# Plant diversity in grasslands of selected nature reserves and adjacent grazing areas within the Gauteng province, South Africa

by

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Submitted in accordance with the requirements
for the degree of

MASTER OF SCIENCE

In the subject

LIFE SCIENCES

at the

UNIVERSITY OF SOUTH AFRICA

SUPERVISOR: DR M V DINGAAN

FEBRUARY 2019

**SUMMARY**

The relations between environmental resources and biodiversity are crucial in the proper management and conservation of grasslands. Three nature reserves were chosen around the Gauteng Province, namely Roodeplaat Nature Reserve (RNR) in Tshwane, Suikerbosrand Nature Reserve (SNR) in Heidelberg, and Abe Bailey Nature Reserve (ANR) in Carletonville. We selected three sites within RNR, SNR and ANR, and paired these with adjacent sites in private farming/grazing areas adjacent to the nature reserves. At each site, species composition, species richness and plant diversity were determined with the use of 50m x 20m Modified-Whittaker plots (MWP), making a total of eighteen plots (MWP) at the nine paired sites. Two paired sites had high Shannon-Wiener Index (*H'*) average values at the adjacent grazing area as compared to the nature reserve area at ANR. Roodeplaat Nature Reserve (RNR) and Suikerbosrand Nature Reserve (SNR) had two paired sites with high *H'* average values in the nature reserve as compared to the adjacent grazing area.

The vegetation structure was similar for the three study locations, consisting of graminoids, herbs and isolated patches of shrubs. The species composition showed similarities between ANR and SNR sites, while RNR showed different species composition. SNR soils had the highest organic carbon (OC), total Carbon (C), total Nitrogen (N), Calcium (Ca), Potassium (K), Magnesium (Mg) and Sodium (Na) as compared to both ANR and RNR. Species richness had a significantly positive relationship with Organic Carbon and Total Nitrogen. Species diversity difference was detected between the nature reserves and adjacent grazing areas and the difference are likely due to a number of factors including soil properties, land disturbance and land use and management. More research is necessary to further understand the aspects impacting species richness, species diversity and species composition in grasslands.

**Key terms:** Protected; grazing area; paired sites; species diversity; grasslands; palatability; species richness; soil nutrients; habitat characteristics; species composition.

**DECLARATION**

I **Moseketsi Mochesane** hereby declare that the dissertation/thesis, which I hereby submit for the degree of **Master of Science in Life Sciences** at the University of South Africa, is my own work and has not previously been submitted by me for a degree at this or any other institution.

I declare that the dissertation /thesis does not contain any written work presented by other persons whether written, pictures, graphs or data or any other information without acknowledging the source.

I declare that where words from a written source have been used the words have been paraphrased and referenced and where exact words from a source have been used the words have been placed inside quotation marks and referenced.

I declare that I have not copied and pasted any information from the Internet, without specifically acknowledging the source and have inserted appropriate references to these sources in the reference section of the dissertation or thesis.

I declare that during my study I adhered to the Research Ethics Policy of the University of South Africa, received ethics approval for the duration of my study prior to the commencement of data gathering, and have not acted outside the approval conditions.

I declare that the content of my dissertation/thesis has been submitted through an electronic plagiarism detection program before the final submission for examination.

Student signature: _____ Date_____

**DEDICATION**

This dissertation is dedicated to my siblings Sipho Mochesane, Mamosa Mochesane, Masaka Mochesane and Relebohile Mochesane (You guys can also get here) and a special dedication to our father Mahase Mochesane who left us during my field work.

**ACKNOWLEDGEMENTS**

I would like to express my sincere gratitude to the following individuals and organisations for their assistance and support towards the completion of this study:

- The National Research Foundation and University of South Africa for the financial support that made this research possible.
- My supervisor Dr Mamokete Dingaan. Your knowledge, guidance, motivation, teaching methods, and of course your patience were all significant in the completion of this research.
- The Roodeplaat Nature Reserve, Suikerbosrand Nature Reserve, Abe Bailey Nature Reserve, and the Gauteng Department of Agriculture and Rural Development for granting us permission to conduct the field work.
- The Ecologists and Biodiversity Officers at the three nature reserves for their expertise and guidance.
- Adjacent land owners for granting us permission to conduct our field work on their land.
- The team that assisted with the field work of this research project, Priscilla, Amukelani, and Ntate Tanki. “You guys were the champions of the field work”.
- Last but not least thank you to my dearest friend Bongi Mhlanga, who had to hold the fort at work on my behalf during the field work.

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# CHAPTER 1: INTRODUCTION

## 1.1 Background

Biodiversity is a term that is used to describe all plant and animal species, and also micro-organisms, that can be found living together within an ecosystem (Vandermeer & Perfecto, 1995). The importance of plant diversity lies in the many ecological services it performs. For example, the vegetative cover provided by plants enhances soil infiltration and reduces water runoff thereby preventing soil erosion; it is also important for groundwater recharge and flood control (Perry, 1994). According to Tilman (1999) and Balvanera et al (2006) biodiversity plays a major role in controlling ecosystem functioning. Furthermore, plant communities characterized by high plant diversity are more productive, while ecosystems with higher plant diversity are better able to retain nutrients and are more stable (Tilman, 2000).

Plant diversity has received less attention in conservation than animals (Goettsch et al., 2015), yet plants are much more important to human livelihood. Plant species diversity is often investigated within a defined ecological community, with land use as one of the key determinants. The effects of land use on plant diversity are varied, mainly because there are various types of land-use, such as grassland management, land abandonment, and fire (Jiang et al., 2003; Gerstner et al., 2014). Other determinants that have been linked to ecological and evolutionary processes at different spatial scales are distribution, interaction and abundance of individuals (Schmida & Wilson 1985; Balvanera et al., 2006; Naeem et al., 2003). Plant species richness in a community is commonly used as a measure of species diversity, this measure probably originated from a discussions involving community's productivity and disturbances (Colwell & Coddington, 1994). The diversity measure is however not confined to the aspect of species richness only in any given community, in some instances species abundance can be more significant than the species number (Whittaker 1972; Purvis & Hector, 2000).

There has been an increased rate of biodiversity loss and extinction, caused by human activities and environmental variables (Balvanera et al., 2006; Hooper et al., 2005; Kennedy et al., 2002; Austin et al., 1996). As a result, biodiversity is regarded as an important matter for both scientific and political concern because of the negative environmental consequences of biodiversity loss (Huston, 1999). There have been severe changes in grass abundance, tree cover and fire regimes with recent studies suggesting climate and elevated $CO_2$ as drivers (Wigley et al., 2010; Kraaij et al., 2013; Masubelele et al., 2014). Biodiversity is further threatened by human-induced drivers such as changes in land cover and use (Dale, 1997).

The grassland biome is the second largest biome in South Africa. This biome is mostly situated on the high central plateau commonly known as the Highveld, and is characterised by a wide range of rainfall and temperature variation (Mucina & Rutherford, 2006). Grasslands mainly consist of an open layer of graminoid communities of the Poaceae family, and also perennial forb species (Carbutt et al., 2011). Throughout the world, grassland ecosystems occur abundantly, and provide important ecological services such as biodiversity preservation, forage production and livestock grazing, as well as soil carbon storage (Parton et al., 1995; Hardy & Jost, 2008; Lee et al., 2010). The grassland biome is maintained by a complex interplay of abiotic and biotic factors such as grazing and fire (Mucina & Rutherford, 2006), which can be managed to influence ecosystem health and thus directly influencing biodiversity (Little et al., 2015).

Grassland vegetation undergoes changes through the concepts of Clementsian succession, in which vegetation progressively develops through a series of plant communities from discrete pioneer stages to a climax stage (O'Connor & Bredenkamp, 1997; Tainton, 1999; Briske et al., 2003). The vegetation develops through these stages in a directional and reversible manner, which means that interventions such as fire or grazing will counteract with secondary succession, thereby influencing the speed and direction of the succession sequence (Tainton, 1999; Fynn & O'Connor, 2000; Briske et al., 2003). This is thought to occur though the influence of herbivores alternately favouring certain species and reducing the competitive ability of others (Howe, 1994; Crawley, 1997; Tainton, 1999). This

phenomenon has given rise to the increaser-decreaser concept in which plant species are classified on the basis of their response to defoliation (Foran et al., 1978; Dobarro et al., 2010).

## 1.2 Problem statement

Grassland biomes globally are undergoing heavy utilisation by human activities. They face increasing anthropogenic pressure as human populations increase, resulting in an increased need for the resources that grasslands provide (Myers et al., 2000; Reyers et al., 2001; Hoekstra et al., 2005). Grassland systems make up around 11% of the world's vegetation (Ramankutty & Foley, 1999), and yet they are still largely under-appreciated and under-conserved. This is all in spite of the increasing realisation that grasslands globally are some of the most threatened vegetation types (Overbeck & Pfadenhauer, 2007; Bond & Parr, 2010). Likewise, South African grasslands are facing increased habitat loss and fragmentation, and a mere 15% remains as natural grassland (Little et al., 2015) with approximately 60% of the grassland biome irreversible transformed (Reyers & Tosh, 2003). These grasslands have thus become severely threatened in South Africa, making them a priority for conservation efforts. Only 2.2 % of the grasslands is conserved in the country (Mucina & Rutherford, 2006).

There is considerable knowledge regarding the ecology and functionality of grasslands in South Africa, for example, most of the research has focused on the grassland production potential for livestock farming, alteration of soil properties and also on maintaining species composition dominated by palatable grasses (Abdalla et al., 2018; Akhazari et al., 2015; Dahwa et al., 2013). However, the research conducted has paid little focus on the biome's diversity, the grassland biome is considered second in species diversity after the fynbos biome in South Africa and has a number of rare and endangered species, most of which are endemic (Low & Rebelo, 1996).

The levels of transformation caused by the different variables, are a concern for the grasslands in South Africa, as the biome encompasses a centre of diversity with an

estimated 3 788 plant species (Gibbs, 1987). In order to properly manage and conserve grassland plant diversity in South Africa, there needs to be cognisance of how plant diversity is affected by resources availability, environmental perturbations, and land use management. Conserving, protecting and preserving natural areas and the reduction of biodiversity loss are fundamental principles of protected area management programmes (Bruner et al., 2001; Ehrlich & Pringle, 2008). This study was initiated to enhance the understanding of how biodiversity and environmental resources interplay and provides better insight into the management of both wildlife-protected and non-protected areas of the South African Grassland Biome.

## 1.3 Aims and objectives

The aim of this study was to investigate the influence of different land uses and management practices on the plant diversity of the grassland biome, Gauteng Province, South Africa.

In order to address the aim of the study, the objectives were:

i. to investigate how plant species composition differs between protected and grazing areas.
ii. to compare plant diversity between protected and grazing areas.
iii. to determine relationships between plant diversity and soil characteristics under different land use types and management.

## 1.4 The research questions

- Are there differences in plant species composition and plant diversity in the protected area as compared to the adjacent grazing fields?
- Are the soil characteristics in the nature reserve be any different compared to the adjacent grazing land?
- How much of an impact do environmental variables (climate; soil characteristics and grazing) have on plant diversity?

## 1.5 Justification of the study

South African grasslands are facing increased habitat loss and habitat fragmentation, and have become one of the critically endangered vegetation types in South Africa (Olson & Dinerstein, 1998; Reyers et al., 2001), making them a priority for conservation efforts (Rebelo, 1997). These grasslands are maintained by a complex interplay of abiotic and biotic factors such as grazing and fire, which can be managed to influence ecosystem health and thus directly influencing biodiversity.

Ecologists have always been interested in understanding the intricate patterns of how species respond to environmental variables. They tend to adopt a continuum approach to vegetation with its assumption of continuous change in composition with position in the multi-dimensional environmental space (Austin, 1999). Although over any large region the distribution of species richness is likely to be governed by two or more environmental gradients (Austin et al., 1996). Species richness studies in relation to environmental variables have mainly focused on single factors such as climate, grazing or human activities. Many studies are conducted to investigate zoological phenomena (Lawton, 1999), even though vegetation studies may have much to offer on general issues concerning biodiversity (Austin, 1999).

There have been several studies conducted in grasslands globally. The studies have been conducted because of the loss of the grassland biome and plant diversity, due to environmental variables such as climate change (Parton et al., 1995), grazing (Burns et al., 2009) and fire (O'Connor et al., 2004). The studies mostly concluded that grazing has an impact on plant loss and some loss of diversity (Milchunas & Lauenroth, 1993; Little et al., 2015).

In South Africa, the Grassland Society of Southern Africa (GSSA) successfully carried a series of workshops in 2004, to deliberate on the effect of various land uses on biodiversity in the grasslands of South Africa. The workshops dealt with different land use issues including the effect of grazing on biodiversity (Short & Du Toit, 2005). The workshops helped inform the production of guidelines on

biodiversity and sustainable grazing systems, and this was achieved in 2014 nearly ten years after the first workshop (SANBI, 2014).

Several studies have been conducted in order to determine plant diversity in protected and communal/grazing lands in South Africa; however, these mainly focused on the savanna and thicket biomes (Fynn & O'Connor, 2000; Shackleton, 2000; Fabricius et al., 2002; Fabricius et al., 2003). In addition, there has been a few studies under taken for maintaining biodiversity in South African grasslands such as those by O'Connor & Kuyler (2009) and O'Connor et al. (2010). The present study aimed to investigate the influence of land use and management practices on the plant diversity of the grassland biome, in the Gauteng Province of South Africa. The study further provided insight on the interplay between environmental resources and biodiversity, which is important for the management of both wildlife-protected and non-protected areas of the South Africa.

## 1.6 Layout of the dissertation

This dissertation have been divided into six chapters as follows:

Chapter 1- introduces the study and provides the problem statement with research questions, motivation and justification for conducting the study.

Chapter 2- provides a literature overview of similar studies and research conducted, with emphasis on plant diversity and species composition, and the impacts that environmental variables such as grazing and soil characteristics have on plant diversity and composition.

Chapter 3- presents the study areas geographically, the Abe Bailey nature reserve, Suikerbosrand nature reserve and the Roodeplaat nature reserve, as well as the topography, climate and vegetation information of each nature reserve.

Chapter 4- provides all the methodologies followed for field surveys and sampling, and data analysis methodologies.

Chapter 5- provides analysis of all observed plant diversity and species composition patterns, including the soil characteristics. The results of the analysis are further interpreted and discussed.

Chapter 6- concludes on the results obtained and the discussion of the results, this chapter also provides recommendations for future research.

# CHAPTER TWO: LITERATURE REVIEW

## 2.1 Introduction

There have been numerous attempts to investigate interactions between plant diversity and ecosystem functions, either experimentally or by using comparative approaches. Many studies have been carried out over the years, which address the relationship between plant diversity, measured as species richness, and ecosystem function. Some have been able to provide indications of strong linkages, and these have been experimental studies in grassland ecosystems, in which species diversity was manipulated directly in replicated treatments. Some of the prominent examples include studies by Tilman (1996), Hector et al. (1999), Isbell and Wilsey (2011), and Reich et al. (2012). In recent decades, studies have further assessed and determined linkages between plant diversity, productivity, environmental variables, and mostly climate change (Parton et al., 1995; Midgley et al., 2002) and grazing (Shackleton, 2000; Rutherford et al., 2012). The understanding of the effects and separate interactions between ecosystem properties and ecosystems types including the environmental heterogeneity will become a challenge for the next generations (Belsky, 1992).

Regardless of the multitude of studies conducted, the relationship between plant diversity and ecosystem functioning still remains a contentious issue. For example, Huston (1997) reviewed equally prominent studies by Naeem et al. (1994), Tilman and Downing (1994) and Tilman (1996), and concluded that these studies did not clearly indicate that ecosystem functioning has improved with an increase of biodiversity. According to Huston (1997), it is most important to first understand how species richness patterns are related to the environment before conclusions can be drawn on how ecosystem processes are affected by biodiversity. Furthermore, there are numerous complexities regarding the studies of species richness which still need clarification, including the role of disturbance and the relative importance of biotic versus abiotic factors (Huston, 1997).

## 2.2 Impact of grazing on plant diversity and species composition

Changes in plant diversity, species composition, and the invasion of exotic species are primarily influenced by the interactions of the evolutionary grazing gradient (Milchunas et al., 1988). There is competition for aboveground resources by herbivores and plants are required to adapt to frequent organ loss (Milchunas & Lauenroth, 1993). However, the synergistic impact of heavy grazing is detrimental to the diversity and structure of plant species (Little et al., 2015). Dumont et al. (2009) found that stocking rates influenced herbage mass and pasture height, with low stocking rates resulting in an abundance of forbs and non-competitive grasses. Grazing can also impact soil properties (Akhzari et al., 2015; Abdalla et al., 2018).

Burns et al. (2009) observed how plant communities responded to the removal of large herbivores in South African and North American grasslands. Moreover, it was found that decreased grazing rates had impact on the structure and composition of plant communities, in as much as, there was a decline in plant diversity.

Cingolani et al. (2005) indicated that grazing can cause irreversible changes to species composition and diversity. The study conducted by Cingolani et al. (2005) showed that tussock canopies are opened by grazing in a reversible process provided that most individual tussocks can survive the reduction of biomass. With moderate grazing, the process can be irreversible due to the death of some tussocks and this then leads to higher species diversity. The above is largely due to the coexistence of grazing-susceptible species protected within the remaining tussocks, and the grazing resistant species that fill the space between tussocks. In areas with intensive grazing, diversity declines because the tussocks disappear almost completely, resulting in the elimination of grazing-susceptible species (Cingolani et al., 2005).

Farmers and ecologist have been on opposing sides when it comes to the advantages (positive impacts) and disadvantages (negative impacts) of high grazing pressure, these include both the short and long term impacts grazing has on sustaining the functionality of an ecosystem. Du Toit et al. (2011) found that short

term increases in stocking rates lead to a linear decrease in the canopy. This was also supported by Ingerpuu and Sarv (2015), who concluded that intense grazing can have significant impacts in plant cover changes. Ingerpuu and Sarv (2015) further reported that over growth of woody plants and reeds can be prevented by grazing and particularly in coastal meadows and grazing also increases plant species. On the other hand, Harrison and Shackleton (1999) demonstrated that important indicators of the functioning of grasslands composition and grass basal cover can undergo rapid change after removal of high and continuous grazing pressure.

According to Hickman et al. (2004) animal stocking density and the grazing system are the two components of a grazing management strategy affecting plant communities. Milchunas and Noy-Meir (2004) found that grazed sites had similar species richness (number of plant species) as compared to ungrazed sites. These findings according to Pakeman (2004) and Kreft and Jetz (2007) propose that the number of species that react may be dependent on context, in the context that their increase is as a response to change in grazing and this is then dependent on the identity of the their neighbours and alternatively the absence of consistency may indicate a complex response to changing grazing regime.

The individual plant size has an effect on the ecosystem functionality regarding the effects of the grazers on plant communities (Wu et al., 2014). Previous studies have shown that the shorter species normally have more tolerance to grazing than the taller species (Hickman et al., 2004; Milchunas & Noy-Meir, 2004; Osem et al., 2004) and that communities with low productivity often show less response to grazing than high-productivity ones (Milchunas et al., 1998).

## 2.3 Plant diversity and soil characteristics

Soil characteristics have an important influence on species diversity and composition, and the highly botanically valued grasses prefer soils with low nutrient status (Vermeer & Berendse, 1983). Species richness declines with increasing nutrient availability and this condition favours competitive species which are capable of rapid resource capture (Groendahl & Fink, 2017). The nutrients that play a role in species richness, diversity and composition are the soil pH, organic Carbon (OC), total Carbon (C), total Nitrogen (N), Calcium (Ca), Potassium (K), Magnesium (Mg) and Sodium (Na). Diekmann et al. (2014) found that calcareous grasslands showed little positive change with the addition of Nitrogen, the grasslands showed more change in species composition as compared to species richness. Berendse et al. (2015) found that the loss of soil fertility due to erosion might accelerate the decline in decline in plant diversity.

A study of temperate grasslands by Critchley et al. (2002) predicted that broad grassland types were clearly differentiated by their soil properties and the findings were in accordance with the prediction made at the beginning of their study. However, the importance of soil properties in differentiating communities or sub-communities varied with grassland type. The grasslands showed clear associations with particular soil properties at different community levels (Critchley et al., 2002). The differences in the ecological amplitude of the soil were also an indication that unimproved mesotrophic sub-communities occurred over a narrower range of soil conditions.

In dry grasslands, Lobel et al. (2006) concluded that the habitat quality for plant species richness is best predicted by soil pH, and further found that the effect of other environmental variables (e.g. soil depth and cover of bare rock) often was low. Similarly, Duprè et al. (2002) reported that in deciduous forests the soil pH was most closely correlated to species richness, whereas other soil parameters were rather non-corresponding.

Linstädter et al. (2014) study resulted in findings that were in contradiction with a lot of previous studies, this study reported a strong correlation between grazing and

soil gradient due to changes in soil properties facilitated by livestock. According to Ingram et al. (2008), overgrazing changed the vegetation composition to a C4 dominated plant community from a C3 dominated plant community. This change increases the possibilities of soil loss via carbon dioxide efflux during low rainfall and or drought, the change in plant community can lead to soil organic carbon accumulation closer to the surface (Ingram et al., 2008).

## 2.4 Effects of climate on plant diversity and composition

Climate variables have an important role in affecting terrestrial organisms (Krebs, 2001). Plant species grow at different temperatures, different levels of rainfall and at different sunlight wavelengths (Salisbury & Ross, 1992). Species have shown different distribution patterns along the different climatic variable gradients (Gao et al., 2017; Sanders, 2002). The climate variables (particularly temperature and rainfall) have shown a change over the past years and the changes are believed to have a role in plant diversity (Kruger & Shongwe, 2004; New et al., 2006; Warburton et al., 2005). The change in these variables has been indicated as one of the major environmental variables which are causing the loss of diversity and altering species composition within the grasslands (Parton et al., 1995; Rutherford et al., 1999; Midgley et al., 2002).

According to Adler and Levine (2007), high plant richness occurs after the drier years as compared to wetter years. Extreme precipitation leads to wetter (waterlogged) and drier conditions, the influence of extreme rainfall on plant growth is not consistent across ecosystems (Zeppel et al., 2014; Zeppel et al., 2015). Schenk and Jackson (2002), as well as Snyder and Williams (2003) found that a decline in the amount of rainfall and occurrences of drought have led to loss of diversity in the grasslands through invasion by shrubs.

Temperature is one of the significant climatic components used by the majority as a gradient to measure diversity (Chapungu & Nhamo, 2016). It has been shown through several studies that increased temperature can influence community and

floristic structure in temperate grasslands (Saleska et al., 2002; Shaver et al., 2000). Increased temperatures can influence community composition and species richness, as they can also modify recruitment patterns, thereby having a bearing on ecosystem health (De Boeck et al., 2007). Studies have also indicated that increased temperatures can modify productivity in grasslands, which has implications for ecosystem functioning (Dukes et al., 2005).

