VEGETATION ECOLOGY OF THE PUTATIVE PALAEO-KIMBERLEY AND PALAEO-MODDER RIVERS AND THEIR CATCHMENTS, FREE STATE, SOUTH AFRICA

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June 2015

DECLARATION

I declare that this dissertation entitled *Vegetation ecology of the putative Palaeo-Kimberley and Palaeo-Modder Rivers and their catchments, Free State, South Africa* is my own independent work, that it has not been submitted for any degree or examination at any other university and that all the sources that I have used or quoted have been indicated and acknowledged by complete references. I furthermore cede copyright of the thesis in favour of the University of the Free State.

Andri Cornè van Aardt June 2015

Signature:...

I dedicate this thesis to my parents, Hans & Cila

and my sister Marga

ABSTRACT

Vegetation ecology of the putative Palaeo-Kimberley and Palaeo-Modder Rivers and their catchments, Free State, South Africa

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The Free State is often seen as a flat and boring landscape with no prominent features in the region. However, when looking at the western Free State an intriguing landscape with numerous pans is revealed. Several researchers have investigated this area and the reason for the existence of these pans is still unclear. Suggestions are that these pans might be the remnants of two putative palaeo-rivers (Palaeo-Kimberley and Palaeo-Modder). This study investigated the present-day vegetation found in the catchment and investigate data from Baden-Baden that can contribute towards the understanding of the vegetation during the past and specifically the Quaternary. This will contribute towards the understanding and predicting the vegetation and climatic changes in the future.

This study was conducted in the western parts of the Free State between the Vet- and Modder Rivers. Southern Africa's geology and topography was influenced by the break-up of Gondwana; some of these imprints are still present today. Geologically the Free State is mostly dominated by the Karoo Super Group with the Beaufort and Ecca Groups as well as dolerite outcrops prominent in the western Free State. The topography is relatively flat with some depressions bordered by the presence of lunette dunes on the south-eastern sides. Dolerite outcrops provide some small hills in the undulating landscape. Climatically the area falls within the Highveld climatic region with cold and dry conditions due to the high elevation. Rainfall is confined to the warm summer months (October to March), while the

winters are mostly cold and dry (summer-rainfall). Thunder storms in the afternoon and early evenings are the main source of precipitation.

The rainfall in the Free State decrease towards the western parts, while the evaporation increase. The high evaporation of the western Free State is much more important in terms of the semi-arid climate than the low rainfall of the area. Summer rainfall is highly variable as the past two years experienced below average rainfall in the area.

Life on land depends on complex interactions between geology, climate, landscapes, organisms and community structures that are shaped by the features, but which themselves also contribute to the evolution of the ecosystem structure. Thus, a strong association exists between habitat shifts and species diversification. The geology, topography, soils and climate of the study area have changed over time. Landscapes are characterised by the three elements of structure, process and change. The landscape makes an imprint on the vegetation and changes in the landscape cause changes in the vegetation. Today's vegetation in the western Free State is thus, the product of the present environment but also of the past.

The region's vegetation falls in two biomes. The Grassland biome (between sea level and an altitude of 2 850 m above sea level) occurs mostly on the central plateau of South Africa and the Savanna biome (present below 1 500 m above sea level) in areas with a strong seasonal rainfall and a dry season mostly in winter. Patches of Inland Azonal Vegetation (present at 1 000 m to 1 600 m above sea level) are also present in the western Free State. Eleven different vegetation types occur in the study area.

During this study 410 sample plots were placed in homogenous vegetation types in the western Free State. The Braun-Blanquet method has been applied to study the present-day vegetation. Analysis of the present day vegetation led to the identification of 24 different plant communities, 43 sub-communities and 29 variants. The communities were grouped into community-groups that occur in the wetland and water related areas, the grassland and karroid communities occurring on the plains

and the woody communities limited to the dolerite outcrops and some deep sandy areas on the plains.

Reconstructing the changes in vegetation during the past is done by using fossil pollen from peat deposits around springs. These pollen deposits are limited to organic sediments which are rare in the semi-arid and arid areas of South Africa and thus the western Free State. Sites such as Florisbad, Deelpan etc. have been investigated in previous studies and revealed an alteration between wet and dry periods from these data sources gaps in the chronological timescale has been revealed. These gaps are partially filled by the data from Baden-Baden, a thermal spring near Annaspan. In this study pollen from the Baden-Baden sediments was extracted, mounted on slides, counted and identified under a microscope. The results revealed the first presence of pollen during isotope stage 2 in the central parts of South Africa. Future research can provide further insights into the development of the Grassland biome and the changes in climate. This will contribute towards understanding and predicting the vegetation and climatic changes in the future.

Keywords:
Palaeo-rivers, Braun-Blanquet, vegetation classification, Baden-Baden, pollen analysis, climate change

June 2015

OPSOMMING

Vegetation ecology of the putative Palaeo-Kimberley and Palaeo-Modder Rivers and their catchments, Free State, South Africa

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Die Vrystaat word gesien as ‘n plat en vervelige landskap met min kenmerkende eienskappe. Wanneer daar egter gekyk word na die westelike Vrystaat, word die landskap gekenmerk deur die teenwoordigheid van verskeie panne. Verskeie navorsers het al die oorsaak van hierdie panne ondersoek. Hul oorsprong is egter steeds onduidelik. Voorstelle dui daarop dat die panne oorblyfsels van twee moontlike oer-riviere (Palaeo-Kimberley en Palaeo-Modder) kan wees. Hierdie studie ondersoek die huidige plantegroei wat in die opvangs gebied gevind word. Verder is data vanaf Baden-Baden bestudeer wat ‘n bydrae kan lewer om die oer-plantegroei, spesifiek uit die Quaternêre periode, te verstaan. Hierdie sal ‘n bydrae lewer tot die kennis en voorspelling van plantegroei- en klimaatsveranderinge in die toekoms.

Die studie het plaasgevind in die westelike dele van die Vrystaat tussen die Vet- en Modderriviere. Die geologie en topografie van suidelike Afrika is beïnvloed deur die opbreek van Gondwana, sommige van hierdie oorblyfsels is steeds vandag sigbaar. Geologies word die Vrystaat deur die Karoo Super Group met Beaufort en Ecca Groepe asook doleriet indringings gedomineer. Hierdie gesteents is ook in die westelike Vrystaat sigbaar. Die topografie is relatief plat met panne wat begrens word deur windgewaaide duine aan die suid-oostelike kante. Die doleriet-indringings veroorsaak lae koppies in die golwende landskap. Klimaatsgewys, is die area in die Hoëveldse klimaat-streek geleë, met koue en droë toestande as gevolg van die hoë

ligging. Reënval is meestal beperk tot die warm somer maande (Oktober tot Maart), hierteenoor is die winters meestal koud en droog (somerreënval). Donderstorms in die middag en vroeë aand is die hoof bron van reënval in die gebied.

Die reënval in die Vrystaat neem af na die weste, terwyl die verdamping toeneem. Die hoë verdamping in die westelike Vrystaat is belangriker in terme van die semi-ariede klimaat as die lae reënval van die gebied. Somerreënval is hoogs wisselend met onder gemiddelde reënval die afgelope twee jaar in die gebied.

Lewe op land, hang van komplekse interaksies tussen geologie, klimaat, landskappe, organismes af en gemeenskapsstrukture word gevorm deur eienskappe wat self ook 'n rol in die ontwikkeling van die ekosisteem se struktuur speel. Dus is daar 'n sterk verband tussen habitats verskuiwings en spesie-afwisseling. Landskappe word gekenmerk deur drie elemente naamlik; strukture, prosesse en veranderings. Die landskap het 'n invloed op die plantegroei en verandering in die landskap veroorsaak veranderings in die plantegroei. Die hedendaages plantegroei van die westelike Vrystaat is dus die resultaat van die huidige omgewing, maar ook van die verlede.

Die area se plantegroei val in twee biome. Die Grasveld-bioom (tussen seevlak en 'n hoogte van 2 850 m bo seevlak) kom meestal voor op die sentrale plato van Suid-Afrika en die Savanna-bioom (teenwoordig laer as 1 500 m bo seevlak) in gebiede met 'n sterk seisoenale reënval en 'n droë seisoen meestal in die winter. Stande van Binnelandse A-sonale plantegroei (teenwoordig tussen 1 000 m tot 1 600m bo seevlak) is ook teenwoordig in die westelike gedeelte van die Vrystaat. Elf verskillende plantegroei-tipes kom in die studie area voor.

Tydens die studie is 410 persele in eenvormige plantegroei-tipes in die studiegebied uitgesit. Die Braun-Blanquet-metode is gebruik om die huidige plantegroei te bestudeer. Die ontleding van die huidige plantegroei het tot die identifikasie van 24 verskillende plant gemeenskappe, 43 sub-gemeenskappe en 29 variante gelei. Die gemeenskappe is in gemeenskap groepe wat in vleilande en water verwante areas voorkom, die grasveld en karoo-agtige gemeenskappe, op die vlaktes, en houtagtige

gemeenskappe wat tot die doleriet-indringings en diep sanderige areas op die vlaktes beperk is, saam gegroepeer.

Die veranderings in die plantegroei gedurende die verlede word met behulp van fossielstuifmeel bepaal. Dit kom in organiese lae rondom fonteine voor. Die stuifmeelafsettings is beperk tot organiese sediment wat in die semi-ariede en ariede areas van Suid-Afrika en ook die westelike Vrystaat skaars is. Fossielstuifmeel uit plekke soos Florisbad, Deelpan en andere is al ondersoek en het ‘n wisseling tussen nat en droë periodes getoon. Uit hierdie inligting is die gapings in die chronologiese tydskaal geïdentifiseer. Hierdie gapings word gedeeltelik aangevul deur data van Baden-Baden, ‘n warmbron naby Annaspan. In hierdie studie is stuifmeel onttrek uit die sediment van die Baden-Baden fontein, gemonteer op voorwerpglasies en onder ‘n mikroskoop getel en geïdentifiseer. Die resultate toon die teenwoordigheid van stuifmeel tydens die tweede isotoop-fase in die sentrale deel van Suid-Afrika. Toekomstige navorsing kan verdere insigte verskaf in die ontwikkeling van die Grasveld-bioom en die veranderinge in die oer-klimaat.

Sleutelwoorde:

Oer-riviere, Braun-Blanquet, plantegroei klassifikasie, Baden-Baden. Stuifmeel analiese, klimaatsverandering

Junie 2015

ACKNOWLEDGEMENTS

I wish to thank the following:

- My Lord, Jesus Christ, for the strength, ability and insight to complete this study.
- Prof. Johann du Preez (promoter), for his guidance and insights.
- Prof. Louis Scott (co-promotor), for the learning of new skills as well as his guidance and insights in the field of palynology.
- Prof. Franci Jordaan for her assistance with the ordination.
- The Water Cluster at the University of the Free State for funding the project.
- The farmers in the western Free State who allowed me access to their properties.
- Linde de Jager for all the hours spent in the field, conducting fieldwork.
- Adriaan Smit, Alex de Gouveia, Beanelri Janecke, Ingrid Allemann, Linde de Jager and Riaan Bouwer for their encouragement and support.
- My parents, Hans and Cila, and sister Marga for all the love, support and encouragement during the study.




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SYMBOLS AND ABBREVIATIONS

AI	Aridity index
a.m.s.l	Above mean sea level
BP	Before present
c.	Approximately
Ca	Calcium
$CaSO_4$	Calcium sulphate
CCA	Canonical Correspondence Analysis
CH_4	Methane
cm	Centimetres
cmol	Centi-mol charge
CO_2	Carbon dioxide
E	East
ESR	Electron spin resonance
etc.	Etcetera
ha	Hectare
ha/km^2	Hectare per square kilometre
HCl	Hydrochloric acid
HF	Hydrofluoric acid
K	Potassium
ka/kyr	Thousand years ago
km	Kilometres
km^2	Square kilometres
KOH	Potassium hydroxide
LSA	Late Stone Age
m	Metre
MAP	Mean annual precipitation
mm	Millimetres
Mg	Magnesium
$mm\ yr^{-1}$	Millimetres per year
m/s	Meters per second
MSA	Middle Stone Age
my	Million years
mya	Million years ago
Na	Sodium
NaCl	Sodium chloride
NE-SW	North-east-south-west
OSL	Optically stimulate luminescence
S	South
SAI	Summer aridity index
Sr	Strontium
yr	Year
$ZnCl_2$	Zinc-chloride
°	Degrees
°C	Degrees Celsius
$\delta^{13}O$	Delta thirteen Oxygen
%	Percent/percentage
µm	Micrometres

±	More or less
>	More than
<	Less than

SECTION I

CHAPTER 1
INTRODUCTION

1.1 GENERAL INTRODUCTION

Plant ecology is seen as the basic building block in every ecosystem (Van Zinderen Bakker, 1967a; Kent and Coker, 1992; Kent, 2007; Kent 2012). This is due to the fact that every ecosystem is comprised of different components including vegetation which in turn is composed of individual plants (Kent and Coker, 1992; Keddy, 2007; Kent, 2012). These individual plants are the primary producers and the physical representation of the ecosystem and therefore shape the habitats for other organisms (Van Zinderen Bakker, 1967a; Kent and Coker, 1992; Kent, 2012).

The future of the ecosystems on earth depends on an ecological understanding of all compartments and interferences of earth's nature and that by understanding natural processes mankind will be able to manage future environmental problems (Van Zinderen Bakker, 1993).

A flat, dry and featureless region of South Africa is what often comes to mind when one thinks about the Free State Province in South Africa, especially its southern and western parts. However, this is a very interesting Province in terms of its geology, landscape and vegetation. The geology is mostly dominated by the Karoo Super Group. The mainly undulating landscape is sloping towards the west. The highest point is situated in the mountainous QwaQwa (eastern Free State, 3 274 m a.m.s.l.). The lowest point in the landscape is near the Modder and Riet River's confluence in the western Free State (1 114 m a.m.s.l.) (Van Rensburg, 1997).

The topography of the province is relatively flat, except for the mountainous areas in the eastern parts. The western parts of the province are particularly very flat. A unique feature of the western Free State is the numerous pans (depressions). The densities of the pans in the Free State are among the highest in the world (Goudie and Wells, 1995). Considering this high pan density the question arises why pans are so numerous in the western Free State?

Marshall (1988) hypothesized that the existence of two putative palaeo-rivers could be related to pan origins, however the true reason for the existence of these pans is to date, still unclear. Several theories about the origin of pans exist. Numerous factors have been considered, e.g., wind erosion, deflation, dry land environmental factors, tectonic activity, volcanism, meteorite impacts, karstic solution, thermokarstic subsidence, glacial excavation, distinct landforms, hoof action of large herds of animals, termite activities, products of relict drainage systems and salinity (Geyser, 1950; Van Zinderen Bakker, 1955; Goudie, 1991; Scott and Brink, 1992; Goudie and Wells, 1995; Partridge and Scott, 2000). Salt pans are also abundant in the western parts of the Free State (Van Zinderen Bakker, 1955; De Bruiyn, 1971).

The climate of the Free State also has a moisture gradient, becoming more arid towards the west and a temperature gradient becoming hotter towards the west (Schulze, 1997). Terrestrial life depends on the complex interactions between geology, climate, landscapes, organisms and community structures that are shaped by the features, but which themselves also contribute to the evolution of the ecosystem structure. The result is a strong association between habitat shifts and species diversification. Over time the geology, topography, soils and climate of the study area have changed. Landscapes are characterised by the elements of structure, process and change. Changes in vegetation are the result of changes in the landscapes and the imprints of these landscapes. The vegetation is comprised of about 3 000 plant species. Today's vegetation of the Free State is therefore the result of the present environment but also of the past as well as the human influences.

Several environmental and vegetation studies were done on parts of the western Free State or areas within the western Free State. These studies include: phytosociological and ecological studies of selected pans and valley-bottom wetlands of the Free State (Collins, 2011), a geological study on the pans in the western Free State (De Bruiyn, 1971), studies on the vegetation of the "Valley of Seven Dams" and wetland and riparian vegetation of natural open spaces in Bloemfontein (Dingaan *et al.*, 2001; Dingaan and Du Preez, 2002), a classification of pans and the vegetation structure with reference to avifaunal communities (Geldenhuys, 1982), vegetation analysis of the Soetdoring Nature Reserve

(Janecke, 2002; Janecke *et al.*, 2003), phytosociological studies on the Ae land type of the Bloemfontein West District (Malan *et al.*, 1994), vegetation ecology studies on the drainage channels of the southern Free State (Malan *et al.*, 2001), phytosociological studies on the vegetation of the central Free State (Müller, 2002), a study on the geomorphological evolution of the north-western Free State (Myburgh, 1997) and a study on the riparian and associated wetland vegetation along the Vet River (Van Aardt, 2010).

Clegg and O'Connor (2012) mentioned that we are living in an era of global change where information on changes in vegetation over time plays a role in decision making. Vegetation studies, describing the vegetation of an area, contribute towards keeping record of the current state of the environment. The understanding of these studies can assist in the understanding of climate change in the future. Vegetation studies can also contribute towards the efficiency of decision making for management programmes and the assembly of conservation policies for ecosystems and biodiversity (Clegg and O'Connor, 2012; Brown *et al.*, 2013).

1.2 OBJECTIVES OF THE STUDY

The aim of this study is to investigate and characterise the vegetation in the western Free State and to search for ecological explanations for its current species composition including the possible role of long-term influences from the Quaternary Period. The vegetation study is supplemented with studies on the preliminary palynological evidence of the study area. Palynology deals with plant remnants in the form of fossil pollen and microscopic charcoal. The intensified study of pollen is used to relate the change in vegetation relationships over time with climatic change (Reitalu *et al.*, 2014).

The objectives of this study are:

- to assess, classify and describe the natural vegetation in the western Free State (vegetation ecology);
- to investigate palaeo-ecological evidence in the literature and

- to investigate if pollen samples from the Baden-Baden could provide palaeo-ecological evidence for the reconstruction of the long-term vegetation history of the study area.

1.3 REPORT STRUCTURE

The aims of the different chapters in this thesis are as follows:

Section I: Chapters 1-6 is an introduction to the thesis and an overview of the study area as well as a literature overview of the topic:

Section II: Chapter 7 discusses the various methods used to assess, classify and describe the present-day vegetation as well as some methods to analyse the palynological data:

Section III: Chapters 8-11 deal with the results and discussions of the various studies conducted:

Section IV: Chapter 12 is the conclusion chapter where various conclusions will be drawn on the results obtained:

Section V: References and Appendixes.

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CHAPTER 2
STUDY AREA

2.1 LOCATION

The area of study falls within the boundaries of the Free State Province which is situated on the Highveld, a high interior plateau of Southern Africa. The Highveld's average height above sea level is 1 500 m a.m.s.l. The landscape of the Free State gradually slopes towards the west and the main drainage systems of the province are the Vaal and Orange Rivers and their tributaries. These two rivers also form the northern and southern borders of the Free State respectively (Holmes *et al.,* 2008). The study area is located in the western part of the Free State province between 25°E and 27°E longitude and 28°S and 29°S latitude.

The study area (Figure 2.1) is surrounded by the towns of Bloemfontein in the south-east, Kimberley in the south-west, Christiana in the north-west and Welkom in the north-east.

The Free State constitutes 12.9 million ha of South Africa's 122.8 million ha (Hensley *et al.*, 2006). Of the 12.9 million ha of the Free State, 11.8 million ha is used for both grazing and crop production purposes (Hensley *et al.*, 2006). The size of the study area is approximately 1.7 million ha.

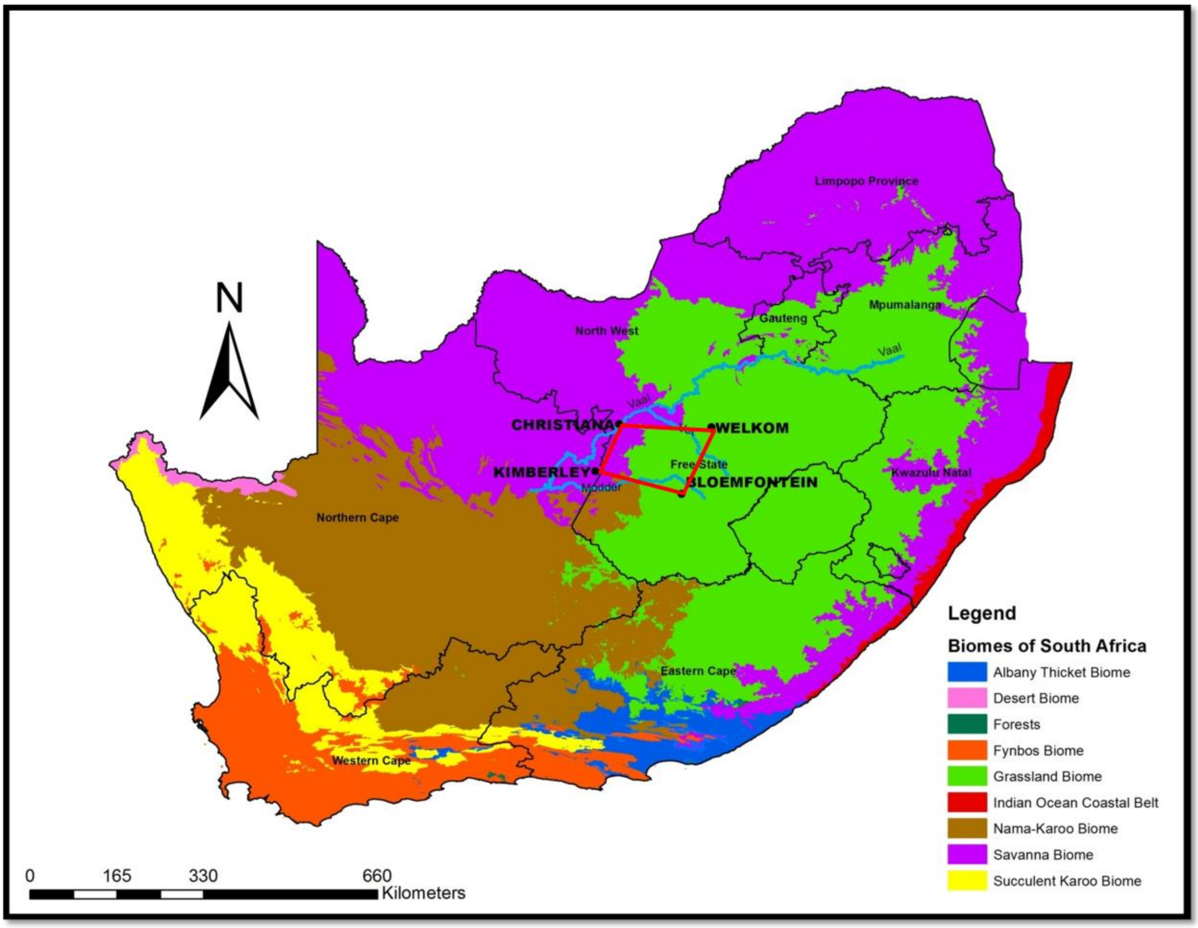

Figure 2.1: Map indicating the study area (red block) between the Vet and Modder Rivers, The major towns near the study area are, Bloemfontein, Kimberley, Christiana and Welkom. Biomes after Mucina and Rutherford (2006).

2.2 ABIOTIC FACTORS

2.2.1 Climate

Macroclimate can be defined as the long range pattern of weather (Schulze, 1997). Of the three great natural patterns (climate, vegetation and soil) that dominate environments present on earth, climate is the most important. Climate is seen as an independent variable that shapes both vegetation and soil patterns. Vegetation is affected by climate in the sense that the life-cycle of a plant is dependent on the variation of climatic processes (Schulze, 1997).

Climatic factors that have an important effect on vegetation development include light, temperature and moisture. All the mentioned factors vary on a sub-continental scale as well as on a meso- and micro-scale. It is important to know that the climatic parameters cannot be treated individually, but must be seen in a combination. The different climatic parameters operate in combination to produce a relatively homogeneous environment that is suitable for certain plants (Schulze, 1997). Climate therefore, influences the vegetation both directly and indirectly. The direct effects include solar radiation, temperature and moisture – determining the distribution of species. The indirect effects include soil conditions, fire regimes, etc. (Schulze, 1997).

2.2.2 Circulation patterns in South Africa

The climate of South Africa is mostly arid to semi-arid, due to the fact that South Africa is almost completely situated within the high pressure belt of the Southern Hemisphere (Schulze, 1972). The high pressure belt occurs above a shallow layer of maritime air and therefore, leads to a temperature inversion due to the subsidence of the upper atmosphere. The inversion is present at plateau level and is strongest on the west coast because of the cold Benguela Current (Schulze, 1972).

A seasonal displacement of 4° latitude moves the high pressure belt to the furthest south in February and to the furthest north in July-August. The difference in heating during summer and winter over the South African landmass causes the high pressure belt to split into two cells; namely, the Atlantic and Indian Ocean High respectively (Schulze, 1972). During the summer months, shallow low pressure persists over the land, which leads to an influx of moist tropical air. An intensified high pressure over the land during winter time prevents the entry of maritime air onto the continent (Schulze, 1972).

The Southern Hemisphere`s westerly circulation dominate the weather changes that occur in South Africa. The effect is, however, more apparent in winter than in summer. The disturbances caused by the westerly circulation occur in the form of cyclones and anticyclones. Cyclones that affect the continent have their origins in the South Atlantic Ocean (Schulze, 1972).

The following components of the macro climate will be discussed in more detail, namely: solar radiation, temperature, precipitation, climate diagrams, potential evaporation and wind.

2.2.2.1 Solar radiation (Sunshine)

Solar radiation is the energy source of almost all ecosystems. Therefore, ecosystems depend on the quantity and quality of incoming solar radiation. This quantity and quality of solar radiation vary seasonally; however, in South Africa, solar radiation seldom limits plant growth (Schulze, 1997). The occurrence of the high pressure belt of the Southern Hemisphere is the reason for the abundant sunshine in South Africa (Schulze, 1972). The duration of possible sunshine vary from 80% on the western interior of South Africa to between 50% and 60% on the southern and eastern coastal areas. The minimum amount of sunshine in South Africa during extreme years seldom falls below 40% (Schulze, 1972).

In the area of study the sunshine received varies between 70 to 80% of the possible sunshine duration. This duration is possible even during the peak rainy season when cloudy days are more frequent (Schulze, 1965).

2.2.2.2 Temperature

Temperature is a term used to describe the energy status of the environment. The energy status of the environment influences the distribution of vegetation (Schulze, 1997).

On the African continent more specifically southern Africa’s temperature variation is induced by the difference in topography. The climate in southern Africa is strongly influenced by the ocean currents. On the east coast, the warm Mozambique Current ensures that the minimum temperature in winter does not average below 8°C (Schulze, 1997). The interior plateau of South Africa may experience temperatures below freezing point, although the average minimum is 0°C (De Bruiyn, 1971; Schulze, 1997). The temperatures in the area of study range between 15°C to 33°C in summer and between 0°C and 17°C in winter (Schulze, 1965). However, Schulze (1965) mentioned that the summer temperatures might reach a high of 41°C and the winter temperatures a low of -11°C.

The occurrence of frost, mostly hoar frost (a thin layer of ice crystals, forming patterns, seen on exposed surfaces that have chilled to below freezing temperature by radiation cooling, thereby reducing the temperature of the air in contact with the surfaces and raising its humidity to saturation (Allaby, 2010)) (Schulze, 1972), in the high-altitude and valley areas of southern Africa`s interior is a common phenomenon (Schulze, 1997). The presence of very dry, cold air from the south can lead to the occurrence of black frost (a dry freeze, without hoar frost resulting in internal freezing and death of vegetation) (Schulze, 1972). Frost occurs in the coldest period of the year, which is during the months of June to August (Schulze, 1997). Schulze (1972) mentioned that frost occur during the winter months, which start in April and end in September. The months in which frost is more likely to occur are from mid-May to mid-September.

A few environmental conditions are favourable for the occurrence of frost (Schulze, 1972):

(1) The interior part of South Africa experiences a loss of heat radiation due to a dry atmosphere and clear skies in winter; this phenomenon is not common along the coastal areas, although frost may occasionally occur along the coast.

(2) Surface layers that prevent the conduction of heat from soil layers lower down in the profile; layers that prevent heat conduction are something such as grass or loosely tilled soil.

(3) An inversion of temperature; due to stratification of air, because of wind absence, is regularly present in the interior of South Africa. The above mentioned conditions are influenced by topography. Topography further influences the north- and south-facing slopes. More heat is received by the north-facing slopes and is, therefore, less susceptible to frost (Schulze, 1972).

The effects of frost are intensified by aridity or along increasing elevation gradients (Mucina and Rutherford, 2006). Frost, therefore, has a critical influence on the distribution of plants. Certain plants have certain physical and biological mechanisms to protect them from freezing; however, none provides complete protection from below zero temperatures (Schulze, 1997). The study area experience between 120 to 150 days of frost during, May to September (Schulze, 1965).

2.2.2.3 Precipitation

Water is seen as the molecule of life, and therefore, plays an important role in the distribution of vegetation on the earth's surface (Schulze, 1972; Van As *et al.,* 2012). Water is important for the development of the plant as well as the physiological and biological processes that occur in the plant – energy exchange and nutrient transportation. Precipitation can occur in different forms, which include rainfall, fog and snow. From a South African perspective rainfall and fog is the most important. All the rain falling on the surface of the earth is not available to the plants; rain can be intercepted by plants, runoff in streams, percolate into the deep soil layers or evaporate (Schulze, 1997).

