/10.1016/j.esd.2012.07.007>.