## 2.5 Biodiversity studies in protected vs non-protected areas in South Africa

A study conducted by Shackleton (2000) in the Mpumalanga province of South Africa provided an interpretive framework for explaining changes in biodiversity in relation to the environmental variables and land uses, in wildlife-protected and unprotected (private / communal) lands in lowveld savanna. Shackleton (2000) found that the adjacent communal lands did not necessarily have less plant species as compared to the protected area. The findings were in agreement with findings reported by Pandey and Singh (1992) conducted on the dry tropical savanna in India.

Hongslo et al. (2009) investigated how grazing and cultivation affect vegetation in communal farming area, private area, and protected area in the Namaqualand for a period of 66 years. The study, which was conducted on an ecotone between the succulent karoo and nama-karoo biomes, found that there are other variables that influence vegetation except land-use and these include climate, soil characteristics and the vegetation type. The study was based on aerial photography only and focused on landscape changes and vegetation cover rather than vegetation diversity and/or productivity.

In the succulent thicket of the Eastern Cape, Fabricius and Burger (1997) reported that the studied reserve had better vegetation cover than the adjacent communal lands surveyed. The study however had certain limitations as the local communities

are not scientifically trained and may have deviated from some scientific processes and the authors also noted this in their study (Fabricius & Burger, 1997).

# CHAPTER 3: STUDY AREA

## 3.1 Introduction

Three study locations were selected in order to provide clear comparisons of plant diversity and the associated environmental variables, between wildlife protected areas and non-protected (private/communal) lands. A study location comprises both protected areas [nature reserves] and non-protected areas [adjacent grazing fields] for comparison to each other, based on the availability of suitable veld. Thus, the study area comprised of three nature reserves and their adjacent areas in the Gauteng Province. The three nature reserves selected for this study are shown in Figure 3.1, and are the Abe Bailey Nature Reserve (26° 19'51.56" S, 27° 20' 54.18" E -Carletonville), the Roodeplaat Municipal Nature Reserve (25°39′00″S, 28°21′44″E -Tshwane), and Suikerbosrand Nature Reserve (26° 29'01.66" S, 28° 13' 45.38" E -Heidelberg). The chosen study locations occur in the mesic (Gm) and dry Highveld (Gh) in the Grassland biome (Abe Bailey Nature Reserve, Suikerbosrand Nature Reserve), and part of the Central bushveld (SVcb) (Roodeplaat Nature reserve) of the Savanna Biome (Mucina & Rutherford 2011). Sampling sites were stratified along land use gradients, thus along the nature reserve fence.

Abe Bailey Nature Reserve (ANR) is within the Merafong Local Municipality, and is located close to the Carletonville town and beside Khutsong Township. The Roodeplaat Dam Nature Reserve (RNR) is within the Tshwane Metropolitan Municipality. It is located on the outskirts of the city of Pretoria at a distance of approximately 26 km from the centre of Pretoria. Suikerbosrand Nature Reserve (SNR) is located near the town of Heidelberg within the Lesedi Local Municipality. All three nature reserves are provincially protected and managed by Gauteng Department of Agriculture and Rural Development.

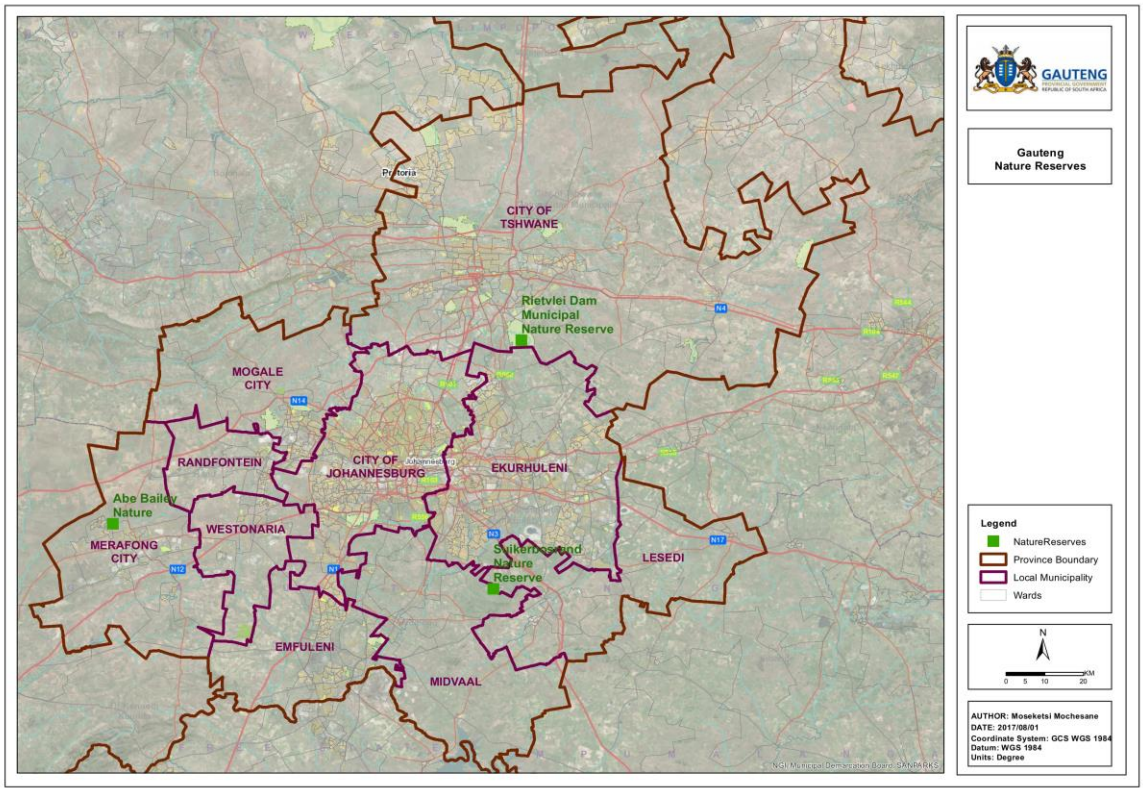
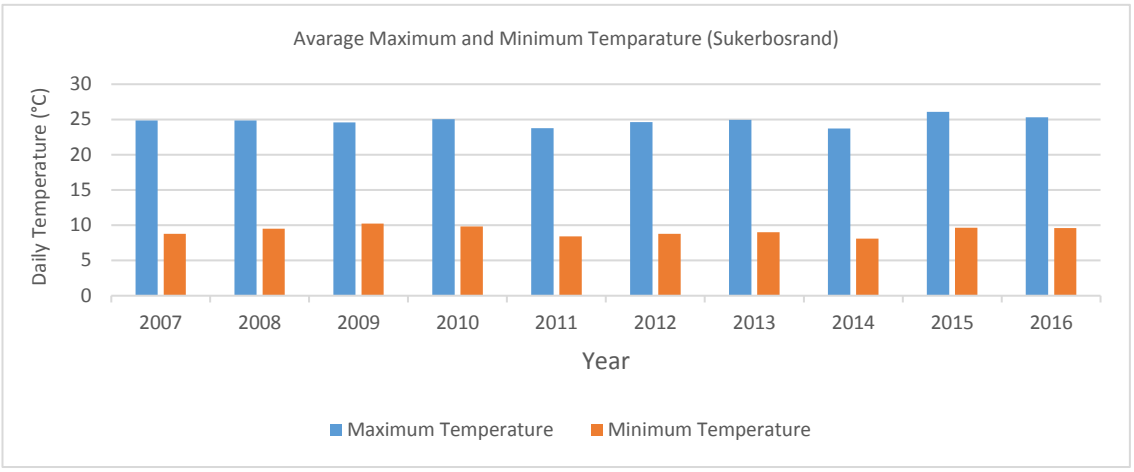


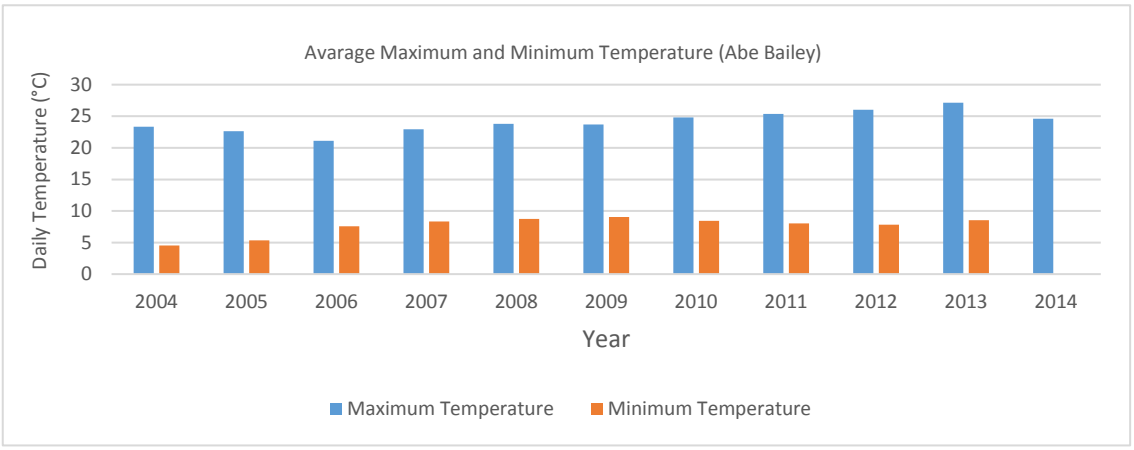

Figure 3.1: Map of the Gauteng Province indicating the three nature reserves and their respective municipalities

## 3.2 Climate

The Gauteng Province has mild climate with warm, moist summers and cool dry winters. There is variation with the mean summer and winter temperatures; the daily mean temperatures vary from a daily mean of 21.2°C in January to 9.8°C in July (Schulze, 1997). The province experiences higher temperatures in the northern part with mean annual temperatures of approximately 19°C as compared to around 15°C on the southern parts of the province. (Schulze, 1997). The average daily temperatures recorded over a 10-year period at three weather stations closest to the chosen study locations are indicated in Figure 3.2; the weather data was provided by the South African Weather Services.




Data from station [0438784 3] – VEREENIGING

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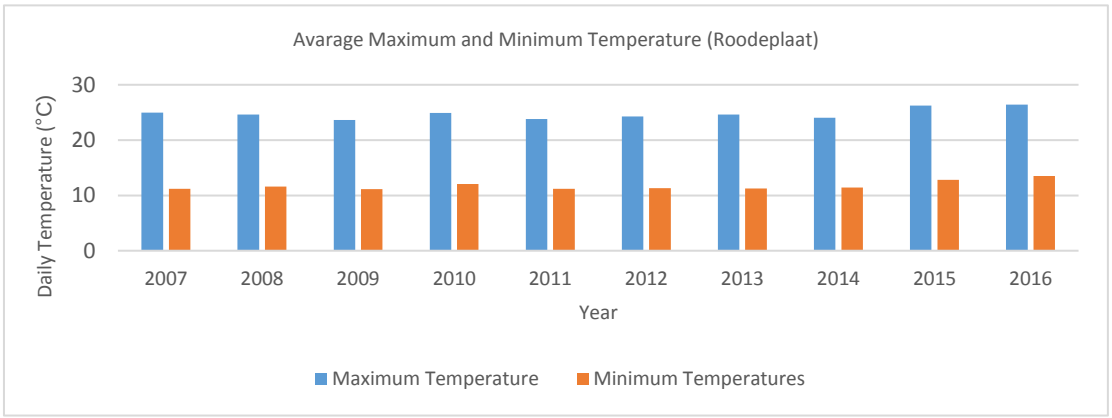



Data for station [0513385A2] - IRENE

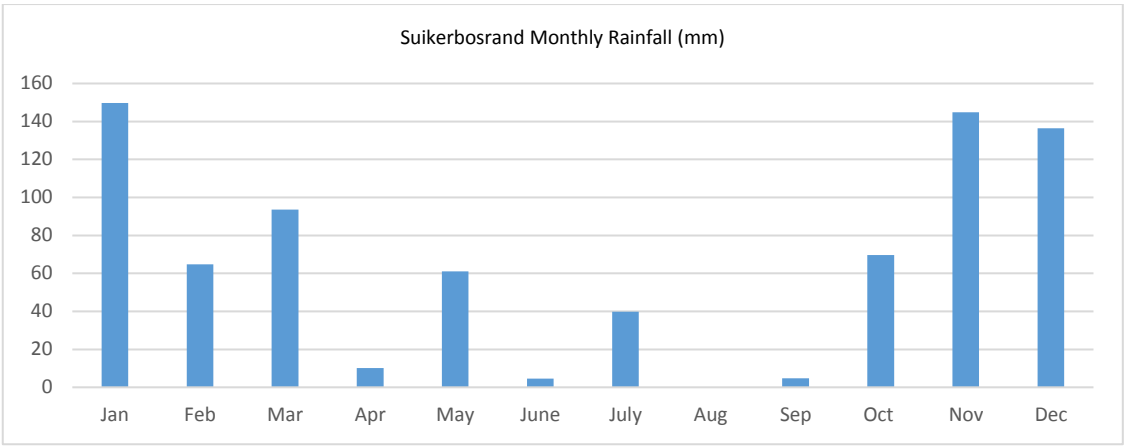
Figure 3.2: Average Daily temperatures recorded (10 year period) at three weather stations

The rainfall mostly occurs from the month of October through to March, with a mean annual precipitation of 668mm (Dent et al., 1989). The mean annual precipitation varies from 900mm in the central higher lying areas to 556mm in the lower lying areas in the northern and southern areas of the province. The monthly rainfall recorded over a 16 year period (2000-2016) at three weather stations within the vicinities of the chosen study locations is indicated in Tables 3.1 to 3.3 and in Figure 3.3; the weather data was provided by the South African Weather Services. The province experiences on average 30 days of frost per year (Schulze, 1997).

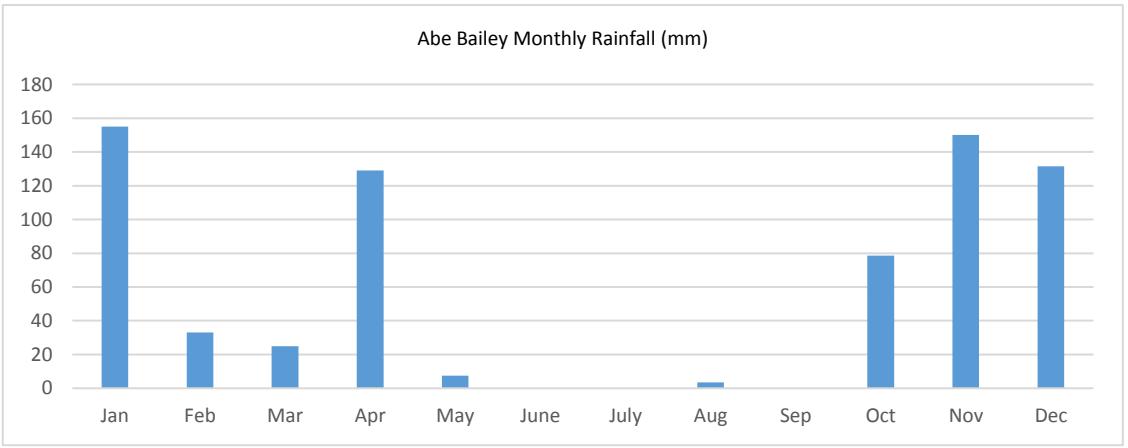
Table 3.1: Monthly rainfall recorded between 2000 and 2016 at Vereeniging weather station within the vicinity of the Suikerbosrand Nature Reserve study location.

| Monthly Daily Rain (mm) - VEREENIGING | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 2000 | 101.6 | 133.6 | 110.6 | 28.6 | 41.2 | 7.4 | 0 | 0 | 32.6 | 103 | 62 | 143.6 |
| 2001 | 27.6 | 112.2 | 33 | 27.8 | 26.4 | 0 | 0 | 5.8 | 27.6 | 116.6 | 93.4 | 66.6 |
| 2002 | 102 | 52.6 | 13.4 | 24 | 36.4 | 23 | 0 | 21.4 | 11.4 | 14.2 | 15.4 | 151.4 |
| 2003 | 45 | 68.8 | 57 | 6 | 0 | 4.2 | 0 | 11.8 | 2.2 | 36.6 | 67.8 | 45 |
| 2004 | 123.4 | 85 | 22.2 | 26.6 | 0 | 10.6 | 5 | 23.8 | 0 | 28.2 | 28.4 | 125.6 |
| 2005 | 173.2 | 41.6 | 120.8 | 73.4 | 5.2 | 0 | 0 | 0.2 | 0.2 | 12.6 | 99.8 | 52.6 |
| 2006 | 154 | 99.2 | 89.8 | 38.7 | 5.2 | 0 | 0 | 22.2 | 3.8 | 32 | 120 | 107.6 |
| 2007 | 25.6 | 34.8 | 17.4 | 38.6 | 0 | 1.6 | 0 | 0 | 61.8 | 32.6 | 33.8 | 32.6 |
| 2008 | 149.2 | 71.2 | 74.2 | 10.4 | 14.2 | 12.2 | 0 | 0 | 0 | 56.4 | 86.2 | 73.6 |
| 2009 | 47.6 | 75.2 | 140.6 | 5.6 | 0.0 | 6 | 15.2 | 25.8 | 6.3 | 91.6 | 101.8 | 168.6 |
| 2010 | 234.4 | 110.2 | 49 | 90.6 | 23 | 0 | 0 | 0 | 0 | 23.4 | 79.4 | 208.6 |
| 2011 | | 7.2 | 66.8 | 65.6 | 18.6 | 25.4 | 0 | 6 | 0.4 | 66 | 28.4 | 147.4 |
| 2012 | 106.4 | 39.2 | 52.2 | 16.8 | 0.8 | 3.8 | 0 | 1.6 | 95.6 | 95.8 | 7.8 | 134 |
| 2013 | 112 | 51.8 | 37.2 | 130 | 3.8 | 0 | 0 | 12.8 | 0 | 44.2 | 47.2 | 55.2 |
| 2014 | 99.6 | 52 | 79.8 | 5.2 | 1.2 | 1.2 | 0 | 13.4 | 10 | 41.2 | 78.2 | 49.2 |
| 2015 | 68.4 | 25.2 | 36.8 | 40.8 | 0 | 0.8 | 3.6 | 0 | 52.8 | 14.6 | 72.8 | 32.8 |
| 2016 | 149.8 | 64.8 | 93.6 | 10.2 | 61 | 4.6 | 39.8 | 0 | 4.8 | 69.6 | 144.8 | 136.4 |

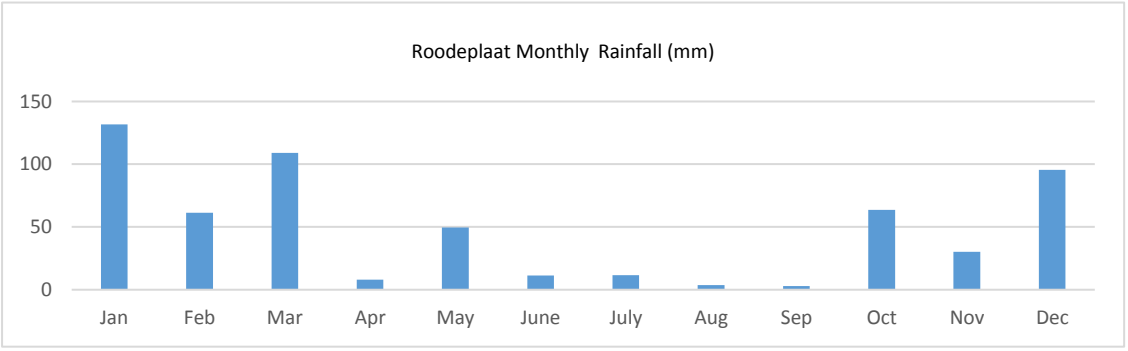
Data Source: South African Weather Service




Monthly Rain (mm) Data for station [0438784 3] - VEREENIGING Measured at 08:00 (year 2016)




Monthly Rain (mm) Data for station [0475528 8] - ZUURBEKOM Measured at 08:00 (year 2013)




Monthly Rain (mm) Data for station [0513385A2] - IRENE WO Measured at 08:00 (year 2016)

Figure 3.3: Monthly rainfall recorded in 2013 and 2016 at three weather stations closest to the chosen study locations.