There is a uniform decrease of mean annual precipitation in a westward direction from the escarpment across the plateau (Figure 2.2) (Schulze, 1972; Schulze, 1997). A quarter of southern Africa receives less than 250 mm yr^{-1} and only 8% of southern Africa has a mean annual precipitation of 750 mm (Schulze, 1997).

Annual rainfall changes from year to year and the variability in rainfall increase in the interior from east to west (Schulze, 1972; Scott, 1989). A wide precipitation range occurs in the Free State, however the province is characterised by a water deficiency as indicated by the Aridity Index (AI). The climate can therefore be seen as semi-arid with an AI of 0.2 – 0.5 (Hensley *et al.*, 2006). This semi-arid climate is due to the fact that evaporation (which is higher than the rainfall) plays a more important role than the low rainfall (De Bruiyn, 1971).

The rainfall in the area of study varies between 250 – 600 mm per year (Schulze, 1965; Geldenhuys, 1982). Not only is the amount of precipitation important, but also the season in which the rainfall occurs. The study area falls within the summer-rainfall region (Schulze, 1965; Schulze, 1997; Geldenhuys, 1982) where rainfall occurs between the months of October to March (Schulze, 1972). Most of the rainfall, in the summer rainfall area's interior, occurs in the afternoon and early evenings in the form of thunderstorms (Schulze, 1972). In early summer thunderstorms are often accompanied by hail. The hail storms can sometimes cause severe damage (Schulze, 1965).

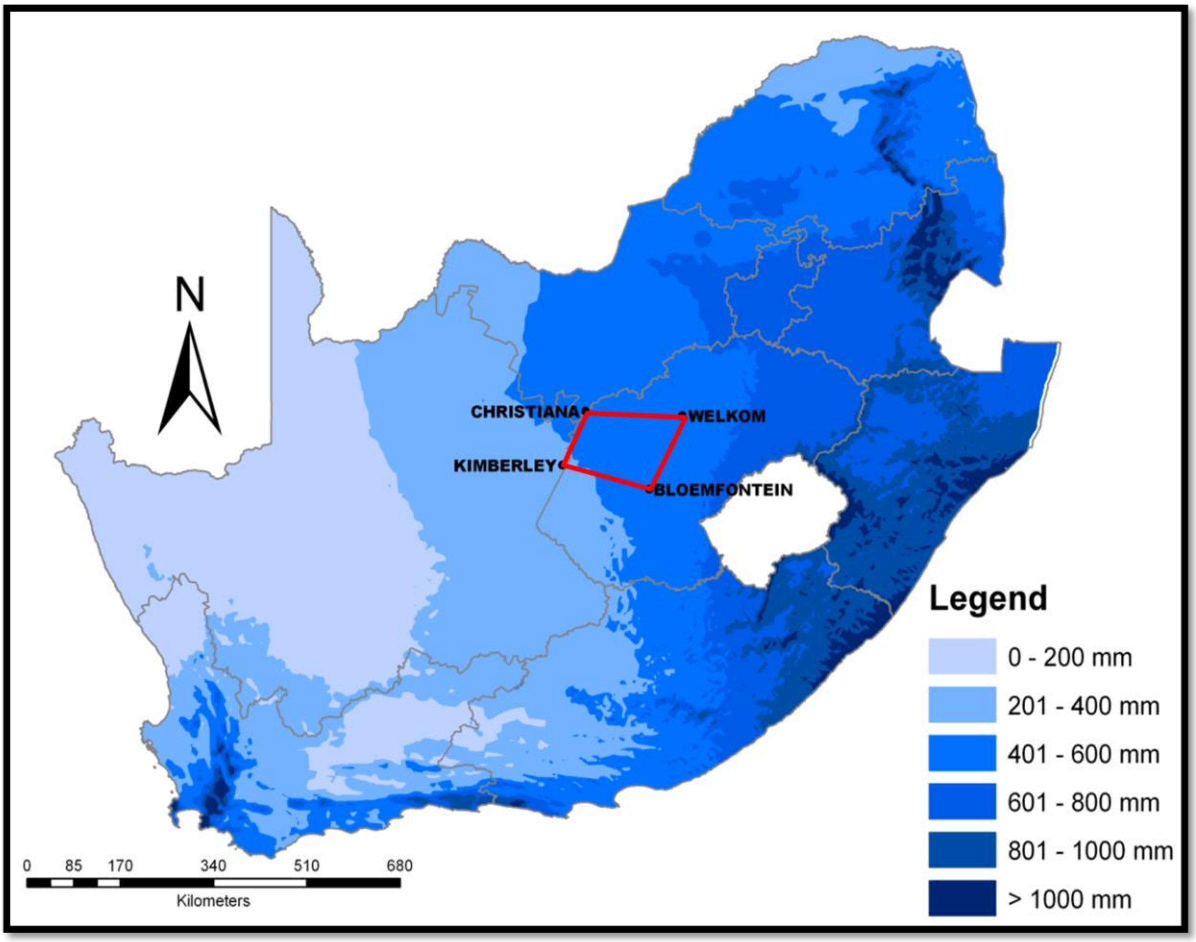

Figure 2.2: Map of the mean annual precipitation in South Africa after Schulze (1997). Red block indicates the study area.

Lightning is considered a natural cause of veld fires in the grassland and savanna biomes of southern Africa. In the summer-rainfall areas, fires ignited by lightning become soon extinguished by the accompanying rainstorm (Schulze, 1997). High lightning flash densities, especially in high-lying areas increase the likelihood of lightning-induced fires (Mucina and Rutherford, 2006).

South Africa and other countries with similar latitudes experience periodic or prolonged droughts. Drought conditions are reached when the total rainfall for a 12 month period is below 75% of the annual average within that region. The drought will persist until rainfall exceeds the below annual average of 75%. The periods of drought may vary in lengths of periods of duration (Schulze, 1972). Schulze (1972) mentioned that in South Africa the drought period can vary from 169 to 331 days.

2.2.2.4 Climate diagrams

Climate diagrams for the study area were compiled from data supplied by the South African Weather Service. The average daily maximum, averaged daily minimum and total rainfall for each month were calculated over a period of eleven years (2000 – 2010). The calculated values are represented for the weather stations at Welkom (Figure 2.3), Bloemfontein (Figure 2.4) and Taung (Figure 2.5).

When looking at the climate diagram of Welkom (Figure 2.3) the average daily maximum and minimum temperatures are cooler during autumn/winter than the spring/summer months. It is also clear that the rainfall of the area is mostly limited to late spring and summer (November to February). However, March also show relative amounts of rainfall.

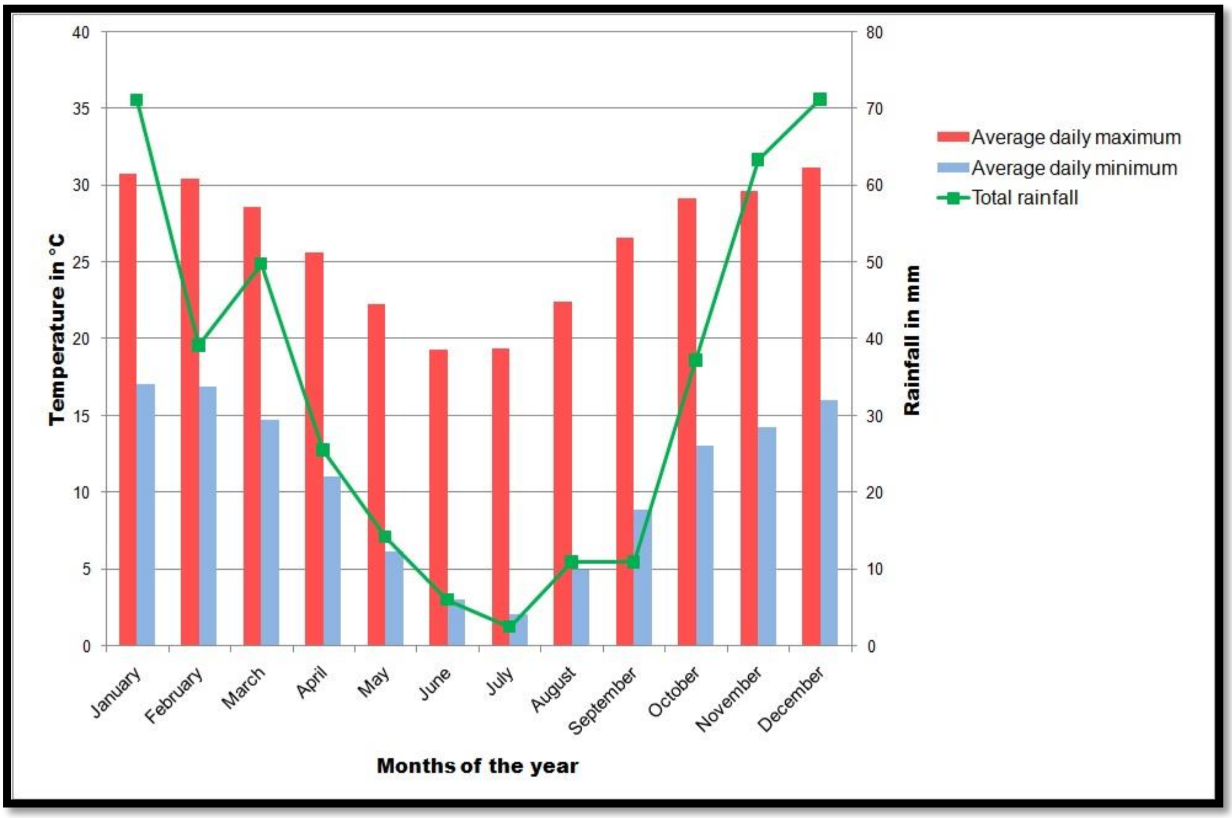

Figure 2.3: Climate diagram for the period 2000 to 2010 from the weather station at Welkom (after the data from the South African Weather Service).

The weather station at Bloemfontein (Figure 2.4) shows temperatures during winter that are below freezing point. This is the only weather station in the area of study that has winter temperatures below freezing point. The trend for temperatures is similar to the station at Welkom. The colder temperatures are limited to the winter months during which the rainfall are also lower. The summer months show high temperatures and higher rainfall.

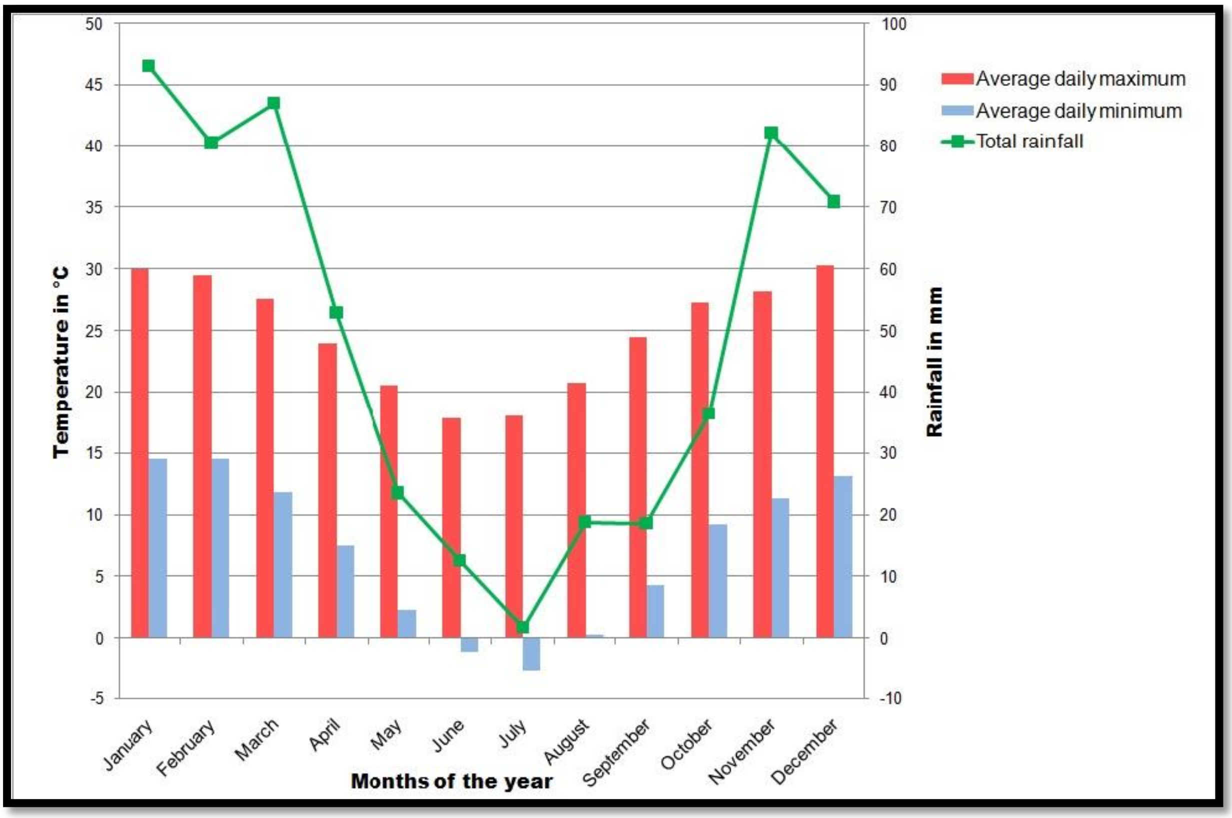

Figure 2.4: Climate diagram for the period 2000 to 2010 from the weather station at Bloemfontein (after the data from the South African Weather Service).

The Taung weather station (Figure 2.5) that occurs close to the north-western boundary of the study area also shows low temperatures and rainfall during the winter months. The higher rainfall and higher temperatures occur during the summer months.

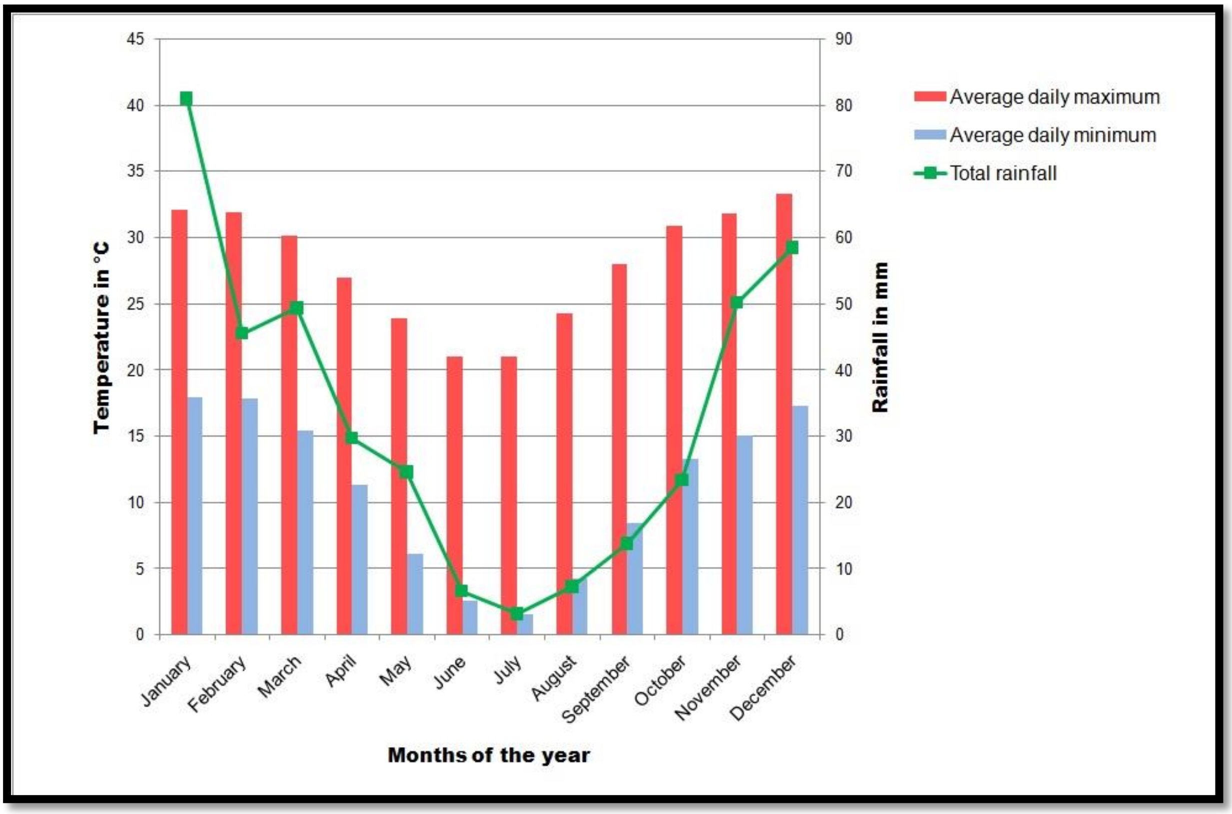

Figure 2.5: Climate diagram for the period 2000 to 2010 from the weather station at Taung (after the data from the South African Weather Service).

When looking at the above three mentioned climatic diagrams it is clear that the study area have low winter temperatures and low rainfall. The high temperatures and high rainfall occur during the summer months.

2.2.2.5 Potential evaporation

Evapotranspiration can be described as the loss of water through the process of transpiration, from the leaves of a growing plant as well as the water that evaporates from the soil and the plant surface. Evaporation is affected by factors such as radiation, wind and vapour pressure deficits. It is estimated that 91% of the mean annual precipitation of southern Africa is returned to the atmosphere via evaporative losses. The global average of evaporative losses is only 65%. Evaporation rates in southern Africa are similar to rainfall patterns; in the sense that areas with the lowest rainfall have the highest evaporation rates (Figure 2.6). Therefore, the evaporation increases from east to west across southern Africa (Figure 2.6) (Schulze, 1997).

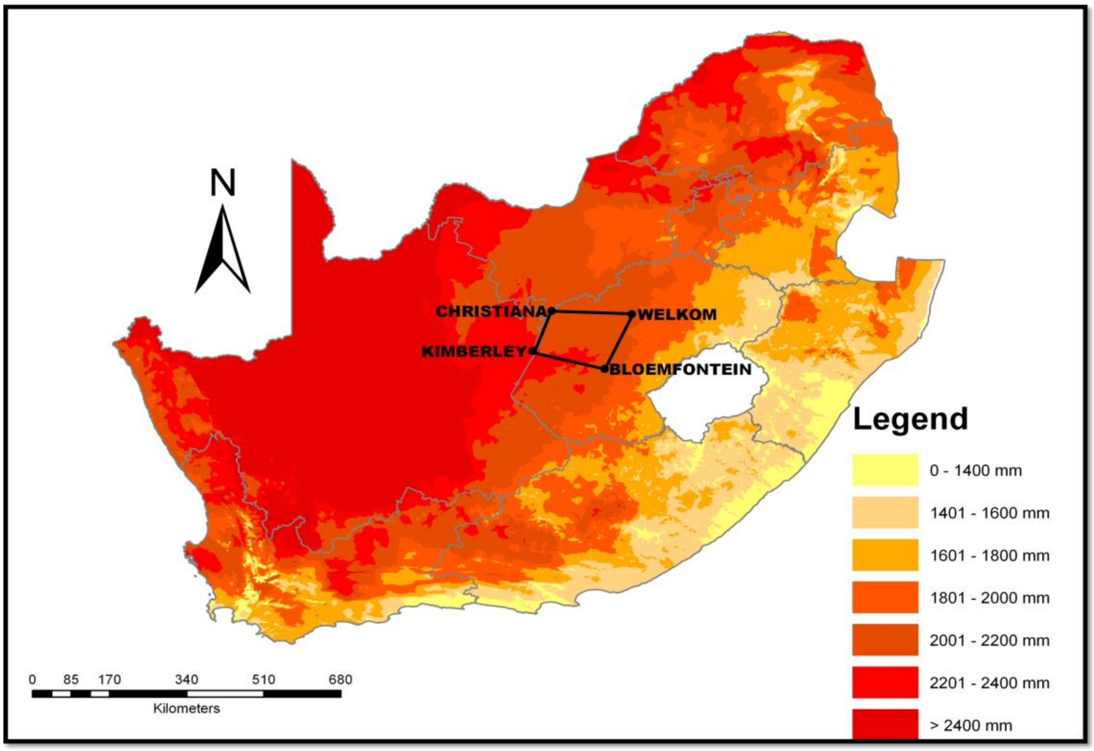

Figure 2.6: Map of the potential evaporation for South Africa. Black block indicates the study area.

2.2.2.6 Wind

Schulze (1972) reported that the central interior of South Africa experiences little seasonal change in wind direction. However, Holmes *et al.* (2008) mentioned the high variability of the present-day winds. Holmes concluded that the main wind direction is north to north-east. During late winter, the north-westerly winds are associated with cold fronts (Holmes *et al.*, 2008). The prevailing wind direction according to Schulze (1972) is from the northern sector, however, the passing of a thunderstorm may change the direction to the southern sector. On hot days, the interior experience whirlwinds or dust-devils which is a common phenomenon (Schulze, 1972). Wind plays an important role in the climate because of an increase in the amount of evaporation (De Bruiyn, 1971).

Different weather stations in the vicinity of the study area were used to determine the prevailing wind direction. Weather stations included are the weather stations of Bloemfontein, Taung and Welkom. From the wind rose for Bloemfontein (Figure 2.4) it is clear that the prevailing wind direction is from the north. Other important wind directions include the north-north-east and the north-east. From figure 2.7, it is also clear that the wind speed is mostly between 3.5 – 5.6 m/s.

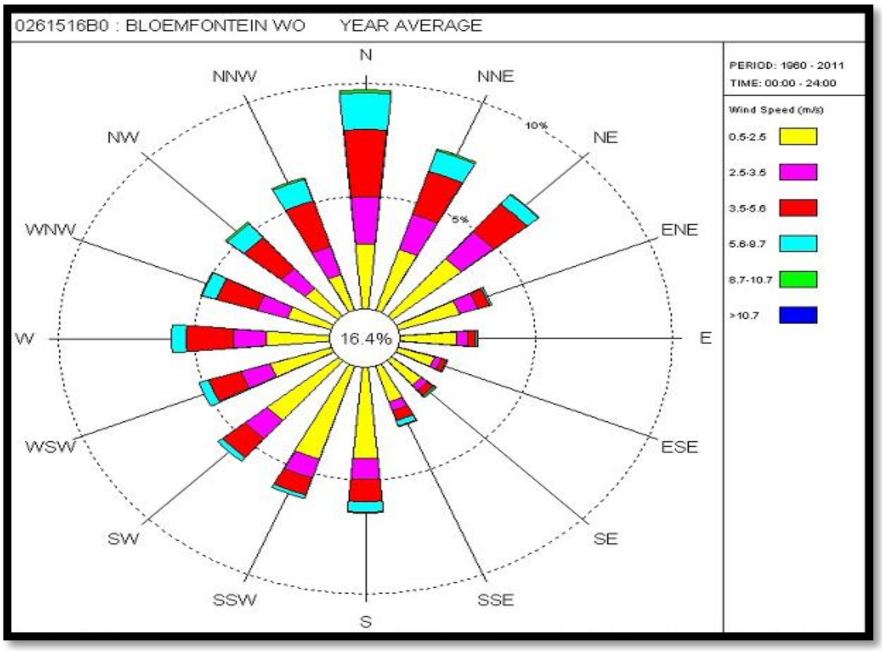

Figure 2.7: Wind rose showing the dominating wind direction in the Bloemfontein area during the period of 1960 to 2011 (supplied by the South African Weather Service).

The wind rose of Taung (Figure 2.8) Weather Station, situated on the north-western side of the study area, indicates that the dominant wind direction is north-north-west. Winds in this area can also occur from the north and the south. At Taung, the wind speed is also mostly between 3.5 – 5.6 m/s.

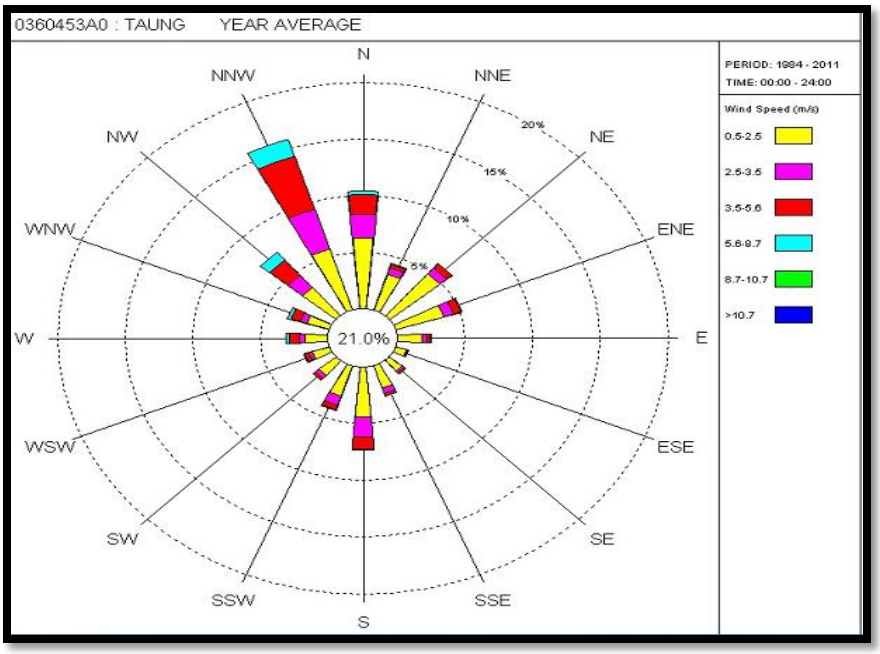

Figure 2.8: Wind rose showing the dominant wind direction in the Taung area during the period of 1984 to 2011 (supplied by the South African Weather Service).

The wind rose of the Welkom weather station (Figure 2.9) indicates that the dominant wind direction is mostly from a northern direction. However, winds from the north-north-eastern and north-eastern directions also occur frequently. The speed of the prevailing winds is mostly 3.5 – 5.6 m/s.

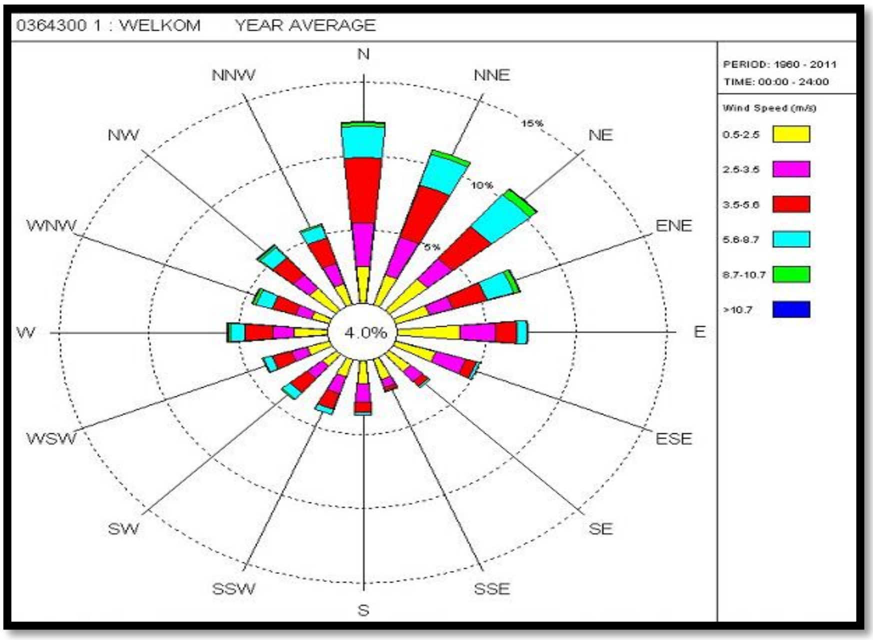

Figure 2.9: Wind rose showing the dominating wind direction in the Welkom area during the period of 1960 to 2011 (supplied by the South African Weather Service).

Lastly, wind also plays an important role in the movement of sand particles, exposed in areas devoid of plant cover. This movement of the sand particles causes erosion in the area of study. Wind erosion is most active during spring, when the prevailing wind comes from the west. During the months of summer, the prevailing wind direction is from the north, with constant wind strength. During the winter a high pressure system dominates the atmosphere in the interior and this causes the wind to blow away from the interior instead of towards the interior (De Bruiyn, 1971).

2.3 GEOLOGY

The African continent is regarded by geologists as a massive plateau which is since the Precambrian (~545 mya) relatively stable, however it has experienced upliftment at a later stage. Volcanic activity is still present on the continent; however, mostly along the Great Rift Valley (Griffiths, 1972). The southern African geology will be discussed in detail in Chapter 3.

The study area's geology is dominated by the Dwyka and Ecca Groups with some parts of the Beaufort Group present in the far east of the study area (Hensley *et al.*, 2006; Johnson *et al.*, 2006). Within these Karoo rocks, post-Karoo dolerite intrusions occur throughout the Free State (Hensley *et al.*, 2006). The grasslands of South Africa occur on a significant portion of the Karoo Supergroup (Mucina and Rutherford, 2006).

The geology mostly comprise of shale, sandy shales and dolerite. The layers of shale erode much easier than the other rocks and therefore, contribute to the undulating landscape. Hills are mostly formed by the presence of dolerite sills and dykes (De Bruiyn, 1971) because dolerite weathers relatively slowly.

2.4 TOPOGRAPHY

The topography of the western Free State is relatively open; a flat area drained by three rivers and their tributaries (Geldenhuys, 1982; Holmes and Barker, 2006). Furthermore, the western part of the Free State, where the study has been conducted, forms the interface between the arid Kalahari to the west and the moister Highveld in the east (Holmes and Barker, 2006).

The landscape of the north-western part of the Free State can be seen as plains with pans (Holmes and Barker, 2006). Numerous deflation pans characterize the western Free State. The altitude ranges from 1 200 to 1 500 m a.m.s.l. (De Bruiyn, 1971; Myburgh, 1997; Geldenhuys, 1982). This area forms the lower-lying areas of the Highveld region. The western parts are irregular plains, with the southern and central parts of the Free State being dominated by lowlands with hills. The eastern part of the Free State has irregular undulating plains with hills, forming low mountains. Most of the slopes occurring in the Free State are less than 5% (Holmes and Barker, 2006).

2.5 SOILS

2.5.1 Introduction

Soil can be defined as the natural, unconsolidated, mineral and organic material occurring on the surface of the Earth; it is a medium for the growth of plants (Allaby, 2010). Brady and Weil (2008) mentioned that most life on Earth depends on soil.

Furthermore, the quality of soil determines the nature of plant ecosystems and their ability to support animal life and society. Soil plays an important role in the ecosystem (Brady and Weil, 2008):

2.5.2 Soil distribution in the study area

Soils are not randomly distributed in the landscape. There are five factors that influence the formation of soil namely: parent material, climate, topography, the interaction of biological factors and time. These processes lead to the development of a specific sequence of horizons forming a soil profile in the landscape. The soil's formation processes in the Free State are mostly dominated by parent material and the climate (Hensley *et al.*, 2006).

Hensley *et al.* (2006) compiled a map (Figure 2.10) which indicates the distribution of different soils in the Free State. In the area of study, most of the soils on the map are present except soils of the I land type.

Soils of the study area are dominated by the presence of aeolian (windblown) sand on rocks of the Beaufort and Ecca Groups. This sand serves as the "parent material" for soils of groups A and B (Figure 2.10). The origin of the sand is mostly from the Vaal River and its tributaries; which has been transported south-eastwards over centuries. This windblown process was enhanced by drier climatic periods in the past. The morphology of the river plays a role in the sand distribution in the study area. The shallow, broad meandering areas of the river have led to the accumulation of more sand on the riverbanks. The sandy soils are divided into group A land types and group B land types (Figure 2.10) (Hensley *et al.*, 2006). In the west, the soils of land type A occur around Petrusville and Hertzogville. While the soils of land type B occurs north-west of Bothaville, Viljoenskroon, Vredefort, Parys and Sasolburg (Hensley *et al.*, 2006).

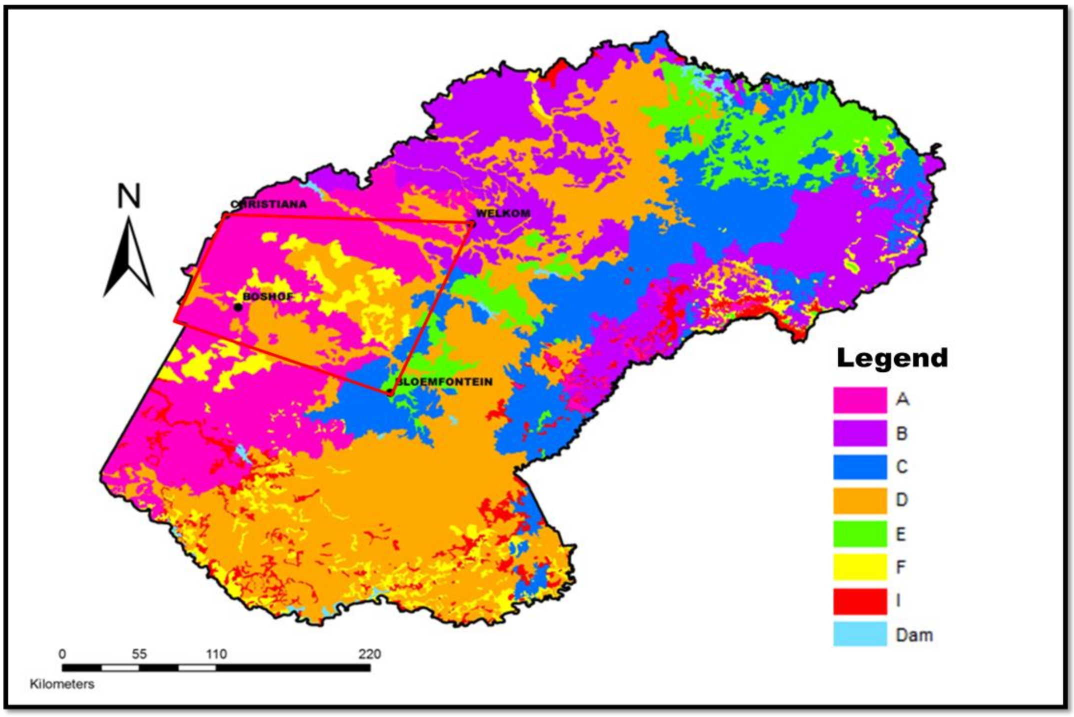

Figure 2.10: Map of the different land types in the Free State Province (after Hensley *et al.,* 2006). Red block indicates the study area.

The soils of land type A (Figure 2.10) are regarded as red-yellow, freely-drained, structureless soils. The soil forms most likely to occur in this region are the Hutton, Clovelly, Kimberley and Plooysburg. This land type covers approximately 16.7% of the Free State. Towards the north, the red apedal B horizon change to a yellow-brown apedal B horizon; due to an increase in rainfall. The result is a shift of the Clovelly Form to the Avalon Form. Other soil forms such as the Molopo and Askham Forms also occur; however, they are rare (Hensley *et al.*, 2006).

Some of the soils in group A are dystrophic (a leached soil with a sum of less than 5 cmol (+) exchangeable Ca, Mg, K and Na (Soil Classification Working Group, 1991) and occur on the plateaus, which are an indication of the influence of time in the process of soil formation (Hensley *et al.*, 2006).

Soils of the B-land type (Figure 2.10) are mostly plinthic catena soils; upland duplex and in rare instances margalitic (an A-horizon, dark in colour, with a high base status and with high Ca and Mg as exchangeable cations (Soil Classification Working Group, 1991)) soils. This land type occupies 17.3% of the Free State. The B-land type of the semi-arid north-west has plinthic soils of the Avalon Form in association with the Westleigh and Pinedene Forms. Hensley *et al.* (2006) reported that the Avalon soils are relatively deep and the Clovelly soils may have plinthic horizons below a depth of 1 500 mm.

Soils from land type C (Figure 2.10) are mostly plinthic catena; upland duplex and margalitic soils, which cover 15.0% of the Free State. These soils are seen as the transition between land types A and B and land type D (Hensley *et al*., 2006).

Soils from the D land type (Figure 2.10) are mostly duplex soils and cover approximately 34.7% of the Free State. Group D land types are mostly dominated by soils of the Valsrivier and Swartland Forms in the uplands and Sterkspruit and Estcourt Forms in the lower parts of the landscape. These soils occur in the arid and semi-arid areas of the Free State. This is due to the homogeneity of the Beaufort and Ecca rocks which weather to form a duplex soil with a coarse textured A horizon and a strong structured clay rich B horizon. The formation of these soils can be attributed to the high sodium content (Hensley *et al*., 2006).

Dark coloured, margalitic clay soils with swell-shrink properties describe the E land type. This land type occupies 7.6% of the Free State. Soils from the E land type are rare, small patches occur between Bloemfontein and Heilbron, as well as between Heilbron and Vrede. The soils of the E land type in the central parts of the province are associated with dolerite dykes and sills. These soils also include small patches of land type F, which include soils of the Mispah and Mayo Forms. North of Heilbron, the dolerite serves as parent material for margalitic black clays with swelling properties such as the – Arcadia and Rensburg Forms as well as the Bonheim and Valsrivier Forms. The B horizon of these soils has strong vertic properties with slickensides, wedge-shaped peds (prisms) and strong structure. The arid areas of the Free State show an absence of land type E, due to the lack of chemical weathering and clay formation because of the lack of water (Hensley *et al*., 2006).

Land type F (Figure 2.10) is mostly present in the mountainous areas of the southern and eastern Free State. This land type has shallow soils on rock (Mispah, Glenrosa and Mayo Forms) and contributes only on 5.5% of the Free State's soils (Hensley *et al*., 2006).

2.6 VEGETATION

South Africa can be subdivided into, nine different biomes (Figure 2.11). A biome is seen as a high-level hierarchical unit where the vegetation structure is composed of similar microclimatic patterns, linked to characteristic levels of disturbance (Mucina and Rutherford, 2006). The study area falls within the boundaries of the Grassland and Savanna biomes. Holmes and Barker (2006) wrote that the western and central Free State can be seen as an ecotone in terms of the rainfall and vegetation. These Grassland and Savanna biomes will be discussed in more detail, together with the various vegetation units within the study area in Chapter 6.

2.7 IMPACT OF AGRICULTURE

The Free State covers 12.9 million ha of South Africa's 122.8 million ha. Of the 12.9 million ha, 11.8 million ha of the Free State is used for farming which includes grazing, dry land and irrigated crop production. Only 270 000 ha of the Free State is available for conservation. Forestry only occurs in 400 ha. The rest of the land which is less than 1 million ha is used for land use other than agriculture, nature conservation and forestry (Hensley *et al.*, 2006). The impacts of agriculture on the natural environment can lead to destruction and degradation (soil erosion, over grazing, fire etc.) which cause the loss of natural habitats and their species (Townsend *et al.*, 2008). Agricultural practices in the study area can be divided into sheep-farming in the south-west and cereal cultivation in the north-east (Geldenhuys, 1982). The intense framing activities in this semi-arid area, with the possibility of changing climate in the future, might cause severe erosion of erodible soils (Wiggs and Holmes, 2011).

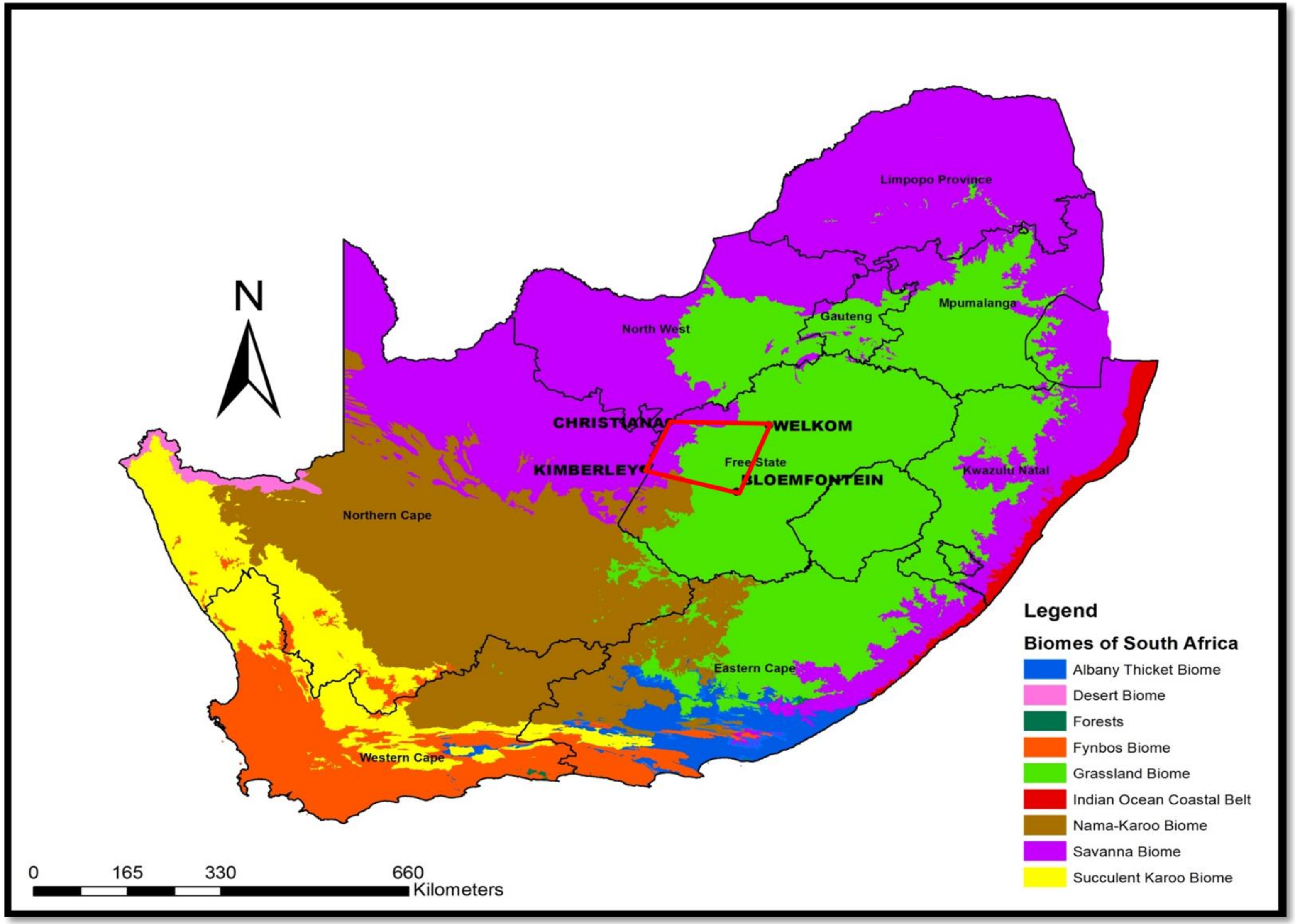

Figure 2.11: The biomes of South Africa after Mucina and Rutherford (2006). Red block indicates the study area.

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CHAPTER 3
THE GEOLOGICAL HISTORY OF AFRICA

3.1 WHY THIS OVERVIEW?

This overview is to put the geology, the southern African landscape, geomorphological features and the palaeontology of the study area in perspective. Since the dawn of time different geological processes shaped the face of southern Africa. Due to all these geological processes and the changes in climate over time southern Africa is rich in minerals, give a clear picture of the history of earth's development and the changes in climate over time as well as provide fossil records on the origin of plants, animals and humans. The erosional processes that shaped southern Africa limited the records of the past, thus records that can be found are of great value. The developments of the different river systems present in southern Africa and how tectonic activity, erosion and the changes in climate over time shaped and influenced these systems will become clear in this overview. Evidence of tectonic activity, shaping the landscape, are visible in the study area and mentioned briefly.

3.2 INTRODUCTION

The African continent differs from most of the northern hemisphere land masses in the sense that it preserves tracts of ancient landscapes. These ancient landscapes had a considerable influence on the evolution as well as the distribution of vegetation. Southern Africa is seen as the face of ancient Africa (McCarthy and Rubidge, 2005; Holmes and Barker, 2006). During the breakup of Gondwana (late Jurassic[1]), Africa occupied the central position of the landmasses, sandwiched between South America (west), Antarctica and India (east) (Maud and Partridge, 1987; Bamford, 2004). Southern Africa is characterised by a coastal plain which is narrow with a low relief. The coastal plain is separated from the inland plateau by a horseshoe-shaped escarpment at more than 1 000 m above sea level (Moore *et al.*, 2009).

[1] Appendix A: Geological timescale.

In terms of geology, South Africa is seen as a very diverse country. Thus, it can be said that South Africa's geology is unique with no other country in comparison. South Africa covers only 1% of the Earth's land surface and within this 1% South Africa produces the following minerals: gold, chromium, diamonds, vanadium, manganese and platinum. As well as other minerals such as: iron, titanium, zinc, coal, fluorspar, refractory minerals and phosphorous as well as copper and lead. South Africa also have a long geological history with rocks dating back some 3 600 million years. These rocks provide insights into the past history of the Earth and the Earth's atmosphere. Lastly, South Africa also provides a long record of life which includes earliest life and the evolution of land plants and animals. The origin of mammals and dinosaurs are also well preserved; however, the best records in South Africa are the origin of hominins (McCarthy and Rubidge, 2005).

Although South Africa is a geological diverse country, there are conflicting views on the development of the continent. This is due to the absence of factual data to produce meaningful evolutionary models (Patridge and Maud, 1987). Moore *et al.* (2009) mentioned that the topography of southern Africa is associated with stress plate kinetics rather than mantle plumes.

3.3 SUPERCONTINENTS

Although scientists are sceptical about the existence of supercontinents, there are indications of sizable continents with an age of at least 3 000 million years. The evidence of older continents is fragmentary. However, there are indications of one older continent; namely Rodinia, about 1 000 million years ago (McCarthy and Rubidge, 2005).

Rodinia's existence provides an understanding of the geological events that had an effect on southern Africa. A high mountain range formed on top of metamorphic rocks. The reduction of this mountain range to normal continental elevation caused the exposure of these metamorphosed rocks, which were once deeply buried, at the Earth's surface at around 1 800 million years ago. At around 1 600 – 1 400 million years ago, rupturing of the continental curst led to the formation of oceanic crust. Around 1 100 million years ago sedimentary and metamorphosed rocks were crumbled and folded with intrusions of multiplicity of granites. This gave rise to complex geological formations. In South Africa, this complex geology resulted in mineral deposits of importance: copper at Prieska and O'kiep and the copper-lead-zinc deposits at Aggenys. These deposits are associated with metamorphosed volcanic and sedimentary rocks (McCarthy and Rubidge, 2005).

The supercontinent, Pangaea (490 – 545 mya), was short-lived and the formation relatively recent, in terms of geological time (McCarthy and Rubidge, 2005). During the Triassic period (250 – 300 mya) the supercontinent was split by the Tethys Ocean (Watkeys, 2006). This has led to the formation of two smaller supercontinents; namely, Laurasia (North America, Greenland, Europe and much of Asia) and Gondwana (South America, Africa, Madagascar, Antarctica, Australia, India and fragments of Europe and Asia) (McCarthy and Rubidge, 2005; Watkeys, 2006).

Gondwana's surface is important to the evolution of geomorphic features in southern Africa. These features include: the high initial elevation of the continent, the existence of the Cape Fold Mountains, the Namaqua highlands, the westward drainage and the tabular Karoo rocks beneath the land surface (Partridge and Maud, 1987).

The break-up of Gondwana (during the late Jurassic (Haddon, 2000)) was seen as the greatest single geological event that had an effect on the southern hemisphere (Watkeys, 2006). However, Holmes and Barker (2006) stated that the southern African landscape owes its geological and geomorphological features to the ancient heritage of Gondwana. During Gondwana's breakup, the shapes of the continents, as well as the formation of great mountain belts were defined. The break-up of Gondwana is an on-going process which started during the late Jurassic Period (Haddon, 2000) and still carries on today (Watkeys, 2006).

From a South African point of view, the break-up can be subdivided into five different stages (Watkeys, 2006): (1) the time of Karoo volcanism (180 to 175 mya); (2) major fracture systems (175 to 155 mya); (3) fracture that occurred across Gondwana (155 to 135 mya) forming East Gondwana (Antarctica, Madagascar, India and Australia) and West Gondwana (South America and Africa) (Patridge and Maud, 1987;

Watkeys, 2006); (4) separation of South America and Africa and changes in the plate configuration (135 – 115 mya); (5) final split of continental linkage between South America and Africa occurred (115 – 90 mya) (Watkeys, 2006).

Partridge and Maud (1987) mentioned that the reconstruction of Gondwana confirms the central position of Africa within the assemblage. Gondwana is important from an economical point of view as 60% of the world's important minerals occur on the continents comprising Gondwana. South Africa is also important, due to the fact that two-thirds of the country is covered by sedimentary and volcanic rock deposits – shaping the landscape. Furthermore these rocks preserve a unique and valuable record of reptile and mammal evolution (McCarthy and Rubidge, 2005).

3.4 THE EARLY HISTORY OF GONDWANA AND ITS FRAGMENTATION

The modern landscape of southern Africa, as we know it today, owes its features to the time after the break-up of Gondwana. However, some of the major elements present in this landscape are inherited architectural elements from before Gondwana's break-up (Partridge, 1997b). Partridge and Maud (1987) stated that the most important of these features is the Great Escarpment. This escarpment separates the elevated interior from the coastal margins.

After continental separation, the interior was characterised by a high interior plateau (Partridge, 1997b) (mean surface elevation of between 2 000 and 2 500 m a.m.s.l (Partridge *et al.,* 2006)) bounded by the horseshoe shaped Great Escarpment (~200 km inland from the original continental margin (Partridge and Maud, 1987)) (Partridge, 1997b; Partridge *et al.,* 2006). The highlands of Lesotho, which exceed 3 000 m, occur as elevations above the interior plateau (Partridge, 1997b). Other parts of the interior are composed of large basins such as; the Kalahari and Transvaal Bushveld basins (Partridge, 1997b). This is supporting evidence that Africa formed the central part of the southern continents (Partridge, 1997b; Partridge *et al*., 2006).

The high escarpment that was created during the rifting of the continents was driven back by erosion (Partridge *et al.,* 2006) above and below the Great Escarpment. The erosion occurred during the humid, tropical climate of the Cretaceous and formed the new base levels of the Atlantic and Indian Oceans. Due to erosion the escarpment receded between 50 km on the west coast and 120 km on the south-eastern coast (Partridge *et al.,* 2006). The foot of the Great Escarpment had a 50 to 200 km wide coastal slope (Partridge, 1997b). It was on this undulating coastal plain that rivers (Orange-Vaal and Limpopo (Partridge and Maud, 1987)) cleft deep gorges to the ocean (Partridge, 1997b). With this receding, the Palaeo-river systems formed a unique nickpoint on the inland areas, the Augrabies Falls on the Orange River being one of them. The coastal hinterlands were more affected by the erosion than the interior parts of the continent (Partridge *et al.,* 2006). An amount of approximately 3 000 m of material was removed from the coastal areas (Partridge *et al*., 2006). These removals have led to the development of a relative coeval surface with a low relief separated by a Great Escarpment (Partridge *et al.,* 2006).

The rejuvenation of inland rivers due to the upwarping of the continental rim leads to the African erosion cycle of the interior of the continent (Partridge and Maud, 1987). This gave rise to the African surface. This African Surface is a single, continuous, low relief surface (Partridge *et al.,* 2006). The African erosion cycle (giving rise to the African surface) had a long duration (Maud and Partridge 1987; Partridge and Maud, 1987). During the Miocene, the erosion cycle was terminated by the uplifting and tilting of marginal areas (Maud and Partridge, 1987).

A global scale epeirogenic uplift occurred at around 50 mya (Eocene) (Partridge and Maud, 1987) which caused rejuvenation of the sluggish drainages crossing the African surface. This has led to renewed incision along valleys (Partridge *et al.,* 2006). In the interior parts of the continent uplift and warping was restricted to episodes of stasis during the evolution of the landscape (Partridge and Maud, 1987). The evolution of the African landscape was brought to an end during the Miocene, when major uplift of the continent occurred (Bird *et al.*, 2006). Significant westward tilting was the result of the uplifting of the subcontinent which caused rejuvenating drainage of the interior plateau (Partridge and Maud, 1987; Moore, 1999).

The area below the Great Escarpment has two younger surfaces; namely, the Post-African I surface and the Post-African II surface (Partridge and Maud, 1987). The Post-African I surface occurred due to uplifting which caused rejuvenation during the

Early Miocene (Partridge and Maud, 1987; Partridge *et al*., 2006). This surface is covered by terrestrial deposits from the Early to Middle Miocene age (Partridge and Maud, 1987; Partridge *et al.,* 2006). This upliftment along the Griqualand-Transvaal Axis caused significant changes in the drainage patterns of the interior (Partridge and Maud, 1987) which led to the formation of the undulating Post-African II Surface (Partridge *et al*., 2006).

The majority of the Post-African II cycle was triggered at the end of the Tertiary, due to the uplifting and warping of the subcontinent – mostly as major dissection of the coastal hinterland. Indications are that aridity increased during this time (Partridge and Maud, 1987). The numerous pans can be seen as the legacy of the earlier drainages of the Pliocene. The pan floors have been deflated, with an overall lowering of the land surface because of pediplanation (Partridge *et al.*, 2006).

3.5 GONDWANA FROM A SOUTH AFRICAN PERSPECTIVE

At around 500 mya Gondwana was located in the southern Hemisphere, situated over the South Pole (Crowell and Frakes, 1972; McCarthy and Rubidge, 2005). Gondwana was moving northward, slowly sliding over the South Pole (McCarthy and Rubidge, 2005). The northward rifting of the supercontinent caused tension which led to stretching and thinning thus, causing rift valleys (McCarthy and Rubidge, 2005). At about 400 million years ago, rapid subsidence deepened the Cape trough which caused the deposition of a variety of marine invertebrate fossils to be deposited. The stretching, thinning environment changed to a shortening and thickening environment. This caused the rising of mountain ranges due to the thickening of the crust and compression of sedimentary rocks (McCarthy and Rubidge, 2005). This rise of mountain ranges caused the formation of a depression/basin which started a new sedimentation cycle – forming the Karoo Supergroup (McCarthy and Rubidge, 2005).

Two-thirds of South Africa is covered by rocks from the Karoo Supergroup (Hamilton and Cooke, 1960; McCarthy and Rubidge, 2005) which include the Free State, where the study was done (Holmes and Barker, 2006). Sediment deposits in the Karoo depression were therefore, glacial deposits (Dwyka Group) (McCarthy and Rubidge, 2005) with an approximate area of 500 by 1 400 km (Crowell and Frakes, 1972). The continuous northward drifting of Gondwana caused the final melting of glaciers. A large inland water body formed across South Africa and the neighbouring regions of Gondwana. Indications are that this inland water body was connected to the open sea. During this time, rivers deposited sediment along the northern shoreline of Gondwana. These deposits formed what we today know as the rocks of the Ecca Group (McCarthy and Rubidge, 2005).

The rocks of the Ecca Group from north to south differ in the sense that the northern Ecca Group rocks contain coal and the southern rocks do not. Rocks from the Ecca Group are important for their contribution to the earliest reptiles of Gondwana (McCarthy and Rubidge, 2005). The Ecca Group accumulated as sediments in shallow intra-cratonic depressions which can either be fresh water or brackish. The western parts of the Free State represent the Ecca Group rocks. These rocks weather and erode to form a flat to undulating landscape in the west. The western Free State landscape is broken up by flat-topped, dolerite-capped mesas with an altitude of approximately 200 m above the surrounding landscape (Holmes and Barker, 2006).

The rocks of the Beaufort Group are composed of sand deposited by northward-flowing rivers (fluvial derived sedimentary rocks (Holmes and Barker, 2006)) flanked by floodplains which periodically deposited mud during floods (McCarthy and Rubidge, 2005). The Beaufort Group dominates the central and eastern parts of the Free State Province (Holmes and Barker, 2006). The landscape has flat-topped hills due to the weathering and eroding of rocks. The relief of the central and eastern parts of the Free State are thus, not as flat as the western parts. The relief is shaped by the presence of dolerite dykes and sills in the central and eastern parts of the Free State (Holmes and Barker, 2006).

The uplifting of the Karoo strata caused the termination of sediment deposition of the Beaufort Group. These changes in the subduction environment in the south are the possible cause for this uplift. Erosion of previously deposited sediment occurred during this time. This process was short-lived and sedimentation was renewed, forming the rocks of the Stormberg Group on top of the eroded Beaufort Group. The Stormberg Group is composed of the Molteno, Elliot (of fluvial origin (Holmes and

Barker, 2006)) and Clarens Formations (of aeolian origin (Holmes and Barker, 2006)) (McCarthy and Rubidge, 2005).

The Molteno Formation was deposited by large braided rivers. These rocks are almost 600 m thick, with sporadic occurrences of coal from localised swamps. The Molteno rocks were deposited during the Triassic Period (251 to 203 mya), a global warmer period. The Elliot Formation was the product of reintroduced meandering rivers which deposited floodplain sediments (McCarthy and Rubidge, 2005). The Clarens Formation (sandstone) (Holmes and Barker, 2006) on top of the Elliot was deposited in desert conditions. The lower most layers of the Clarens Formation show indications of ephemeral salt pans and river activity. However, at the time when the upper Clarens Formation was deposited, desert conditions with a "sand sea" prevailed (McCarthy and Rubidge, 2005).

The relaxation of the compression that prevailed throughout the deposition of the Karoo Supergroup caused the crust to rupture. This intrusion of basaltic lava occurred at around 182 mya and covered almost the whole of southern Africa and portions of other Gondwana continents. These volcanic rocks are known as the Drakensberg Group (McCarthy and Rubidge, 2005). Some of the magma did not reach the surface but instead intruded the horizontal sedimentary layers of the Karoo Supergroup. These are today known as dolerite sills which are a few centimetres or hundreds of meters thick. Dolerite dykes were also formed when the magma solidified within the fissures. Both dolerite dykes and sills are resistant to weathering and therefore, erosion (McCarthy and Rubidge, 2005). These dolerite intrusions have an optimal occurrence in the Beaufort Group, decreasing higher up in the Karoo rocks (Holmes and Barker, 2006). During this time, other intrusions like Kimberlites (some containing diamonds) occurred in the western Free State (Holmes and Barker, 2006).