Table 3.2: Monthly rainfall recorded between 2000 and 2014 at Zuuebekom weather station within the vicinity of the Abe Bailey Nature Reserve study area.

| Monthly Daily Rain (mm) - ZUURBEKOM | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 2000 | 11.6 | 253.5 | 143.5 | 20 | 26 | 5.5 | 0 | 0 | 32 | 105 | 53.5 | 140.2 |
| 2001 | 79.8 | 72.5 | 50.5 | 18 | 29 | 15.5 | 0 | 2 | 50.5 | 177 | 51 | 130 |
| 2002 | 90.8 | 75 | 60 | 18 | 50 | 15.5 | 0 | 17.5 | 6.8 | 123.7 | 21 | 107 |
| 2003 | 81 | 10.0 | | 9 | 0 | 9.5 | 0.0 | 0 | | 0 | 98.7 | 80 |
| 2004 | 155 | 63.5 | 50 | 41.5 | 41.5 | 6.5 | 10.5 | 38 | 0 | 36.5 | 46 | 177 |
| 2005 | 52 | 40 | 0 | 50 | 3.1 | 0 | 0 | 0 | 0 | 50.5 | 11 | 29 |
| 2006 | 61 | 147.2 | 148.5 | 39 | 3.5 | 0 | 0 | 29.5 | 0 | 68.5 | 56 | 17.5 |
| 2007 | 0 | 14.5 | 17 | 27 | 0 | 47 | 0 | 0 | 67.5 | 113 | 23.3 | 131 |
| 2008 | 240 | 49.5 | 131 | 0 | 24.5 | 31.5 | 0 | 0 | 0 | 60.5 | 42.5 | 96 |
| 2009 | 102.5 | 55.5 | 44 | 0 | 36.5 | 13 | 5 | 23.5 | 6.5 | 52 | 80 | 140.5 |
| 2010 | 284 | 159.5 | 83 | 42.4 | 29.5 | 0 | 0 | 0 | 0 | 7 | 72.1 | 237.5 |
| 2011 | 151 | 32.5 | 106 | 97.5 | 21 | 31 | 0 | 1.5 | 0 | 54.5 | 82.5 | 105.5 |
| 2012 | 134.6 | 45.5 | 96 | 26 | 0 | 4.5 | 0 | 0 | 100 | 66.5 | 122.5 | 121.8 |
| 2013 | 155 | 33 | 25 | 129 | 7.5 | 0 | 0 | 3.5 | 0 | 78.5 | 150.1 | 131.5 |
| 2014 | 107.5 | 97 | 142.5 | 18.3 | 1.5 | 0.2 | | | | | | |

Data Source: South African Weather Service

Table 3.3: Monthly rainfall recorded between 2000 and 2016 at Irene weather station within the vicinity of the Roodeplaat Dam Nature Reserve study area.

| Monthly Daily Rain (mm) - IRENE | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 2000 | 138.6 | 235.2 | 146.5 | 38.2 | 24.7 | 0 | 2 | 0 | 20.1 | 176.7 | 0 | 91.9 |
| 2001 | 110.5 | 92.3 | 46.1 | 28.3 | 60.8 | 9.7 | 0 | 2.1 | 19.5 | 56.7 | 150.4 | 131.7 |
| 2002 | 3.6 | 90 | 26.3 | 36.5 | 32 | 18.2 | 0 | 15.3 | 2 | 49.6 | 20.4 | 126.3 |
| 2003 | 122.9 | 56.7 | 55.6 | 3.9 | 0 | 12.7 | 0 | 0.7 | 3.2 | 0 | 32.5 | 52.1 |
| 2004 | 84.8 | 178.1 | 150.7 | 93.2 | 8.6 | 1.4 | 3.4 | 2 | 0 | 12.8 | 107.8 | 97.2 |
| 2005 | 219.4 | 54.2 | 74.4 | 55.1 | 0 | 0 | 0 | 0 | 0 | 9.2 | 121.4 | 49 |
| 2006 | 186.9 | 130.7 | 35.3 | 22.9 | 3.2 | 0 | 0 | 54.4 | 0.6 | 16.3 | 116.2 | 152.5 |
| 2007 | 56.6 | 31.5 | 14.2 | 37.9 | 0 | 27 | 1 | 0 | 35.4 | 140.2 | 39.5 | 86.2 |
| 2008 | 199.3 | 56.9 | 145.9 | 6.4 | 46.5 | 8.3 | 2.6 | 0 | 0 | 56.4 | 137.9 | 43 |
| 2009 | 129.9 | 94.1 | 74.5 | 3.5 | 10.4 | 36.1 | 2.4 | 6.6 | 39.7 | 60.9 | 100.4 | 125.7 |
| 2010 | 162.6 | 138.4 | 77 | 105.7 | 42.5 | 0 | 0 | 0 | 0 | 24.2 | 62.8 | 197.7 |
| 2011 | 196.3 | 117.8 | 106.2 | 64.9 | 5.7 | 25.5 | 0 | 4.4 | 0 | 83.7 | 80.8 | 171.4 |
| 2012 | 72.9 | 62 | 0.0 | 0 | 0 | 0 | 0 | 0 | 81.1 | 84.3 | 104.8 | 118.3 |
| 2013 | 70.2 | 66.6 | 34.4 | 79.4 | 0.5 | 0 | 0 | 4.4 | 1.4 | 83.3 | 86.2 | 183 |
| 2014 | 149.2 | 208.3 | 236.1 | 9.3 | 1.2 | 0 | 0.6 | 5.5 | 0.8 | 47.7 | 124.4 | 193.3 |
| 2015 | 47.2 | 21 | 101.5 | 28.1 | 0 | 2.2 | 5.6 | 0 | 39.5 | 20.9 | 57.2 | 93.4 |
| 2016 | 131.7 | 61.3 | 109 | 8.1 | 49.6 | 11.4 | 11.7 | 3.8 | 2.9 | 63.7 | 30.2 | 95.6 |

Data Source: South African Weather Service

## 3.3 Topography and vegetation

### 3.3.1 Abe Bailey study location

The Abe Bailey Nature Reserve occurs within the Carletonville Dolomite Grassland (Gh 15) vegetation unit (Mucina & Rutherford, 2006), at an elevation of 1477m. The Carletonville Dolomite Grassland is characterised by important taxa such as *Aristida congesta*, *Heteropogon contortus*, *Crabbea angustifolia*, and *Elephantorrhiza elephantina.* The landscape of this grassland is characterised by slightly undulating plains and is dissected by rocky chert ridges (Mucina & Rutherford, 2006). The geology is mostly dolomite and chert of the Malmani Subgroup (Mucina & Rutherford, 2006).

The reserve is surrounded by open grassland in three directions namely, north, west and east. South of the nature reserve is a built up area consisting of a residential area called Khutsong Township. The township extends towards the center of the reserve but falls outside its demarcation. The nature reserve is located within Carletonville, which is known as a gold mining town. The areas surrounding the nature reserve also occur within the Carletonville Dolomite Grassland (Gh 15) vegetation unit (Mucina & Rutherford, 2006).

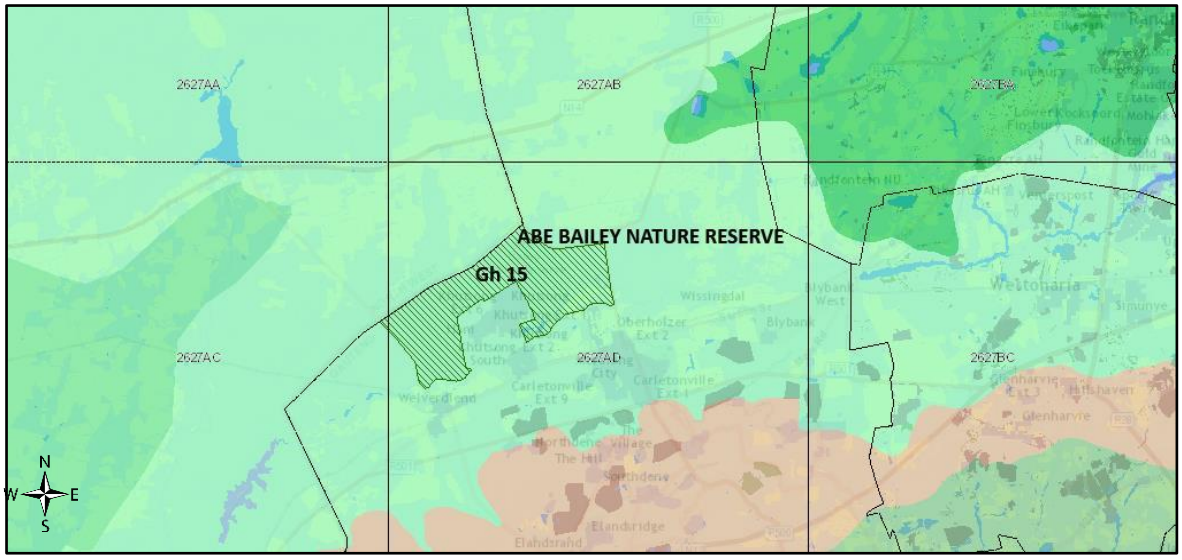



Figure 3.4: Vegetation units and study sites within the Abe Bailey nature Reserve and surrounding area- Carletonville Dolomite Grassland (Gh 15 ). Study sites

### 3.3.2 Roodeplaat study location

The Roodeplaat Dam Municipal Nature Reserve occurs within the Marikana Thornveld (SVcb 6) vegetation unit (Mucina & Rutherford, 2006). The Marikana Thornveld includes important taxa such as *Themeda triandra, Setaria sphacelata, Ziziphus mucronata,* and *Barleria macrostegia* (Mucina & Rutherford, 2006).The landscape is slightly undulating with valleys and hills, and is characterised by an open *Vachellia* (*Acacia*) *karoo* woodland (Mucina & Rutherford, 2006).

The Roodeplaat Dam Nature Reserve is surrounded by the Roodeplaat Dam and build up areas. The build-up areas are not dense and some of the land is still used for smallholder farming purposes. These surrounding areas are also within the Marikana Thornveld (SVcb 6) vegetation unit (Mucina & Rutherford, 2006).

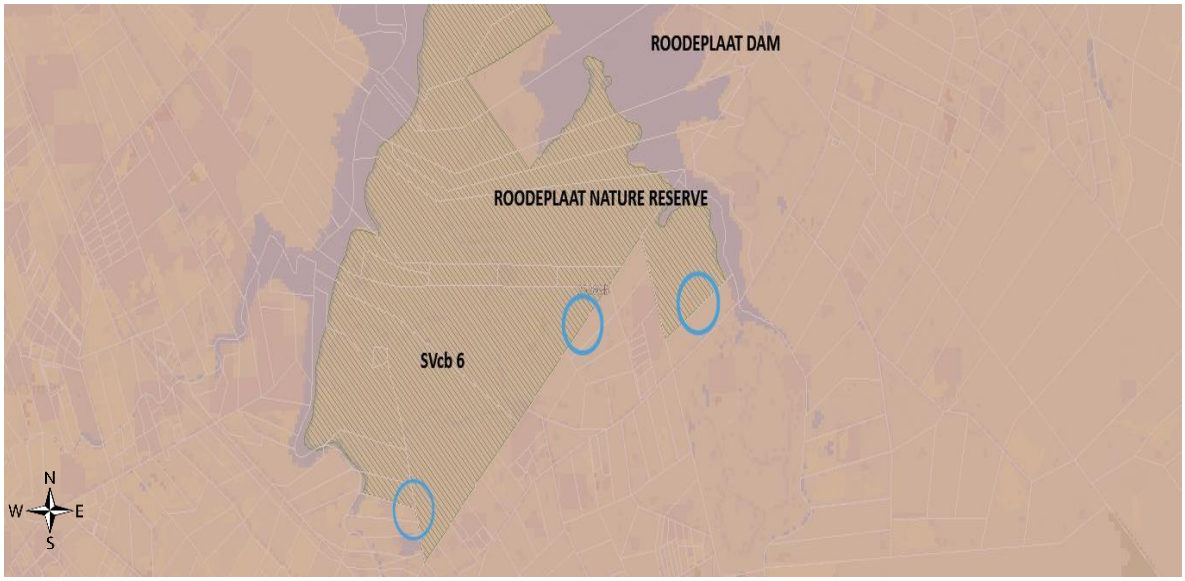



Figure 3.5: Vegetation units and study sites within the Roodeplaat Dam Nature Reserve and surrounding area- Marikana Thornveld (SVcb 6 ). Study sites

### 3.3.3 Suikerbosrand study location

The Suikerbosrand Nature Reserve mainly occurs within the Tsakane Clay Grassland (Gm9), with a smaller occurrence of the Andesite Mountain Bushveld (SVcb11) vegetation unit (Mucina & Rutherford, 2006). The altitude varies between 1545 and 1917 m above sea level. The Tsakane Clay Grassland extends from Soweto to the town of Springs in the Gauteng Province and is distributed in patches southwards to Nigel and Vereeniging. The vegetation unit also occurs in parts of the Mpumalanga Province between Balfour and Standerton and also in the northern side of the Vaal Dam. Tsakane Clay Grassland includes important taxa such as A*ndropogon schirensis, Eragrostis racemosa, Senecio inornatus* and *Anthospermum rigidum* subsp*. pumilum* (Mucina & Rutherford 2006). The landscape is flat to slightly undulating, with low hills also present in some areas of the grassland.

The Andesite Mountain Bushveld vegetation unit is spread in the Gauteng, Free State, North West and Mpumalanga Provinces, and the distribution is in patches throughout the provinces. It occurs on undulating landscapes on hills and valleys. The Andesite Mountain Bushveld includes important taxa such as *Digitaria eriantha* and *Elionurus muticus* (Mucina & Rutherford, 2006).

The Suikerbosrand Nature Reserve is surrounded by open fields, mostly agricultural fields in three directions in the north, west and south. The eastern side of the nature reserve consists of built up residential and business areas (Heidelberg). The N3 highway lies to the east of the nature reserve, while the R59 road lies to the west. The surrounding areas also occur within the Tsakane Clay Grassland (Gm9), the Andesite Mountain Bushveld (SVcb11), and the Carletonville Dolomite Grassland (Gh 15) vegetation units (Mucina & Rutherford, 2006).

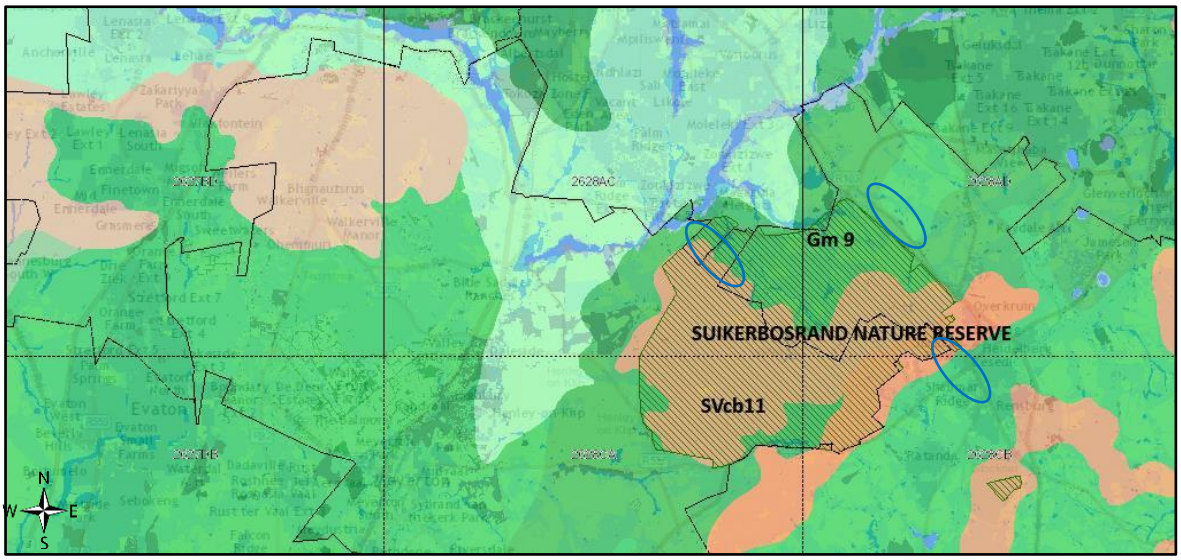



Figure 3.6: Vegetation units and study sites within the Suikerbosrand Nature Reserve and surrounding area- Tsakane Clay Grassland (Gm9 ); Andesite Mountain Bushveld (SVcb11 ); Carletonville Dolomite Grassland (Gh 15 ); Sampling area

# CHAPTER 4: RESEARCH DESIGN AND DATA COLLECTION

## 4.1 Site identification and selection

The first step of the survey entailed the stratification of vegetation prior to sampling. Preliminary habitat types were noted on suitable aerial imagery such as Google Earth and appropriate sites (i.e sites representing natural grasslands) were identified for Abe Bailey Nature Reserve **(ANR),** Roodeplaat Dam Nature Reserve **(RNR),** and Suikerbosrand Nature Reserve **(SNR)**. These sites were later identified on the ground and paired with corresponding areas outside the nature reserves. The research design as shown in Figure 4.1 comprised of three study locations, three (paired) sites at each location, and nested multiple scale sample plots at each site.

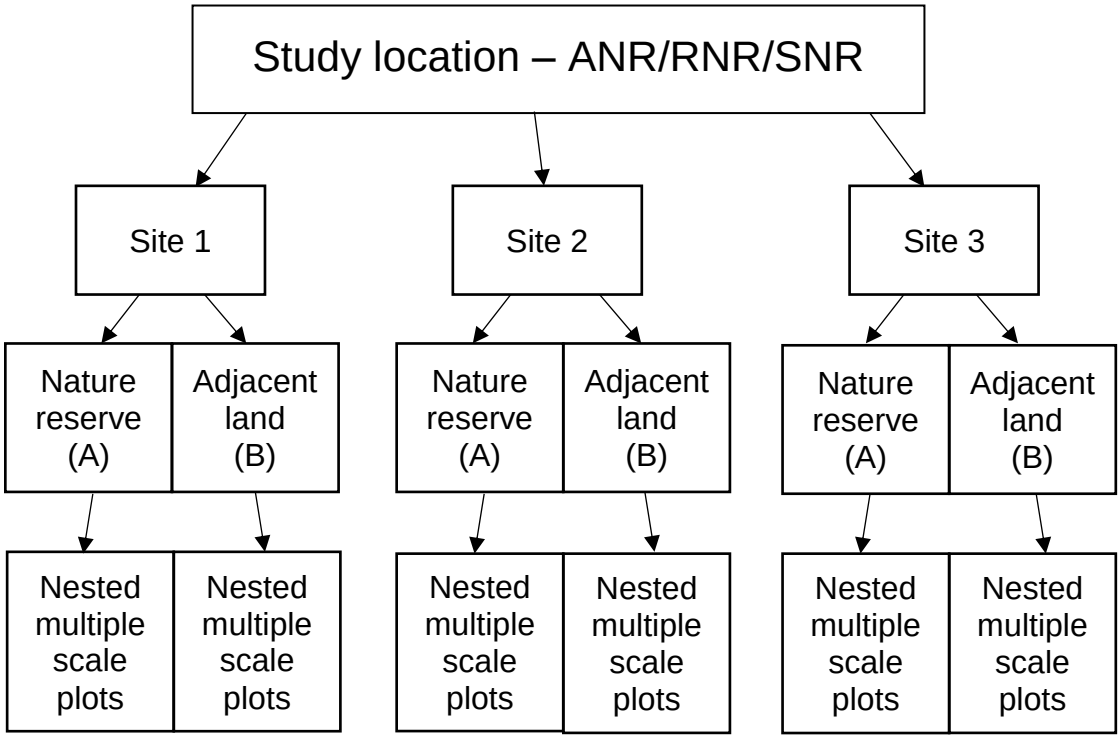



Figure 4.1: A schematic representation of the sampling design showing the study location, paired sites and sample plots. The design is applicable to each of the three study locations.

Sites were selected to represent natural grasslands close to the border fence between the selected nature reserves and adjacent grazing areas. A 100m buffer area was left on either side of the fence to avoid edge effects and to avoid the vegetation treatment areas (eg. vegetation burning and fire breaks for nature reserves). Care was taken in ensuring that the paired sampling sites were in comparable landscapes, avoiding places with major differences in habitat such as aspect, rockiness and slope. Sites selected had similar topography and were adjacent to one another. Two sites at ANR were paired with areas on a livestock farm, the third site was paired with an abandoned area used for communal cattle grazing. All sites at RNR were paired with smallholder areas (privately owned land) with very little or occasional animal presence. At SNR, two sites were paired with livestock farms while the third site was paired with a communal grazing land. The type of animals present in the nature reserves are presented in Table 4.1.

Table 4.1: Grazer types and stocking densities of the three nature reserves, according to Gauteng Department of Agriculture and Rural Development

| **ANR** | | |
|---|---|---|
| **Grazer Type** | **Large animal units (LAU)** | **Recommended LAU** |
| Bulk grazers | 168.3 | 254.29 |
| Selective grazers | 184.5 | 254.29 |
| Mixed feeders/ browsers | 30.075 | 50.86 |
| **RNR** | | |
| Bulk grazers | 51 | 29 |
| Selective grazers | 26 | 29 |
| Mixed feeders/ browsers | 40 | 15 |
| **SNR** | | |
| Bulk grazers | 492 | 492 |
| Selective grazers | 461 | 492 |
| Mixed feeders/ browsers | 211 | 246 |

## 4.2 Habitat analysis

Habitat conditions were recorded for each site at all the three study locations. In particular, the physical appearance of each site was noted which included the vegetation cover, plant defoliation and trampling (visually), burning, presence of bare patches and bare rock, the amount of visible rocks and stones, as well as animal activity. Land use was determined for the adjacent areas as either communal or privately owned land and any activities occurring on the land noted. The activities identified were mostly cattle grazing. In both nature reserves and adjacent land, animals seen within the vicinity of each site were recorded. Animal activity was noted by checking for footprints, footpaths, furrows and animal dung present on each site. Animal grazing was visually estimated based on the amount of plant defoliation and trampling, soil disturbance, amount of dung, and animal footpaths. Three grazing intensities were distinguished: low/no grazing, moderate grazing, and heavy grazing.

## 4.3 Vegetation survey

### 4.3.1 Data collection

At each site, data sampling for species composition and plant diversity was completed with the use of the method developed by Stohlgren et al. (1995) known as the Modified-Whittaker plot. The Modified-Whittaker plot (MWP) is an adaption of the method developed earlier by Whittaker (Shmida, 1984). The Modified-Whittaker plot samples the plant diversity over multiple spatial scales in methodical systematic surveys (nested plots). The nested plots within the MWP extend from $1m^2$; $10m^2$ and $100m^2$ and are all within a $1000m^2$ area. Within each of the $1000m^2$ MWP (50m x 20m), there are ten sample plots of $1m^2$ (2mx0.5m) size, two of $10m^2$ (5m x 2m) size, and a single 100 $m^2$ (20m x 5m) plot (Figure 4.2). The $1m^2$ plots were placed systematically on the edge boundary of the $1000m^2$ and $100m^2$ plots, and were also systematically numbered from 1-10.

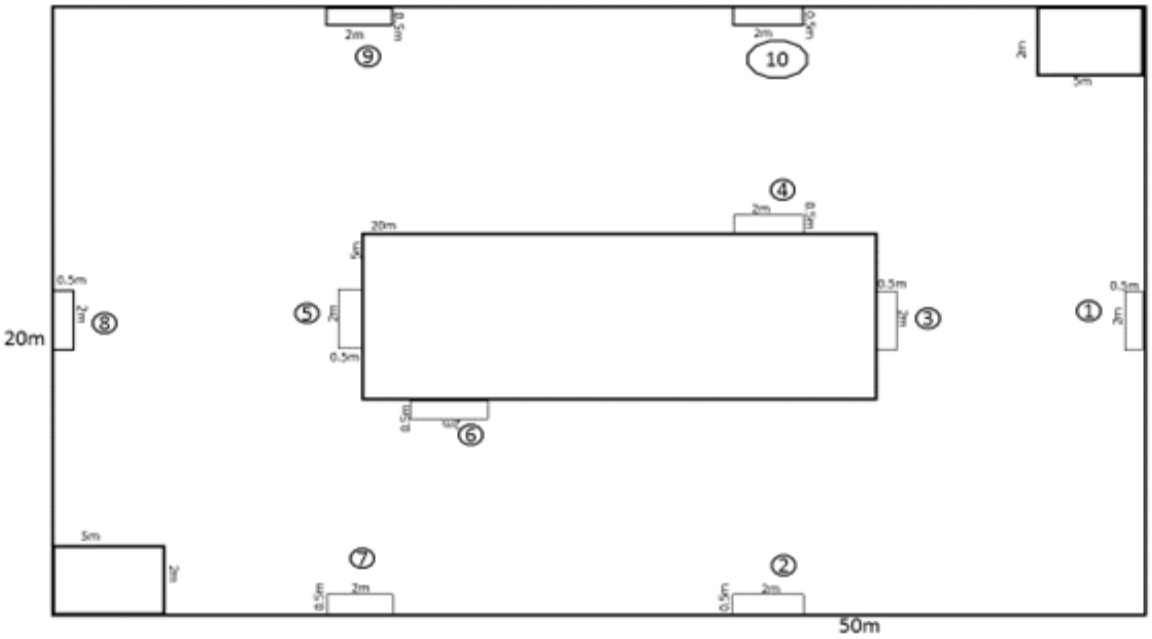



Figure 4.2: Modified Whittaker Plot (adapted from Stohlgren et. al (1995). Numbers in circles indicate identification of small plots.