The sedimentation of the Karoo Supergroup was brought to an end by a volcanic episode which was very short-lived in South Africa (less than two million years). The continuous deposition of sediment in southern Africa ended, after nearly 300 million years. The process dominating the interior of South Africa since then is erosion (McCarthy and Rubidge, 2005).

3.6 QUATERNARY DEPOSITS

These are deposits younger than 2 mya. The deposits are widely distributed and are composed of unconsolidated sand, calcrete, alluvial and colluvial material deposited (Holmes and Barker, 2006). The origin of these sediments is not always clear (Barker, 2002).

3.6.1 Sand

The unconsolidated sand in the Free State is a feature of the ephemeral stream beds in the province (Holmes and Barker, 2006). This unconsolidated sand is widely spread in the western parts of the Free State (Barker, 2002). Furthermore, on the basis of the sand's morphometric properties, sand can be seen as aeolian. Sand can also be present in the form of lunette dunes, which are currently evident along fence lines and roads in the western Free State. These are the result of current aeolian processes (Holmes and Barker, 2006).

3.6.2 Calcrete

Barker (2002) stated that calcium carbonate deposits in the Free State occur in three different forms: laminated hard bank calcrete, nodular calcrete and calcrete of the toefa-deposits. Laminated hard bank calcrete is associated with high lying areas and the Ecca Group, away from drainage lines. It is speculated that the evaporation of groundwater is responsible for the formation of calcrete (Barker, 2002). The second type of calcrete is the nodular calcrete, which forms in unconsolidated material and can reach depths of 10 m in pan floors or lunette dunes. The third type of calcrete is the toefa-deposits which occur around springs with Florisbad being an example. Calcretes mostly occurs in the semi-arid and arid (Myburgh, 1997) western parts of the Free State (Myburgh, 1997; Barker, 2002). Carbonates of different ages occur and cannot be associated with a particular calcrete formation (Myburgh, 1997). Thus, these calcretes serve little purpose as palaeo-environmental indicators (Holmes and Barker, 2006).

3.6.3 Alluvial and colluvial deposits

Alluvial deposits are restricted to river floodplains in the Free State (Barker, 2002; Holmes and Barker, 2006). These materials, deposited along the rivers, consist of cross bedding and lenticular conglomerates in which fossils are found (Barker, 2002). Colluvial deposits are restricted to hills where dolerite blocks occur on the slope. However, gravitation make these dolerite blocks move down the slope (Barker, 2002).

3.7 PALAEO-FLUVIAL GEOMORPHOLOGY IN SOUTHERN AFRICA

Palaeo-drainage lines can be viewed as old drainage lines which are not necessarily indicated by valleys, but are mostly remnants of river gravels found on higher levels (Cooks, 1968). Research into palaeo-fluvial geomorphology in southern Africa was important from a mining and an academic perspective. These systems played a major role in the lives of people for thousands of years (Dollar, 1998). Present day fluvial systems owe its existence to the geological template and the rifting of Gondwana during the Jurassic (Dollar, 1998). The functioning of most of the river systems in southern Africa are influenced by the tectonic uplift during the Miocene and the Pliocene. These tectonic uplift occurred after long periods of tectonic stability (African, post-African I and post-African II erosion surfaces) (Dollar, 1998). Thus, according to Dollar (1998) the geological structure, super-imposition and tectonic movement of the earth provided the template on which fluvial changes occurred. Climate and marine cycles also played a role together with the geological factors (Dollar, 1998). There is, however, no single cause responsible for the fluvial patterns. During the last three billion years, southern African fluvial systems have undergone extensive modification (Dollar, 1998). The older trends (early to mid-Pleistocene) that emerged are usually described due to tectonic activity. The younger activities (late Pleistocene to Holocene) in fluvial geomorphology are due to climatic oscillations (Dollar, 1998).

Sedimentation peaks during the Eocene, Miocene and Pliocene are indications of high relief. The tectonic phases are associated with climatic changes which cause wet and dry periods. The various wet and dry periods are associated with changes in vegetation cover, runoff, erosion, weathering rates and environmental changes. Rivers on the flat African erosion surface were rejuvenated due to uplift in the Miocene and the Pliocene. This uplift was the cause of the incised nature of the coastal rivers (Dollar, 1998). However, superimposition was the common explanation for the rivers in southern Africa. Thus, the river incisions were through the Karoo sediments onto the pre-Karoo surface (Dollar, 1998).

Two major river systems drained the southern part of Africa since the early Cretaceous (Moore and Blenkinsop, 2002; Kounov *et al.,* 2008). In contrast to this Dollar (1998) records that the major river systems in southern Africa include: the Vaal River, the Orange River, the Molopo River, the Sundays River and the Zambezi River. The two rivers mentioned by Moore and Blenkinsop (2002) and Kounov *et al.* (2008) are the Kalahari and Karoo River systems which drained in a westerly direction. The rivers flowed in a south-west to western direction. The Kalahari River drained the northern parts and entered the Atlantic Ocean where the Orange River mouth is currently situated. The Orange River as we know it today formed part of the Karoo River, which was located almost 200 km south of the present day position. It is postulated that the Karoo River drained into the Atlantic Ocean near the mouth of the present day Olifants River. This is the cause of the abundance of alluvial diamonds in the marine deposits offshore. Scientists differ in view about the existence of the Karoo River. Some propose that the river existed during the Cretaceous and was captured by the Kalahari River in the Paleogene. Others argued that the Karoo River was only established in the Paleogene and existed until the Neogene (Kounov *et al.*, 2008).

The African surface had a well-integrated network of drainage systems by the late Cretaceous (Partridge *et al*., 2006). However, the drainage systems of the south-central parts of Africa have been modified since the lower Cretaceous (Moore, 1999; Moore and Blenkinsop, 2002). The modification includes river captures due to the epeirogenic uplift of the sub-continent (Moore, 1999; Moore and Blenkinsop, 2002). Remnants of these palaeo-drainage surfaces survived as high-lying alluvial gravels. Other rivers that existed were destroyed by erosion (Partridge *et al.*, 2006). This can be due to the fact that the drainage systems of southern Africa changed from depositional to erosional (Holmes and Barker, 2006). These rivers can be identified by the reworking of diamonds into drainage systems, where the catchment lies in areas were kimberlites are absent (Partridge *et al.,* 2006).

One of these rivers was identified by Marshall (1988) as the Kimberley River which drained the northern panveld of the Free State. It was hypothesised that the Kimberley River formed part of the Karoo River that eroded the kimberlite pipes in the Boshoff and Kimberley areas. It is believed that the Karoo River was the source of diamonds that occur in the channels of the Geelvloer Valley/Commissioners Valley/Koa Valley. This river system drained the western half of the Northern Cape during the Miocene (Partridge *et al.,* 2006). Another of these palaeo-drainage systems was the northerly river named the Kalahari River, which drained the southern part of the Kalahari Basin. This palaeo-drainage system deposited diamondiferous gravels of the Lichtenburg area and flowed towards Schweizer-Reneke (Partridge *et al.,* 2006).

Remnants of the Late Cretaceous river systems play an important role in the understanding of the evolution of drainage systems in South Africa. These remnants were more extensive and better integrated than the drainage systems of the Cenozoic and therefore, formed a better understanding in their evolution. Reorganisation of these drainage systems were due to late basining and upwarp rises such as the Griqualand-Transvaal and Kalahari-Rhodesia axes (Partridge *et al.,* 2006). However, the aridification of climates during the Cenozoic also played a role. The wetter conditions which prevailed during the Neogene can be seen in existing rivers like the Orange, Vaal, Limpopo and Sundays. During these wetter times, major fluvial activity lead to defunct systems of high terraces in the above mentioned rivers (Partridge *et al.,* 2006).

The Koa Valley formed part of the lower Orange as we know it today. This river was northward-flowing during the Early and Middle Miocene. This valley system was more or less 200 m wide, with coarse, braided channel deposits. The gravels present at Bosluis pan and Galputs were deposited during degradation of the river channel in the Post African cycle of erosion. These gravels contain vertebrate fossils with an Early to Middle Miocene age. Sand and silt depositions occurred and have led to the formation of a floodplain. This floodplain developed into a series of disconnected saline lakes which are typical of semi-arid environments. Other catchments in the western hinterland contain a similar sequence. These changes are therefore, linked to the aridification of South Africa`s western seaboard during the end of the Middle Miocene. This period of aridification is initiated by cold upwelling of the Benguela Current, due to the establishment of an East Antarctic ice sheet around 14 mya (Partridge *et al.,* 2006).

The Koa Valley provides a number of Miocene fluvial sequences in South Africa. Among these are indications from fauna preserved in basal gravels of Early Miocene age. These fossils are evidence of progressive aridification which include heavy calcification of gravels, channel deepening and gravel deposition. There are also indications that the head waters of the Orange River were in humid areas. However, areas in the river experienced low energy or episodic flow regimes even during arid times characterised in the western areas of the country. Evidence provides that the hyper-arid Namib Desert were a wooded environment during the Early Miocene (Partridge *et al.,* 2006).

Aridification which characterised the western parts of South Africa, during the Middle and Late Miocene, led to the development of mature calcretes on the Post-African Surface. This aridification was interrupted by a more humid Late Pliocene (Partridge *et al.,* 2006). This is an indication of extensive river systems in the now semi-arid areas of the Northern Cape. An example is the Carnarvon Leegte system which was an extensive floodplain with a few meandering channels which carried flood discharges of great magnitude. The gravels contain fossils which represent Plio-Pleistocene grassland spesies; thus, an indication of complete vegetation covers in contrast to the shrubland of the present day. The climate was more sub-humid than semi-arid. These fluvial deposits are covered by wind-blown sands with the same dominating north-westerly wind direction (Partridge *et al.,* 2006).

As already mentioned, Dollar (1998) found that there were five rivers draining southern Africa. In this section the five rivers and their postulated development will be discussed:

3.7.1 The Vaal River

Interest in this river was due to diamondiferous gravels postulated to be deposited by a much larger river than the Vaal we know today. It is proposed that this larger river was part of the present Molopo River. However axial (Griqualand-Transvaal axis) uplift during the late Tertiary reversed the drainage causing the Molopo to flow into the Limpopo. Dollar (1998) argues that the Okovango River joined the Limpopo River; but due to axial arching, the drainage was interrupted, forming the Makgadikgadi Pans. Therefore, drainage evolution can be caused by tectonic activity; however, climate change may also play a role. The uplift of up to 350 m that took place might have resulted in climate change – increased rainfall (Dollar, 1998). Indications are that the palaeo-fluvial geomorphology of southern Africa was influenced by the glacial/interglacial cycles in European and North American literature. Believes are that the Vaal River terraces developed in a single cycle due to axial warping during the Pliocene. The Vaal River further follows the contact between the Karoo and Ventersdorp systems (Dollar, 1998).

The Vaal River did not deviate much from its present day flow path (Dollar, 1998). However, vegetation cover, chemical weathering, mass movement and sediment delivery ratio's play an important role in the formation of the river. The pans and terraces of the Vaal River can be seen as remnants of successional land surfaces left behind due to the incision of the river into bedrock. The palaeo-Harts River drained into the present day Harts River which drained into what we today know as Botswana. The uplifting of the Griqualand-Transvaal axis caused the Vaal River to be diverted which reduced the flow remarkably (Dollar, 1998).

During the mid-Tertiary, the palaeo-Harts have been cut off from the Vaal River by the Dry Harts. This cut-off caused the unconformity between the younger and older gravels. Aggradation was interrupted during the late Pliocene/early Pleistocene due to climatic change. By analyzing morpho-tectonics discoveries showed that the Vaal River had a left bank tributary, extending south of Christiana. The mid-Tertiary saw the cut-off of the left bank tributary by headward erosion of the Kimberley River. This cut-off tributary contributed diamondiferous gravels to the Vaal River in the vicinity of Christiana (Dollar, 1998). The Kimberley River headwaters were captured by the Modder River; thus the alluvial diamonds had a local origin (Dollar, 1998). Soutpan (where Florisbad is situated) formed part of the palaeo-valley, a tributary of the Modder River. Excessive bed loads choked the river system. Deflation by the prevailing north-western winds removed the sand. The palaeo-valleys are mostly underlain by calcrete with salt accumulation accelerating chemical weathering (Van Zinderen Bakker, 1989).

3.7.2 The Orange River

The Orange River is well known due to the discovery of the first diamond on the river banks. The terraces of the Orange River are of mid- to late-early Miocene in age. These terraces correspond with terraces along the Sak River. Suggestions are that the river entered the Orange River from the north, contributing to the carrying capacity of the Orange River we know today. This northern tributary was named the Trans-Tswana River and drained south-central Africa. Thus the Kalahari basin might have formed part of the river's extensive drainage network (Dollar, 1998).

During this time, the mouth of the present day Orange River was some 500 km to the south, at the present Krom/Olifants River mouth. This change was due to drainage reorientation during the late Cretaceous. The Orange River was part of a smaller system during the Oligocene. However, during the late Oligocene/early Miocene, the Orange River was captured by the Koa River. During this time flow in the Koa Valley stopped. The capturing of the upper Orange River by the lower Orange River, lead to the formation of the present day channel (Dollar, 1998).

The Orange River was thus composed of two drainage systems: 1) the Upper Orange/Vaal River linking with the Olifants River; and 2) the Lower Orange which drained southern Namibia and Botswana, linking to the palaeo-Molopo River. This system was termed the Kalahari River (Dollar, 1998). Similar fish species further show that the present Koa Valley captured the Tertiary Koa River and the Krom River (Dollar, 1998).

Dollar (1998) stated that De Wit mentioned periods during which fluvial systems were more active. These periods were: the late Cretaceous, the middle Miocene and Plio-Pleistocene. During the late Mesozoic two major river systems were active. These are: the Upper Orange/Vaal/Olifants system (Southern or Karoo River) and the northerly Kalahari River draining Namibia and Botswana. According to Dollar (1998) these rivers were high discharge rivers, caused by tropical climatic conditions. However, during the early Cainozoic, the climate desiccated causing reduced flow and limited sediment transport. During the early Tertiary the Kalahari River captured the Karoo River (Dollar, 1998).

3.7.3 The Molopo River

The Molopo River is important due to its diamondiferous deposits that are associated with the system. The association with diamondiferous deposits can be assign to the karst topography, the dolomitic basement and the palaeo-drainage lines. Indications are that the gravels were deposited by the palaeo-Harts from eastern Botswana, the Dwyka Glaciers from the Limpopo Province and Lesotho. The gravels were transported to the area of the Molopo River due to tectonic upheaval and climatic changes (Dollar, 1998).

The history of the Molopo River can be contributed to the uplifting of intra-continental tectonic axes (Griqualand-Transvaal axis and the Kalahari-Zimbabwe axis), as well as the subsidence of the Bushveld basin (mid-Tertiary) and climatic changes. Most of the diamondiferous deposits occur on the northern boundary of the Karoo Basin. The reasons therefore, are: the pre-Karoo surface topography trap coarse debris, the weathering of the Dwyka tillite of the Karoo system and the exfoliation of the Ventersdrop lavas provide coarse debris (pebbles, cobbles and boulders) (Dollar, 1998).

3.7.4 The Sundays River

The terraces found in the Sundays River valley are indications of sea-level changes which can be linked to marine transgressions during the late Quaternary. The channel gradient reduction and concomitant aggradation are associated with base-level rises. These base-level rises can be associated with transgressive events. During periods of regression the increase in gradients caused more stream power which lead to incisions. A sequence of 13 terrace levels were discovered and ascribed as a response to climate and base-level changes (Dollar, 1998).

Indications are, however, that the Sundays River was formed due to a combination between climate change and a landscape that were tectonically active. During the Miocene and late Pliocene the tropical climate conditions contributed to a high sediment load. Periods of aggradation and degradation during the Quaternary sea-level changes resulted in the younger terrace formation (Dollar, 1998).

3.7.5 The Zambezi River

The Zambezi River was two separate systems, developing separately from each other. The Upper Zambezi formed part of the Limpopo system, while the Middle Zambezi formed part of the Shire system. Due to tectonics, the palaeo-Middle Zambezi experienced an increase in stream power, while down-warping caused the capturing of the Upper Zambezi. However, indications are that the middle catchment of the Upper Zambezi joined the Upper and Middle Zambezi due to headward retreat of earlier knickpoints or by the overtopping of the palaeo-Lake Makgadigadi (Dollar, 1998).

3.8 DEPOSITS OF PALAEO-DRAINAGE SYSTEMS

Colluvial deposits occur on hill slopes and are widespread in South Africa in areas with topographic relief. These deposits usually occur in areas where erosion processes did not counter balance accumulation. The accumulation and fan deposits can be referred to humid intervals, characteristic of the Early Miocene. The largest fan deposit is the Knersvlakte, situated below the Great Escarpment. These colluvial deposits are susceptible to donga erosion and can lead to the formation of palaeo-sols. These palaeo-sols can have variations in profile characteristics which points to changing environments especially drainage conditions (Partridge *et al*., 2006).

Spring deposits are numerous in South Africa and lead to local deposition, early man occupied these areas or they contain useful evidence of palaeo-environmental data and are therefore, well studied. The Florisbad Formation contains interbedded sands and peats with mammalian fauna of Middle Stone Age. Several similar areas have been studied in South Africa. These include sites such as Aliwal North, Eastern Cape, Amanzi near Port Elizabeth and Wonderkrater in the Northern Province. Wonderkrater`s peat provided good temperature and moisture fluctuation records for the past 30 000 years. These changes were determined using preserved fossil pollen. Dolomitic springs have different accumulations which lead to the build-up of relatively pure calcite which can be exploited as source of lime and cement (Partridge *et al*., 2006).

Cave deposits represent the terrestrial records of the Late Pliocene and Quaternary in South Africa. These deposits were dominated by faunal and hominid remains which were evidence of the daily activities of the early humans. Most of these caves contain fine-textured sediments which entered the caves through small openings into standing water. These openings were also the death traps for hominoids and other animals. The climate and effectiveness of the vegetation outside the caves had an influence on the change in sediment rates inside the caves and can therefore, be related (Partridge *et al.,* 2006).

Lake deposits in South Africa are few as the lakes are perennial. The ephemeral pans (playas) are however, widespread in South Africa. In the past, lakes were more common and produced useful records of the late Upper Pleistocene. The most well preserved lake is the Pretoria Saltpan (Tswaing crater). This lake produced well-defined periodic variation in rainfall records which was compared to microfossil assemblage variation of a deep-sea sediment core of the north African coast. This indicated that the rainfall in the Late Pleistocene increased by 70% from a low 535 mm to almost 900 mm. The Tswaing crater was a freshwater lake which changes in composition to hypersaline at around 94 000 years ago as the climate became drier toward the end of the Last Interglacial (Partridge *et al.,* 2006).

3.9 GEOMORPHOLOGY OF THE FREE STATE

The topography of the Free State can be seen as nearly flat in the west with rolling, hilly to mountainous in the eastern parts. This landscape is the result of denudation and dissection under arid and semi-arid conditions. This gave rise to broad plainlands capped or preserved by dolerites (Myburgh, 1997).

The plains of the Free State were formed because of the weathering of the Ecca shales, siltstones and mudstones. The processes of pediplanation also played a role in the formation of the plains. These undulating plains occur next to the mountains and hills, but slope away from these features. The plains are mostly dominated by sand and clay. The run-off from higher ground collect on the plains as the drainage channels are poorly developed. The plains are characterized by shallow valleys and numerous pans and depressions in the north-west. The western Free State is dominated by deeply weathered sand, shale, sandstone and dolerite outcrops. The depth of this sand cover can be a few centimetres on the dolerite hills and ridges or a few metres in continuous sheets (Myburgh, 1997).

3.10 LANDFORMS OF THE WESTERN FREE STATE

3.10.1 Rivers

The western Free State is drained by two river systems; namely, the Vet-Sand River to the northeast and the Modder River to the southwest (Myburg, 1997).

The Vet and Sand Rivers flow on alluvial flats in the north-west; however, in the south-east, the channels are deeply incised into large dolerite sills. The headwaters of the rivers are very narrow and floodplains are limited. Downstream of the confluence of the Vet and Sand Rivers, the valley broadens and forms a broad floodplain with numerous scars of meandering patterns on both sides of the channel. The present river valleys are deep, V-shaped incisions in sand which meander across the old floodplains. The steeper sections that occur within the river correspond to more resistant lithologies like dolerite outcrops (Myburg, 1997).

The Modder River on the southern edge of the study area drains towards the north-west with an abrupt change towards the west in the vicinity of the Krugersdrif Dam. At the headwaters of the Modder River, valleys are narrow and sometimes incised into dolerite. The remainder of the river is relatively flat, with a broad floodplain of calcrete, which the river has carved into a deep, V-shaped meandering course. The steeper sections of the river are again determined by the presence of dolerite in the lithology (Myburg, 1997).

3.10.2 Terraces

Within both drainage basins of the Vet-Sand and Modder Rivers, the modern floodplains lie between well preserved terraces. These terraces are present as benches, which border the rivers or as remnants of flat or nearly flat spur that cut into the river valleys (Myburg, 1997)

3.10.3 Pans

Pans contribute to the general drainage characteristics of the north-western Free State (Myburg, 1997). The pans are numerous and surrounded by planar surfaces or ridges. The drainage is centripetal, except during times of high rainfall and flooding. Therefore, the pans contribute to the low drainage density characteristics that are present in the north-western Free State. Furthermore, the pans form distinct concentrations across the landscape. There are two major concentrations; namely, the Wesselsbron panveld (west of Welkom and north of the Vet-Sand River in the vicinity of Wesselsbron) and the pans north-west of Bloemfontein with Kimberley as the western border. The area between the pans is covered by thick sand (Myburg, 1997). The difference between the Wesselsbron panveld and the pans north-west of Bloemfontein is that the pans to the north-west are associated with dolerite outcrops along the margins and in some cases dykes are perpendicular to the longitudinal axes of the pans (Myburg, 1997). The pans in the area are very flat and 5 to 20 m below the surrounding land surface. The Wesselsbron panveld was reconstructed by Marshall (1987), who confirms the existence of well integrated stream systems. However, due to disruptions which caused basining or back-tilting the dendritic drainage pattern were converted to a centripetal pattern (Marshall, 1987). Some pans are vegetated and some are permanently inundated. Furthermore, smooth windward margins and lunettes of windblown sands occur on the leeward sides of the pans (Myburg, 1997). Pans will be fully discussed in Chapter 4.

3.11 NEOTECTONIC ACTIVITY IN THE STUDY AREA

South Africa can be seen as an intraplate region which experience seismicity in a sparse and scattered manner along known geological features (Andreoli *et al.,* 1996). The earthquakes experienced are due to poorly constrained forces that affect stable continental and oceanic crusts. Earthquakes experienced due to the above mentioned seismic activities occurred in the south-western Cape, eastern Transvaal, northern KwaZulu-Natal, western Free State and Northern Cape.

Indications are that the seismogenic activities of the Late Cenozoic were more widespread in South Africa than previously known. These activities are associated with contrasting stress fields of which the origin is unclear (Andreoli *et al.,* 1996). Seismicity occurs in the south-western Cape (Southwestern Cape Domain), the north-west Cape (Namaqualand Domain) and the Free State, Gauteng and KwaZulu-Natal (North-eastern Domain). The study area however, falls within the North-eastern Domain and will therefore, be discussed in full (Andreoli *et al.,* 1996).

The seismicity that occurs in the North-eastern Domain is sparse, but indications are that the seismicity was catastrophic during the Late Pleistocene-Holocene. Andreoli *et al.* (1996) mentioned that palaeo-seismicity occurred at the thermal spring, Florisbad. Furthermore, the discovery of a fault zone appearing at the surface near Bultfontein can confirm the presence of several high magnitude earthquakes during the Late Pleistocene-Early Holocene in the western Free State (Andreoli *et al*., 1996).

The fault present at the surface (near Bultfontein) has soils that are softer and more moist (Andreoli *et al*., 1996). The fault is a linear feature which appears as a flat bottom furrow, approximately 50 cm deep and a few meters wide. This furrow can be seen as a belt which has been depressed due to extensional faulting (Andreoli *et al.*, 1996). A calcrete exposed quarry also provides evidence of faulting, with complex and well developed slickensides. These seismogenic features are confirmed to be faults of tectonic origin by the NE-SW (Wegener stress anomaly (the resistance of the unbroken lithosphere to plate rotation – Somalia plate moving away from the African plate) dominated azimuth which matches with the regionally geomorphological trends. The slickensides associated with the morphology are also tectonic rather than pedogenic (Andreoli *et al*., 1996). This tectonic activity is linked with the rise of the Griqualand-Transvaal axis during the Miocene and the Pleistocene (Andreoli *et al.*, 1996). Tectonic instability during the Mio-Pleiocene, causing movement along the Griqualand-Transvaal axis, might be responsible for upliftment of the Wesselsbron dome (Marshall, 1987).

A fault can be defined as a fracture surface along which rocks have been displaced (Holmes, 1965). Hamilton and Cooke (1960) termed rocks that fractured under the application of great pressure a fault. Although faults are the cause of earthquakes, the displacement is usually no more than a few feet at a time (Holmes, 1965). Faults are the result of forces which can either be tensional (subside under gravity) or compressional (become elevated) (Hamilton and Cooke, 1960). Fault descriptions can include: dip-slip movements (horizontal) or strike-slip movements (vertical). The walls of faults have slickensides, which are due to the polished action of friction between the blocks of rock. The slickensides then also indicate the direction of the latest movement (Hamilton and Cooke, 1960; Holmes, 1965).

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CHAPTER 4
PANS: POSSIBLE REMNANTS OF PALAEO-RIVERS

4.1 INTRODUCTION

Pans are unique features of the landscape in the study area. When looking at the different definitions of pans it is clear that there are uncertainties to what exactly cause pans to form. This chapter will try to provide insight into the several theories scientists have about the origin and development of pans. Some of the theories are confirmed by research from other parts of the world. Most of the pans present in the study area seem to be remnants of palaeo-river systems. Furthermore, some of the pans and nearby springs such as Florisbad, Baden-Baden, Deelpan and Kathu Pan play an important role in contributing towards the understanding of climatic and vegetation changes over times. In some instances these unique features also contribute towards the understanding of human evolution.

4.2 NAMES AND DEFINITIONS OF PANS

Several names and definitions exist for pans. Pans can also be called “playas” or “depressions” in geomorphological literature (Le Roux, 1978). Several authors defined pans as: enclosed basins which range in size from a few square metres to between 1-16 km^2 (Verhagen, 1990; Goudie, 1991; Holmes and Meadows, 2012). Depressions can also be defined as a wetland or aquatic ecosystem with closed (or near-closed) elevation contours, which increases in depth from the perimeter to a central area of greatest depth and within which water typically accumulates (Ollis *et al.,* 2013). The shape of these pans can vary from clam-shaped or kidney-shaped to pork-chop shaped (Goudie, 1991; Goudie and Wells, 1995). However, Allan *et al.* (1995) mentioned that circular and oval are also shapes to be considered. In the case where two pans combined, the shape might be kidney-shaped or lobed wetlands (Allan *et al*., 1995). The basins can even be bigger, like Groot Vloer, Etosha and the Makgadikgadi pans. In contrast to this Geyser (1950) see pans as temporary landforms which occur in a transition period between one erosion cycle and another. Pans can also be seen as river floodplain wetlands that become inundated when the river overflows its banks and remain flooded after the receding of the river (Van As *et al.,* 2012). Verhagen (1990) regards pans as enigmatic features of the southern African landscape.

Wetlands in dry regions are inundated ephemerally and irregularly (Allan *et al.*, 1995). Pans can be seen as endorheic, flat, periodically inundated, unvegetated basins with an area of several square kilometres or more (Holmes *et al.*, 2008). This wetland type can also be seen as closed depressions mostly occurring in dryland areas or arid zones (Geldenhuys, 1982; Goudie, 1991; Allan *et al.*, 1995; Partridge and Scott, 2000; Holmes *et al.*, 2008) of the world. The pans are also mainly dry due to water loss through evaporation (Geldenhuys, 1982). According to Verhagen (1990) pans can be seen as fossil landforms which developed under climatic conditions that differed from the present climatic conditions.

4.3 DISTRIBUTION FACTORS AFFECTING PANS

The pans in southern Africa are widely distributed and range from the Agulhas Plains in the south, to western Zambia, north of Mongu (Holmes and Meadows, 2012). Great numbers of pans occur in the southern Kalahari, Northern Cape province and areas of the north-western Free State (including parts of the study area) (Lancaster, 2000). Pans are features of regions with low topographic relief (Verhagen, 1990). Thus, pans and surface drainage features are mutually exclusive.

4.4 ORIGIN AND DEVELOPMENT OF PANS

4.4.1 Background

There are several theories on the origin of pans. This is understandable because not all pans are formed in the same way. The distribution of pans and their origin are closely related. Pans can be seen as impermanent lakes which usually occur in semi-arid to arid regions (Partridge and Scott, 2000). Goudie (1991) reported that pans are characteristic geomorphological features of arid environments. On the other hand, Geyser (1950) mentioned that pans occur in both wet and dry environments in South Africa. Pans can be formed due to deflation activities or can be a source of aeolian sediment (Goudie, 1991). Most of the South African pans are typical deflation features (Scott and Brink, 1992). The world's pans occur in dry zones with topographic lows, which are closed basins (Goudie and Wells, 1995). Furthermore, pans might also be the result of dryland environmental factors rather than processes like tectonic activity, volcanism, meteorite impact, karstic solution, thermokarstic subsidence and glacial excavation. Some arid regions were geomorphologically inactive; however, distinct landforms can be present. These distinct landforms can be ascribed to extreme periods of drought during the Holocene or longer climatic changes in the Pleistocene. Around the world the formation of pans can be described to deflation, the excavation by herds of buffalo, the activities of termites as well as salts (causing material to become susceptible to deflation). Pans can also be the product of relict drainage systems or occur on the boundaries of palaeo-lacustrine surfaces (Goudie and Wells, 1995).

4.4.2 The role of water in pan formation

As in the study area, most pans occur in areas with an annual rainfall of less than 550 mm per annum (Le Roux, 1978). Southern African pans occur on the arid side of the 500 mm mean annual precipitation isohyte (Goudie and Wells, 1995). In the Bethlehem area, the concentration of pans is relatively high with the rainfall at around 700 mm per annum (Le Roux, 1978). Precipitation can therefore, not be regarded as the main factor controlling pan formation (Le Roux, 1978). Goudie (1991) mentioned that the arid side of the 500 mm mean annual isohyets is the area where most of the southern African pans occur. However, according to Partridge and Scott (2000) pans occur in areas where the annual evaporation exceeds the precipitation. Thus, the groundwater rise and seep into the floor of the basin. The water evaporates and the pans become saline due to the accumulation of dissolved salts (Partridge and Scott, 2000). Pans furthermore, also occur within the 1 000 mm surface evaporation loss isoline; however, there are exceptions (Goudie and Wells, 1995). Allan *et al.* (1995) confirms that the water regime and factors which include rainfall intensity, evaporation rates and the level of groundwater, have an effect on the existence of pans. Therefore, pans are fairly common in the western Free State (study area), Northern Cape and the North West Province of South Africa. Pans also occur in southern Botswana, western Zimbabwe and western Zambia (Partridge and Scott, 2000).

During dry times, animals will concentrate along water bodies (Goudie, 1991; Scott and Brink, 1992). This will lead to overgrazing (Partridge and Scott, 2000) of the limited vegetation (Goudie and Wells, 1995) which results in the removal of sediments by animals hoofs. The search for salts by animals can also be important (Scott and Brink, 1992; Partridge and Scott, 2000). Aridity further increases the accumulation of weathered salts (Goudie, 1991) and impedes the further growth of vegetation (Goudie and Wells, 1995). Furthermore, the natural drainage can be interrupted due to aeolian blocking which in turn leads to the accumulation of water (Goudie, 1991; Goudie and Wells, 1995).

According to Marshall and Harmse (1992) groundwater seepage on the pre-Kalahari bedrock also plays a role. This, along with the underground drainage and lithology, also contribute to the formation of pans. Other lithological landscapes such as karst landscapes, dolomite and limestone are also susceptible to corrosion and subsidence. These landscapes can also give rise to closed depressions with or without water (Marshall and Harmse, 1992). Thus, a susceptible substrate alone is not enough for the formation of pans, flowing water and geological structures play an additional role (Marshall and Harmse, 1992).

4.4.3 The role of drainage in pan formation

The drainage systems of the Free State show a lack in drainage networks in the western parts of the Free State (study area). The lack in drainage networks can be ascribed to a possible disruption (Le Roux, 1978). The disruption of streams was thought to be the cause for the formation of pans (Geyser, 1950). The drainage disruption is an indication of palaeo-drainage systems (Myburgh, 1997). The pans on the eastern side of the Free State (east of 27^{o}E) show little to no connections with disrupted drainages systems. The drainage disruption may have occurred during the early Miocene and caused the Geelvloer-Commissioners-Koa drainage system in the Northern Cape due to late Miocene desiccation and tectonism. Another example is that the pans in the north-western Free State, which can be linked to compaction of the subsurface structures, resulted in the disruption of the pre-existing Kimberley River and Wesselspruit drainage (Partridge and Scott, 2000). Disruption of drainage lines and pan development are also present in Australia (Goudie and Wells, 1995). The low occurrence of pans in the southern, eastern and northern parts of the Free State can be related to the higher relief in these areas (Le Roux, 1978).

4.4.4 The role of geology in pan formation

Around the world it is important that the lithologies on which pans develop should produce **particles with a small grain size** (Goudie, 1991). This small grain size would ensure transport in suspension, saltation or surface creep. This is the reason why shales and fine sandstones are favourable as they produce fine-grained material. The presence of the appropriate salts in the lithology is important for the production of fine grained debris (Goudie, 1991). Other results of pan formation may include **excavations of sediment or those pans associated with ancient drainage lines**. Some pans even develop in coastal surfaces (Texas coastal plain) (Goudie, 1991).

Pans occur on land surfaces that are **susceptible to weathering** (De Bruiyn, 1971; Marshall and Harmse, 1992). This, however, may also lead to the formation of pans at joint, fracture, fault or dyke intersections, where the rocks are already weakened. Therefore, the rocks are susceptible to weathering as well as the through flow of groundwater. The concentration of water can cause the enhancing of erosion and decomposition of the rocks. This enhancing of weathering also cause the liberation of salts which further enhance weathering (Marshall and Harmse, 1992). The variability of seasonal climatic conditions can also contribute to the weathering of shale and other sedimentary rocks (De Bruiyn, 1971).

The substrates for pan formation **need to be susceptible surfaces** which **are easily weatherable** (Goudie, 1991; Marshall and Harmse, 1992; Goudie and Wells, 1995). These susceptible surfaces in South African include the unconsolidated Pleistocene deposits (Kalahari sands) or shales (Goudie, 1991) and Dwyka tillite from the Karoo Sequence (Marshall and Harmse, 1992). These Pleistocene (Appendix 1) deposits are widely distributed throughout the study area (Holmes *et al.*, 2008). In 1950, Geyser explained that pans occur on different geological formations and different erosional factors affect the development and distribution of pans. Most of the pans in the Free State occur on the soft shales of the Ecca Group (Figure 4.1) (De Bruiyn, 1971; Le Roux, 1978; Geldenhuys, 1982; Deacon and Lancaster, 1988; Goudie, 1991; Allan *et al.*, 1995; Holmes and Barker, 2006) or unconsolidated surficial sands (Allan *et al.,* 1995). To the north of the province, pan densities are very low even on the Ecca Group. Pans also occur on the Beaufort Group (Allan *et al.*, 1995) with a high concentration around Bethlehem (Le Roux, 1978). Holmes *et al.* (2008) mentioned that the sedimentary rocks of the Ecca Group dominate the landscape of the study area (western Free State), while the eastern Free State is dominated by fluvial rocks from the Beaufort Group. Rocks from both the Beaufort and Ecca

Groups weather into flat-to-undulating landscapes with the occasional dolerite intrusions (flat topped mesas and buttes ~ 200 m). Dolerite intrusions (sills and dykes) mostly occur in the eastern parts (especially in the Beaufort Group) of the Free State which causes the more pronounced relief in comparison to the western parts (Holmes *et al*., 2008). The Stormberg series has a low concentration of pans (Le Roux, 1978; Allan *et al.*, 1995). With the above mentioned in mind, it is clear that the occurrence of pans cannot be ascribed to the bedrock only. The variation in percentage occurrence is not satisfactory (Le Roux, 1978).

The disintegration of cracks can be ascribed to sodium sulphate crystallisation and hydration (Goudie, 1977).

4.4.5 The role of animals and humans in pan formation

The floors of these pans over time become more saline due to evaporation of water, which causes brine development (Verhagen, 1990). The presence of salts might **further attract animals to pans**. The phenomenon of geophagy (animals including invertebrates, reptiles, birds, mammals (Johns, 1986) and humans eating clay) is still not clearly understood. However, indications are that the clay serves as a detoxification mechanism in the bodies of both humans and animals (Johns, 1986; Slamova *et al.*, 2011). Other explanations include easing of gastrointestinal upsets, supplementation of minerals and easing of hyperacidity (Slamova *et al*., 2011). The ingestion of soil can either be accidental or incidental where the soil can be a source or sink of essential elements and potentially harmful elements (Abrahams, 2012). Most pan floors consists of clay, therefore, burrowing antelopes might contribute to the deflation processes and the loosening and removal of soil by animals (Goudie and Wells, 1995). Pans become watering points for traditional gatherings (Verhagen, 1990). The excavation of the pans is then due to the adhering of clay to animal hoofs and legs in wet conditions. During wet years, with standing water, clay may accumulate on the bottom and level the depression (Verhagen, 1990). The dry climate in the pan areas favour the accumulation of salts which cause disintegration of rocks (Goudie and Wells, 1995). Pans that accumulate salts are used for salt extraction, e.g. Soutpan near Bloemfontein and Petrusburg (Van As *et al.*, 2012).

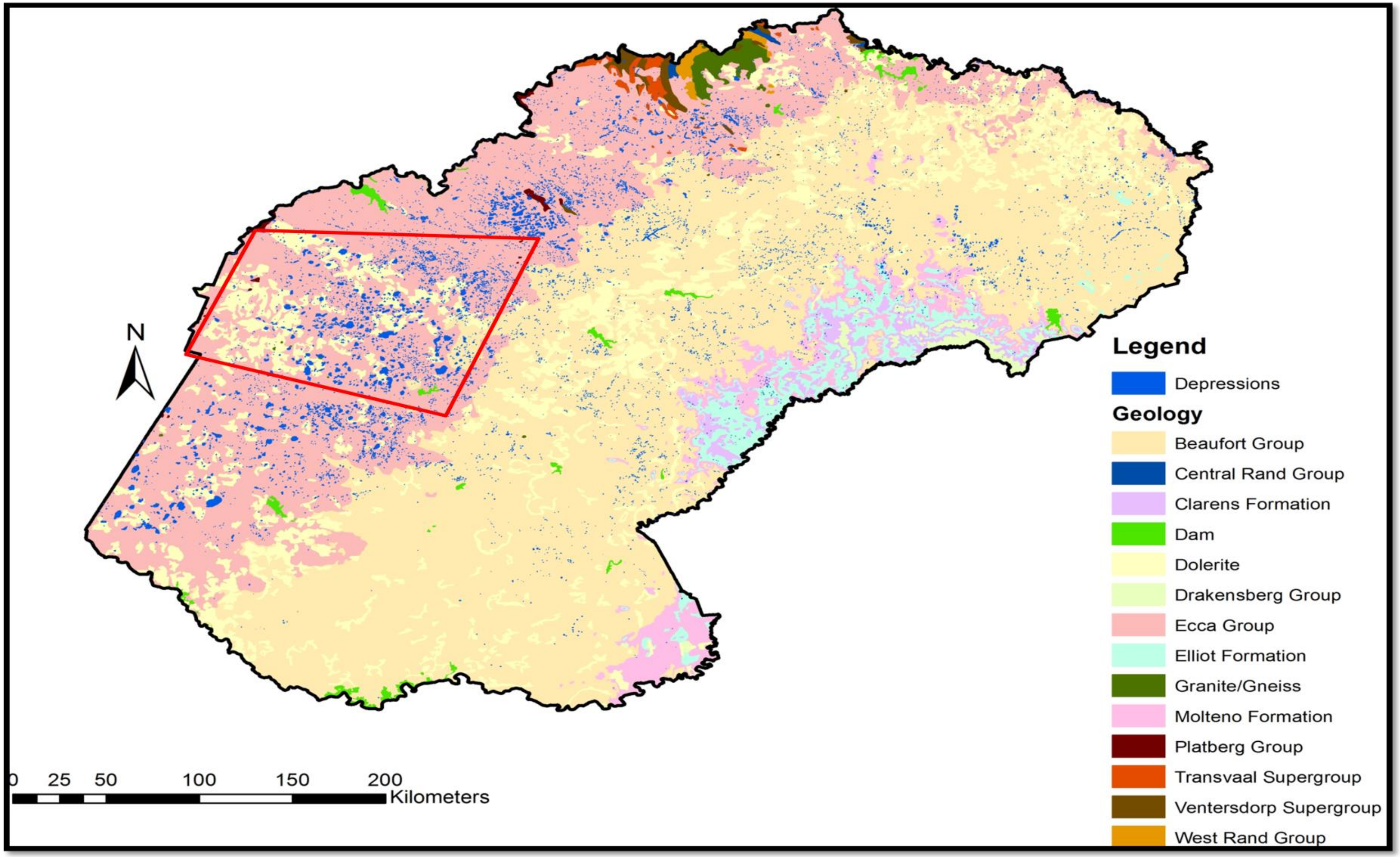

Figure 4.1: Map of the different geological formations in the Free State (after Johnson *et al.*, 2006) with the depressions. Red block indicates the study area.

4.5 PAN DISTRIBUTION, DENSITIES AND SIZES

The plains of the study area have the greatest pan concentration in South Africa and the world (Deacon and Lancaster, 1988; Goudie and Wells, 1995; Holmes *et al.,* 2008). The frequencies of these pans vary from 14 per 100 km^2 to 100 per 100 km^2 (Goudie and Wells, 1995). The pans in the study area more or less cover between 1 and 7 ha/km^2 (Holmes *et al.*, 2008).

The occurrence of pans gradually decreases from west to east across the Free State (De Bruiyn, 1971; Le Roux, 1978). Along this gradient, it is not only the geology that varies, but also the climate, slope and drainage conditions. Towards the south, the climate, slope and drainage conditions are relatively similar for both the Ecca and the Beaufort Group. Here, it is evident that there are much more pans on the Ecca Group than on the Beaufort Group (Figure 4.1). The mechanisms for pan formation in this area are clearly more favourable on the shale-rich Ecca bedrock. The northern part of the province shows little difference in the pan density between the Ecca and the Beaufort Groups. This can be ascribed to the similar lithology of the Ecca and Beaufort Group (Le Roux 1978). The low occurrence of pans on the Beaufort Group can be related to the fact that salts are scarce in the freshwater beds of the Beaufort (De Bruiyn, 1971). Lithologies susceptible to pan formation are those with a high concentration of salts which can be chemically leached or mechanically removed from the pans (Du Bruiyn, 1971). The Ecca shales are, therefore, more susceptible to pan formation because they are a major salt source (Verhagen, 1990; Goudie and Wells, 1995).

As mentioned above, the distribution of pans in the Free State can be influenced by physical factors which include bedrock or suitable substrate (sedimentary material, particularly saline tillites and shales from the Dwyka and Ecca Groups, rock type and soil-forming processes), drainage or disruption of drainage (tectonic influence or climate change), slope or geological structures (dolerite sills and fracture intersections, volcanism, etc.) and climate (Le Roux, 1978; Marshall and Harmse, 1992; Partridge and Scott, 2000).

Le Roux (1978) mentioned that the pans in the Free State are found on all the different geological formations, however, the majority of pans occur on the shales of the Karoo Supergroup. The western part of the Free State is mostly dominated by the Ecca Group with shales form the Karoo Supergroup (Le Roux, 1978). In terms of densities, Holmes and Barker (2006) specified that the Beaufort Group contains 2 924 pans with a mean pan size of 3.02 ha, the Ecca Group has 10 253 pans with a mean size of 8.11 ha, the rest of the Karoo system has 2 482 pans with a mean size of 4.62 ha, the rest of the western Free States geological substrates only contain 1 152 pans with a mean size of 1.90 ha.

4.6 GENERAL DISCUSSION ON PAN DEVELOPMENT AND ORIGIN

The occurrence of pans in a normal or sub-normal system is not a normal phenomenon. The presence of pans in these systems does not fit the laws of system development. The processes in which the landscape develops follow certain laws; the first is the young state, where the valleys are deep and sharply cleft, while the ridges have steep slopes. Over time, the landscape develops and the valleys are separated by ridges, with rivers eroding the landscape. Under ideal conditions, this landscape will develop into an elderly landscape where the rivers will flow on the same level and erosion will dominate. The plains are more or less level and the rivers form dykes while mountains are limited with only a few hills on the plains (Geyser, 1950).

These different landforms are formed by the rivers which transport parts of the land surface downstream to accumulate at the river mouth. However, the rivers never excavate the landscape. This is due to the fact that water cannot flow upstream and, therefore, deposit substances in hollow areas. Thus, the land surface cannot be excavated to form hollow areas as this will contrast with the laws of the erosion curve. With this in mind Geyser (1950) mentioned that there is no place for the pans in landscape development. Thus, pans cannot be the result of water erosion. Other factors must contribute to the formation of pans (Geyser, 1950).

4.6.1 Origin of pans with specific references to those in the study area

Several mechanisms can be responsible for the formation of pans. These mechanisms include drainage instability, wind erosion as well as animal removal of dissolved salts and clay (Le Roux, 1978).

Both wind erosion and disruption of drainage plays an important role in the formation of pans. Drainage disruption can be caused by different processes. In the area near Bultfontein, drainage was interrupted by the deposition of silt and sand of aeolian origin. Pans in the Bultfontein area formed within the channel of a palaeo-stream. Drainage disruption as the only pan forming factor are ruled out due to the widespread occurrence of pans in the Free State (Le Roux, 1978).

Wind as a role player in the formation of pans must be taken into consideration (Le Roux, 1978). Wind plays a primary role in the development of pans; many are elongated and aligned to the related wind direction (Grobler *et al.,* 1988; Goudie and Wells, 1995). However, wind as a hollowing factor, plays a minimum role in terms of pan formation (Geyser 1950; Grobler *et al.,* 1988). Thus, it can be said that only a few pans were created via wind-hollowing activities. The amount of sand that occurs on the pan borders is not equivalent to the amount removed from the hollow of the pan (Geyser, 1950). Marshall and Harmse (1992) reported that wind should rather be seen as a propagated mechanism rather than initiating mechanism. Neither wind erosion nor deposition by wind can explain the distribution of pans. Factors such as the uniform cover of bedrock composed of shale and clayey sandstone that occurs throughout the province must be kept in mind. This similarity of the bedrock is the reason for the Free State`s comprehensive plains (Le Roux, 1978).

No evidence of wind erosion as the main pan forming factor occurs in areas where pans are present (Geyser, 1950). The pans are surrounded by environments where water erosion is dominant. Another factor that contributes to Geysers statement is the fact that the pan floors are not uneven, as would be expected in a wind erosion dominated environment. All the pan floors are as even as a table top. Wind, however, plays an important part in the maintenance of pans (Geyser, 1950; Marshall and Harmse, 1992). This is supported by the presence of sand dunes outside the pans (Geyser, 1950). Pans of the Free State and North-West Province are well-shaped; however, their orientation is some tens of degrees out with the alignment of the prevailing wind resultants (Goudie and Wells, 1995).

Weathering as a forming factor should be taken into account. Karoo shales have a low chemical weathering resistance and therefore, weather quickly on exposure. A more important factor than weathering might be the dispersion of clay colloids due to sodium ions in soils with varying salinities (Le Roux, 1978).

Evaporation of water from soils with a high salinity leads to the saturation of the soil solution and later the formation of a salt crust at the soil surface. Dissolved salts will accumulate in such an area; this leads to an increase in size which might lead to the formation of pans. This formation of pans may occur in two ways: (1) High sodium content leads to poor structural conditions with sparse vegetation; thus, a high susceptibility to wind erosion exists. (2) Salt at the surface attracts larger mammals which loosen up the soil by trampling. The loosened soil is then removed from the area (Le Roux, 1978). Though Geyser (1950) agrees that pans have clay on the surface, it is however, impossible for animals to remove that amount of mud from the pan surface. Most of the pans in the Highveld are covered with vegetation. Although the pans contain clay, these clays are only slippery and not sticky (Geyser, 1950).

Geyser (1950) doubted the statements made by Alex du Toit, on the formation of pans:

The reopening of glacier hollows through water erosion. However, according to Geyser (1950) this cannot be due to water erosion as water will only fill up the hollow areas. This might be due to wind erosion, however it is not understandable how wind will only open up a certain area when the rest of the environment is carved in by valleys (Geyser, 1950).

Erosional processes; where the erosion moves through a dolerite sill to from a pan on the Karoo sediment (Geyser, 1950). The pan is then surrounded by dolerite hills. Research by Geyser (1950) could only confirm two pans where this statement could have been made. However, the dolerite surrounding the pans was deeper than the pan floor itself. The location of dolerite dykes can cause the disorganisation of drainage due to different weathering and erosional susceptibility in comparison to other rocks (Goudie and Wells, 1995).

Numerous pans characterise the landscape of the study area. The altitude generally varies between 1 200 m and 1 500 m above mean sea level (Myburgh, 1997). Marshall (1988) reported that although the modification of the pans in the study area can be assigned to wind erosion, salt accumulation and deflation the exact reason for their existence is unclear. The disturbance of natural runoff patterns by migratory animals and wind erosion was seen as the forming factors of pans. However, the pans that occur in the study area between the Vaal, Vet-Sand Rivers up to the western parts of Welkom are remnants of a disrupted palaeo-drainage system. Geyser (1950) mentioned that the disruption of the river systems can be due to upliftment in the earth’s crust.

Geyser (1950) argued that the disruption of streams might be an alternative for pan formation, but evidence is required. He explained it as follows:

- Pans form systems with one pan following on the other, between pans are dykes;
- Pan systems can be followed until it opens into a valley that forms part of a drainage system;
- The fact that pans form in valleys where there are inflow from side systems;
- The presence of pebbles and quicksand on the edges of the pans are also indications;
- The relationship between pan floor heights in the same pan system;
- In areas where the pan forms a mouth, the soil is much deeper;
- At the outflow ends of pans in dry areas, one will find lime or in wetter areas laterite. This is due to the fact that either lime or iron is precipitated;
- Pans have a very poor water holding capacity – drying much quicker than dams of the same size;
- In the Highveld, pans are surrounded by cliffs which are difficult to describe, other than remnants of previously active rivers;
- Pans usually occur in areas with low relief, where rivers are easily disrupted on these old terrains;
- The direction of river valleys in the vicinity of pan systems also contribute to our understanding of their origin;

- The conditions of the river valley above and below the pan system also contribute to our understanding.

From Geyser’s (1950) explanations it is clear that almost all the pans are the remnants of some or other disturbance of the normal water flow, usually in the form of stream capture.

4.6.2 Morpho-tectonic analysis

The pans that occur in the western Free State (study area) are **not** randomly scattered in the landscape. The pans are located in specific areas when looking at their numbers and frequency of occurrence. The pans present in the western Free State (study area) occur parallel to the Vaal River in a northeast-southwest direction. Within the panveld there are pans that show a secondary northwest-southeast trend. The two trends found within the panveld can be ascribed to structural control in the area. This control also affected the topography of the Kaapvaal Craton (Marshall 1988).

Marshall (1988) argues that the analysis of fluviomorphic patterns and interpretation of LANDSAT images indicated a major palaeo-stream. This palaeo-stream, the Kimberley River, occurred parallel to the Modder River’s middle reaches. The presence of this palaeo-river system is confirmed by the presence of channel confluence scars about two kilometres upstream of the confluence with the Vaal River. The reconstructed palaeo-Kimberley River run through a lot of the pans, thus, some pans are remnants of the ancient stream system. Reconstruction also indicated the presence of some palaeo-tributaries for both the Vaal and Modder Rivers (Marshall 1988).

The evolutionary history of the Kimberley-Modder River system becomes more complex when looking at the concentration patterns of the pans present in the area between Christiana and the Modder River. Indications are that the Upper Modder drained in a north-westward direction, into the Vaal River at Christiana. This Upper Modder was captured by both the Kimberley and Modder Rivers (Marshall 1988).

Structural and tectonic events influencing the Kimberley River can be observed when analysing both the river and topographic profiles (Marshall, 1988). The surface, on which the panveld developed, has been down-warped/trough (Marshall, 1988). The development of the pans occurred on the Post African I surface (Miocene ~23 mya) and the Post African II surface (Pliocene ~5 mya) due to uplifting along the Griqualand Transvaal axis (Marshall, 1988). This tectonic event was responsible for the down-warping of the Kimberley River. Therefore, the minimum age of the Kimberley River is Miocene (~23 mya) (Marshall, 1988). Marshall and Harmse (1992) explained that the uplifting as well as the decrease in rainfall and temperatures changed the hydrodynamics of the palaeo-drainage system from degrading to aggrading.

The down-warping of the Griqualand-Transvaal axes is confirmed by the Bloemhof (southern) and Winburg (northern) lineaments (faults). The movements that occurred along these faults both indicated that the study area has been downthrown (Marshall 1988). The down-warping is confirmed in the south by the uplifting along the marginal upwarp and the Griqualand-Transvaal axis in the north (Marshall 1988). The borders of the subsurface graben (a block, generally long compared to its width, that has been downthrown along faults relative to the rocks on either side (American Geological Institute, 1975)) in the vicinity of the Kimberley River is defined in the west as a basement ridge between Kimberley and the Schweizer-Reneke dome. The eastern border is defined by a basement ridge with a northward trend through the Wesselsbron dome. These four basement features of the Post African I surface are responsible for reactivated uplift and, therefore, down-warping (an area that has been downthrown; generally used for broad anticlines (American Geological Institute, 1975)) of the centre of the surface. The disruptions of the river channel, due to the back-warping of the palaeo-Kimberley River, lead to the present day panveld. Marshall (1988) stated that the semi-arid climate that dominated the Quaternary (Appendix 1) has led to the formation of dry lakes or pans.

According to Marshall (1988) the middle and lower reaches of the ancestral Modder River is represented by a linear zone of pans between the Modder River and Christiana. These pans developed on the African surface after the final rifting of Gondwana (Marshall, 1988). Tectonic inactivity that dominated the Quaternary was disrupted during the Miocene. The uplifting along the marginal up-warp was responsible for the accelerated headward erosion of the Kimberley and Lower Modder Rivers. This accelerated erosion lead to the capturing of the middle reaches of the ancestral Modder River by the Kimberley River, north-east of Boshof. The Lower Modder persisted with headward erosion and captured the headwaters of the present-day Modder River. The time of this event is unclear; it may have occurred before the upheaval in the Pliocene (~5 mya) or as a result of this uplift. This event is the main factor for the desiccation of pans, due to the reduction in the volume of water in the Kimberley River valley (Marshall, 1988).

The second event in the area of the Kimberley River, during the Pliocene, caused the down-warping of the Post-African I surface as well as the Kimberley River. The tectonic disruption not only affected the Kimberley River, but also the right bank tributaries of the Modder River. The modification into pans was taken further by processes which include wind erosion, deflation and the accumulation of salt (Marshall, 1988).

The Wesselsbron panveld is also a remnant of a structurally disrupted drainage system (Marshall, 1987). This panveld formed part of the well-integrated Wesselsspruit. This panveld was the result of back-tilting of the basin (Marshall 1987). From the Wesselsbron panveld analysis, it became clear that this system experienced major changes since the Cretaceous. Drainage patterns showed that the post-Karoo drainage lines were north-westerly orientated. Marshall (1987) argued that the change in the Wesselspruit drainage might have been due to the subsidence of the Ventersdorp and Karoo Supergroups around the Wesselsbron dome. However, it must be kept in mind that the Mio-Pliocene period was tectonically instable. During this time, movement occurred along the marginal up-warp and Griqualand-Transvaal axis which might have led to the uplift of the Wesselsbron dome. In contrast to this, Grobler *et al.* (1988) mentioned that climate change could have reduced the vegetation cover, allowing movement of aeolian sands. Grobler and his fellow scientists, thus, deduced the following model for the formation of pans (Grobler *et al.*, 1988):

- Before pan formation, the area already had a low topographic relief, subjected to tilting by tectonic forces or underwent climate change such as lower rainfall and/or lowered temperatures.
- Alluvial sorting removes fine grains, thus, accumulating the coarser alluvial deposits forming point bars, levees and floodplains. With a low water table, these will dry out during the dry season.
- A centripetal drainage formed towards the hollows. Groundwater evaporation exceeded infiltration and formed calcrete – transforming the original stream into a series of pans.
- Rapid evaporation leads to accumulation of NaCl, responsible for the deflocculation of soils thus, easy wind deflation.
- Deflated material will accumulate as crescentic lunettes on the down-wind side; growing towards the downwind side.
- The growth of a pan might be affected by :
  - Calcretization of the accumulated salts in the lunette;
  - Establishment of vegetation on the lunette during wetter times;
  - Reaching the dolerite base – resistant to weathering.

4.7 TOPOGRAPHIC FEATURES AROUND PANS

4.7.1 Lunette Dunes

Pans are mostly bordered by lunette dunes on their southern or south-eastern margins (Lancaster, 2000; Holmes *et al.,* 2008). In contrast to this, Goudie and Wells (1995) mentioned that the lunettes occur on the eastern and southern sides of pans in the interior of South Africa. The dunes on the southern or south-eastern margins imply that the deflation of the pan sediment was dominated by north-westerly winds (Grobler *et al.*, 1988; Holmes *et al*., 2008). In the Kalahari evidence indicates that two different palaeo-wind systems caused the direction of the dune patterns. In the northern area, the dunes were formed by north-westerly and northerly winds; while in the south, dunes were formed due to westerly winds (Heine, 1989).