The MWP was used for sampling in both the nature reserve and the adjacent grazing lands, thus there were three MWP's within the nature reserve and three MWP's at the adjacent grazing lands. The above mentioned process was repeated for all three study locations (ANR, SNR and RNR), making a total of 18 MWP's (Table 4.2).

Table 4.2: Total plots surveyed in different sizes.

| Plots size | Total number of plots surveyed |
|---|---|
| $1m^2$ (0.5m x2m) | 180 plots |
| $10m^2$ (2mx5m) | 36 plots |
| $100m^2$ (5mx20m) | 18 Plots |
| $1000m^2$ (20mx50m) | 18 Plots |

### 4.3.2 Species cover and abundance

All vascular plants in the 1000m$^2$, 100m$^2$, and 10m$^2$ plots were recorded. In the 1m$^2$ plots, more detailed surveys were conducted. All vascular plants present were recorded and the number of individuals for each species within a plot were also recorded. The cover-abundance for the recorded species was visually estimated using the Braun-Blanquet scale (Kent, 2012; Mueller-Dombois & Ellenberg, 1974; Van der Maarel, 2005) (Table 4.3). Plant species were identified on the spot with the use of field guides and plant species that could not be identified were photographed and assigned a species number, to ensure that they could be identified if encountered again during the sampling process. The photographed specimens were later identified with the use of field guides (Van Wyk & Malan, 1998; Van Oudtshoorn, 2014).

Table 4.3: Braun Blanquet cover-abundance scale

| | |
|---|---|
| r | Very small cover, rare occurrence |
| + | Few individuals; cover less than 1% |
| 1 | Abundant; cover between 1-5% |
| 2a | Cover between 6-12% |
| 2b | Cover between 13-25% |
| 3 | Cover between 26-50% |
| 4 | Cover between 51-75% |
| 5 | Cover more than 75% |

## 4.4 Soil sampling and analysis

Soils were sampled at all the 1m$^2$ plots within the 1000m$^2$ MWP's (50m x 20m), using a bucket auger of 75mm diameter. One soil sample was taken in the centre of the 1m$^2$ plot, but where certain 1m$^2$ plots were too rocky at the centre points, the

soil samples were collected at the edges of the plots. The soil samples were taken to a depth of 30cm. A total of 180 soil samples were collected but due to financial constraints pertaining to the analyses, the number of samples was reduced to 54 composite samples i.e. from ten individual samples to three composite samples per 1000$m^2$ plot. The three composite samples were derived as follows: samples from 1$m^2$ plots 1, 2 and 10 were mixed into one sample; samples from plots 3, 4, 5, and 6 were mixed together; and the third composite sample was from plots 7, 8, and 9 (refer to Figure 4.2). The soil samples were sent out for analyses at a laboratory of the Agricultural Research Council – Soil, Climate, and Water. The following chemical properties were analysed: phosphorus (P) (Bray No 1); potassium (K), calcium (Ca), magnesium (Mg), and sodium (Na) (Ammonium Acetate), total nitrogen (N), organic and total carbon (C), and pH (water).

## 4.5 Climate data

Temperature and rainfall data were sourced from the South African Weather Service, for Vereeniging, Zuurbekom, and Irene weather stations. These are the stations closest to the three study locations.

## 4.6 Data analysis

Analytical and statistical methods were utilised to interpret the differences and or similarities between the species compositions and diversity in the nature reserves and the adjacent grazing areas. Detrended Correspondence Analysis (DCA) (Hill, 1979) was performed in order to determine trends in species composition at the three study locations, using Community Analysis Package 4.

### 4.6.1 Species dominance

The species dominance was determined as Importance Value Index (IVI), which was calculated per 1000$m^2$ plot using species density and percentage cover averaged for the 1$m^2$, and the frequency of the species. The following formulas

were used to calculate relative frequency (RF), relative cover (RC) and relative density (RD) and finally the IVI.

$$RC = \frac{\text{Total number of species}}{\text{Total number of individuals of all species recorded}} \times 100$$

$$RD = \frac{\text{Total number of individuals of a particular species in all quadrats}}{\text{Total number of individual of all species in all quadrats}} \times 100$$

$$RF = \frac{\text{Number of quadrats in which a species occurred}}{\text{Total number of quadrats studied}} \times 100$$

IVI = Relative frequency + Relative dominance + Relative density

### 4.6.2 Species overlap

Species overlap and similarity in species composition between the paired sites was calculated for $100m^2$ plots, using the Jaccard similarity coefficient ($C_J$) and Sorenson similarity index ($C_S$), which are based on presence/absence data. The Sorenson coefficient puts emphasis on species that are common between samples and doubles their weight (Kent, 2012). The formulae used for calculation of $C_J$ and $C_S$ were as follows:

$$C_J = \frac{a}{a+b+c}$$

$$C_S = \frac{2a}{2a+b+c}$$

where:

a = number of species common to (shared by) sample plots,

b = number of species unique to the first sample plot, and

c = number of species unique to the second sample plot.

The Bray-Curtis (dis)similarity index (BC) (Magurran, 2004; Kent, 2012) was calculated for the $1m^2$ plots, using abundance data i.e. the number of individuals of each species in a sample plot. BC was calculated as follows:

$$BC_{ij} = 1 - \frac{2C_{ij}}{S_i + S_j}$$

where:

i = total number of individuals in plot i,

j = total number of individuals in plot j, and

Cij = the sum of the lower of the two abundance for species found in plots i and j.

One-way ANOVA was conducted to determine significant differences in the dis/similarity coefficients i.e. compare the coefficients between the three study locations.

### 4.6.3 Diversity indices

There are several ways of defining and measuring species diversity; these include species abundance and species richness (Magurran, 2004). Species richness is the simplest measure, which is regarded as the number of species in an area or community. Diversity indices provide important information about rarity and commonness of species in a community. Species diversity measures consist of species richness indices and indices that are based on the proportional abundance of species (Ludwig & Reynolds, 1988; Krebs, 1989; Magurran, 2004). The species richness indices measure the number of species in a sampling area, while species abundance indices such as Shannon Weiner index describe the proportional abundance of species (Ludwig & Reynolds, 1988; Krebs, 1989; Magurran, 2004) i.e. they indicate the proportions of the individuals of each species in a sample plot (Fowler et al., 1998).

The Shannon- Wiener diversity index (*H'*) and species evenness (*J'*) were calculated for each $1m^2$ quadrat in all the three study locations.

The equation used to calculate the Shannon-Weiner was:

$$H' = \sum_{i=1}^{S} p_i \ln p_i$$

where
*S* is the number of species (richness) and
*pi* is the proportion *S* made up of the *i*-th species.

The Shannon -Wiener index reaches maximum when all species in a sample area are represented by the equal number of individuals, which then means that there is an even distribution of abundances (Ludwig & Reynolds, 1988). Theoretically *H'* values can reach very high values with the increases in the number of species in a community, however this has not been the case from practice as the values never seem to exceed 4.0 or 5.0 (Krebs, 1989; Magurran, 2004).

The evenness index calculated is derived from the Shannon index, which as a measure includes a degree of evenness (Magurran, 2004). Pielou's evenness (J') was calculated as:

$$J' = H'/H'_{max} = H'/\ln S$$

Student's t-tests were conducted to compare the diversity indices between sites A and B at the three study locations.

### 4.6.4 Soil

Student's t-test was conducted to determine whether soil properties were significantly different between nature reserves and adjacent areas.

# CHAPTER 5: RESULTS AND DISCUSSION

## 5.1 Habitat characteristics

Habitat conditions and grazing intensity were determined at each study site.

### 5.1.1 Abe Bailey study location

Site ANR1A (Figure 5.1) had animal dung, animal tracks and animal burrows which indicated the presence of grazing animals. The grazing level was visually determined as moderate grazing. The site also had ant mounds, bare ground rock and a few bare ground patches. Site ANR1B had a lot of bare ground patches and animal tracks with animal dung. There was a lot of animal (cattle) movement with animal and or human footpaths and the grazing level was determined to be heavy grazing.

Site ANR2A had ant mounts present and bare ground patches, and grazing was visually determined to be moderate grazing. There was presence of animal tracks and animal dung, and black wildebeests and zebras were spotted in the vicinity of the site. Site ANR2B had ant mounds present and bare ground patches and grazing was visually determined to be heavy grazing.

Site ANR3A showed to have been recently burnt and the vegetation was in patches with a lot of bare ground, visually the vegetation was dominated by *Eragrostris lehmanniana*. Black wildebeests were spotted in the vicinity of the site and grazing was visually determined to heavy grazing. Site ANR3B had visible bare rock with a few bare ground patches. The site also had animal tracks and trampling with animal droppings and ant mounds. Grazing was visually determined to be moderate grazing.

Abe Bailey site ANR1A

Abe Bailey Site ANR1B

Abe Bailey Site ANR2A

Abe Bailey Site ANR2B

Abe Bailey Site ANR3A

Abe Bailey Site ANR3B

Figure 5.1: Photographs of study sites at Abe Bailey Nature Reserve (ANR) and adjacent areas

### 5.1.2 Roodeplaat study location

Site RNR1A (Figure 5.2) had animal droppings, tracks and trampling. The site also had footpaths with ant mounts and bare ground patches. The animals spotted in the vicinity of the site included zebras and blue wildebeest. This site was in upslope of the Roodeplaat Dam. The grazing was visually determined to be moderate grazing. Site RNR1B had very dense vegetation with little to no evidence of animal activity, thus no large grazing animal tracks or droppings were spotted on site. The site was visually dominated by *Eragrostris lehmanniana* and the grazing was visually determined to be little or no grazing.

At Site RNR2A there was presence of zebras and blue wildebeest in the vicinity of the site, animal droppings were observed on site and these showed to be of small and large animals. The site had loose rocks and stones and showed signs of burning. The grazing was visually determined to be moderate grazing. Site RNR2B had dense vegetation with the presence of small to medium rocks with very little to no evidence of animal activity. The grazing level was visually determined to be little to no grazing. Site RNR3A was in close proximity to an electrical powerline with the small and large animal droppings observed on site. There were ant mounds and animal burrows and tracks. The grazing was visually determined to be moderate grazing.

Site RNR3B had presence of animal droppings and animal burrows; the site was in close proximity of an electrical powerline with ant mounds observed. The grazing level was visually determined to be little to no grazing.

Roodeplaat Site RNR1A

Roodeplaat Site RNR1B

Roodeplaat Site RNR2A

Roodeplaat Site RNR2B

Roodeplaat Site RNR3A

Roodeplaat Site RNR3B

Figure 5.2: Photographs of study sites at Roodeplaat Dam Nature Reserve (RNR) and adjacent areas

### 5.1.3 Suikerbosrand study location

Site SNR1A (Figure 5.3) showed a homogenous vegetation which was visually dominated by *Heteropogon contortus*. The site was upslope a wetland and electrical powerlines, there were animal droppings observed and bare rock. The site was previously a farm before it was a nature reserve. The grazing was visually determined to be moderate grazing.

At Site SNR1B, the vegetation was in patches and was visually dominated by *Eragrostris lehmanniana*. The site was upslope an electrical powerline and a wetland/stream. There was animal (cattle) movement in the vicinity of the site and grazing was visually determined to be moderate grazing. Site SNR2A had dense vegetation and was at the foot slope of a hill in a westward direction. There were animal droppings observed and there was presence of electrical powerlines downslope the site. Grazing was visually determined to be moderate grazing. Site SNR2B was downslope from electrical powerlines and bare ground patches with cattle dung were present. There was a lot of animal (cattle) movement in close vicinity to the site. Grazing was visually determined to be moderate grazing.

Site SNR3A had a lot of animal activity observed, there were animal burrows, animal droppings, animal tracks and animal trampling. The site was uphill an animal watering hole. There were loose rocks and stones observed on site. The site visually had a thick herbaceous layer compared to the graminoid layer, with the dominant species visually observed to be *Berkheya setifera*. Grazing was visually determined to be heavy grazing. Site SNR3B was visually dominated by *Hyparrhenia hirta* and the site was situated on a downward slope of the hill, the site was rocky with loose stones. The site showed signs of being previously burned and the grazing was visually determined to be moderate grazing. Baboon activity was observed and heard on site.

Suikerbosrand Site SNR1A

Suikerbosrand Site SNR1B

Suikerbosrand Site SNR2A

Suikerbosrand Site SNR2B

Suikerbosrand Site SNR3A

Suikerbosrand Site SNR3B

Figure 5.3: Photographs of study sites at Suikerbosrand Nature Reserve (SNR) and adjacent areas

## 5.2 Analysis of vegetation structure

The different land uses (protected nature reserves and non-protected land) were analysed for species composition, plant diversity and soil properties. The total number of species recorded in the three study locations was 235. The families that were strongly represented were the Poaceae family with 53 species recorded and Asteraceae with 15 species.

### 5.2.1 Species composition

The vegetation structure was similar throughout the three study locations and consisted of a grass layer, herbaceous layer and isolated patches of shrubs. This vegetation composition is indicated in Figure 5.4 for all 18 Modified Whittaker plots (i.e. 1000$m^2$ plots). At Abe Bailey study location, all study sites had comparable proportions of grasses, herbs and shrubs both within and outside the nature reserve. ANR3 however had a much higher number of grass species, both within and outside the nature reserve. At Roodeplaat Dam study location, RNR1 and RNR2 had comparable proportions of the three plant growth forms inside and outside the nature reserve but RNR3 had a much lower number of herbaceous species in the adjacent area. At Suikerbosrand study location the A and B sites had comparable proportions of the three plant growth forms, but the vegetation consists of far more herbs and forbs than grasses at all the paired sites.

An ordination analysis in the form of Detrended Correspondence Analysis or DCA (Hill, 1979) was conducted to determine patterns of species composition for the three study locations. The species composition of Roodeplaat Dam is different from Abe Bailey and Suikerbosrand as can be seen in the distribution of the RNR study sites on the ordination plot (Figure 5.5). The sites of ANR and SNR are grouped together indicating some similarity in species composition.

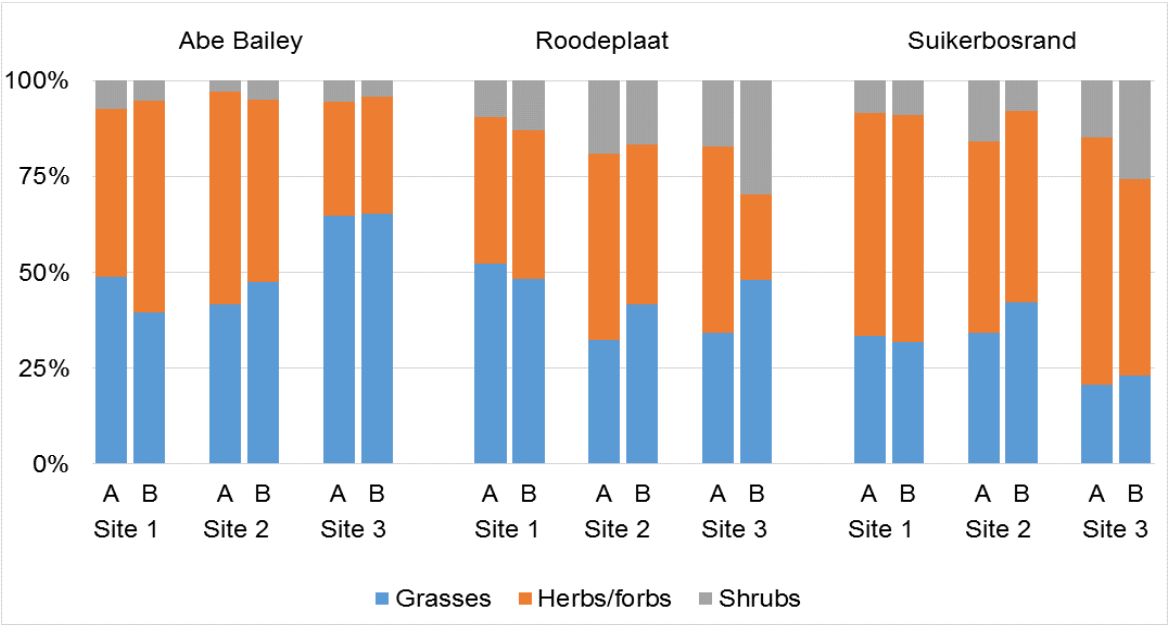



Figure 5.4: Species life forms in 1000 $m^2$ plots at (A) nature reserves and (B) adjacent grazing lands

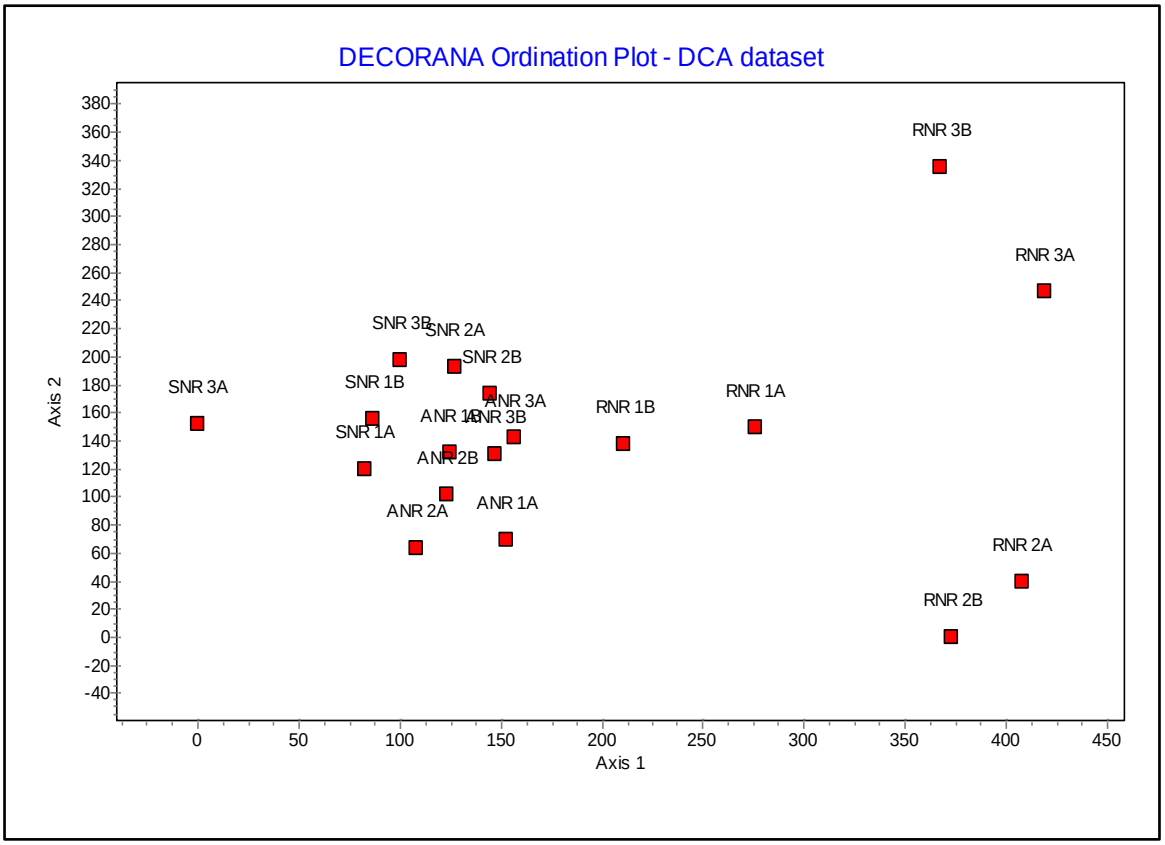



Figure 5.5: A detrended correspondence analysis ordination plot showing the distribution of the study sites (red squares) along Axis 1 and Axis 2.

### 5.2.2 Species dominance

The most dominant species at all three study locations were grasses. At Abe Bailey, ANR1A, ANR2A, and ANR3A sites within the nature reserve were dominated by species such as *Themeda triandra, Diheteropogon amplectens* and *Eragrostis lehmanniana* (Table 5.1)*,* respectively, whilst ANR1B, ANR2B, and ANR3B plots at the adjacent grazing areas were dominated by species such as *Melinis repens, Setaria sphacelata* and *Triraphis andropogonoides. Tristachya leucothrix* and *Eragrostis lehmanniana* dominated the sites at the nature reserve side at RNR, while the adjacent areas were dominated by species such by *Hyparrhenia* sp*, Tristachya leucothrix* and *Heteropogon contortus.* At the SNR *Heteropogon contortus*, *Hyparrhenia tamba* and *Eragrostis lehmanniana* dominated the plots in the nature reserve, with *Eragrostris curvula*, *Eragrostris lehmanniana* and *Aristida congesta* being the most dominant at the adjacent grazing area.