The lunette dunes surrounding pans display a characteristic curve sickle-shaped morphology (Goudie and Wells, 1995; Holmes *et al.*, 2008). However, the dunes in the Kalahari have different patterns: reticulate, parallel-dendritic, dendritic to clustered dendritic, clustered dendritic, parallel, sheets of reticulate and linguoid and sand sheets (Heine, 1989). These lunette dunes are mostly composed of sand, silt, clay and carbonates from the adjacent pan (Goudie and Wells, 1995; Lancaster, 2000). Goudie and Wells (1995) noted that the lunette dunes in South Africa have a low clay content (2 to 9%). The lunette dunes appeared to be characteristic in areas where the precipitation is between 100 and 700 mm per year, at present (Goudie and Wells, 1995). The deflation of desiccated pan surfaces during dry periods is an important mechanism for the formation of lunette dunes on the leeward side of pans (Deacon and Lancaster, 1988; Partridge and Scott, 2000). In this case, the lithology should, however, be subjected to rapid weathering in saline environments (Partridge and Scott, 2000).

The lunette dunes at some pans have the oldest dunes furthest away from the present-day pan (Holmes *et al.,* 2008). These lunettes may attain heights of 60 m and can be some kilometres long (Goudie and Wells, 1995). Most of the semi-arid pans are associated with lunette dunes (Partridge and Scott, 2000). These lunettes are frequently calcified and have textural variations. Within these variations, there are indications of clay aggregates derived from the pan floor which form part of the different horizons (Partridge and Scott, 2000). Verhagen (1990) mentioned that the barrenness of the pans and the surroundings cause animals to congregate in the area. The animals loosen material such as sand and eroded calcrete pebbles which are deflated by wind. These materials are then deposited on the leeward side, building the lunette dunes (Verhagen, 1990).

The lunette dunes in the study area (western Free State) were dated using optically stimulated luminescence (OSL) dating, revealing a preserved record of the past 18 000 years. Holmes *et al*. (2008) mentioned that there is no evidence of extensive aeolian activity in the Free State during the Pleistocene. The presence of lunette dunes, however, suggests that there had to be sufficient energy from wind for their formation, from local sources. The phases of accumulation occurred at 12-10 ka, 5.5-3 ka, 2-1 ka and 0.3-0.07 ka which corresponds with what happened in the south-western Kalahari. The accumulation of lunette dunes vary between 1.3 to 2 m over 330 to 200 years (Holmes *et al.*, 2008).

The lunette dunes studied in the Free State by Holmes *et al.* (2008) are also gullied. This is an indication that the sediment of the lunette dunes are returned to the pan floor. However, this gullying of the lunette dune affects the sediment preservation and thus the accumulation of sediment. Dunes in the Free State have a much longer palaeo-record due to their higher preservation potential (Holmes *et al.*, 2008).

The presence of lunette dunes is not an indication of aridity. These dunes rather indicate the availability of sediment during windy conditions, as this sediment is moved and accumulate on the downwind margins of pans. However, Holmes *et al.* (2008) mentioned that the dunes in southern Africa accumulated during dry periods in the interior of southern Africa. The formation of lunette dunes occurred at more or less the same time as the colonization by Europeans. The colonization could have had the same effect as the build-up of fence line dunes in the western Free State due to wind erosion under tillage. However, the thought whether the modern dunes are due to landscape instability and enhanced aeolian activity during the time of the colonization remains a subject of debate (Holmes *et al.,* 2008). Holmes *et al.* (2008) noted that currently dunes are degrading, therefore, vulnerable to erosion and the recycling of sediment back to the pan floor.

4.7.2 Plains surrounding pans

4.7.2.1 Karst

Karst landscapes are usually areas with limestone and dolomite. The solubility of these rocks created unique surface and sub-surface features. The karst landscapes are driven by carbonic acid, a weak acid, formed when CO_2 dissolves in rain water. This weak acid then dissolves the carbonate rocks forming distinctive geomorphological features (Holmes and Meadows, 2012).

The dissolution of the limestone and dolomite in the karst landscapes create unique surface features which include potholes, sinkholes, dolines, uvalas, large depressions, poljes, swallow holes, springs and dry valleys. The underground component of karst forms caves and caverns as well as underground streams. The caves from the karst landscape are valuable archives for palaeo-environmental reconstruction. Another distinctive feature of the karst landscapes are the absence of surface drainage (Holmes and Meadows, 2012).

4.7.2.2 Granites, flood basalts and dolerite

Granites are very common in southern Africa's geology. Granites occur from the northern parts of Zimbabwe to the extreme southern parts of the Cape Peninsula. Rocks which are physically similar to granite but differ lithologically can produce forms that are relatively similar to granite when weathered. These rocks include gabbro, diorite, dolerite and basalt. Dolerite usually occurs in the form of dykes and sills (Holmes and Meadows, 2012).

4.8 IMPORTANCE OF PANS

Pans play an important role as wetland habitats in the study area. These pans are the grounds where Palaearctic waders spend their winters. Furthermore, ducks use these pans as breeding habitats while the pans are also widely used by two, South African Red data listed birds namely the Lesser and Greater Flamingos (Geldenhuys, 1982).

Farmers with grass covered pans on their properties, *Leptochloa* (*Diplachne*) *fusca* (Pan grass), use the pans as pastures during the dry winter months, especially after good raining seasons. The pans are mostly grazed by cattle and sheep (Geldenhuys, 1982).

Pans in South Africa played an important role in uncovering the history of early humans. Pans which played an important role include Florisbad, Baden Baden, Deelpan and Kathu Pan. Deelpan and Klipkoppen contributed to the studies in climatic changes; however, the evidence from Kathu Pan is contradictory to what was found at Deelpan (Partridge and Scott, 2000).

4.8.1 Florisbad

The discovery of an early subspecies of *Homo sapiens* in 1932 by T.F. Dreyer has led to an academic interest in Florisbad. The deposit of roughly 300 000 years old (Scott and Rossouw, 2005), was associated with a warm, saline spring on the southern shore of the Hagenstadt salt pan. The records found at Florisbad indicated several wet and dry cycles in the Middle Pleistocene alone. The pollen found here were mainly of Ericaceae and Restionaceae which indicate cooler, wetter conditions similar to current conditions found in the high mountains of Lesotho. The presence of faunal fossils such as hippopotamus and lechwe are also indications of good moisture availability in the area. The fossils also suggest that the paleo-lake at Florisbad never dried up even during relative arid phases similar to today (Partridge and Scott, 2000). According to van Zinderen Bakker (1967b) Florisbad provides evidence of a shift from warmer, drier vegetation to grassland type vegetation between 26 000 and 19 600 BP. Indications are that the humidity must have been higher (double the present), but depend on the type of grassland (van Zinderen Bakker, 1967b).

4.8.2 Baden-Baden

Baden-Baden is a spring mound site with archaeological remains next to a pan similar to Florisbad. Although palaeo-environmental research at this site has been carried out over a number of years by B. Bousman, J. Brink and L. Scott, the results are still unpublished. Pollen in some peaty layers of the spring mound is investigated as part of this study to form a better understanding of long term climate and vegetation changes in the western Free State and to complement previous research at Florisbad (Chapter 11).

4.8.3 Deelpan

The lunette dune at Deelpan provided material for dating. It indicates a regional climate change (Partridge and Scott, 2000).

4.8.4 Kathu Pan

Kathu pan, an organic marshland with a broad surface provides the best palaeoenvironmental sequence for the Kalahari Basin. This marshland is maintained by artesian seepage from the surrounding Kuruman Hills and Korannaberg (Butzer 1984a; Butzer 1984b). This pan provides archaeological and faunal records which were also used for dating and the reconstruction of climatic conditions (Butzer, 1984b; Partridge and Scott, 2000). Earlier and Middle Stone Age artefacts occur in the 4-6 m of silty sand peats of the Kathu Pan. Other information provided by this pan include long term groundwater trends which reflect environmental changes and well sorted fine sands derived from aeolian components (Butzer, 1984a; Butzer, 1984b; Deacon and Lancaster, 1988).

Butzer (1984a) and Butzer (1984b) noted the oscillation between wet and dry periods. During the dry periods caused by a drop in the water table, the accumulated peat/organic matter were volatized by peat fires. The wet periods were characterised by sudden recharges leading to repeated “spring-eye” eruptions. During these eruptions coarse and gravelly sands were squeezed through the sediments – Acheulian artifacts were linked to these vent facies. Kathu pan however, were less sensitive to the shifts in short term environmental changes such as rainfall seasonality and evaporation (Butzer, 1984b)

4.9 THREATS TO PANS

The biological diversity of pans are endangered by the human activities: restriction of run-off water by either cultivated fields or dams, pesticide accumulation, boreholes causing physical damage, ploughing and dumping as well as industrial effluent (Geldenhuys, 1982).

4.9.1 Agricultural development

The major threat to endorheic pans are agricultural orientated as many of the pans are surrounded by crop fields. These fields might encroach upon the pan periphery (Figure 4.2) and even impinge the basins of the smaller, well-vegetated pans. Due to this encroachment the pans are subjected to contamination and eutrophication by pesticides and fertilizers. Due to the fact that most pans are endorheic the toxins in the pan build up and pose a particular threat to wildlife. Furthermore, the vegetation on the shores of pans is damaged by ploughing, overgrazing and trampling by livestock. This damage caused by the livestock increases wind erosion and causes siltation of the pan basins. Farmers can also dam pans to supply water for livestock or construct fence lines to control the movement of livestock. Power lines and fence lines pose a threat to waterfowl which frequently collide with these lines and become entangled (Allan *et al.*, 1995).

Figure 4.2: The encroachment of agricultural fields on the pan periphery.

4.9.2 Road-building operations

Pans are also threatened by the construction of roads. Pans are seen as lines of least resistance by constructers planning roads. Road building is a particular threat to pans in the central highveld (Allan *et al.*, 1995).

4.9.3 Mining and industrial development

Open cast mines to mine coal can totally destroy pans. Power lines are associated with these open cast mines. These power lines and even telephone lines are major sources of water bird mortalities, the birds collide with the structures and conductors. The mines are also in need of a large amount of water, thus, lowering the water table which, in turn, affect the inundation period of the pans. The run-off water from mine dumps contaminates the water. This contamination has an influence on the water quality, which in turn influences the fauna and flora (Allan *et al.*, 1995). Some of the pans in the study area are mined for salt (Figure 4.3).

Figure 4.3: A pan near Soutpan where salt is mined.

4.9.4 Urbanization

Factors associated with urbanization include recreational and residential development which affects many pans. The disturbance of wildlife and excessive littering are results of urbanization. In such urban areas, rubble is frequently dumped in these aquatic environments to provide foundations for construction. In rural areas, the pans also serve as areas to build homesteads which in turn also disturb the wildlife. The increase in littering along the pans in rural areas is also a matter of concern (Allan *et al.*, 1995).

4.9.5 Afforestation and the encroachment of alien trees

Commercial afforestation around pans is ever growing in the eastern Transvaal Highveld. The planting of forests with alien species such as wattle, pine and *Eucalyptus* trees along the pans increase evaporation which in turn affects the water table. This results in a decrease (700 mm to 400 mm) in the amount of water draining into the pans (Allan *et al.*, 1995).

4.10 ECONOMIC INTEREST OF RIVERS IN THE STUDY AREA

The ancestral Modder and palaeo-Kimberley Rivers flowed over and eroded a number of kimberlite pipes and fissures. The estimated age of this ancestral landscape over which these rivers flowed were late-Cretaceous to Tertiary in age.

Therefore, it is a possibility that these palaeo-rivers transported alluvial diamonds with their bedload during floods (Marshall, 1988).

Marshall and Baxter-Brown (1995) stated that the Boshof kimberlites and the Vaal River are disrupted drainage lines of the late-Cretaceous. The well-known diamond fields of South Africa are fossil terrace, remnants of tropical rivers which were active during the late-Cretaceous to Pleistocene (Marshall and Baxter-Brown, 1995).

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CHAPTER 5
CLIMATE FROM THE PAST TO THE PRESENT

5.1 INTRODUCTION

Climate change is as old as the atmosphere (Tyson and Preston-Whyte, 2004). Climatic variation occurs in both time and space and is the principal source of variability in an environment (Bartlein, 1988). The history of ecosystems can be studied using palaeo-climatic data (Deacon and Lancaster, 1988). Palaeo-climatological studies provide key explanations for the evolution of current biomes, global change in palaeo-environments and the adaptation of prehistoric people to their natural environment (Scott *et al.,* 2012). The understanding of Africa's climatic variability is important in predicting the future climatic changes (Nash and Meadows (2012). Climates have changed in the past in southern Africa and climate change in the future is certain. The Free State has been climatically sensitive to changes in the past environments (Holmes *et al.,* 2008). Only when one understands the causes of past climatic fluctuations, will one be able to anticipate forecasts of climates in the future (Bradley, 1999). .

Climate is more complex than the simple function of the atmospheric circulation over a period of time. Climate system can be considered as a multitude of interactions between subsystems (atmosphere, oceans, biosphere, land surface (Surface lithosphere) and cryosphere (snow and ice)) (Bartlein, 1988; Bradley, 1999). The subsystems are connected in some ways, therefore, change in one subsystem may cause change in another subsystem (Bradley, 1999). The sub-systems are connected by flows of both mass and energy. The response time and the thermal characteristics of the individual subsystems differ from one another (Bartlein, 1988).

The atmosphere is the most variable of the sub-systems due to the low heat capacity and the rapid response to external influences. The atmosphere is connected to other climatic sub-systems by the energy exchange that occurs at the surface. The surface is seen as the atmospheric boundary layer. At the surface layers chemical interactions are important as it affects the atmospheric composition. The variations in atmospheric composition and turbidity through time may play a fundamental role in the prediction of past climatic variations (Bradley, 1999).

The oceans are seen as a sluggish component of the atmosphere. The surface layers of the oceans are much more susceptible to external changes over months or years. However, the deep layers of the ocean experience change much slower – it may take centuries for changes to occur at depth. This is due to the fact that water has a higher heat capacity and can, therefore, store large quantities of energy. The ocean's affect on climate is the single most important factor affecting climate after latitude and elevation (Bradley, 1999).

At present, the oceans comprise 71% of the earth's surface and, therefore, have an extensive influence on the climate. The oceans are more extensive in the Southern Hemisphere and least extensive in the Northern Hemisphere. The atmospheric circulation between the Northern and Southern Hemisphere is affected by the distribution of land and sea (Bradley, 1999).

The chemical balance of the atmospheric systems is also affected by the oceans, especially the carbon dioxide levels. The high CO_2 levels in solution of the oceans play an important role in the climate. A small change in the oceanic CO_2 balance can have profound effects on the radiation balance of the atmosphere and, therefore, affect the climate. The CO_2 in the oceans are important to understand the climatic variation of the past and to have insight into the future trends of CO_2 in the atmosphere (Bradley, 1999).

The biospheric subsystem is mostly consisting of animals and plants. The vegetation has an effect on the albedo, roughness and evapotranspiration characteristics of an area. Furthermore, the vegetation also affects the chemical composition of the atmosphere, due to the removal of carbon dioxide and the production of aerosols and oxygen. The absence of vegetation can cause a significant increase in particulate loading in the atmosphere. This, in itself, plays a significant role in altering the climate. The world's forests play an important role in the removal of carbon dioxide from the atmosphere, while the deserts of the world contribute wind-blown dust (Bradley, 1999). The sequestration of carbon by terrestrial plants varied over time, due to the glacial-interglacial cycles (Bradley, 1999).

Humans (part of the biosphere) also have an effect on the climate system as they form part of the biosphere. Their activities play an ever increasingly important role in climatic system. These changes include: an increase in the atmospheric carbon dioxide concentration, changes in the natural vegetation, an increase in the particulate loading of the troposphere's lower part and a reduction in the atmospheric ozone concentrations of the stratosphere (Bradley. 1999).

The Earth's land surfaces interact with the other climatic components of the climate system on all timescales. The movement of continents had a major effect on the climates of the world. Thus, continental glaciations increased as the plates moved to polar positions. In contrast to the movement towards the polar regions, mountain building also affected the climate of the world – presence of snow throughout the year (Bradley, 1999). The global and regional climate is fundamentally influenced by the latitudinal distribution of both land and sea (Bradley, 1999).

The cryosphere (mountain glaciers, ice sheets, seasonal snow and ice cover on land) causes a high albedo effect. Currently, about 8% of the earth's surface is covered by snow and ice. With seasonal expansion this can double. Most of the permanent ice of the Southern Hemisphere is located on the Antarctic continent and are, therefore, land-based. Seasonal changes are dependent on the increase in sea-ice formation. By mid-winter, the Southern Hemisphere's continents are covered by 13% snow and ice. The relatively short period of time for the changes in ice and snow-cover has important implications for theories on climatic change (Bradley, 1999). These parts of the cryosphere has a very short response time in contrast to glaciers and ice sheets which respond slowly to change on a timescale (decades to centuries or even millennia) (Bradley, 1999).

With all the above in mind, it is clear that climate has the ability to change vegetation composition in any area on earth. This is supported by the statement of Patterson III and Backman (1988) that climate is the driving force of vegetation change on a time scale of thousands of years.

5.2 CLIMATES BEFORE THE LAST GLACIAL MAXIMUM

Climate during the Archaean (2 870 mya) was much more humid than today (Tyson, 1986). This humid climate changed to a semi-arid to arid climate at around 2 620 to 2 020 mya. During the late Proterozoic (1 080 – 520 mya) (Appendix 1) the earth was glaciated, the first glacial event. The second glacial event occurred at around 742 mya, climatic conditions were extensively wet and cold. The cooling during the second glacial event is a result of major atmospheric cooling rather than movement towards the polar region (Tyson, 1986).

The most striking feature of the late Palaeozoic era is the glaciations of the Karoo basin (Tyson, 1986). The estimated time for these glaciations is around the late Carboniferous period. Pearson (1978) mentioned that glaciers have radiated from several centres in South Africa during the early Carboniferous. This indicates that glaciations may have reached a maximal extent during the late Carboniferous period (Pearson, 1978). The Permian period was associated with cool, temperate, wet conditions responsible for the coals of the Ecca. During the transition from the Permian period to the Triassic period (Permo-Triassic), lengthy periods of warm, equable climates prevailed (Beaufort Times). The Triassic is known for its intense aridity and the build-up of the Clarens Formation (Tyson and Preston-Whyte, 2004).

The fragmentation of Gondwana during the Cretaceous period had an influence on the climate of the subcontinent due to the formation of the Southern, Indian and Atlantic Oceans (surrounding southern Africa by water on three sides) (Tyson, 1986; Tyson and Preston-Whyte, 2004). These proto-oceans which developed at around 80 mya as stated by Tyson (1986) had a profound effect on the climate of southern Africa. The climatic conditions were hot, humid in the east to semi-arid in the south and west (Maud and Partridge, 1987). A decline in temperature started in the late-Cretaceous period (Tyson and Preston-Whyte, 2004). This decline in climate resulted in a strong environmental gradient between the tropics and the poles. Climates everywhere declined from the late-Cretaceous onwards (Tyson, 1986).

The early Palaeocene epoch, was dominated by semi-arid environments which caused possible major change in the atmosphere’s chemical composition. During the late Palaeocene low rainfall and run-off were experienced in the interior, much lower than today (Tyson, 1986). The high temperature of the surface water of Antarctica indicated that southern Africa must have been influenced by a tropical climate (Coetzee, 1967). The early Eocene epoch was also dominated by arid conditions especially in the west of the subcontinent (Tyson, 1986; Tyson and Preston-Whyte, 2004). Thus, the prevailing east-west climate gradient across southern Africa might have been established in the early Cenozoic era (Tyson, 1986; Partridge, 1997a; Tyson and Preston-Whyte, 2004). During the Eocene (60-40 mya) a consistent lowering in temperature occurred (Tyson, 1986; Tyson and Preston-Whyte, 2004). Little is known about the climates of the Oligocene (Tyson and Partridge, 2000).

Major climatic changes occurred since the late Oligocene/early Miocene. These changes included significant global oceanic warming. This influenced the regional atmospheric circulation patterns which produced rain, which regularly penetrated into the present day arid west (Maud and Partridge, 1987; Tyson and Partridge, 2000). The early Miocene was characterised by warm, humid, sub-tropical climates (Tyson, 1986) able to sustain large lakes in today's semi-arid western interior (Partridge and Scott 2000). This phenomenon occurred prior to the upwelling of the cold Benguela Current, thus, moist air from both the Atlantic and Indian oceans contributed to wetter conditions. Thus, the Benguela Current and the strong upwelling along the west coast were established by the late Miocene, (Tyson, 1986; Partridge, 1997a; Tyson and Preston-Whyte, 2004) ending the humid interval of the early Miocene.

The semi-arid character of the central interior of southern Africa was temporarily interrupted by warmer and more mesic conditions during the Pliocene. The rainfall was dominated by summer rainfall with moisture from the western Indian Ocean. Tectonism on the south-eastern and eastern hinterland caused massive uplift of 700 – 900 m in southern Africa. This caused a precipitation gradient from east to west. Precipitation was concentrated on the windward side of the uplifted areas causing a rain-shadow effect on the western sides (Tyson and Partridge, 2000). This gradient of east-west climate is similar to the modern climatic gradient (Tyson, 1986; Maud and Partridge, 1987; Tyson and Preston-Whyte, 2004) and was established during the mid-Miocene (Partridge and Scott, 2000).

Climate during the Pliocene was much cooler than at present (Tyson, 1986; Maud and Partridge, 1987). The runoff and spring discharge was greater, indicating higher precipitation than today (Tyson, 1986).

It was only in the last 4 million years that major environmental changes occurred (Tyson and Preston-Whyte, 2004). The Pliocene and Pleistocene experienced marked cold-temperature cycles and later glacial-interglacial cycles which affected the physical factors affecting plant life (Saarnisto, 1988). The continental ice alone during this period was more or less 30% of the continental areas – creating physical barriers for plant life (Saarnisto, 1988).

Boelhouwers and Meiklejohn (2002) mentioned that the temperatures decreased with between 5 – 10°C for southern Africa during the Last Glacial Maximum. Indications are that the coldest part of the Quaternary was more arid than at present and the high altitude regions of southern Africa received 70% of the present day precipitation (Boelhouwers and Meiklejohn, 2002). At around 2.5 mya stronger cooling occurred this was responsible for the mass extinctions of flora and fauna (Tyson and Preston-Whyte, 2004). Southern Africa was not glaciated during the Quaternary. Cooling, with temperatures 5 – 9°C lower than today, were experienced during the Quaternary time. Changes in the rainfall pattern during this time are evident in the landforms, sediment and fossils from the fauna and flora (Deacon and Lancaster, 1988).

Records for the Pleistocene climates are sparse and fragmentary (Partridge *et al*., 2004; Scott *et al.,* 2008). The Tswaing impact crater near Pretoria (South Africa) provides information for the period ~200 kyr to present. During this time the emergence of the world's first "modern" humans occurred in South Africa with their Middle-Stone Age tool-kits (Partridge *et al*., 2004). Together with the Middle-Stone Age industry, water-loving species (hippopotamus and lechwe) were found at Florisbad (Free State Province, South Africa). The change in climate and the declining in temperature were evident in the technologies of the human population. The change in tool making was one of the responses to climate change (Partridge *et al*., 2004). The biomes of Africa was influenced by the climatic changes of the

Pleistocene, this in turn, affected the distribution of species and humans (Scott *et al.*, 2008).

The climate of southern Africa changed in accordance with the global climate during the mid- and late Pleistocene. Glacial and interglacial conditions occurred periodically with an interval of about 100 000 years due to the change in the earth's orbit (Tyson and Partridge, 2000). At around 125 000 BP, global warming occurred throughout the region; however, cooling occurred and the coldest conditions prevailed at around 20 000 BP (the Last Glacial Maximum) (Tyson and Partridge, 2000). The western parts of southern Africa were influenced by the northward movement of the winter-rain regime. This caused an increased rainfall during the Last Glacial Maximum (Shi *et al.,* 2000). Climatic fluctuation during the Pleistocene glaciations caused major changes in the sea levels of the globe due to the growth of ice sheets (Deacon and Lancaster, 1998). The cool conditions during the Pleistocene are confirmed by Maud and Partridge (1987). Conditions thereafter improved due to global warming during the Holocene (Tyson and Partridge, 2000). The higher $\delta^{13}O$ average during the Pleistocene reflects the lower atmospheric CO_2 levels during this time (Holmgren *et al.*, 2003).

5.3 CLIMATES SINCE THE LAST GLACIAL MAXIMUM (21–18 kyr) TO THE HOLOCENE ALTITHERMAL (8–6 kyr)

Southern Africa's climate during the Holocene was affected by the moisture rather than the temperature. The coastal aridity of the west coast is mostly linked to the cold Benguela upwelling and the associated atmospheric circulation systems of the South Atlantic. Furthermore, South Africa does not have the influence of other continents (Scott and Lee-Thorp, 2004). For the determination of Holocene climates the resolution required are greater, however, the evaporation and desiccation in the region resulted in low quality deposits (Scott and Lee-Thorp, 2004).

The period between 125 000 – 16 000 BP was characterised by rapid warmings and slow declines to lower minima in the higher latitudes. These records were obtained from the Vostok ice core. South Africa was characterised by similar variations (Tyson and Partridge, 2000; Tyson and Preston-Whyte, 2004). This decline in temperatures is confirmed by the wide spread desiccation of lakes (Tswaing Crater became brackish or dried out completely) (Partridge *et al*., 2004). At around 94 000 – 97 000 BP the Tswaing crater changed from a freshwater system to a highly alkaline and saline system, which did not change for the rest of the crater's history. After 90 000 BP, the rainfall records decreased remarkably (Partridge *et al*., 2004). Pollen analysis from the high-lying grassland in the Free State indicate moist conditions with a dry episode at around 25 000 BP and the returning of wetness at around 24 000 BP. The coldest phase in South Africa occurred between 24 000 BP and 23 000 BP. However, another cold phase occurred between approximately 22 400 BP to 17 500 BP in the high altitude grasslands of the eastern Free State (Scott *et al.*, 2012). The cold phase of the interior was directly related to a widespread increase in moisture, which was not confirmed in the Cape region. Between 20 000 BP and 19 000 BP a slight warming occurred (Scott *et al*., 2012).

During the time of 21 000 – 18 000 BP distinctive climatic conditions prevailed over southern Africa. Rainfall was lower over the whole sub-continent, 40% less than the present mean annual rainfall over the Kalahari (Partridge *et al*., 2004; Tyson and Preston-Whyte, 2004). The temperatures had a clear south to north gradient and were depressed by 5 – 6°C at the Last Glacial Maximum in the southern parts of South Africa (Partridge *et* al., 1999; Partridge *et al*., 2004; Tyson and Preston-Whyte, 2004). Evidence shows that rapid warming occurred in southern Africa after 16 000 BP (Tyson and Preston-Whyte, 2004) to 15 000 BP (Partridge *et al*., 2004). Scott *et al.* (2012) confirms this increase in temperature towards 15 000 BP. Dry and moist fluctuations also occurred during this time (Scott *et al.*, 2012). Deacon and Lancaster (1988) mentioned that a more or less 12 – 16.5 m deep lake with an area of 24 – 44 km^2 occurred at Alexandersfontein (near Kimberley). Thus, suggesting rainfall of between 670 – 860 mm with a temperature of 6°C lower than today. There are, however, indications of dry intervals at around 14 500 BP and after 13 600 BP (Deacon and Lancaster, 1988). The period between 13 500 BP to 11 500 BP was dominated by fluctuating wetter and drier climates (Deacon and Lancaster, 1988; Scott *et al.*, 2012).

At around 11 000 BP, sudden cooling occurred which punctuated the general amelioration (Tyson and Partridge, 2000). After this sudden cooling, temperatures again started to rise over the sub-continent (Tyson and Partridge, 2000; Tyson and

Preston-Whyte, 2004). The period between 11 000 – 7 500 BP in southern Africa was relative arid except in the south-western winter rainfall region, which was relatively mesic (Scott and Lee-Thorp, 2004). Dry conditions were well established at around 10 500 BP (Scott *et al.,* 2012). In the highlands of the eastern Free State, the increase in C_3-grasses indicated cool conditions at around 10 000, 9 500 and 8 000 BP. At around 9 900, 9 000 and after 7 600 BP conditions were warmer, due to more C_4-grasses. During this early Holocene, the south-western winter rainfall experienced mesic climatic conditions (Scott and Lee-Thorp, 2004). Variation in the early Holocene suggests that the associations between temperature and moisture conditions were not fixed. The Southern Drakensberg experienced aridity from ~11 000 BP to 8 700 BP and at around 7 100 BP. Along the south coast high rainfall has been experienced during winter and summer. In contrast to this the south-western winter rainfall region experienced mesic conditions during the early Holocene (Scott and Lee-Thorp, 2004). Summer and winter rainfall areas of southern Africa experienced a maximum Holocene warming between 8 000 and 5 000 BP (Partridge, 1997a).

At around 7 500 BP, the temperature optimum was set with an improvement in moisture in the summer rainfall region (Scott and Lee-Thorp, 2004). At around 7 500 BP, the higher latitudes experienced an increase in the annual moisture received at the Tropic of Capricorn (Tyson and Partridge, 2000). The optimum temperature for South Africa during the Holocene was manifested at around 7 000 and 4 500 BP (Tyson and Partridge, 2000; Tyson and Preston-Whyte, 2004). This temperature was around 2°C higher than the present climates of the sub-continent. With the increase in temperature, rainfall also increased with the maximum rainfall occurring at different times in different places (Tyson and Partridge, 2000; Tyson and Preston-Whyte, 2004). This led to noticeable variation in rainfall, with the north-eastern parts of the summer rainfall area in South Africa experiencing reduced rainfall. Together with this, the Kalahari experienced wetter conditions (Partridge *et al.*, 1999). The summer was displaced westward, with the eastern areas becoming drier due to the quasi-stationary tropical easterly wave (Partridge *et al.*, 1999; Tyson and Partridge, 2000; Tyson and Preston-Whyte, 2004). In contrast to this Scott *et al.* (2012) mentioned that warm conditions occurred during the middle Holocene, but temperatures decreased towards the Late Holocene (6 000 to 1 500 BP).

Indications are that the Last Glacial Maximum over South Africa was dominated by the westerlies, easterlies and disturbances of weather patterns therein (Scott and Lee-Thorp, 2004). Due to this the amount of winter rainfall found in the summer rainfall areas were higher than today. With this change in mind the mean annual rainfall was still much less than at present. The circulation that dominated during the time of the altithermal had the opposite effect. This circulation was dominated by tropically-induced disturbances in the easterlies. Thus, rainfall during winter in the summer rainfall areas was the same or less than at present. This warming and increase in rainfall occurred over the south from the tropical northern parts of South Africa, reaching the southern coast last. The increase in annual moisture only became evident on the southern coast of South Africa at around 3 500 BP (Tyson and Partridge, 2000).

During this Last Glacial Maximum, the temperatures over the southern parts of 24° of Southern Africa decreased with between 5°C – 6°C. The reconstruction of the palaeo-temperatures also indicates a south-to-north temperature gradient. The rainfall over the sub-continent was also lower, ranging from a decrease of 30% in the Kalahari to 70% in the eastern parts of the present day values. The climate during this time was similar to the seasonal climatic systems we know today. The winter rainfall area was restricted to the south-west, dominated by C_3-grasses and Fynbos. The summer rainfall area was restricted to the remainder of the sub-continent, dominated by C_4-grasses (Tyson and Partridge, 2000).

5.4 CLIMATE AFTER THE HOLOCENE ALTITHERMAL

The Cango Cave high resolution isotope record for some time provided the longest continuous terrestrial climatic series for the post-Holocene period. From this, two major cool events occurred in the third to fifth millennia before the present times in southern South Africa. This cooling is confirmed by the findings of Holmgren *et al.* (2003) that the cooling occurred between 6 and 3 ka at both Makapansgat (near Polokwane) and Wonderkrater (near Mokopane). The first was about 4 700 to 4 200 BP and the second from 3 200 to 2 500 BP known as the neoglacial period (Tyson and Preston-Whyte, 2004). Widespread dry events occurred throughout the sub-continent from approximately 4 000 to 2 000 BP (Scott *et al.,* 2012). The Neoglacial's end was marked by rapid warming after 2 500 BP. The period between these two cool events experienced mild climates (Tyson and Preston-Whyte, 2004). The period after 2 000 BP showed eventful phases however, the oscillations were not uniform throughout southern Africa (Scott *et al.,* 2012).

The last indications of climate change during the Holocene (Tyson and Partridge, 2000; Tyson and Preston-Whyte, 2004), comes from the Cold Air Cave in Makapansgat Valley's (south-west of (Polokwane) Pietersburg) stalagmite, for the central plateau of the summer rainfall region (Tyson and Partridge, 2000; Tyson and Preston-Whyte, 2004). The colour variation of the stalagmite indicates the variation in climate. A high percentage of ^{18}O and ^{13}C represent warmer, wetter conditions with a decrease in cooler and drier environments. The darker colour indicates warmer conditions and the lighter colour cooler conditions (Tyson and Partridge, 2000). Tyson and Preston-Whyte (2004) declares that the widths of the growth-layers are positively correlated with the rainfall.

This stalagmite have a decade-by-decade variability throughout the last 6 600 years (Tyson and Preston-Whyte, 2004). The variability was sometimes pronounced, for instance the rapid change of $\delta^{18}O$ (~2%) in 40 years occurred between 1 180 and 1 220 BP (Tyson and Partridge, 2000; Tyson and Preston-Whyte, 2004). A rapid oscillation in the ^{18}O and ^{13}C occurred at around 6 000 BP and again between 4 000 and 3 700 BP (Tyson and Partridge, 2000). The stalagmite underwent rapid growth at around 4 000 BP (Tyson and Preston-Whyte, 2004). Between 3 800 to 3 400 BP there was a decrease in $\delta^{18}O$ and an increase in $\delta^{13}C$ which caused a colour change in the composition of the stalagmite. This is an indication of a cooler environment. This period of time was followed by the neoglacial period of cooling between 2 700 to 3 100 BP (Tyson and Partridge, 2000; Tyson and Preston-Whyte, 2004). This period was followed by a further cooling known as the five centuries of the Little Ice Age between 1 300 and 1 800 BP (Tyson and Partridge, 2000). A further decrease during the last phase of the Little Ice Age from 1 300 to 1 810 lead to the lowest value in the entire record at around 1 700 BP. During this time, the mean annual maximum temperature was between 1 – 2°C below the present temperature. The following 110 years experienced an enrichment of ^{18}O (more than 3%). The Little Ice Age came to an end at around 1 810 BP (Tyson and Partridge, 2000). Tyson and

Preston-Whyte (2004) stated that the cooling of the Little Ice Age was associated with aridification and an increase in the frequency of major flooding events.

The early part of the Makapansgat Valley record indicates a period of warming up to just after 6 000 BP. Conditions during this time were highly variable. Warmer conditions again prevailed before 4 000 BP and again at around 2 400 BP. The period from 900 – 1 300 BP (four centuries) was characterised by warmer and highly variable conditions. The warmer periods were followed by short cooler periods (Medieval Warm Epoch). The period from 40 to 440 BP was known as the most prolonged and consistently warm period of the last three millennia (Tyson and Partridge, 2000; Tyson and Preston-Whyte, 2004). During the last two millennia, the most pronounced warm period occurred between 500 and 600 BP. The period from around 250 – 450 BP was consistently and sustained warmer in the entire record. The period of 500 – 1 300 BP was generally cooler. Several research papers support the climatic variability described above (Tyson and Partridge, 2000). Records from the Makapansgat Valley show comparison with evidence found in parts of Greenland and Scandinavia (Tyson and Preston-Whyte, 2004).

5.5 PRESENT DAY CLIMATE

The climate of southern Africa is influenced by the position of the sub-continent in relation to the circulation features of the southern hemisphere (Tyson, 1986; Deacon and Lancaster, 1988). The complexity of southern Africa's climate is due to the intersection of the tropical, subtropical and temperate climatic systems (Nash and Meadows, 2012). The rainfall of southern Africa decreases from east (>800 mm/ 1 000 mm) to west (almost complete aridity/50 mm) (Tyson, 1986; Nash and Meadows, 2012) and is highly seasonal (Tyson, 1986). The 400/500 mm isohyets divide South Africa into a wetter eastern part and a drier western part (Tyson, 1986; Deacon and Lancaster, 1988). Southern Africa is dominated by dry climates with strong seasonal precipitation (Deacon and Lancaster, 1988). Very wet years are more frequent in regions which are very dry; thus, the rainfall will exceed 125% (Tyson, 1986). Regions experiencing very dry years with 75% below normal rainfall also occur in the very dry areas of southern Africa. Therefore, it can be said that the dry western parts of South Africa experiences a highly variable quantity of rainfall (Tyson, 1986).

Another factor influencing the climate of southern Africa is the ocean currents: the northward flowing cold Benguela current and the southward flowing warm Mozambique current (Deacon and Lancaster, 1988). The western interior of the sub-continent always experience lower humidity (Tyson, 1986). This is due to the fact that the tropical Indian Ocean (the source of moisture) occurs on the eastern side of the sub-continent (Tyson, 1986; Deacon and Lancaster, 1988). The moisture gradient from the east to the west of the sub-continent is more pronounced in summer than in winter (Tyson, 1986).

Land configuration and altitude have an influence on the air temperature in southern Africa. Southern Africa is a sub-continent with varying altitudes ranging from sea-level to a plateau (1 250 m) to high lying mountains exceeding 3 000 m, this also affects the temperature considerably (Tyson, 1986). The Great Escarpment of southern Africa also contributes to the aridity of the interior (Gasse *et al.*, 2008). Maximum temperatures exceeding 30°C show a west to east gradient, the west is having higher temperatures more frequent (Tyson, 1986).

The understanding of the climatic changes in the past to shape the present will contribute towards predicting and understanding the possible climatic changes in the future.

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CHAPTER 6
VEGETATION OVERVIEW: FROM PAST TO PRESENT

6.1 INTRODUCTION

We often tend to take the vegetation present around us for granted. However, plants could only invade barren, dry terrestrial surfaces after they have evolved the ability to absorb and retain enough water to avoid desiccation (McCarthy and Rubidge, 2005). Around three thousand million years ago, oxygen-releasing life forms, blue-green algae, started producing oxygen in the atmosphere (Tyson and Preston-Whyte, 2004). Life on land only originated at the end of the Ordovician (±490 mya). Plants also began to contribute to the oxygen content of the atmosphere. During the Permian, the glossopterids and gymnosperms followed, evolved and formed extensive forests. Angiosperms only evolved during the Lower to Middle Cretaceous (Anderson *et al.*, 1999) and today they are the dominant plants on the planet.

The southern parts of Africa have records of the oldest forms of life (cyanobacteria) in the Onverwacht Fromation (Bamford, 2004). Fossils of the earliest terrestrial plants dating back to 400 million years were found in the old Bokkeveld Group (McCarthy and Rubidge, 2005; Van As *et al.*, 2012). It is clear that environmental factors such as atmospheric and crustal changes have influenced the vegetation during different periods (Scott *et al.,* 1997). These fossils helped to answer important questions regarding the origin of life.

Through the process of evolution, major environmental perturbations and modern plant communities were established during the latter part of the Cenozoic. Long term Tertiary and Quaternary studies such as palynology (pollen analysis), faunal, micro-faunal, archaeological and isotopic studies, showed that vegetation composition and boundaries were regularly changed by shifts in environmental conditions. The earliest terrestrial vegetation history in South Africa was reconstructed using macrofossils and to a lesser extent fossil pollen and spores. The fossils were found in Palaeozoic and old Mesozoic rocks (Scott *et al.,* 1997). Although southern Africa has some of the earliest land plants, this part of the continent is best known for the long and almost complete biotic record of the Upper Carboniferous to Lower Jurassic in the Karoo (Bamford, 2004).

Vegetation science plays an important part in understanding many ecological, biogeographical and evolutionary problems (Huntley and Webb III, 1988). Vegetation anywhere is a result of change, controlled by the environmental conditions and more important the climate (Adamson, 1938). This is why it is important to understand the forces that shaped the evolution of species. Geographical distribution of vegetation is dependent on elevation as well as the intensity, duration and timing of the wet season (Dupont *et al.,* 2007). Therefore, the palaeo-environments and palaeo-communities of the last 20 mya are important to gain insight (Huntley and Webb III, 1988). The palaeo-vegetation records provide vital information to the understanding of climatic and vegetation feedback processes (Dupont *et al.,* 2007).

6.2 EVOLUTION OF LAND PLANTS IN SOUTHERN AFRICA/PANGAEIC PHASE

6.2.1 Late Palaeozoic – The early vascular plants (390-360 Myr)

Flowering plant emergence during the Mesozoic, as part of the world's dominant flora, was a major event (Pearson, 1978). The major radiation of flowering plants started in the Upper Jurassic and developed slowly during the Lower Cretaceous until it accelerated in the Upper Cretaceous (Pearson, 1978; Magallón and Sanderson, 2001). This is confirmed by palynological data (Pearson, 1978).

Although the earliest vascular plants colonized the land in the Late Silurian (443 – 417 mya) the first records in southern Africa only occur in the Middle to Late Devonian (Scott *et al.,* 1997). Fossil flora of the Late Devonian, 350 mya, included clubmosses, lycopods, ancestral gymnosperms and algae. Some of these plant groups still have living representatives on Earth today (McCarthy and Rubidge, 2005). Plant associations during this time were monospecific or of very low diversity (Scott *et al.,* 1997).

6.2.2 Late Palaeozoic, Early Mesozoic – The coal-forming Glossopterid forests (280 Myr)

South Africa, being part of Gondwana, drifted northwards away from the South Pole at around 300 million years ago. The melting of ice and glaciers led to the exposure of new land surfaces which were colonised by plants. These plants included clubmosses, ferns and horsetails. The success of these plants was due to their environmental, reproductive and dispersal adaptations (McCarthy and Rubidge, 2005). In terms of reproduction; the plants developed more small male spores and fewer large female spores. This has led to the development of sexual reproduction and cross-pollination with genetic advantages (McCarthy and Rubidge, 2005).

The rich coal deposits found in South Africa is due to the abundance of *Glossopteris* dominated forests during the late Lower Permian (Scott *et al.,* 1997; Bamford, 2004; McCarthy and Rubidge, 2005; Van As *et al.*, 2012). *Glossopteris* species were plants best adapted for survival, dispersal and germination during those climates of the Permian (retreating ice sheets and a general warming period (Anderson *et al.,* 1999)) (McCarthy and Rubidge, 2005). Although the *Glossopterids* quickly diversified, they became extinct early in the Triassic (Bamford, 2004; McCarthy and Rubidge, 2005; Van As *et al.*, 2012).

During the early Permian the flora was dominated by various glossopterid (seed fern) and some lycopod genera. Horsetails, ferns, ginkgos and conifers were also present, but to a lesser extent. The vegetation along the sea was dominated by medium to diverse glossopterid forests and woodlands along the river banks and elevated ground, with dense monospecific lycopod stands along pans and swamps (Scott *et al.* 1997; Bamford, 2004). Lycopods dominated the vegetation of Gondwana until the Early Triassic. Thereafter, vascular plants, horsetails and gymnosperms were dominant (Anderson *et al.,* 1999).

At around 251 million years ago (end of the Permian) the greatest extinction event occurred. This mass extinction event possibly extended over more or less 100 000 years; however, the reason for the extinction is still unknown. The vegetation was dramatically affected by this event. Glossopterids became extinct with clubmosses and horsetails sharply decreasing in diversity. Vacant niches were occupied by new types of seed ferns, *Dicroidium,* with protected seeds instead of sporangia. These seed ferns showed a diversity peak during the Late Triassic, occupying a variety of ecological niches together with other species such as cycads, ginkgos, clubmosses and horsetails (McCarthy and Rubidge, 2005; Van As *et al*., 2012). Their existence was short lived as they also became extinct after the Late Triassic (McCarthy and Rubidge, 2005).

6.2.3 Late Triassic – Biodiversity peak (210 Myr)

Flora of the Late Triassic is the richest and best preserved fossil flora in Africa (Scott *et al.,* 1997). The Late Triassic presented the richest times of plant history (McCarthy and Rubidge, 2005) yielding some 204 species which is an indication of rich biodiversity of this period (Scott *et al.,* 1997). The fossilised taxa mostly represent pteridophytes and gymnosperms (Anderson *et al.*, 1999). The vegetation was comprised of seed-ferns, conifers, horsetails, ferns, cycads and ginkgos which were either diverse or very abundant (Scott *et al.,* 1997). A peak occurred in the seed fern diversity during the Late Triassic, as these ferns occupied a variety of ecological niches (from wetlands to open woodland habitats) (McCarthy and Rubidge, 2005).

At the end of the Triassic Period (210 mya) southern Africa became more arid (McCarthy and Rubidge, 2005). In this arid climate seed ferns disappeared; however, ferns survived. Little fossil evidence is present about the Jurassic Period in South Africa. The fossil record is represented by a few cycads in South Africa but in contrast to this, the vegetation of the world contained cycads, cycadeoids and conifers during this period (McCarthy and Rubidge, 2005). The vegetation of Gondwana was dominated by conifers during the Jurassic (Anderson *et al.,* 1999). Fossil records of the Middle and Upper Jurassic are almost absent due to the Drakenberg volcanic eruptions during the Jurassic (Bamford, 2004).

6.2.3.1 Wood assemblages

Phillippe *et al.* (2004) analyzed the woody assemblages present on Gondwana during the Jurassic-Early Cretaceous. With the focus on southern Africa, the following were found: A large part of southern Africa, with the exception of the south and east coast, fall within the winter wet zone of Gondwana. Within this zone, there are no distinct endemic genera. However, two genera, *Protelicoxylon* and *Prototaxoxylon* are found only in this region of Gondwana (also found on Laurasia). During the early Cretaceous, the winter wet zone was dominated by *Podocarpoxylon*, whereas other regions of Gondwana were dominated by

Agathoxylon. The distribution of Podocarpaceae is mainly influenced by climate and strongly corresponds with the fossil distribution (Philippe *et al.*, 2004).

The southernmost part of Africa (east and south coast) falls within the warm temperate zone of Gondwana. This climatic zone has the greatest diversity of the geological timescales discussed by Phillippe *et al.* (2004). The genera *Sahnioxylon* and *Protocupressinoxylon* (member of the extinct family Cheirolepidiaceae (Bamford, 2004)) are restricted to this part of Gondwana. These two genera, however, also occurred on Laurasia. Other genera that occurred in both the warm temperate and winter wet zones include *Cupressinoxylon, Ginkgoxylon* and *Taxaceocylon.* Although these two zones have strong similarities, *Protocircoporoxylon* and *Protopodocarpoxylon* occur in the winter wet zone, but are absent from the warm temperate zone (Philippe *et al.*, 2004).

6.3 VEGETATION DURING THE CRETACEOUS PERIOD (145-65 MYA)

The vegetation present in the Lower Cretaceous is mostly dominated by pre-angiosperm groups, characterized by the extinct, cycad-like Bennettitales (Scott *et al.,* 1997). Although the early angiosperms already evolved, they were not present in the fossil record of the Lower Cretaceous (Scott *et al.,* 1997). The abundance of fossil tree trunks suggested that the vegetation were dominated by forests along the coastline of southern Africa (McCarthy and Rubidge, 2005). Other vegetation present during this time includes ferns, cycads, conifers (Scott *et al.,* 1997; Bamford, 2000) and cycadeoids (Bamford, 2000). According to Bamford (2004) a number of dicotyledonous leaves and “flowers” were preserved, but these plants cannot be identified to modern family level. When looking at the leaf physiognomy the palaeo-climate was dry and/or cool (Bamford, 2000).

Plant records of the Upper Cretaceous contain members of some of the modern flora plant families. These plant deposits were collected in the Northern Cape Province at Mahura-mutwa, Vryburg, Graspan and Roodepan (interior Ghaap plateau) (Bamford, 2000). The leaves studied from these deposits indicated a mesophytic habitat. Gymnospermous species from the Araucariaceae and Podocarpaceae families were found in these deposits. This is an indication that the climate was probably wetter and the area more densely vegetated than today. The family Araucariaceae is absent from Africa today and probably disappeared from the continent during the Cenozoic (Bamford, 2000). Today the Araucariaceae is found in South America and Southwest Asia-Western Pacific region (Kershaw and Wagstaff, 2001).

The Eastern Cape yielded several types of gymnosperms and primitive angiosperm fossils which include Monimiaceae and Euphorbiaceae (Bredenkamp *et al.,* 2002). The presence of Monimiaceae on the Ghaap plateau indicates that this family was common in the Upper Cretaceous flora of Africa (Scott *et al.*, 1997). In parts of southern Namibia the vegetation, in the Cretaceous or post-Cretaceous include horsetails, ferns, gymnosperms and possible angiosperms (Kelber *et al.,* 1993; Scott *et al.* 1997).

The climate during mid- and late Cretaceous (142 – 65 mya) was mostly warm (Scott *et al*. 1997) but McCarthy and Rubidge (2005) stated that the climate at the end of the Cretaceous was cooler and wetter than today. The vegetation on the Bushmanland landscape was dominated by tall conifers (*Araucaria spp.*). Towards the end of the Cretaceous, Angiosperms worldwide were well established and had a relatively high diversity (Magallón and Sanderson, 2001; Bredenkamp *et al.*, 2002). Although the palaeo-botany information is limited for southern Africa, studies by the Southern Oil Exploration Corporation indicate that the microfloras of the mid-Cretaceous confirm with other microfloras of the southern hemisphere continents. *Clavatipollenites* was recorded as the first angiosperm in southern Africa as well as the world (Scott *et al,.* 1997; Bredenkamp *et al.*, 2002).

The general belief is that a meteorite impact event at the end of the Cretaceous blew a lot of dust high into the atmosphere. This caused a global reduction in the amount of solar radiation reaching the ground for months or even years. The result was the destruction of the global ecosystem. The survivors had to start rebuilding on the range of new environmental niches available. The angiosperms of this time had a superior reproductive ability; therefore, the rapid evolution of species of both fauna and flora occurred (McCarthy and Rubidge, 2005).

Representatives of the vegetation were well preserved in the fossil pollen remains of the Cretaceous to early Tertiary. The vegetation that occurred in the Namaqualand region was mostly dominated by subtropical trees, including lianas, epiphytes and mosses (Scholtz, 1985). The fossil record, however, also includes characteristic species of the fynbos namely the Proteaceae, Ericaceae and Restionaceae. This fynbos type vegetation occurred under different climatic, topographic and edaphic conditions that differ from the modern day fynbos environment. Unlike the fynbos of the early Tertiary the modern day fynbos occurs in a winter rainfall area and on oligotrophic soils (Scholtz, 1985).

The development of distinct characteristics for the African vegetation occurred during the Cretaceous-Tertiary transition (Scott *et al.,* 1997). However, McCarthy and Rubidge (2005) found that palaeontological evidence is missing information for the uppermost of the Late Cretaceous and the lower most of the Tertiary.

6.4 VEGETATION DURING THE TERTIARY PERIOD

Periods on the geological timescale can be divided into sub-periods; namely, the Palaeogene (65 – 24 mya) and the Neogene (24 – 2 mya). The Palaeogene can be divided into the Paleocene (65 – 55 mya), Eocene (55 – 34 mya) and Oligocene (34 – 24 mya) epochs. The Neogene can be divided into the Miocene (24 – 5 mya) and Pliocene (5 – 2 mya) epochs (Johnson *et al.,* 2006).

6.4.1 Palaeogene sub-period

6.4.1.1 Palaeocene Epoch (65 – 56 mya)

This epoch has no information regarding macroplant fossils (Bamford, 2000).

6.4.1.2 Eocene Epoch (56 – 34 mya)

Deposits in the vicinity of Bogenfels in Namibia resulted in wood fossils from the Balanitaceae, Burseraceae, Euphorbiaceae, Lauraceae, Leguminosae and Myrtaceae. Bamford (2000) stated that these families are still well represented in southern Africa today. The Balanitaceae and Burseraceae families represent plants of the dry bushveld as well as semi-arid to arid environments. The Lauraceae in southern Africa are dominated by plants that occur in forested areas. The remaining tree families that occurred during this Epoch occupied in a wide variety of habitats. Due to the presence of these families the habitats present during this time were very diverse, ranging from dry bushveld to forest vegetation (Bamford, 2000).

Podocarpus, Widdringtonia and some monocotyledons and dicotyledon fossils, present in silcrete deposits from Fort Grey, represent an age of no later than the Eocene (Scott *et al.,* 1997). Pollen from marine deposits off the west coast suggest that early forms of Asteraceae (Mutisiae) had already developed in the Namaqualand region during the Eocene epoch (Zavada and de Villiers 2000; Scott *et al*., 2006).

According to Anderson *et al.* (1999) grassland pastures occurred for the first time during the Eocene. This allowed the evolution of new tetrapod vertebrates. Grassland was a widespread vegetation type by Oligocene times.

6.4.1.3 Oligocene Epoch (34 – 23 mya)

Macroplant fossils during this epoch are rare and questionable. However, there are suggestions that the conditions during this time were moist and semi-swampy, but this can be doubted, due to difficulty with identification of the woody species (Bamford, 2000). Therefore, Bamford (2000) proposed that more research is needed to determine the conditions during this time.

6.4.2 Neogene sub-period

Research in palaeo-botany both on- and offshore of southern Africa indicated that the plant communities evolved into equivalents to the modern biomes known today. Although the fossils and material for chronometric dating were scarce, anaerobic conditions prevailed in depositional basins, found offshore. The climatic conditions and erosional nature of the central interior of the continent were unfavourable for the preservation of organic matter and the subsequent fossilization of plants (Scott, 1995; Scott *et al.,* 1997).

The Neogene sub-period was a period of marked climate change in southern Africa, characterised by the cooling of ocean waters and growing of the Antarctic Ice Sheet, as well as the development of the *circum*-Antarctic current in the southern ocean. Global environmental changes led to changes in angiosperm diversification and plant communities evolved with modern antelopes as well as the hominid genera that appeared in the African interior (Brink, 1987b; Coetzee, 1978; Scott *et al.,* 1997; Kuman *et al.*, 1999; Roberts *et al*., 2011).

Vegetation on the west coast, Namaqualand and Karoo areas can be reconstructed based on pollen data from offshore marine bore holes along the Angolan coast. The data gathered indicated that the current arid climate of the west coast regime is a feature from the Neogene (Van Zinderen Bakker, 1984).

6.4.2.1 Miocene Epoch (23 – 5 mya)

Fossil wood species from the Geelvloer paleo-valley (south-east of Pofadder in the Northern Cape) were identified as species belonging to the Dipterocarpaceae, Myrtaceae, Fagaceae, Rutaceae, Oleaceae and Polygalaceae families (Bamford and De Witt, 1993). These families indicated a tropical to sub-tropical climate during the mid-Miocene. The wood structure also indicates a wetter climate during this time. This wetter climate is in contrast to the semi-arid climate that currently prevails in the area. Furthermore, the year rings of the trees are indistinct, which indicate minimal seasonality, with a diameter greater than 50 cm (Bamford, 2000).

The Lower and Middle Miocene are represented by silicified woods found in the Olifants River near Vredendal, south western-Cape. The families present here are the Combretaceae and Meliaceae which are indications of wet, forested environments. Taxa found in this area are either forest trees or trees that occur in savannas, but require a lot of water or grew along water courses and permanent water bodies such as pans (Bamford, 2000).

Fossil wood found on the Namibian side of the Orange River, at Auchas, are members of the Combretaceae (which represent savanna woodland), Leguminosae (diverse habitat), Meliaceae (forested environments) and Burseraceae (drier habitats or semi-desert). The fact that a variety of plant families, from different habitats, occur here indicates that they were transported to the area. Thus, the environments further inland varied from wetter riverine to drier habitats (Bamford, 2000).

Plant families present on the West Coast, Namaqualand and Karoo areas included Poaceae, Chenopodiaceae and Asteraceae which dominated the region since the Late Miocene (Van Zinderen Bakker, 1984). Pollen from palm and other trees suggested a more tropical climate, however, palm dominated vegetation could also indicate warm maxima during the Early (19 mya) and Middle (14 mya) Miocene

(Coetzee, 1978). Pollen assemblages on the south-western coast of Africa indicated that the presence of palm vegetation was related to relatively warm phases in the climate. The presence of Podocarpaceous pollen was indicative of relatively cool periods (Coetzee, 1980). Furthermore, the cyclic occurrence of Chenopodiaceae, Asteraceae and Poaceae pollen indicates wetter grassy conditions. These cycles relate to the earth's orbital movements which is a 41 000 year obliquity pattern (Scott *et al.*, 1997). The high occurrence of Asteraceae pollen is attributed to colder winter rainfall conditions between 2.32 and 2.4 mya. In the Brandvlei area of Bushmanland, currently covered by dry Nama-Karoo shrubland, subtropical and wetter climates occurred during the mid-Miocene. The evidence is found in the fossil plant remains of the Dipterocarpaceae, Fagaceae, Myrtaceae, Oleaceae, Rutaceae and Combretaceae (Bamford and De Wit, 1993; De Wit and Bamford, 1993).

In the Namaqualand region, the plant fossil record suggests a moist climate dominated by woodland and forest elements, differing from the succulent Karoo vegetation at present. The vegetation comprised of pollen from *Podocarpus, Olea*, Proteaceae, Myrtaceae, fern spores and Asteraceae (Scott, 1995). The vegetation dates probably from the Miocene (Roberts *et al*., 2013). Further evolution of Asteraceae took place and has led to more diverse long-spine and other pollen forms in the Neogene (Scott *et al*., 1997; Scott *et al*., 2006). Younger pollen of grasses (Poaceae), sedges (Cyperaceae), Asteraceae and aquatics indicate conditions that can be compared to the present day Nama-Karoo or Highveld grassland regions present in the interior of South Africa (Scott *et al.,* 1997).

The vegetation of the southern and south-western coasts can be reconstructed using pollen; however, precise dating is not possible. New research by Roberts *et al*. (2013) confine the Cape sequence from Noordhoek, to a shorter interval excluding parts of the Palaeocene than previously suggested by Coetzee (1983) and Coetzee and Muller (1984). This is done by means of correlation of transition from subtropical forest to fynbos with the ^{18}O chronology from the south-eastern Indian Ocean, the fluctuations in global sea-level and the development of the cool Benguela Current (Roberts *et al.*, 2013). The vegetation during the early Neogene was subtropical forests with palms. Faunal evidence indicated that the vegetation in the area was relatively open with some woody elements (Hendey, 1984).

The abundance of Asteraceae pollen is an indication of a drier climate that prevailed at the time of accumulation. The presence of fern spores indicated high moisture conditions which were either localized or seasonal (Scott *et al.,* 1997).