Table 5.1: Overall results with relative frequency, relative cover, relative density and Importance Value index of the five most dominant species for each site (A- represents sites in the Nature reserve and B –represents the adjacent private land).

| # | Dominant species | Relative Cover (%) | Relative Density | Relative Frequency | Importance Value Index (IVI) |
|---|---|---|---|---|---|
| **Abe Bailey (ANR)** | | | | | |
| **ANR 1A** | *Cymbopogon caesius* | 21.68 | 7.45 | 12.12 | 41.25 |
| | *Eragrostis lehmanniana* | 13.55 | 7.45 | 12.12 | 33.12 |
| | *Setaria sphacelata* | 25.75 | 12.2 | 18.18 | 56.12 |
| | *Themeda triandra* | 44.72 | 9.21 | 15.15 | 69.08 |
| | *Triraphis andropogonoides* | 1.36 | 21.68 | 3.03 | 26.07 |
| | | | | | |
| **ANR 1B** | *Cymbopogon caesius* | 18.64 | 7.14 | 22.50 | 48.28 |
| | *Cynodon dactylon* | 13.18 | 24.31 | 10 | 47.5 |
| | *Eragrostis lehmanniana* | 22.98 | 11.91 | 17.5 | 52.38 |
| | *Melinis repens* | 28.06 | 21.03 | 22.50 | 71.59 |
| | *Tragus racemosa* | 4.71 | 16.50 | 5 | 26.21 |
| | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| **ANR 2A** | *Diheteropogon amplectens* | 47.33 | 19.17 | 27.78 | 94.28 |
| | *Eragrostris racemosa* | 20.63 | 19.26 | 16.67 | 56.55 |
| | *Eustachys paspaloides* | 4.85 | 18.44 | 5.56 | 28.85 |
| | *Heteropogon contortus* | 6.07 | 5.74 | 8.33 | 20.14 |
| | *Setaria sphacelata* | 12.14 | 11.59 | 19.44 | 43.17 |
| | | | | | |
| **ANR 2B** | *Cymbopogon caesius* | 14.62 | 6.62 | 13.51 | 34.75 |
| | *Diheteropogon amplectens* | 5.64 | 8.1 | 8.11 | 21.85 |
| | *Setaria sphacelata* | 31.79 | 10.09 | 18.92 | 60.81 |
| | *Themeda triandra* | 24.36 | 18.22 | 10.81 | 53.39 |
| | *Triraphis andropogonoides* | 5.13 | 12.14 | 5.41 | 22.68 |
| | | | | | |
| **ANR 3A** | *Aristida canescens* | 3.04 | 3.19 | 14.58 | 20.82 |
| | *Cynodon dactylon* | 17.15 | 16.1 | 14.58 | 47.83 |
| | *Eragrostris curvula* | 14.72 | 8.09 | 10.42 | 33.22 |
| | *Eragrostis lehmanniana* | 44.77 | 13.42 | 20.83 | 79.02 |
| | *Eragrostris pseudosclerantha* | 3.65 | 14.92 | 2.08 | 20.36 |
| | | | | | |
| **ANR 3B** | *Aristida congesta* | 8.56 | 5.92 | 10.81 | 25.29 |
| | *Eragrostis superba* | 5.14 | 8.88 | 5.41 | 19.2 |
| | *Heteropogon contortus* | 6.85 | 15.79 | 2.7 | 25.34 |
| | *Setaria sphacelata* | 17.81 | 9.87 | 16.22 | 43.89 |
| | *Triraphis andropogonoides* | 41.44 | 17.76 | 18.92 | 78.12 |
| **Roodeplaat (RNR)** | | | | | |
| **RNR 1A** | *Aristida canescens* | 11.18 | 10.34 | 12.50 | 34.02 |
| | *Eragrostis lehmanniana* | 41.67 | 28.88 | 25 | 95.55 |
| | *Eragrostis gummiflua* | 19.31 | 24.14 | 21.88 | 65.32 |
| | *Loudetia simplex* | 4.04 | 10.34 | 3.13 | 17.53 |
| | *Setaria sphacelata* | 16.26 | 15.95 | 25 | 57.21 |
| | | | | | |
| **RNR 1B** | *Aristida canescens* | 7.97 | 6.06 | 14.63 | 28.66 |
| | *Eragrostris racemosa* | 10.17 | 36.33 | 2.44 | 48.94 |

| | | | | | |
|---|---|---|---|---|---|
| | *Eragrostris gummiflua* | 13.90 | 10.52 | 9.76 | 34.17 |
| | *Heteropogon contortus* | 28.81 | 10.28 | 19.51 | 58.60 |
| | *Setaria sphacelata* | 14.41 | 8.61 | 14.63 | 37.65 |
| | | | | | |
| **RNR 2A** | *Melinis repens* | 9.27 | 6.71 | 10.34 | 26.32 |
| | *Setaria incrassata* | 13.73 | 11.19 | 3.45 | 28.36 |
| | *Digitaria sanguinalis* | 5.72 | 7.16 | 17.24 | 30.12 |
| | *Tristachya leucothrix* | 35.93 | 19.76 | 20.69 | 76.38 |
| | *Eragrostis lehmanniana* | 12.81 | 11.19 | 10.34 | 34.35 |
| | | | | | |
| **RNR 2B** | *Pogonarthia squarrosa* | 2.98 | 8.05 | 5.71 | 16.74 |
| | *Heteropogon contortus* | 12.30 | 9.84 | 17.14 | 39.29 |
| | *Tristachya leucothrix* | 48.61 | 18.79 | 22.86 | 90.26 |
| | *Eragrostis racemosa* | 3.17 | 4.70 | 11.43 | 19.3 |
| | *Panicum coloratum* | 19.84 | 22.82 | 5.71 | 48.37 |
| | | | | | |
| **RNR 3A** | *Eragrostis lehmanniana* | 48.34 | 11.15 | 21.05 | 80.55 |
| | *Melinis repens* | 9.39 | 16.73 | 10.53 | 36.65 |
| | *Pogonarthia squarrosa* | 6.08 | 14.87 | 7.89 | 28.84 |
| | *Heteropogon contortus* | 11.60 | 8.92 | 13.16 | 33.68 |
| | *Setaria pumila* | 7.18 | 7.43 | 15.79 | 30.14 |
| | | | | | |
| **RNR 3B** | *Pogonarthia squarrosa* | 35.47 | 11.19 | 23.68 | 70.35 |
| | *Hyparrhenia* sp | 34.87 | 15.75 | 23.68 | 74.31 |
| | *Eragrostis lehmanniana* | 14.63 | 18.65 | 15.79 | 49.07 |
| | *Heteropogon contortus* | 8.42 | 15.85 | 10.53 | 34.80 |
| | *Setaria sphacelata* | 3.01 | 9.95 | 7.89 | 20.85 |
| **Suikerbosrand (SNR)** | | | | | |
| **SNR 1A** | *Heteropogon contortus* | 79.91 | 12.28 | 34.48 | 126.67 |
| | *Setaria sphacelata* | 6.16 | 18.83 | 17.24 | 42.23 |
| | *Themeda triandra* | 2.49 | 6.14 | 13.79 | 22.42 |
| | *Brachiaria serrata* | 3.67 | 17.74 | 10.34 | 31.75 |

| | | | | | |
|---|---|---|---|---|---|
| | *Diheteropogon amplectens* | 5.43 | 20.46 | 10.34 | 36.23 |
| | | | | | |
| **SNR 1B** | *Themeda triandra* | 19.55 | 6.56 | 11.76 | 37.87 |
| | *Hyparrhenia hirta* | 7.42 | 5.00 | 20.59 | 33.00 |
| | *Eragrostris lehmanniana* | 23.60 | 20.12 | 14.71 | 58.42 |
| | *Heteropogon contortus* | 22.47 | 18.80 | 14.71 | 55.98 |
| | *Aristida congesta* | 20.45 | 22.74 | 14.71 | 57.89 |
| | | | | | |
| **SNR 2A** | *Eragrostris lehmanniana* | 40.75 | 26.81 | 13.04 | 80.60 |
| | *Themeda triandra* | 15.11 | 19.15 | 6.52 | 40.78 |
| | *Aristida canescens* | 13.41 | 13.46 | 15.22 | 42.09 |
| | *Brachiaria serrata* | 9.17 | 11.95 | 10.87 | 31.99 |
| | *Setaria sphacelata* | 9.68 | 8.90 | 17.39 | 35.97 |
| | | | | | |
| **SNR 2B** | *Eragrostris lehmanniana* | 18.44 | 16.55 | 12.73 | 47.71 |
| | *Hyparrhenia hirta* | 17.50 | 5.35 | 10.91 | 33.76 |
| | *Cynodon dactylon* | 13.22 | 20.05 | 7.27 | 40.55 |
| | *Themeda triandra* | 16.95 | 8.47 | 14.55 | 39.96 |
| | *Setaria sphacelata* | 3.91 | 6.54 | 10.91 | 21.36 |
| | | | | | |
| **SNR 3A** | *Hyparrhenia tamba* | 64.52 | 12.82 | 28.57 | 105.91 |
| | *Setaria sphacelata* | 12.90 | 20.51 | 28.57 | 61.99 |
| | *Brachiaria serrata* | 8.06 | 41.03 | 7.14 | 56.23 |
| | *Eragrostris lehmanniana* | 8.06 | 15.38 | 14.29 | 37.73 |
| | *Hyparrhenia hirta* | 3.23 | 5.13 | 14.29 | 22.64 |
| | | | | | |
| **SNR 3B** | *Brachiaria serrata* | 25.25 | 7.75 | 26.92 | 59.93 |
| | *Eragrostris racemosa* | 2.21 | 7.75 | 7.69 | 17.65 |
| | *Eragrostris curvula* | 37.20 | 32.88 | 19.23 | 89.31 |
| | *Setaria sphacelata* | 6.31 | 20.16 | 7.69 | 34.16 |
| | *Hyparrhenia hirta* | 27.46 | 15.95 | 26.92 | 70.33 |

### 5.2.3 Species overlap

Three similarity coefficients i.e. Jaccard, Sorenson, and Bray-Curtis coefficients were used to assess and compare the composition of species within and outside the nature reserves. The Jaccard coefficient was used because it is regarded as one of the simplest and suitable methods for assessing how similar the species composition is between sample plots (Stohlgren, 2007; Kent, 2012). Sorenson coefficient also measures species similarity between sample plots but puts emphasis on common species and doubles their weight. High values of similarity coefficients indicate a high number of common species between sample plots.

The Bray-Curtis coefficient, on the other hand, can be calculated as both a similarity and a dissimilarity coefficient, the latter of which determines how sample plots differ in species composition. The coefficient has been widely used because it is easy to calculate and interpret (Waite, 2000). In this study, the Bray-Curtis coefficient was calculated as a dissimilarity measure, according to Magurran (2004) and Kent (2012). The high values of the Bray-Curtis coefficient indicate a high degree of dissimilarity in species composition.

According to the results of the species composition assessments, there is low species overlap between the paired sites (Table 5.2). The sites at ANR have the highest similarity in species composition than RNR and SNR sites, as can be seen in the relatively higher values of Bray-Curtis, Jaccard, and Sorenson coefficients. According to Stohlgren (2007), the assessment of species composition overlap can be influenced by many factors, which include plot size. The overlap assessment for the three study locations was done at two scales: in small $1m^2$ plots using the Bray-Curtis coefficient, and in larger plots ($1000m^2$) using Jaccard and Sorenson coefficients.

As can be seen in Table 5.2, the Jaccard and Sorenson values indicate higher species overlap in the larger plots at all three study locations, while the Bray-Curtis values reveal lower overlap in the smaller plots. However, according to Gotelli and Ellison (2004), the similarity coefficients for small plots can be relatively high, mainly

because the small plots may have a few common and dominant species. In this way when plot size is increased, the larger plots can often capture rare species which may not be encountered in the smaller ($1m^2$) plots (Stohlgren, 2007). The inclusion of rare species thus decreases species overlap in the larger plots (Gotelli & Ellison, 2004; Stohlgren, 2007). The discrepancy in the Bray-Curtis values for the three study locations could be due to the sensitivity of the coefficient to the abundant species (outlying values); such sensitivity can distort the dissimilarity/slash distance between plots (Digby & Kempton, 1987; Waite, 2000).

Table 5.2: Similarity and dissimilarity coefficients for the nature reserves and the adjacent grazing lands

| | **Abe Bailey (ANR)** | **Roodeplaat (RNR)** | **Suikerbosrand (SNR)** |
|---|---|---|---|
| Jaccard's coefficients | | | |
| | 0.30 | 0.30 | 0.27 |
| | 0.38 | 0.24 | 0.36 |
| | 0.59 | 0.19 | 0.35 |
| Average | 0.42 | 0.24 | 0.33 |
| Standard Deviation | 0.15 | 0.05 | 0.05 |
| Sorensen coefficients | | | |
| | 0.46 | 0.46 | 0.43 |
| | 0.55 | 0.38 | 0.53 |
| | 0.74 | 0.32 | 0.52 |
| Average | 0.58 | 0.39 | 0.49 |
| Standard Deviation | 0.15 | 0.07 | 0.06 |
| Bray-Curtis coefficients | | | |
| | 0.74 | 0.67 | 0.81 |
| | 0.69 | 0.62 | 0.51 |
| | 0.88 | 0.67 | 0.65 |
| Average | 0.77 | 0.65 | 0.66 |
| Standard Deviation | 0.10 | 0.03 | 0.15 |

## 5.3 Plant diversity

### 5.3.1 Species richness

Species richness was analysed at multiple spatial scales i.e. at $1m^2$, $10m^2$, $100m^2$, and $1000m^2$ scales.

***Species richness at $1m^2$ scale***

The average number of species recorded in the $1m^2$ plots (*S*) is presented in Figure 5.6 and Table 5.4. At Abe Bailey study location, ANR1 had a slightly higher number of species recorded in the adjacent area than in the nature reserve; the number of species was similar at ANR2, but at ANR3 there was higher average number of species recorded in $1m^2$ plots in the adjacent grazing area than in the nature reserve. The Student's t-test revealed that there were no significant differences in species richness between the $1m^2$ plots in the nature reserve and those on the adjacent areas at all the three sites of the Abe Bailey study location.

At Roodeplaat Dam study location, there were more species recorded in the nature reserve at RNR2 and RNR3 compared to the adjacent area. RNR1 had fewer species within the nature reserve than in the adjacent land. Only RNR1 had significantly different number of species recorded, while those at RNR2 and RNR3 were not significantly different.

At Suikerbosrand study location, SNR1 had fewer species recorded in the nature reserve, SNR2 had similar number of species recorded in the nature reserve and the adjacent farm, whilst there were more species recorded in the nature reserve than in the adjacent grazing area at SNR3. However, these numbers of recorded species were not significantly different at all three sites of the Suikerbosrand study location.

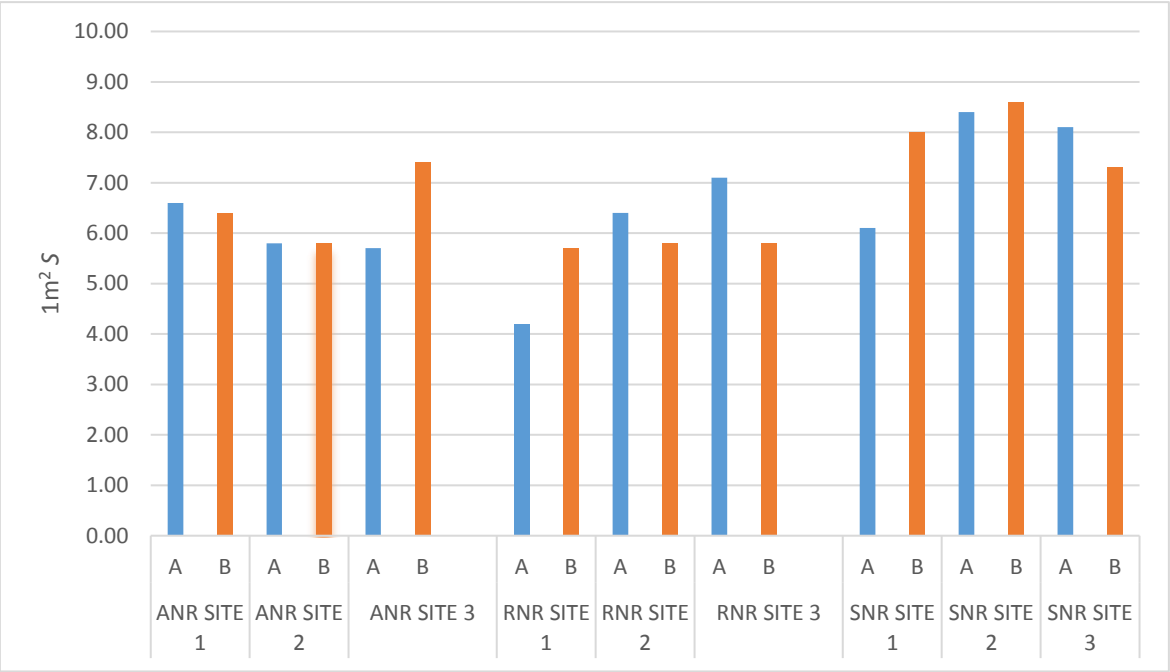



Figure 5.6: Species richness in 1 $m^2$ plots at (A) nature reserves and (B) adjacent grazing lands

### *Species richness at 1000$m^2$ scale*

In the 1000$m^2$ plots, species richness (*S*) was similar at two paired sites at Abe Bailey study location i.e. ANR1 and ANR2 (Figure 5.7). ANR3 had lower *S* in the nature reserve than in the adjacent grazing area. At Roodeplaat Dam study location, *S* was similar at RNR2 but lower within the reserve than in adjacent area at RNR1. At RNR3, S was higher in the nature reserve compared to the adjacent area. At Suikerbosrand study location, SNR2 had similar *S* within the reserve and in the adjacent grazing area. SNR1 and SNR3 had higher *S* in the grazing area than in the nature reserve.

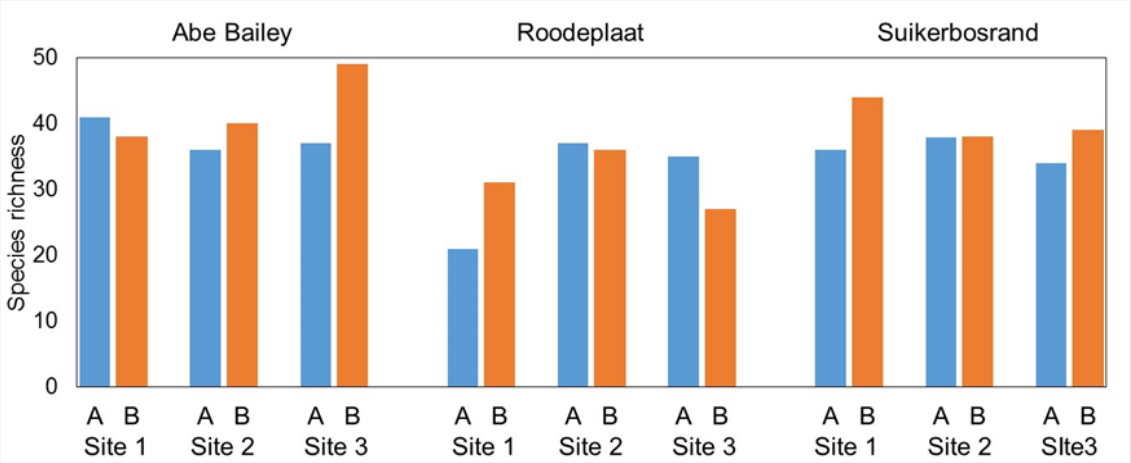



Figure 5.7: Species richness in 1000 $m^2$ plots at (A) nature reserves and (B) adjacent grazing lands

### *Species richness at multiple spatial scales*

Species richness comparisons between sample plot sizes are shown in Figure 5.8. The cumulative total number of species recorded showed a clear difference between the $1m^2$ quadrats and the $10m^2$ quadrants, and the cumulative number of species recorded in the $100m^2$ were higher and were increasing as compared to the $10m^2$ plots. The species recorded in the $1000m^2$ were almost double to all the species recorded in the $100m^2$ plots and almost ten times those recorded in the $1m^2$ plots. This pattern was observable across all study sites and locations.

According to Stohlgren (2007), the design of the Modified Whittaker Plot allows for species richness to be analysed at multiple spatial scales and this gives a clearer picture of plant diversity patterns within a landscape. For example, Figure 5.8 shows that species richness in $1m^2$ plots at ANR and RNR appear similar but SNR is slightly higher. However, at $10m^2$ and beyond, RNR has lower species richness.

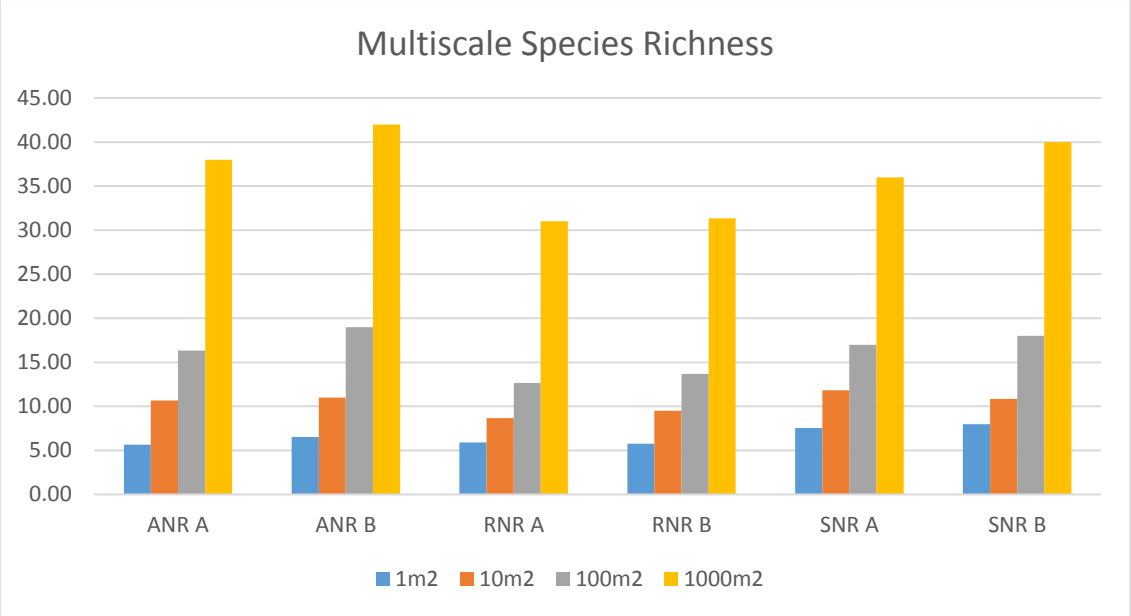



Figure 5.8: Total cumulative number of species in all $1m^2$, $10m^2$, $100m^2$ and $1000m^2$ quadrats and in each of the paired sites at the three study locations (ANR, RNR and SNR)

### *Species richness comparisons between study locations*

The overall species richness for the three study locations was determined at $1000m^2$ plot scale for ANR, RNR and SNR (Table 5.3). Both ANR and SNR had higher *S* in the adjacent area as compared to the nature reserve side. RNR had similar *S* both inside and outside the nature reserve. The overall species richness for the three study locations was not significantly different between the nature reserves and the adjacent areas. These findings indicate that differences in species richness are only detectable at individual paired sites, and cannot be generalised for the three study locations.

Table 5.3: Average species richness and standard deviations per study location at (A) nature reserves and (B) adjacent grazing lands

| | Abe Bailey | | Roodeplaat | | Suikerbosrand | |
|---|---|---|---|---|---|---|
| | A | B | A | B | A | B |
| Average | 39.33 | 42.3 | 31.0 | 31.3 | 36.0 | 40.3 |
| Standard Deviation | 4.93 | 5.86 | 8.72 | 4.51 | 2.0 | 3.21 |
| *P*-value (one-tail) | 0.320 | | 0.478 | | 0.102 | |

Similar findings were reported by Venter et al. (1989) who found no significant difference in species richness between a game reserve and an adjacent livestock grazing area in Lowveld savanna of KwaZulu-Natal. However, our findings differ from those reported by Shackleton (2000) for a study explaining changes in biodiversity in relation to the environmental variables and land uses, in protected and unprotected (communal) lands. Shackleton (2000) conducted the study in Lowveld savanna in Bushbuckridge and found that the adjacent communal lands in general had more plant species as compared to the protected areas. On the global scale, Gray et al. (2015) reported that there are more species in protected areas than in unprotected areas.

### 5.3.2 Shannon-Wiener diversity

The Shannon-Wiener diversity (*H'*) values for $1m^2$ plots results are presented in Figures 5.9 to 5.11. The highest average *H'* values were obtained for the adjacent grazing areas in all three paired sites at ANR (Table 5.4) and lower *H'* values in the nature reserve. The *H'* values were only significantly different between nature reserve and adjacent area at ANR3, while those at ANR1 and ANR2 were not significantly different. At RNR, highest average *H'* values were obtained in two paired sites in the nature reserve (RNR2A and RNR3A) and one paired site had high *H'* value in the adjacent grazing area (RNR1B). None of the *H'* values were significantly different. SNR had high *H'* values at two paired sites in the nature reserve (SNR2A and SNR3A) and the other one paired site had higher *H*' value in the adjacent grazing area (SNR1B). High *H'* values were reflected in plots with high species richness. None of the *H'* values were significantly different between inside and outside of the nature reserves.

The *H'* values for the three study locations fall within the range that is commonly reported, which is usually between 1.5 and 3.5; the values rarely go beyond 4 and this only happens when sample plots have high numbers of species (Magurran, 2004). When a single species dominates an area the Shannon-Wiener diversity index decreases regardless of the high overall species richness (Drescher, 1998).

The Shannon-Wiener diversity reaches maximum when all species in a sample area are represented by the equal number of individuals, which then means that there is an even distribution of abundances.

Table 5.4: Average values of Species richness (S), Shannon-Wiener diversity index (*H*') and Pielou's evenness index (*J'*)

| **ANR** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Site | Avg S | Avg *H'* | Avg *J'* | Site | Avg S | Avg *H'* | Avg *J'* |
| 1A | 6.60 | 1.65 | 0.85 | 1B | 6.40 | 1.30 | 0.74 |
| 2A | 5.80 | 1.42 | 0.79 | 2B | 5.80 | 1.48 | 0.85 |
| 3A | 5.70 | 1.24 | 0.73 | 3B | 7.40 | 1.59 | 0.83 |
| **RNR** | | | | | | | |
| 1A | 4.20 | 1.17 | 0.84 | 1B | 5.70 | 1.40 | 0.82 |
| 2A | 6.40 | 1.49 | 0.81 | 2B | 5.80 | 1.36 | 0.77 |
| 3A | 7.10 | 1.63 | 0.86 | 3B | 5.80 | 1.35 | 0.77 |
| **SNR** | | | | | | | |
| 1A | 6.10 | 1.36 | 0.78 | 1B | 8.00 | 1.51 | 0.73 |
| 2A | 8.40 | 1.79 | 0.86 | 2B | 8.60 | 1.70 | 0.81 |
| 3A | 8.10 | 1.77 | 0.85 | 3B | 7.30 | 1.59 | 0.81 |

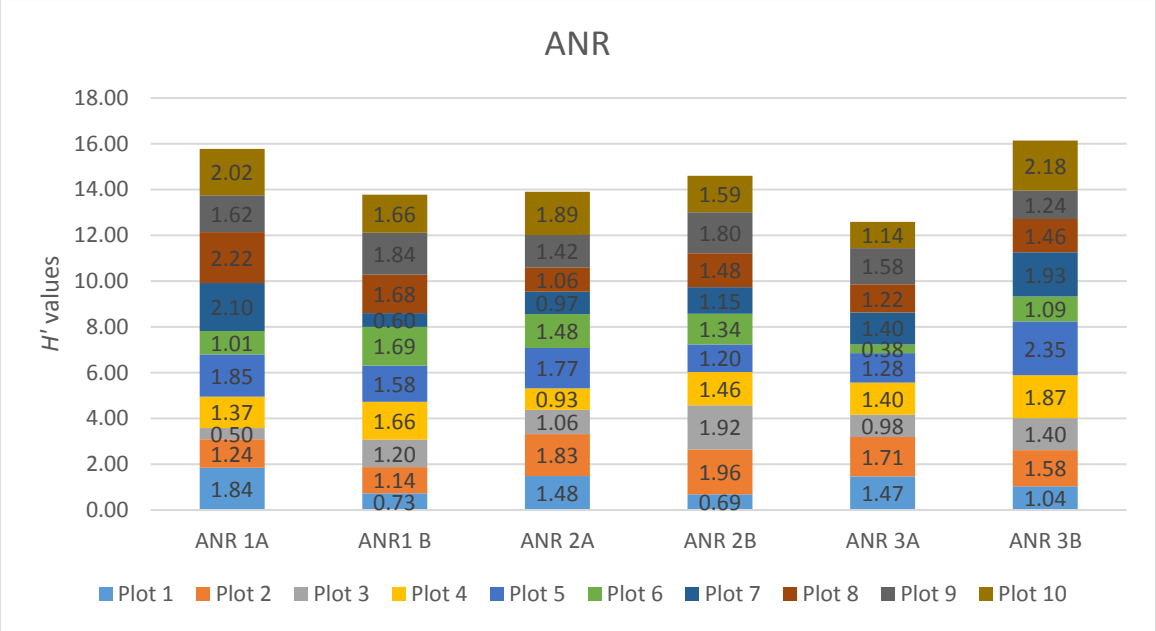



Figure 5.9: *H*' values obtained for all the ten 1m$^2$ within six 1000m$^2$, in the ANR study location

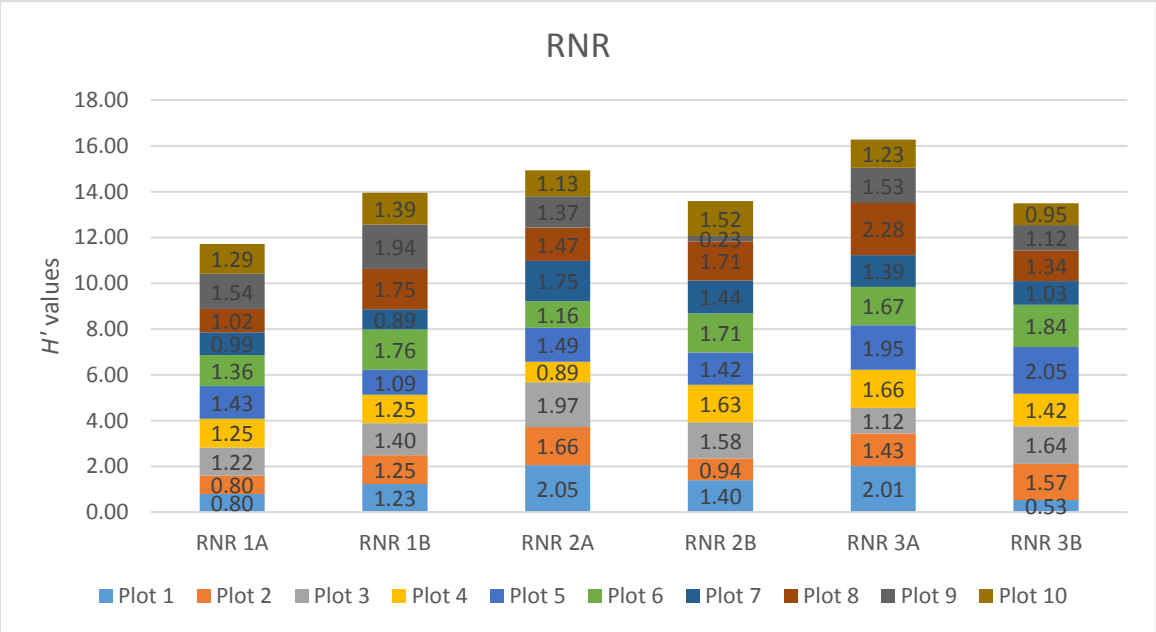



Figure 5.10: *H'* values obtained for all the ten 1m$^2$ within six 1000m$^2$, in the RNR study location

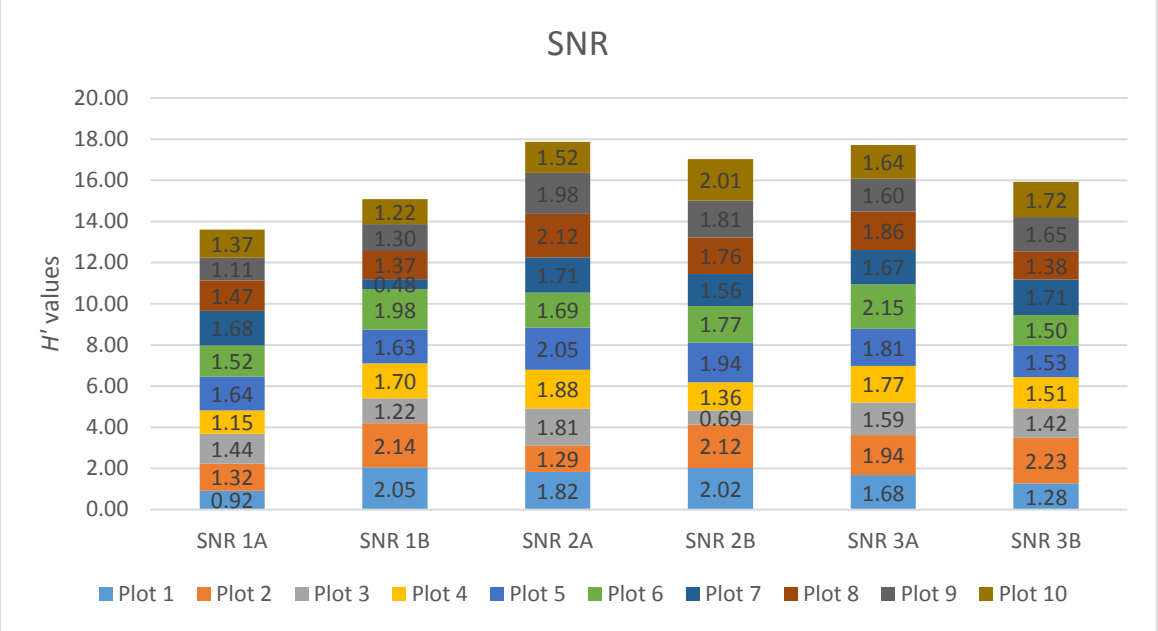



Figure 5.11: *H'* values obtained for all the ten 1m$^2$ within six 1000m$^2$, in the SNR study location

### 5.3.3 Species evenness

Species evenness (*J'*) was relatively high for all study locations, and the range was between 0.3 and 0.94 (Figures 5.12 to 5.14). The highest average *J'* values were obtained for the adjacent grazing areas in all three paired sites at ANR (Table 5.4) and lower evenness in the nature reserve. Only *J'* values at ANR3 were significantly different between the reserve and adjacent area. At RNR the highest average *J'* values were obtained at all sites in the nature reserve than in the adjacent grazing area. None of the *J'* values were significantly different. Similarly, SNR had the highest average *J'* values at all sites in the nature reserve than in the adjacent grazing area but none of the *J'* values were significantly different.

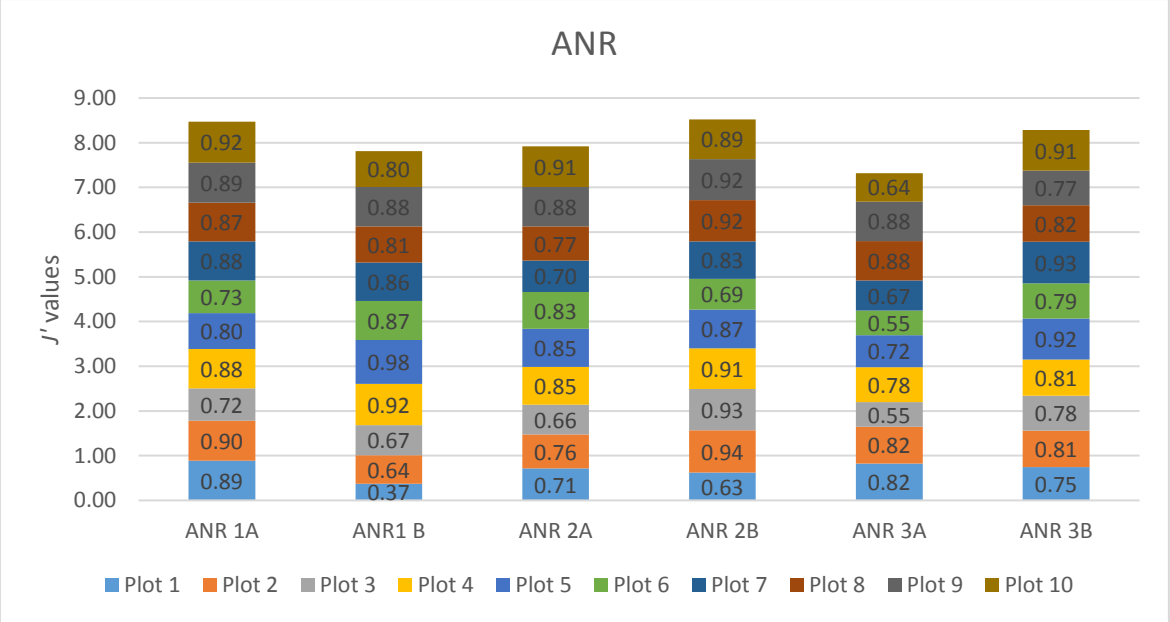



Figure 5.12: *J'* values obtained for all the ten 1m$^2$ within six 1000m$^2$, in the ANR study location

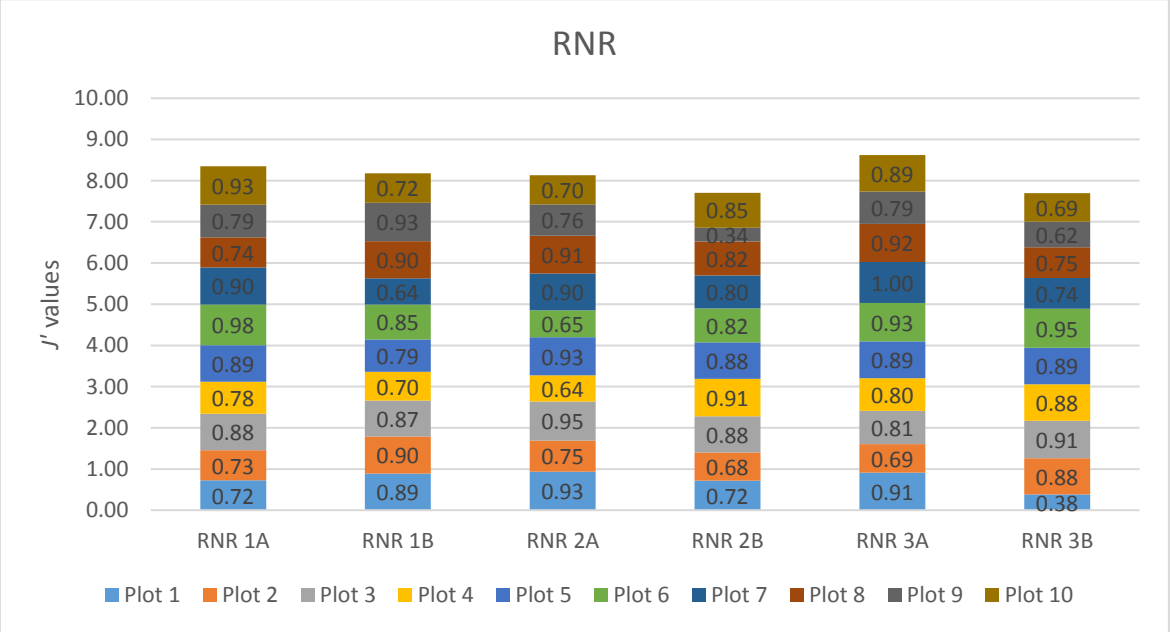



Figure 5.13: *J'* values obtained for all the ten 1m$^2$ within six 1000m$^2$, in the RNR study location

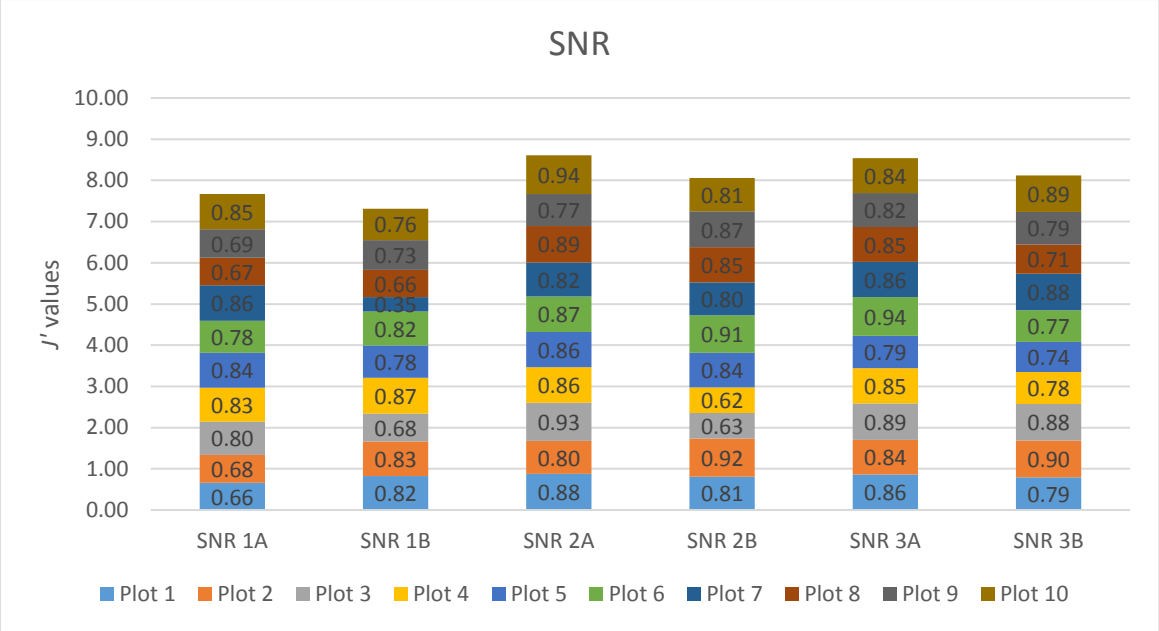



Figure 5.14: *J'* values obtained for all the ten 1m$^2$ within six 1000m$^2$, in the SNR study location

## 5.4 Impact of grazing on plant diversity

Grazing has a huge impact on grassland composition and structure (Augustine & McNaughton, 1998), and can affect species cover and diversity (Belsky, 1992). Numerous studies have found that species richness is affected by different grazing intensities, with low species richness at low and high grazing intensities, and a high number of species at moderate grazing intensities (Li et al., 2011; Oba et al., 2001). At the three study locations, species richness increased with the decreasing of grazing intensity from HG to MG and species richness decreased with the decrease of grazing intensity from MG to LG. The sites with HG had lower species as compared to the sites with MG, this result was similar throughout the sites except for one site at ANR, where HG had a higher number of species compared to the MG site. This may be due to a number of factors, including soil nutrient levels as reported by Critchley et al. (2002), Diekmann et al. (2014), and Janssens et al. (1998).

Shannon-Weiner diversity and species evenness also differed with grazing intensities; both indices were higher in HG than MG sites, and also higher in MG

than LG sites. Similar findings have also been reported by Burns et al. (2009), who highlighted that herbivore grazing in protected areas is extremely important because regardless of the intensity of grazing, the absence or reduction in herbivore density can result in low species richness and diversity.

The intensity of grazing can be determined by the stocking rates of grazers at a given area (Tainton, 1999). The changes in the grassland species composition are seen with the increase of species resistant to grazing as stocking rates increase, whilst species that are susceptible to grazing decrease. The animal type in the grazing system have different impacts on the grasslands (Hardy & Tainton, 1995), as some animals are bulk grazers (these include animals such as zebras; buffalos and rhinoceros) whilst others are selective grazers (these include animals such as wildebeest; antelope etc). In the three study locations, the animals in the nature reserves were a mix of bulk grazers, selective grazers, and mixed feeders (Table 4.1), while the adjacent areas were mainly grazed by cattle.

The intensity of grazing can also be determined by the palatability of species present in an area. Augustine and McNaughton (1998) define palatability as the level at which a plant is consumed by the animals, in comparison to the plant's abundance. The palatability status of the grass species found in the three study locations is shown in Table 5.5. The nature reserve had in general a lower number of palatable grass species as compared to the adjacent grazing lands (Table 5.6). Although it can be expected that sites with many palatable species can undergo heavy utilisation by herbivores, the grazing intensities at the three study locations however cannot be attributed to plant palatability alone.

Herbivores can alter plant species composition because when selective grazers feed specifically on palatable species, this can lead to the dominance of unpalatable species as the grazing intensity increases. On the other hand, intensive long-term grazing has also been shown to increase the dominance of palatable species (Augustine & McNaughton, 1998).

Table 5.5: Palatability of the grasses found throughout the three study areas, according to Van Oudtshoorn (2014)

| Name | Palatability |
|---|---|
| *Aristida diffusa* | Poorly palatable |
| *Aristida canescens* | Poorly palatable |
| *Aristida congesta* | Poorly palatable |
| *Aristida stipatata* | Poorly palatable |
| *Arundinela naplansis* | Palatable |
| *Brachiaria serrata* | Reasonably palatable |
| *Cymbopogon caesius* | Poorly palatable |
| *Cymbopogon pospischilii* | Poorly palatable |
| *Cyonodon dictalyon* | Palatable |
| *Digitaria diagonalis* | Poorly palatable |
| *Digitaria eranthia* | Palatable |
| *Digitaria sanguinalis* | Palatable |
| *Digitaria tricholaenoides* | Palatable |
| *Diheteropogon amplectens* | Poorly palatable |
| *Elionurus muticus* | Poorly palatable |
| *Eragrostris superba* | Reasonably palatable |
| *Eragrostris capensis* | Reasonably palatable |
| *Eragrostris curvula* | Reasonably palatable |
| *Eragrostris gummiflua* | Poorly palatable |
| *Eragrostris inamoena* | Palatability status unknown |
| *Eragrostris lehmanniana* | Reasonably palatable |
| *Eragrostris micrantha* | Palatability status unknown |
| *Eragrostris planiculumis* | Reasonably palatable |
| *Eragrostris racemosa* | Reasonably palatable |
| *Eragrostris patentipilosa* | Poorly palatable |
| *Eustachys paspaloids* | Palatable |
| *Heteropogon contortus* | Reasonably palatable |
| *Hyparrhenia hirta* | Poorly palatable |
| *Hyparrhenia dichroa* | Poorly palatable |
| *Hyparrhenia tamba* | Poorly palatable |
| *Loudetia Flavida* | Poorly palatable |
| *Loudetia Simplex* | Poorly palatable |
| *Melinis nerviglumis* | Reasonably palatable |
| *Melinis repens* | Poorly palatable |
| *Panicum coloratum* | Palatable |
| *Paspalum scrobiculatum* | Poorly palatable |
| *Pogonarthia squarrosa* | Poorly palatable |
| *Schizachyrium sanguineum* | Poorly palatable |
| *Setaria incrassata* | Reasonably Palatable |
| *Setaria pumila* | Palatable |

| | |
|---|---|
| *Setaria sphacelata* | Palatable |
| *Sporobolus africanus* | Poorly palatable |
| *Themeda triandra* | Palatable |
| *Trachypogon spicatus* | Palatable |
| *Tragus racemosa* | Palatability status unknown |
| *Trichoneura grandiglumis* | Poorly palatable |
| *Triraphis andropogonoides* | Palatable |
| *Tristachya leucothrix* | Palatable-seasonally |
| *Urochloa oligotricha* | Palatable |

Table 5.6: Number of palatable grasses and grazing intensity.

| **ANR** | | | | | |
|---|---|---|---|---|---|
| **1A** | **1B** | **2A** | **2B** | **3A** | **3B** |
| 11-MG | 8-HG | 7-MG | 13-HG | 11-HG | 19-MG |
| **RNR** | | | | | |
| 4-MG | 3-LG | 7-MG | 7-LG | 5-MG | 6-LG |
| **SNR** | | | | | |
| 8-MG | 7-MG | 6-MG | 9-MG | 3-HG | 6-MG |

**Heavy grazing- HG; Moderate grazing – MG; Light grazing - LG**

## 5.5 Comparison of soil properties in nature reserves and adjacent lands

The three study locations occur on acidic soils with average pH values ranging from 5.48 for sites at Abe Bailey study location to 5.96 at Suikerbosrand study location (Table 5.7). The values are within the range that is favourable for plant growth, which is 5.5-6.5 (Taiz & Zaiger, 1991). SNR sites also had the highest average values for all the other seven tested attributes except for P i.e. Organic C, Total C, Total N, K, Ca, Mg, and Na. In fact, the highest organic C content was recorded for SNR3A, where the vegetation was most heavily grazed. This is a surprising result because several studies have reported lower soil Organic C content for overgrazed sites (Yates et al., 2000; Snyman & Du Preez, 2005). Heavy grazing removes plant cover thereby affecting the amount of litter and eventually Organic C content (Yates et al., 2000). However, Li et al. (2011) have reported similar results of high Organic C in areas of high grazing intensity.

Table 5.7: Soil chemical properties for study sites within nature reserves and adjacent areas, averaged per study location

| Properties | Unit | ANR | | RNR | | SNR | |
|---|---|---|---|---|---|---|---|
| | | Site A | Site B | Site A | Site B | Site A | Site B |
| pH($H_2O$) | | 5.48 | 5.54 | 5.83 | 5.88 | 5.96 | 5.82 |
| OrgC | % | 0.85 | 0.97 | 1.63 | 1.28 | 3.64 | 3.09 |
| TC | % | 0.88 | 1.00 | 1.70 | 1.35 | 3.75 | 3.23 |
| TN | % | 0.07 | 0.09 | 0.13 | 0.11 | 0.26 | 0.23 |
| K | mg/kg | 74 | 67 | 128 | 112 | 386 | 270 |
| Ca | mg/kg | 167 | 216 | 535 | 563 | 1344 | 1221 |
| Mg | mg/kg | 74 | 80 | 119 | 121 | 370 | 406 |
| Na | mg/kg | 8.9 | 9.5 | 13.1 | 13.9 | 14.1 | 14.8 |
| P | mg/kg | 3.89 | 2.45 | 2.70 | 2.19 | 1.38 | 1.35 |

Comparisons between sites in the nature reserves and those in adjacent areas show that there were no significant differences in P and Na at all sites of the three study locations, while Organic C, Total C, Total N, and Ca were the variables that differed significantly at many sites (Table 5.8).

Table 5.8: Statistical analysis (t-test) for comparisons of soil chemical properties between the nature reserve (Site A) and its adjacent private land (Site B)

| Location | ANR | | | RNR | | | SNR | | |
|---|---|---|---|---|---|---|---|---|---|
| Soil property | Site 1 | Site 2 | Site 3 | Site 1 | Site 2 | Site 3 | Site 1 | Site 2 | Site 3 |
| pH(H2O) | ns | ns | ns | ns | ns | ns | ns | ns | * |
| Organic C (%) | ns | * | ns | * | ns | ** | *** | ns | ** |
| Total C (%) | ns | ns | ns | * | ns | * | ** | ns | * |
| Total N (%) | ns | * | ns | * | ns | * | ** | ns | ** |
| P (mg/kg) | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| Ca (mg/kg) | ns | ** | ns | * | ns | ns | * | * | ns |
| Mg (mg/kg) | ns | ns | ns | ns | ns | ns | * | * | ns |
| K (mg/kg) | ns | ns | ns | ns | ns | * | * | * | ns |
| Na (mg/kg) | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| ns: not significant; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ | | | | | | | | | |

## 5.6 Relationships between soil properties and plant diversity

Species richness has significant (p<0.5) positive linear relationships with Organic C, Total C, Total N, K, Ca, and Mg at adjacent sites (Table 5.9; Figure 5.15). This differs with the results of Roem and Berendse (2000), who reported negative correlations of species richness and diversity with Organic C and Total N. Janssens et al. (1998) reported positive species richness and Total N association in their study, where the optimum levels of Total N were about 0.5% dry soil. This means that species richness increased at low Total N levels but as Total N content in soil increases, species richness begins to decrease. The Total N content of the soils of the three study locations, as indicated on Table 5.9, is lower than the optimum level suggested by Janssens et al. (1998) and similar results have been reported by Dingaan et al. (2017) for semi-arid grasslands of the Free State Province. Positive linear relationships for pH and Ca have been reported in other grasslands, for example by Roem and Berendse (2000).

Table 5.9: Correlation coefficient (r) for the relationship between diversity indices and soil variables

| Soil property | Species richness (*S*) | | Shannon Weiner diversity index (*H'*) | | Species evenness (*J'*) | |
|---|---|---|---|---|---|---|
| | A | B | A | B | A | B |
| pH | ns | ns | ns | ns | ns | -0.424* |
| OrgC | 0.334# | 0.386* | 0.374# | ns | ns | ns |
| TC | 0.333# | 0.384* | 0.370# | ns | ns | ns |
| TN | 0.336# | 0.397* | 0.384* | ns | ns | ns |
| K | ns | 0.452* | ns | ns | ns | ns |
| Ca | ns | 0.443* | ns | ns | ns | ns |
| Mg | 0.346# | 0.603*** | 0.391* | 0.428* | ns | ns |
| Na | ns | ns | ns | ns | 0.494** | ns |
| P-Brayl | ns | ns | ns | ns | ns | ns |
| # p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001 | | | | | | |

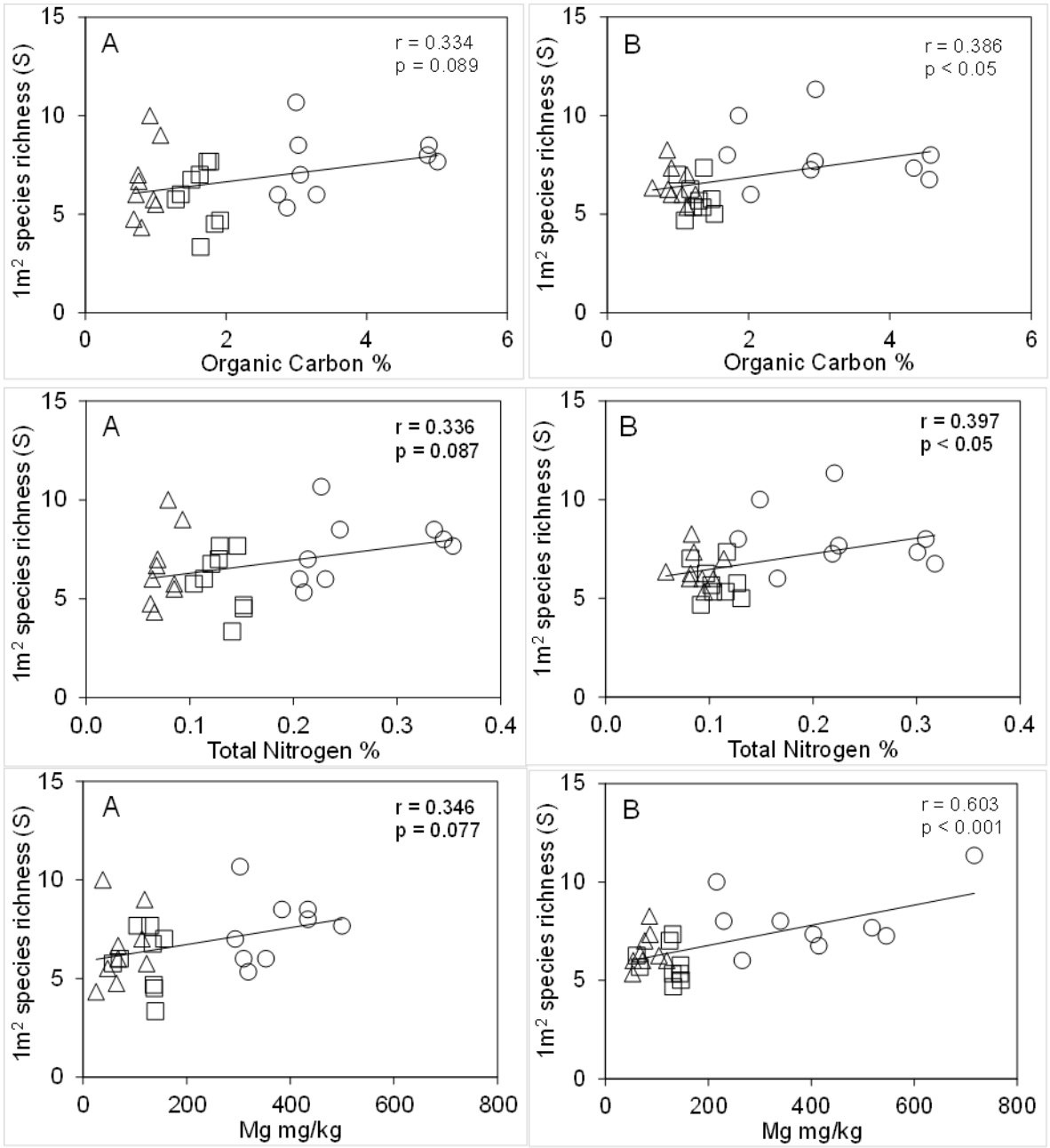



Figure 5.15: Relationship between species richness and soil variables for A and B sites across all study locations ( □ RNR ○ SNR △ ANR )

# CHAPTER 6: CONCLUSION

The main purpose of the study was to compare plant diversity, species composition and determine relationships between plant diversity and soil characteristics under different land use and management in protected areas and adjacent unprotected areas. Differences were observed during the study but these differences were not consistent throughout all three chosen study locations and this may be due to a number of reasons such as soil chemical properties and grazing. The areas with a vegetation that showed signs of disturbance had slightly more species as compared to the non-disturbed areas. In particular, a difference was seen between areas with heavy, moderate and light grazing. The moderately grazed areas showed a slightly higher *S* as compared to the heavily grazed, and this was applicable in both the nature reserve and the adjacent grazing areas. The adjacent areas had a more disturbed vegetation structure at the ANR and SNR and two of these sites had more species richness and diversity in the adjacent areas. At the RNR the adjacent areas had dense vegetation with very light to no grazing and these had less species richness and diversity as compared to the sites at the nature reserve, though the difference was not significant.

The level of nutrients in the soil has been shown to have a role in species richness, according to studies conducted by, among others, Critchley et al. (2002) and Janssens et al. (1998). The soil chemical properties in the three study locations had a very significant role in species richness, particularly total nitrogen and carbon. The content of the soil organic carbon also had a significant role in species richness and diversity. SNR had higher organic C, total C, and total N as compared to ANR and RNR and as such the highest diversity indices and species richness were recorded at that study location. However, ANR had the lowest organic C, total C and total N as compared to SNR and RNR, but had equally high diversity indices and species richness compared to RNR. Most importantly, species richness across all study locations showed positive correlations with Organic C, total N, and Mg. These results clearly indicate that soil chemical properties have an important role in

species richness, species diversity and species composition, however other factors such as disturbance (grazing and human disturbance) are also important.

Protected areas are regarded as important in the long-term conservation of biodiversity. Such areas are said to be biodiversity hotspots and presumably have higher biodiversity than the unprotected areas. There have been studies measuring the effectiveness of protected areas in conserving biodiversity, however some studies have found that protected areas somehow lost the species along the way (Nicholls et al., 1996; Newmark, 1996). Protected areas have also been found to reduce human disturbances and prevent habitat loss (Gray et al., 2015).

There are studies that have found more diversity in the protected compared to the unprotected areas. Cazalis et al., 2018 found no significant difference in bird species richness between the protected and unprotected areas, Zisadza-Gandiwa et al. (2013) also found no significant difference in grass species between the protected and the unprotected areas. Similarly, Coetzee et al. (2014) found no significant difference in plant species between the protected and unprotected areas. All the above mentioned studies had a similar result with to our results, we found no significance difference in plant diversity between the protected and unprotected areas.

There are also some studies which had higher species richness in the unprotected areas with significant difference. Zisadza-Gandiwa et al. (2013) found more tree species in the unprotected areas as compared to the protected areas, Shackleton (2000) found significantly higher plant diversity in unprotected areas than in protected areas. Protected areas seem to have higher diversity regarding the animals more than plant diversity and protected areas can at least guarantee no habitat loss as compared to the unprotected areas.

In conclusion, there is a need for more research on South African grasslands to better understand the different aspects that impact on species richness, diversity

and composition. Grasslands are facing a global decline and such studies will help in their protection and hopefully lessen the rate that grasslands are decreasing. South African nature reserves need to also pay more attention to the protection and conservation of plants species, without giving more focus on the animals.

# REFERENCE LIST


Abdalla, M., Hastings, A., Chadwick, D.R., Jones, D.L., Evans, C.D., Jones, M.B., Rees, R.M. & Smith, P. 2018. Critical review of the impacts of grazing intensity on soil organic carbon storage and other soil quality indicators in extensively managed grasslands. *Agriculture, Ecosystems and Environment* 253: 62–81.

Adler, P.E. & Levine, J.M. 2007. Contrasting relationships between precipitation and species richness in space and time. *Oikos* 116: 221- 232.

Akhzari, D., Pessarakli, M. & Ahandani, S.E. 2015. Effects of Grazing Intensity on Soil and Vegetation Properties in a Mediterranean Rangeland. *Communications in Soil Science and Plant Analysis*: 2798-2806.

Augustine, D.J. & McNaughton, S.J. 1998. Ungulate effects on the functional species composition of plant communities: Herbivore selectivity and plant tolerance. *Journal of Wildlife Management* 62: 1165-1183.

Austin, M.P. 1999. The potential contribution of vegetation ecology to biodiversity research: *Ecography* 22: 465-484.

Austin, M.P., Pausas, J.G. & Nicholls, A.O. 1996. Patterns of tree species richness in relation to environment in south-eastern New South Wales, Australia. *Australian Journal of Ecology* 21: 154-164.

Balvanera, P., Pfisterer, A.B., Buchmann, N., He, J., Nakashizuka, T., Raffaelli, D., & Schmid, B. 2006. Quantifying the evidence for biodiversity effects on ecosystem functioning and services. *Ecology Letters* 9: 1146–1156.

Belsky, A.J. 1992. Effects of grazing, competition, disturbance and fire on species composition and diversity in grassland communities. *Journal of Vegetation Science 3*: 187-200.

Berendse, F., van Ruijven, J., Jongejans, E. & Keesstra, S. 2015. Loss of Plant Species Diversity Reduces Soil Erosion Resistance. Ecosystems: DOI: 10.1007/s10021-015-9869-6.

Bond, W.J. & Parr, C.L. 2010. Beyond the forest edge: Ecology, diversity and conservation of the grassy biomes. *Biological Conservation* 143: 2395-2404.

Briske, D.D., Fuhlendorf, D. & Smeins, F.E. 2003. Vegetation dynamics on rangelands: a critique of the current paradigms. *Journal of Applied Ecology* 40: 601-614.

Bruner, A.G., Gullison, R.E., Rice, R.E. & da Fonseca, G.A.B. 2001. Effectiveness of parks in protecting tropical biodiversity. *Science* 291: 125-128.

Burns, C.E., Collins, S.L. & Smith, M.D. 2009. Plant community response to loss of large herbivores: comparing consequences in a South African and a North American grassland. *Biodiversity and Conservation* 18: 2327-2342.

Carbutt, C., Tau, M., Stephens, A. & Escott, B. 2011. The conservation status of temperate grasslands in Southern Africa. *Grassroots* 11: 17-23.

Cazalis, V., Belghali, S. & Rodrigues, A.S.L. 2018: Using a large-scale biodiversity monitoring dataset to test the effectiveness of protected areas in conserving North-American breeding birds. *bioRvix International Licence*.

Chapungu, L. & Nhamo, L. 2016. An Assessment of the Impact of Climate Change on Plant Species Richness through an Analysis of the Normalised Difference Water Index (NDWI) in Mutirikwi Sub-catchment, Zimbabwe. *South African Journal of Geomatics* 5*:* 244-268.

Cingolani, A.M., Noy-Meir, I. & Diaz, S. 2005. Grazing effects on rangeland diversity: a synthesis of contemporary models. *Ecological Applications* 15: 757-773.

Coetzee, B.W.T., Gaston, K.J. & Chown, S.L. 2014. Local Scale Comparisons of Biodiversity as a Test for Global Protected Area Ecological Performance: A Meta-Analysis. *PLOS One* 9: 1-11.

Colwell, R.K. & Coddington, J.A. 1994. Estimating terrestrial biodiversity through extrapolation. *Biological Sciences* 354: 101-118.

Crawley, M.J. 1997. Plant-herbivore dynamics. In Crawley, M.L. (ed.) *Plant Ecology*. Blackwell, Cambridge, 410-474.

Critchley, C.N.R., Chambers, B.J., Fowbert, J.A., Sanderson, R.A., Bhogal, A. & Rose S.C. 2002. Association between lowland grassland plant communities and soil properties. *Biological Conservation* 105: 199-215.

Dahwa, E., Mudzengi, C. P., Hungwe, T., Shoko, M.D., Poshiwa, X., Kativu, S. & Murungweni, C. 2013. Influence of grazing intensity on soil properties and shaping herbaceous plant communities in semi-arid Dambo wetlands of Zimbabwe. *Journal of Environmental Protection* 4: 1181-1188.

Dale, V.H. 1997. The relationship between land-use change and climate change. *Ecological Applications* 7: 753-769.

De Boeck, H.J., Lemmensa, C.M.H.M., Gielen, B., Bossuyt, H., Malchair, S., Carnol, M., Merckx, R., Ceulemans, R. & Nijs, I. 2007. Combined effects of climate warming and plant diversity loss on above- and below-ground grassland productivity. *Environmental and Experimental Botany* 60: 95–104.

Dent, M.C., Lynch, S.D. & Schulze, R.E. 1989. Mapping mean annual and other rainfall statistics over southern Africa. Water Research Commission, Pretoria. WRC Report, 109/1/89.

Diekmann, M., Jandt, U., Alard, D., Bleeker, A., Corcket, E., Gowing, D.J.G., Stevens, C.J. & Duprè, C. 2014. Long-term changes in calcareous grassland vegetation in north-western Germany – no decline in species richness, but a shift in species composition. *Biological Conservation* 172: 170–179.

Digby, P.G.N. & Kempton, R.A. 1987. *Multivariate analysis of ecological communities*. Chapman and Hall, London.

Dingaan, M.N.V., Tsubo, M., Walker, S. & Newby, T. 2017. Soil chemical properties and plant species diversity along a rainfall gradient in semi-arid grassland of South Africa. *Plant Ecology and Evolution* 150: 35-44.

Dobarro, I., Valladares, F. & Peco, B. 2010. Light quality and not quantity segregates germination of grazing *increasers* from *decreasers* in Mediterranean grasslands. *Acta Oecologica* 36: 74-79.

Drescher, A.W. 1998. Hausgärten in afrikanischen räumen. bewirtschaftung nachhaltiger produktionssysteme und strategien der ernährungssicherung in zambia und zimbabwe. sozioökonomische prozesse in asien und Afrika, vol 4. centaurus, pfaffenweiler. *Ecosystems and Environment* 41:189-207.

Du Toit, G.V., Snyman, H.A. & Malan, P.J. 2011. Physical impact of sheep grazing on arid karoo subshrub/grass rangeland, South Africa. *South African Journal of Animal Science* 3: 280-287.

Dukes, J.S., Chiariello, N.R., Cleland, E.E., Moore, L.A., Shaw, M.R., Thayer, S., Tobeck, T., Mooney, H.A. & Field, C.B. 2005. Responses of grassland production to single and multiple global environmental changes. *Plos Biology* 3: E319.

Dumont, B., Farruggia, A., Garel, J.P., Bachelard, P., Boitier E. & Frain. M. 2008 How does grazing intensity influence the diversity of plants and insects in a species-rich upland grassland on basalt soils? *Grass and Forage Science*, 64, 92–105.

Dupré, C., Camilla, W. & Diekmann, M. 2002. Species richness in deciduous forests: effects of species pools and environmental variables. *Journal of Vegetation Science* 13: 505-516.

Ehrlich, P.R. & Pringle, R.M. 2008. Where does biodiversity go from here? A grim business-as-usual forecast and a hopeful portfolio of partial solutions. *PNAS*: 11579–11586.

Fabricius, C. & Burger, M. 1997. Comparison between a nature reserve and adjacent communal land in xeric succulent thicket: An indigenous plant user's perspective. *South African Journal of Science* 93: 259-262.

Fabricius, C., Burger, M. & Hockey, P.A.R. 2003. Comparing biodiversity between protected areas and adjacent rangeland in xeric succulent thicket, South Africa: arthropods and reptiles. *Journal of Applied Ecology* 40: 392-403.

Fabricius, C., Palmer, A.R. & Burger, M. 2002. Landscape diversity in a conservation area and commercial and communal rangeland in Xeric Succulent Thicket, South Africa. *Landscape Ecology* 17: 531-537.

Foran, B.D., Tainton, N.M. & Booysen, P. de V. 1978. The development of a method for assessing veld condition in three grassvelds in Natal. *Proceedings of the Grassland Society of South Africa* 13: 27-33.

Fowler, J., Cohen, L. & Jarvis, P. 1998. Practical statistics for field biology. John Wiley & Sons, West Sussex.

Fynn, R.W.S. & O'Connor, T.G. 2000. Effect of stocking rate and rainfall on rangeland dynamics and cattle performance in a semi-arid savanna, South Africa. *Journal of Applied Ecology* 37: 491-507.

Gao, J. & Liu, Y. 2017. Climate stability is more important than water–energy variables in shaping the elevational variation in species richness. *Ecology and Evolution*: 6872–6879.

Gerstner, k., Dormann, C.F., Stein, A., Manceur, A.M & Seppelt, R. 2014. Effects of land use on plant diversity – A global meta-analysis. *Journal of Applied Ecology* 51: 1690-1700.

Gibbs, R. G.E. 1987. List of species of southern Africa. 2nd edn, Part 2. *Memoirs of the Botanical Survey of South Africa* 56: 1- 270.

Goettesch, B., Hilton-Taylor, C., Cruz-Pinon, G. & Duffy, J.P. 2015. High proportion of cactus species threatened with extinction. *Nature Plants* DOI:10.1038/NPLANTS.2015.142.

Gotelli, N.J. & Ellison, A.M. 2004. *A primer of ecological statistics*. Sinauer Associates, Inc., Massachusetts.

Gray, C.L., Hill, S.L.L., Newbold, T., Hudson, L.N., Börger, L., Contu, S., Hoskins, A.J., Ferrier, S., Purvis, A. & Scharlemann, J.P.W. 2015. Local biodiversity is higher inside than outside terrestrial protected areas worldwide. *Nature Communications* DOI: 10.1038/ncomms12306.

Groendahl, S. & Fink, P. 2017. Consumer species richness and nutrients interact in determining producer diversity. *Scientific Reports* 7:44869: 2-8.

Hardy, M.B. & Tainton, N.M. 1995. The effects of mixed-species grazing on the performance of cattle and sheep in Highland Sourveld. *African Journal of Range & Forage Science* 12: 97-103.

Hardy, O.J. & Jost, L. 2008. Interpreting and estimating measures of community phylogenetic structuring. *Journal of Ecology* 96: 849-852.

Harrison, Y.A. & Shackleton, C.M. 1999. Resilience of South African communal grazing lands after the removal of high grazing pressure. *Land Degradation & Development* 10: 225 239.

Hector. A, Schmid, B. Beierkuhnlein, C. Caldeira, M. C. Diemer, M. Dimitrakopoulos P. G., Finn, J. A. Freitas, H. Giller, P. S. Good, J. Harris, R. Högberg, P. Huss-Danell, K. Joshi, J. Jumpponen, A. Körner, C. Leadley, P. W. Loreau, M. Minns, A. Mulder, C. P. H. O'donovan, G. Otway, S. J. Pereira, J. S. Prinz, A. Read, D. J. Scherer-Lorenzen, M. Schulze, E.-D. Siamantziouras, A.-S. D. Spehn, E. M. Terry, A. C. Troumbis, A. Y. Woodward, F. I. Yachi, S. & Lawton, J. H. 1999. Plant diversity and productivity experiments in European grasslands. *Science* 286: 1123-1127.

Hickman, K.R., Hartnett, D.C., Cochran, R.C. & Owensby, C.E. 2004. Grazing management effects on plant species diversity in tallgrass prairie. *Journal of Range Managemen*t 57: 58 -65.

Hill, M.O. 1979. *DECORANA: A fortran program for detrended correspondence analysis and reciprocal averaging*. Cornell University, New York.

Hoekstra J.M., Boucher T.M., Ricketts T.H. & Roberts, C. 2005. Confronting a biome crisis: global disparities of habitat loss and protection. *Ecology Letter*s 8: 23-29.

Hongslo, E., Rohde, R. & Hoffman, T. 2009. Landscape change and ecological processes in relation to land-use in Namaqualand, South Africa, 1939 to 2005. *South African Geographical Journal* 91: 63-74.

Hooper, D.U., Chapin, F S., Ewel, J. J., Hector, A., Inchausti, P., Lavorel, S., Lawton, J. H., Lodge, D. M., Loreau, M., Naeem, S., Schmid, B., Setala, H., Symstad, A.J., Vandermeer, J. & Wardle, D.A. 2005. Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. *Ecological Monographs* 75: 3-35.

Howe, H.F. 1994. Managing species diversity in tallgrass prairie: assumptions and implications. *Conservation Biology* 8: 691-704.

Huston, M.A. 1997. Hidden treatments in ecological experiments: re-evaluating the ecosystem function of biodiversity: *Oecologia* 110: 449-460.

Huston, M.A. 1999. Local processes and regional patterns: appropriate scales for understanding variation in the diversity of plants and animals. *Oikos* 86: 393-401.

Ingerpuu, N. & Sarv, M. 2015. Effect of grazing on plant diversity of coastal meadows in Estonia. *Annales Botanici Fennici* Vol. 52: 84-92.

Ingram, L. J., Stahl, P. D., Schuman, G. E., Buyer, J. S., Vance, G. F., Ganjegunte, G. K., Welker, J. M. & Derner, J. D. 2008. Grazing Impacts on Soil Carbon and Microbial Communities in a Mixed-Grass Ecosystem. *Soil Biology & Biochemistry* 72: 939-948.

Isbell, F. I. & Wilsey, B. J. 2011. Increasing native, but not exotic, biodiversity increases aboveground productivity in Ungrazed and intensely grazed grasslands. *Oecologia* 165: 771-781.

Janssens, F., Peeters, A., Tallowin, J.R.B., Bakker, J.P., Bekker, R.M., Fillat, F. & Oomes, M.J.M. 1998. Relationship between soil chemical factors and grassland diversity. *Plant and Soil* 202: 69-78.

Jiang, Y., Kang, M., Gao, Q., He, L., Xiong, M., Jia, Z. & Jin, Z. 2003. Impact of land use on plant biodiversity and measures for biodiversity conservation in the Loess Plateau in China – a case study in a hilly-gully region of the Northern Loess Plateau. *Biodiversity and Conservation* 12: 2121-2133.

Kappelle, M., van Vuuren, M.M.I. & Baas, P. 1999. Effects of climate change on biodiversity: a review and identification of key research issues. *Biodiversity and Conservation* 8: 1383-1397.

Kennedy, T.A., Naeem, S., Howe, K.M., Knops, J.M.H., Tilman, D. & Reich, P. 2002. Biodiversity as a barrier to ecological invasion. *Letters to Nature*. 636-638.

Kent, M. 2012. *Vegetation description and data analysis: a practical approach*. John Wiley & Sons, Chichester.

Kraaij, T., Cowling, R.M. & van Wilgen, B.W. 2013. Fire regimes in eastern coastal fynbos: Imperatives and thresholds in managing for diversity. *Koedoe* 55: 1-9.

Krebs, C.J. 1989. *Ecological methodology*. Harper and Row, New York.

Krebs, C.J. 2001. Ecology: The experimental analysis of distribution and abundance, 6th Edition. Benjamin Cummings Pearson.

Kreft, H. & Jetz, W. 2007. Global patterns and determinants of vascular plant diversity*. Proceedings of the National Academy of Sciences* 104: 5925-5930.

Kruger, A.C. and Shongwe, S. 2004. Temperature trends in South Africa: 1960–2003. *International Journal of Climatology*: 1929–1945.

Lawton, J.H. 1999. Are there general laws in ecology? *Oikos* 84: 177-192.

Lee, M., Manning, P., Rist, J., Power, S.A. & Marsh, C. 2010. A global comparison of grassland biomass responses to $CO_2$ and nitrogen enrichment. *Philosophical Transactions of the Royal Society B* 365: 2047-2056.

Li, W., Huang, H.Z., Zhang, Z.N. & Wu, G.L. 2011. Effects of grazing on the soil properties and C and N storage in relation to biomass allocation in an alpine meadow. *Journal of Soil Science and Plant Nutrition* 11: 27-39.

Linstädter, A., Schellberg, J., BrùSer, K., Garcĭa, C.A.M., Oomen, R.J., Du Preez, C.C., Ruppert, J.C. & Ewert, F. 2014. Are there consistent grazing indicators in drylands? Testing plant functional types of various complexity in South Africa's Grassland and Savanna Biomes. *Plos One* Vol. 9: Issue 8:E104672.

Little, I.T., Hockey, P.A.R. & Jansen, R. 2015. Impacts of fire and grazing management on South Africa's most highland grasslands: A case study of the Steenkampsberg Plateau, Mpumalanga, South Africa. *Bothalia* 45, Art. #1786, 15 pages. http:// dx.doi.org/10.4102/abc. v45i1.1786.

Löbel, S., Dengler, J. & Hobohm, C. 2006. Species richness of vascular plants, bryophytes and lichens in dry grasslands: the effects of environment, landscape structure and competition. *Folia Geobotanica* 41: 377-393.

Low, A.B. & Rebelo, A.G. (eds.) 1996. Vegetation of South Africa, Lesotho and Swaziland. Pretoria.

Ludwig, J.A. & Reynolds, J.F. 1988. Statistical ecology: a primer on methods and computing. Wiley & Sons, New York.

Magurran, A.E. 2004. *Measuring Biological Diversity*. Blackwell Publishing, United Kingdom.

Masubelele, M.L., Hoffman, M.T., Bond, W.J. & Gambiza, J. 2014. A 50 year study shows grass cover has increased in Shrublands of semi-arid South Africa. *Journal of Arid Environments* 104: 43-51.

Midgley, G.F., Hannah, L., Millar, D., Rutherford, M.C. & Powrie, L.W. 2002. Assessing the vulnerability of species richness to anthropogenic climate change in a biodiversity hotspot. *Global Ecology & Biogeography* 11: 445-451.

Milchunas, D.G. & Lauenroth, W.K. 1993. Quantitative effects of grazing on vegetation and soils over a global range of environments. *Ecological Monographs* 63: 327-366.

Milchunas, D.G. & Noy–Meir, I. 2004. Geologic Grazing Refuges and Grassland Diversity: A Shortgrass Steppe Study. *Journal of Range Management* 57:141 -147.

Milchunas, D.G., Burke, I.C. & Lauenroth, W.K. 1998. Livestock grazing: animal and plant biodiversity of shortgrass steppe and the relationship to ecosystem function. OIKOS 83:1: 65-74.

Milchunas, D.G., Sala, O.E. & Lauenroth, W.K. 1988. A generalised model of the effects of grazing by large herbivores on grassland community structure. *The American Naturalist* 132: 87-106.

Mucina, L. & Rutherford, M. C. 2006. The Vegetation of South Africa, Lesotho and Swaziland. *Strelitzia* 19, Pretoria.

Mucina, L. & Rutherford, M.C. (eds). Reprint 2011. The vegetation of South Africa, Lesotho and Swaziland. *Steritzia* 19. South African National Biodiversity Institute, Pretoria.

Mueller-Dombois, D., & Ellenberg, H. 1974. *Aims and methods of vegetation ecology*. John Wiley & Sons, New York.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., Fonseca, G.A.B. & Kent, J. 2000. Biodiversity hotspots for conservation priorities. *Nature* 403: 853-858.

Naeem, S. & Wright, J.P. 2003 Disentangling biodiversity effects on ecosystem functioning: deriving solutions to a seemingly insurmountable problem. *Ecology Letters*: 567–579.

Naeem, S., Thompson L.J., Lawler, S.P., Lawton, J.H. & Woodfin, R.M. 1994. Declining Biodiversity can Alter the Performance of Ecosystems. *Letters to Nature* 368: 734-737.

New, M., Hewitson, B., Stephenson, D.B., Tsiga, A., Kruger, A., Manhique, A., Gomez, B., Coelho, C.A.S., Masisi, D.N., Kululanga, E., Mbambalala, E., Adesina, F., Saleh, H., Kanyanga, J., Adosi, J., Bulane, L., Fortunata, L., Marshall L. Mdoka, M.L. & Lajoie, R. 2006. Evidence of trends in daily climate extremes over Southern and West Africa. *Journal of geophysical research*: 1-11.

Newmark, W.D., 1996. Insularization of Tanzanian Parks and the Local Extinction of Large Mammals: *Conservation biology*: 1549-1556.

Nicholls, A.O., Viljoen, P.C., Knight, M.H., & van Jaarsveld, A.S. 1996. Evaluating population persistence of censused and unmanaged herbivore population from the Kruger National Park, South Africa. *Biological Conservation 76*: 57-67.

O'Connor, T.G. & Bredenkamp, G.J. 1997. Grassland. In R.M. Cowling, D.M. Richardson & S.M. Pierce (eds.). *Vegetation of Southern Africa.* Cambridge University Press, United Kingdom. pp. 215-257.

O'Connor, T.G. & Kuyler, P. 2009. Impact of land use on the biodiversity of the moist sub-biome of the grassland biome, South Africa. *Journal of Environmental Management* 90: 384-395.

O'Connor, T.G., Kuyler, P. & Corcoran, B. 2010. Which grazing management practices are most appropriate for maintaining biodiversity in South African grassland? *African Journal of Range & Forage Science* 27: 67-76.

O'Connor, T.G., Uys, R.G. & Mills, A.J. 2004. Ecological effects of fire-breaks in the montane grasslands of the southern Drakensberg, South Africa. *African Journal of Range & Forage Science* 21: 1-9.

Oba, G., Vetaas, O.R. & Stenseth, N.C. 2001. Relationships between biomass and plant species richness in arid-zone grazing lands. *Journal of Applied Ecology* 38: 836–845.

Olson, D.M. & Dinerstein, E. 1998. The Global 200: A representation approach to conserving the Earth's most valuable ecoregions. *Conservation Biology* 12: 502- 515.

Osem, Y., Perevolotsky, A. & Kigel, J. 2004. Site productivity and plant size explain the response of annual species to grazing exclusion in a Mediterranean semi-arid rangeland. *Journal of Ecology* 92: 297–309.

Overbeck, G. E. & Pfadenhauer, J. 2007. Adaptive strategies in burned subtropical grassland in southern Brazil. *Flora* 202: 27-49.

Pakeman, R.J. 2004. Consistency of plant species and trait responses to grazing along a productivity gradient: a multi-site analysis. *Journal of Ecology* 92: 893–905.

Pandey, C.B. & Singh, J.S. 1992. Influence of rainfall and grazing on herbage dynamics in a seasonally dry tropical savanna. *Vegetation* 102: 107-124.

Parton, W.J., Scurlock, J.M.O., Ojima, D.S., Schimel, D.S., Hall, D.O. & Scopegram Group Members. 1995. Impact of climate change on grassland production and soil carbon worldwide. *Global Change Biology* 1: 13-22.

Pausas, J.G. & Austin, M. 2001. Patterns of plant species richness in relation to different environments. *Journal of Vegetation Science* 12: 153-166.

Perry, D.A. 1994. *Forest Ecosystems*. Johns Hopkins University Press, Baltimore, MD, 649.

Purvis, A. & Hector, A. 2000. Getting the measure of biodiversity. *Nature* 405: 212-219.

Ramankutty, N. & Foley, J.A. 1999. Estimating historical changes in global land cover: croplands from 1700 to 1992. *Global Biogeochemical Cycles* 13: 997-1027.

Rebelo, A.G. 1997. *Vegetation of Southern Africa*. Cambridge University Press, United Kingdom. Pages 571-589.

Reich, P.B., Tilman, D., Isbell, F., Mueller, K., Hobbie, S.E., Flynn, D.F.B. & Eisenhauer, N. 2012. Impacts of biodiversity loss escalate through time as redundancy fades. *Science* 336: 589-592.

Reyers, B. & Tosh, C.A. 2003. National Grasslands Initiative: Concept Document. Gauteng Department of Agriculture, Conservation and Land Affairs.

Reyers, B., Fairbanks, D. H. K., Van Jaarsveld, A. S. & Thompson, M. 2001. Priority areas for the conservation of South African vegetation: a coarse-filter approach. *Diversity and Distributions* 7: 79-95.

Roem, W.J. & Berendse, F. 2000. Soil acidity and nutrient supply ratio as possible factors determining changes in plant species diversity in grassland and heathland communities. *Biological Conservation* 92: 151-161.

Rutherford, M.C., Powrie, L.W. & Husted, L.B. 2012. Plant diversity consequences of a herbivore-driven biome switch from Grassland to Nama-Karoo shrub steppe in South Africa. *Applied Vegetation Scien*ce 15: 14-25.

Rutherford, M.C., Powrie, L.W. & Schulze, R.E. 1999. Climate change in conservation areas of South Africa and its potential impact on floristic composition: a first assessment. *Diversity and Distributions* 5: 253-262.

Saleska, S.R., Shaw R., Fischer, M.L., Dunne, J.A., Still, C.J., Holman, M.L. & Harte, J. 2002. Plant Community Composition Mediates Both Large Transient Decline and Predicted Long-Term Recovery of Soil Carbon under Climate Warming. *Global Biogeochemical Cycles*: 16 1055.

South African National Biodiversity Institute (SANBI). 2014. Grazing and Burning Guidelines: Managing Grasslands for Biodiversity and Livestock Production. Compiled by Lechmere-Oertel, R.G. South African National Biodiversity Institute, Pretoria.

Sanders, N.J. 2002. Elevational gradients in ant species richness: area, geometry, and Rapoport's rule. *Ecography Pages*: 25-32.

Schenk, H.J. & Jackson, R.B. 2002. The global biogeography of roots. *Ecological Monographs*: 311–328.

Schulze, R.E. 1997. South African Atlas of Agrohydrology and Climatology. Water Research Commission, Pretoria, Report TT82/9.

Shackleton, C.M. 2000. Comparison of plant diversity in protected and communal lands in the Bushbuckridge lowveld savanna, South Africa. *Biological Conservation* 94: 273-285.

Shaver, G.R., Canadell, J., Chapin Iii, F. S., Gurevitch, J., Harte, J., Henry, G., Ineson, P., Jonasson, S., Melillo, J., Pitelka, L. & Rustad, L. 2000. Global warming and terrestrial ecosystems: a conceptual framework for analysis. *Bioscience*: 871-882.

Shmida, A. & Wilson, M.V. 1985. Biological determinants of species diversity. *Journal of Biogeography* 12:1-20.

Shmida, A. 1984. Whittaker's plant diversity sampling method. *Israel Journal of Botany.*

Short, A., & Du Toit, F. 2005. The effect of grazing on biodiversity in the grassland biome: Proceedings of a workshop held at Umgeni Valley, 29-30 September 2004. *Grassroots: Newsletter of the Grassland Society of South Africa* 5: 8-15.

Snyder, K. A. & Williams, D. G. 2003. Defoliation alters water uptake by deep and shallow roots of Prosopis velutina (Velvet Mesquite). *Functional Ecology*: pp. 363−374.

Snyman, H.A. & Du Preez, C.C. 2005. Rangeland degradation in a semi-arid South Africa – II: influence on soil quality. *Journal of Arid Environments* 60: 483-507.

Stohlgren, T.J, Falkner, M.B. & Schell, L.D. 1995: A Modified-Whittaker nested vegetation sampling method: *Vegetatio* 117: 113-121.

Stohlgren, T.J. 2007. *Measuring plant diversity: lessons from the field*. Oxford University Press, New York.

Tainton, N.M. 1999. Veld management in South Africa. *African Journal of Range & Forage Science* 16: 126-127.

Taiz, L. & Zeiger, E. 1991. *Plant physiology*. Benjamin/Cummings Publishing, California.

Tilman, D. & Downing, J.A. 1994. Biodiversity and stability in grasslands *Nature*·367: 363-365.

Tilman, D. 1996. Biodiversity: population versus ecosystem stability. *Ecology* 77: 350-363.

Tilman, D. 1999. The ecological consequences of changes in biodiversity: a search for general principles. *Ecology* 80: 1455-1474.

Tilman, D. 2000. Causes, consequences and ethics of biodiversity. *Nature* 405: 208-211.

Van der Maarel, E. 2005. *Vegetation Ecology*. Blackwell, Oxford.

Van Oudtshoorn, F. 2014. *Guide to grasses of southern Africa*, third edition. Briza Publications, Pretoria-South Africa.

Van Wyk, B. & Malan, S. 1998. *Field guide to the wild flowers of the highveld*, Second edition. Struik Publishers, Cape Town-South Africa.

Vandermeer, J. & Perfecto, I. 1995. *Breakfast of biodiversity: the truth about rainforest destruction*. Food First Books, Oakland.

Venter, J., Liggitt, B., Tainton, N.M. & Clarke, G.P.Y. 1989. The influence of different land-use practices on soil erosion, herbage production and on grass species richness and diversity. *Journal of the Grassland Society of Southern Africa* 6: 89-98.

Vermeer, J. G. & Berendse, F. 1983. The relationship between nutrient availability, shoot biomass and species richness in grassland and wetland communities. *Vegetatio* 121-126.

Waite, S. 2000. *Statistical Ecology in practice: A guide to analysing environmental and ecological field data*. Pearson Education Limited, Essex.

Warburton, M. & Roland Schulze, R. 2005. Climate Change and the South African Commercial Forestry Sector. Acrucons Report 54 December 2006.

Wells, M.P. 1996. The social role of protected areas in the new South Africa. *Environmental Conservation* 23: 322-331.

Whittaker, R.H. 1972. Evolution and measurement of species diversity. Taxon 21: 213-251.

Wigley, B., Bond, W.J. & Hoffman, M.M. 2010. Thicket expansion in a South African savanna under divergent land use: local vs. Global drivers? *Global Change Biology* 16*:* 964-976.

Wu, J., Shen, Z., Shi, P., Zhou, Y. & Zhang, X. 2014. Effects of grazing exclusion on plant functional group diversity of alpine grasslands along a precipitation gradient on the northern Tibetan plateau. *Arctic, Antarctic, and Alpine Research* 46: 419–429.

Yates, C.J., Norton, D.A. & Hobbs, R.J. 2000. Grazing effects on plant cover, soil and microclimate in fragmented woodlands in south-western Australia: implications for restoration. *Austral Ecology* 25: 36-47.

Zeppel, M.J.B., Harrison, S.P., Adams, H.D., Kelley, D.I., Li, G., Tissue, D.T., Dawson, T.E., Fensham, R., Medlyn, B.E., Palmer, A., West, A.G. & McDowell, N.G. 2015. Drought and resprouting plants. *New Phytologist*: 583–589.

Zeppel, M.J.B., Wilks, J.V. & Lewis, J.D. 2014. Impacts of extreme precipitation and seasonal changes in precipitation on plants. *Biogeosciences* 11: 3083- 3093.

Zisadza-Gandiwa, P., Mabika, C.T. & Kupika, O.L. 2013. Vegetation Structure and Composition across Different Land Uses in a Semiarid Savanna of Southern Zimbabwe. *International Journal of Biodiversity.* 1-5.