6.4.2.2 Pliocene Epoch (5 – 1.8 mya)

Many cave deposits in South Africa represent the hominoid development during the Plio-Pleistocene. However, vegetation records for these periods are fragmentary. The fragments of vegetation present in these caves are members of the Dichapetalaceae and Scrophulariaceae families (Bamford, 2000). The growth forms are mostly trees and lianas which currently represents riverine forests in central and West Africa (Bamford, 2000).

The vegetation of the Highveld summer-rainfall plateau changed from dense woodland to more open vegetation around Plio/Pleistocene times (Bamford, 2000) which could have included open *Protea* savanna (Scott and Bonnefille, 1986).

However, the site at Gladysvalle provided fossil wild date palm seeds together with vertebrate and hominoid remains of Plio- and Pleistocene age. Radio-carbon dating provided an age of 6 000 yr for these *Phoenix reclinata* seeds. The date palms occur in a wide variety of environmental conditions, but prefer watercourses and coastal environments. This implies that the current environmental conditions – grassland/savanna habitat – are very different to the environmental conditions that prevailed during the Pliocene Epoch but interpretation of the paleoclimate will only be possible after inspecting more macro-plant fossils (Bamford, 2000). However, the environmental conditions of the south-western Cape region and northern Namibia were relatively close to the modern day conditions (Scott, 1995).

6.5 VEGETATION DURING THE QUATERNARY PERIOD

During the Quaternary period, a number of archaic genera still flourished, these floras only became extinct in recent times. Modern floras also developed during this time (Pearson, 1978). The contribution of man to the extermination of species can be dated back to the earliest tool-using humans (Pearson, 1978).

Glacial-interglacial climatic changes were the reason for the shifts in modern phytochoria. The Quaternary vegetation history is incomplete and is built up from several pollen profiles, some of which confirm each other in showing certain patterns (Scott *et al.,* 2012). The oldest pollen records are from the Pretoria Saltpan and Port Durnford near Richards Bay (Scott *et al*., 1992; Scott 1999). These pollen records indicate that the modern biomes were well established during the Quaternary but shifts in the biome composition are due to the marked cycles of vegetation changes. These changing cycles are due to fluctuating temperatures, precipitation and seasonal distribution of moisture patterns that result from different forcing mechanisms like orbital, atmospheric and oceanic circulation changes (Scott *et al.,* 1997; Scott *et al.*, 2012).

The broad trends for changes in vegetation were identified for the Late Pleistocene, however, the conditions that prevailed during the warmest phase of the Last Interglacial is still poorly understood. Suggestions are that this resembles the Holocene. Pollen samples from different regions indicate that forests were widespread at times and this was attributed to more moist conditions and vegetation belts were lowered by an estimated 1 000 m in altitude during the Last Glacial Maximum as a respond to an approximate 5°C drop in temperature (Scott *et al.,* 1997). Fluctuations in temperature and precipitation could have a similar effect on the fossil pollen spectra and therefore, their roles are difficult to separate in interpretations of past climate. There are indications from palaeo-botanical data that the precipitation rates fluctuated during the end of the Pleistocene (Scott *et al*., 1997). The cooler conditions during this time must have lowered evaporation rates which led to the effective use of available moisture. Climatic conditions became more favourable and precipitation increased. In some areas in the interior, rainfall declined drastically at the beginning of the Holocene, while on the west coast it was wetter (Scott *et al.*, 2012). Afterwards, the biomes began to reflect their modern pattern but small scale shorter term variation occurred constantly (Scott *et al.,* 1997). Bond (1997) stated that the importance of fire and herbivory should also be taken into account when looking at Pleistocene and Holocene vegetation changes.

Fire played an important part in shaping the vegetation of southern Africa. However there is a lack in studies on the importance of fire as an evolutionary factor. The evolution of flammable plants (grasses – summer rainfall regions and shrubs – winter rainfall regions) would have led to regular fires with profound effects on the flora of the area. Bond (1997) stated that the spread of grasses in grass-dominated vegetation is relatively recent. Southern African grassy vegetation is dominated by C_4-grasses which evolved in the Miocene 6-8 Myr ago (Cerling *et al.,* 1997; Hopley *et al.,* 2007) and were preceded by C_3-grasses for several millions of years. The origin of C_4-grasses is supported by evidence from palaeo-sols and tooth enamel of mammals (Cerling *et al.*, 1997). Cerling *et al.* (1997) further mentioned that C_4-grasses are present when the CO_2 levels in the atmosphere is below 500 parts per million by volume. During this time, the temperatures of the growing season should also be high. Cerling *et al.* (1997) further noted that the expansion of C_4-grasses occurred on a global scale during the late Miocene and are still persisting at present.

The increase in C_4-grasses led to the dominance of grazing species in large herds at around 7 to 5 Myr ago in Africa. Therefore, the grass-dominated vegetation is relatively recent in origin. The diversification of the grasslands as well as the savanna and fynbos are, therefore, relatively recent. The embryonic flora of the fynbos, savanna and grasslands were in place during the late Miocene, however major diversification occurred in the Pliocene (Bond, 1997). Hopley *et al.* (2007) mentioned that the C_3 and C_4 grass distribution in the modern-day are influenced by the seasonality of climatic systems. C_4 grasses dominate the summer rainfall eastern and interior parts of South Africa. The C_3 grasses dominate the fynbos and south-western regions which received winter rainfall. A combination of the C_3 and C_4 grasses occurs in the zone between the summer and winter rainfall areas (Hopley *et al.*, 2007).

Scott *et al.* (1997) has provided extended explanation of the different biomes, whereas in this study I will only look at the Grassland biome, Savanna biome and Nama Karoo biome.

6.5.1 Grassland biome

The grassland biome became a widespread vegetation type in southern Africa during the Oligocene (Bredenkamp *et al.*, 2002). Scott (2002b) mentioned that palynological analyses indicate that grasslands were established around 300 000 yr ago in the interior of South Africa. The grassland biome is widespread in the interior plateau with fynbos-like vegetation present in the higher-altitude moist areas. Isotope studies from animal bones (from Melikane Cave, Lesotho) indicated that C_3-plants became more prominent in the animal diet since the Late Pleistocene (Vogel, 1983). Indications are that the grassland migrated to lower elevations during the Last Glacial Maximum (Scott, 1989). Vegetation belts in general were lowered by about 1 000 m during the Last Glacial Maximum (Bredenkamp *et al.*, 2002). The presence of shrubby fynbos pollen among the grasses suggests the spread of "cold" grassland during glacial periods. The problem with this is that changes in grass species composition cannot be detected that easily as the grass pollen can only be identified up to family (Poaceae) level (Scott *et al.,* 1997).

The downward shifts of zones during the Quaternary lead to the expanding of the grasslands at the expense of woody vegetation. Therefore, the Grassland biome occupied a larger area to the north during the cooler past than what we presently know. Data from Florisbad (north of Bloemfontein) indicate that there were cyclic changes in the vegetation during the Pleistocene. These fluctuations were an alternation between grasses and local halophytic spring plants (van Zinderen Bakker, 1989).

The vegetation data from Clarens higher lying grasslands indicate the downward spread of dry mountain fynbos elements during the cold Last Glacial Maximum (26 500 – 19 000 BP) (Scott *et al*., 2012). However, the grasses remained the most important vegetation component during the Late Pleistocene (O`Connor and Bredenkamp, 1997; Scott *et al*., 1997). This is confirmed by the charcoal analysis where *Protea* and *Cliffortia* were used for firewood during the Late Pleistocene. In contrast to that, *Buddleja* and *Maytenus* were used during the Holocene (Scott *et* al., 1997). Although there were boundary shifts and differences in composition, the grasslands have been present throughout the Holocene and even more widespread during the Pleistocene. Scott *et al.* (1997) mentioned that the climatic changes influenced the grasslands long term history in Southern Africa. An example thereof is the downward spreading of C_3-grasses and Afromontane fynbos from the upper slopes of mountains due to lower temperatures and less seasonal rainfall.

Pollen analyses from the Noupoort area (7 790 BP) indicated the high occurrence of Asteraceae pollen. The conditions during this time might have been cooler and drier with less marked rainfall patterns (Scott *et al*., 2005). Charcoal analysis from the western Drakensberg at around 7 000 BP also indicates dry conditions. There are also indications that during the "climatic optimum" (or warmest, wettest phase) around 7 000 BP in the middle Holocene, the Savanna Biome shifted further towards the south in the vicinity of Rietvlei Dam to the northern parts of the Highveld. Data from the Late Holocene (4 000 – 1 000 BP) indicates that with favourable conditions, the grassland boundary also shifted further westwards to areas near Deelpan and Alexandersfontein (near Kimberley). Furthermore, data from charcoal analysis from Drakensberg sediments indicate that relatively moist conditions occurred around 2 400 BP (February, 1994).

The grasslands were only affected by humans, with their agricultural activities, since the Late Holocene (Scott *et al.,* 1997). Human influences in the grassland biome can be restricted to the very late Holocene (Bredenkamp *et al.*, 2002). However, O`Connor and Bredenkamp (1997) stated that the demand for wood during the Iron Age might have affected the boundaries of the Grassland biome. The grassland was in place throughout the Holocene, however, more widespread during the Pleistocene (Bredenkamp *et al.*, 2002).

6.5.2 Savanna biome

The Savanna biome, during the Quaternary, was studied with pollen and charcoal specimens from spring, swamp, lake and cave deposits. The available pollen history of woodland vegetation in the Pleistocene starts with the period from ca. 200 000 years ago from samples from Tswaing Crater, north of Pretoria. However, large gaps exist in the pollen and plant fossil record (Scott, 1999). During this period, there is, however, evidence of major shifts in the vegetation patterns. The Late Pleistocene and Holocene are covered at Wonderkrater from around 50 000 years ago (Scott, 1982; Scott, 1999). These marked alterations occurred between woodland savanna (warm inter glacial phases) to cool open upland grasslands with fynbos elements (glacial maximum) and mesic woodlands with *Podocarpus* forests (intermediate phases) (Scott, 1982; Scott, 1999; Scott *et al*., 1997)

Phases of more intense fires in the bushveld were experienced in the past. Suggestions indicate that the fires during the Pleistocene were not dependent on vegetation type, but depended on the activities of humans and their occupation of the area (Scott, 2002a). The end of the Pleistocene saw a dramatic change in the vegetation in the current savanna biome, which consisted of grassy fynbos dominated by Ericaceae and *Podocarpus* forest patches that changed to semi-arid savanna in the early Holocene (*c.* 8 000 BP). At around 7 000 BP, the broad-leaved savanna was established (Scott *et al*., 2012).

The most detailed fossil pollen record of savanna vegetation is represented by the Quaternary (Wonderkrater and Pretoria Saltpan). There are, however, gaps in terms of spatial and temporal fossil pollen records. One can therefore conclude that the Savanna biome's southern boundaries shifted northwards during the cold glacial phases. Mountain slopes that should have been occupied by savanna vegetation were colonised by forests during mesic conditions. At around 7 000 BP, the broad-leaved savanna developed but the structure as we know it today only came into existence at about 1 000 BP (Scott *et al*., 1997).

6.5.3 Nama-Karoo biome

The environmental conditions did not favour the preservation of organic matter and, therefore, few fossil records occur in this biome. Although pollen is available in the Blydefontein, Winterberg and Sneeuberg, these areas are too high above sea level and thus, form part of the grassland biome. Old Pleistocene deposits are present at the Haaskraal Pan, but lack fossil pollen. Therefore, data for vegetation during the Pleistocene are lacking. At the end of the Pleistocene, karroid shrublands had a much wider distribution with records in the southern Kalahari, at Equus and Wonderwerk Cave (south of Kuruman) where the presence of *Passerina* in the pollen spectra indicated that the climate was cooler and seasonally altered (Scott, 1987; Brook *et al.,* 2010).

Spring deposits in the area of Aliwal North show evidence of altering cycles of grassy and karroid veld at the end of the Pleistocene. The Holocene spring deposits at Badsfontein (near Aliwal North) implied a less grassy environment than the pollen sequences elsewhere. The presence of grass in the vegetation was low in the early Holocene alluvial deposits at Blydefontein (south west of Aliwal North), but returned in abundance by the middle Holocene. The decline in the grassy component of the vegetation has led to the dominance of the present karroid vegetation (Coetzee, 1967; Scott *et al*., 1997).

Pollen samples from a wetland in the Nuweveldberge indicate relative stable vegetation, with fluctuations between mountain grassland and different karroid veld types. At the eastern part of the Nuweveldberge, hyrax middens indicate that the vegetation was dominated by shrubby members of the Asteraceae. This change in vegetation composition can be ascribed to the change in climate rather than grazing, as this occurred before the time of modern grazing practices. However, the mismanagement by European farmers and the grazing by stock owned by the KhoiKhoi could have contributed to the deterioration. These palynological interpretations are not strongly supported by archaeological deposits found at the Abbot`s Cave. This is due to the micro-mammal remains found at the cave (Scott *et al*., 1997).

Palynological data indicates that the karroid shrubland were well established and more widespread in the interior of South Africa during the late Pleistocene. During the middle Holocene, the Nama-Karoo had a higher grass cover but the grass to shrub ratio continued to alternate. This alteration can be ascribed to climatic changes; however, with the arrival of domestic stock the change in vegetation can be due to both climate change and land management (Scott *et al.,* 1997).

6.6 PRESENT DAY VEGETATION OF THE STUDY AREA

South Africa has nine different biomes of which two are present in the study area. Only these two biomes and the vegetation from the Inland Azonal Vegetation type and the different vegetation units in each biome present in the study area will briefly be discussed (Mucina and Rutherford, 2006).

6.6.1 Grassland Biome

The term grassland is often misused by both vegetation ecologists and other users. The misuse of this term often leads to the assumption that any piece of land dominated by grasses can be called grassland.

Mucina and Rutherford (2006) define grassland as herbaceous vegetation of relatively short and simple structure that is dominated by graminoids, from the family Poaceae. In this type of vegetation the woody plants are often absent or confined to specific habitats – escarpments or rocky outcrops. Grasslands usually occur on deep fertile soils (Mucina and Rutherford, 2006) however, O`Connor and Bredenkamp (1997) noted that well-drained, loose, deep sandy soils are also favourable. A strong seasonal precipitation trend occurs, with the growing season only lasting for half the year (Mucina and Rutherford, 2006).

In South Africa, the vegetation structure and environmental factors (summer rainfall and minimum winter temperature) define the extent of the biome. The Grassland biome is present on the high central plateau, the inland areas of the eastern seaboard, the mountain areas of KwaZulu-Natal as well as the central parts of the Eastern Cape. The topography of this biome varies from flat to rolling with mountainous areas and the escarpment. The elevation varies from 300 m above sea level to around 3 482 m above sea level in the Maluti Mountains. In these mountainous areas the temperature differences and the frequent frost have an effect on the vegetation (Mucina and Rutherford, 2006). According to O`Connor and Bredenkamp (1997) the tree cover of this biome is related to the number of growing days, slope as well as the area's topographic complexity.

Mucina and Rutherford (2006) mentioned that the activity of vegetation in the Grassland biome is strongly seasonal with a maximum vegetation activity occurring in late summer. This might be due to the relatively high rainfall which results in high plant productivity (O`Connor and Bredenkamp, 1997). The activity of the vegetation is near complete or terminated during the winter months (Mucina and Rutherford, 2006). The result of seasonal growth and the presence of frost, which cause above ground biomass to die off, contribute to a high fuel load for veld fires (O`Connor and Bredenkamp, 1997). In the western half of the biome, where the study is conducted the active growing season is during the months of February, March and April (Mucina and Rutherford, 2006).

The grassland biome in southern Africa occupy almost 349 174 km^2 of the central parts of the country. The biome covers a large range of rainfall, temperature and altitude ranges from the mountain tops down to sea level. The mean annual rainfall is important, as this determines the primary production across the biome. The vegetation of the grassland biome is usually uniform in structure although there are considerable variations in the species composition of different areas (O`Connor and Bredenkamp, 1997).

The boundaries of the grassland biome is mainly determined by climatic factors which include the number of days with sufficient soil moisture for the growth of plants, the mean temperature of such days as well as the mean temperature of days to dry for the occurrence of growth. The grassland biome experiences longer growing seasons and higher temperatures during the non-growing seasons (O`Connor and Bredenkamp, 1997).

The south-western boundary of the grassland biome is dry and interfaces with the Nama-Karoo. The south-western boundary is determined by altitude and thus, also annual rainfall and high rainfall uncertainty. The effects of overgrazing by livestock led to the expansion of the Nama-Karoo into the Grassland biome. This almost led to the elimination of perennial grasses; however, in years with higher spring-summer rainfall these grasses dominate the vegetation. In contrast, in years with higher autumn-winter rainfall the karoo bushes dominate the vegetation. With the absence of grazing in the Grassland Biome, grasses can be dominated by pure perennial grassland (O`Connor and Bredenkamp, 1997).

The mono-specific *Vachellia karroo* [*Acacia karroo*] communities present in the savanna forms the largest boundary interface with the grassland biome. This tall shrub or tree has invaded the grasslands throughout the biome due to a decline in grass biomass because of sustained heavy grazing by livestock. The reduction in the frequency and intensity of fires are reducing the mortality of *V. karroo* seedlings. Individuals of *V. karroo* serves as the starting point for the establishment of bird-dispersed woody species such as Common Karee (*Searsia lancea*) (O`Connor and Bredenkamp, 1997). Bond *et al.* (2001) mentioned that *Vachellia karroo* occurs on higher altitudes of the Hlyhluwe Game Reserve, while the juveniles are far more abundant and widespread than the adult trees. This phenomenon can be due to the physiological constraints that are accompanied with drier conditions in the lower lying areas. The establishment of *Vachellia karroo* is affected by rainfall of less than 500 mm (Bond *et al.*, 2001). *Vachellia karroo* is preferred by browsers, affecting the juvenile plants. However, *V. karroo* is more tolerant to fire and have the ability of resprouting after frequent and intense fires (Bond *et al.*, 2001).

The growth form of the *Vachellia karroo* trees in savanna areas has evolved in such a way that the trees grow vertically to escape fires and herbivory. In the savanna areas the *Acacia* (*Vachellia* or *Senegalia*) trees have smaller canopies, the area covered by leaves is smaller, the shoots are more elongated, the stems are narrower and the wood of these trees are less dense (Archibald and Bond, 2003).

The mountains of the Eastern Cape also have extensive grasslands, although these grasslands are not part of the Grassland Biome. In these grasslands fynbos occur on nutrient-poor aeolian sandy soils in areas that are protected from fire. The alternation between grassland and fynbos in this area are determined by the frequency of fire as well as the impact of grazing animals. Some fynbos species in this area are also vulnerable to drought as this is the transition between winter and summer rainfall. The dominance of the vegetation type is, therefore, determined by the above mentioned factors (O`Connor and Bredenkamp, 1997). Mucina and Rutherford (2006) noted that the northern and southern parts of the Drakensberg grasslands show links to the East African Mountains of to the post-Gondwanan flora of the Cape. Thus, most of the species currently present on the Drakensberg is firmly embedded within the clades of the Cape flora. The Karoo Escarpment might have been the bridge between the Cape and the Drakensberg – two-way migration (Mucina and Rutherford, 2006).

Forests on the eastern sector of the great escarpment also form interfaces with the grassland. Most of the forests occur on the steep southern slopes of mountains due to reduced radiation load and therefore, an increased soil moisture regime during the dry season. The margins of forests are vulnerable to fire because of the high fuel availability which in turn determines the fire intensity. The absence of fire for as much as 40 years can lead to the conversion of grasslands adjacent to forests into scrub forests (O`Connor and Bredenkamp, 1997).

O`Connor and Bredenkamp (1997) mentioned that the distribution of the Grassland Biome are, therefore, a result of the interplay between climate, topography, fire and grazing. Of the above mentioned factors climate, fire and grazing are the most important in determining the boundaries of the biome. However, the importance of fire in the biome is dependent upon the relative climate, topography and soil type (O`Connor and Bredenkamp, 1997).

Themeda triandra is the most dominant grass species found in the grassland biome. However, prominent species like *Eragrostis curvula, Cymbopogon pospischilli* [now *C. plurinodis*]*, Setaria sphacelata, Digitaria eriantha, Hyparrhenia hirta* and *Cynodon dactylon* also occur throughout the Grassland Biome (O`Connor and Bredenkamp, 1997). In arid areas, were overgrazing occurs, karroid shrubs and forbs may become dominant while sedges are dominant around wetlands (O`Connor and Bredenkamp, 1997).

6.6.2 Vegetation units of the Grassland Biome

6.6.2.1 Bloemfontein Dry Grassland (Gh 5)

The Bloemfontein Dry Grassland (Figure 6.1) is restricted to the central parts of the Free State with Bloemfontein situated in the middle. The boundaries of the unit is defined by the towns of Petrusburg (west) and Reddersburg (south) as well as the Rustfontein Dam (east) and the Soetdoring Nature Reserve (north) (Mucina and Rutherford, 2006).

The landscape is an undulating bottomland with an altitude of between 1 200 m and 1 480 m above mean sea level. The vegetation is composed of tall, dense grassland that alternate with patches of karroid shrubs that occur on calcrete (Mucina and Rutherford, 2006).

Sedimentary mudstone and layers of sandstone from the Adelaide Subgroup are present in the area. In the western parts, mudstones of the Ecca Group dominate the area. The soils are deep red sand layers of aeolion origin that cover the clayey B-horizons. The soil forms in the area are Hutton, Bainsvlei and Bloemdal. There is, however, also shallow, gravelly soils underlain by sheets of dolerite (Mucina and Rutherford, 2006)

6.6.2.2 Central Free State Grassland (Gh 6)

The Central Free State Grassland (Figure 6.1) occurs in the Free State as well as small parts of Gauteng. The area covered by this vegetation unit is around Sasolburg in the north to Dewetsdorp in the south. Other towns in the area include Kroonstad, Ventersburg, Steynsrus, Winburg, Lindley and Edenville (Mucina and Rutherford, 2006).

The altitude of this vegetation unit range from 1 300 m to 1 640 m above mean sea level. The plains are undulating and support short grasslands. In severely degraded clayey bottomlands dwarf karoo bushes will establish. The low lying areas are prone to *Vachellia karroo* [*Acacia karroo*] encroachment due to over grazing and trampling on heavy clayey soils (Mucina and Rutherford, 2006).

Mucina and Rutherford (2006) stated that sedimentary mud- and sandstone of the Adelaide Subgroup and the Ecca Group occur in the area. This geology contributes to the rise of vertic, melanic and red soils of the Arcadia, Bonheim, Kroonstad, Valsrivier and Rensburg forms. In the landscape numerous dolerite intrusions are also present and support dry clayey soils (Mucina and Rutherford, 2006).

6.6.2.3 Winburg Grassy Shrubland (Gh 7)

Mucina and Rutherford (2006) stated that the Winburg Grassy Shrubland (Figure 6.1) is restricted to the Free State and occur on rocky outcrops from Trompsburg through Bloemfontein and Winburg to Ventersburg.

The solitary hills, slopes and escarpments form a mosaic of habitats which range from grassland to shrubland. The altitude of these areas range from 1 300 m to 1 660 m above mean sea level. Tall shrubs and small trees are sheltered against frequent frost during winter and veld fires during late winter and early spring (Mucina and Rutherford, 2006).

Dolerite sills form ridges, plateaus and slopes of koppies, with small escarpments making erosion terraces. The sills have alternating sandstones and mudstones of sedimentary origin. The soil forms are mostly stony Mispah and gravel-rich Glenrosa (Mucina and Rutherford, 2006).

6.6.2.4 Bloemfontein Karroid Shrubland (Gh 8)

This vegetation unit (Figure 6.1) occurs in both the Free State and southern Mpumalanga. Isolated patches occur within the dry Highveld grassland and sometimes a karroid grassland are found on dolerite outcrops and ridges. The Bloemfontein Karroid Shrubland occurs over an extended region between Bloemfontein, Verkeerdevlei and Lindley in the south-east. This vegetation unit is also present near Heilbron in the northern Free State and Standerton in Mpumalanga (Mucina and Rutherford, 2006).The dolerite outcrops on the plateaus and sloping flanks support low shrubland vegetation dominated by dwarf small-leaved karroid and succulent shrubs. Grasses only occur in depressions and crevices filled with fine soils. An outstanding feature of this vegetation unit is the presence of geophytic herbs (Mucina and Rutherford, 2006).

Dolerite intrusions from the Jurassic are embedded in sediments of the Adelaide Subgroup. This habitat has a shallow layer of aeolian sand that overlies the sheets of dolerite (Mucina and Rutherford, 2006).

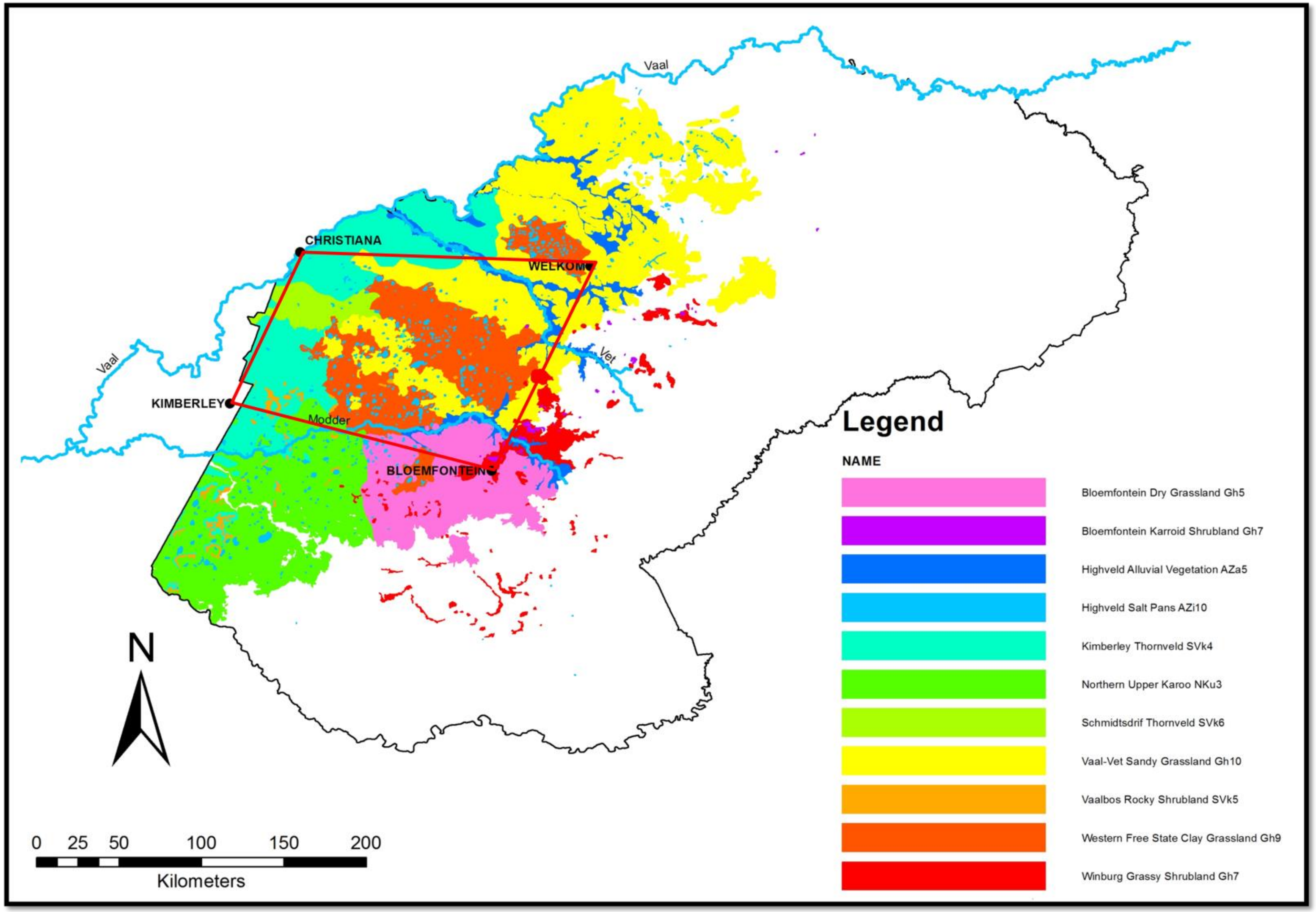

Figure 6.1: Map of the different vegetation units within the study area (after Mucina and Rutherford, 2006). Red block indicates the study area.

6.6.2.5 Western Free State Clay Grassland (Gh 9)

This vegetation unit (Figure 6.1) occur in the Free State in the vicinity of Bloemfontein, Boshof, Hertzogville, Wesselsbron and Brandfort. The southern and middle sections of the unit are separated by an elevated area of dolerite hills between Hertzogville, Boshof and Soutpan. The valley of the Vet River separates the middle and the northern sections from each other (Mucina and Rutherford, 2006)

The altitude of this vegetation unit varies from 1 200 m – 1 420 m above mean sea level. The vegetation is restricted to flat bottomlands with a high number of salt pans. The vegetation is mostly species poor grasslands with dwarf karroid shrublands around the pans in disturbed areas (Mucina and Rutherford, 2006).

The geology is mostly dominated by sandstone, mudstone and shale from the Volksrust Formation and the Ecca Group. There are also intrusions of dolerite hills in these flat to undulating plains. A unique feature of the landscape is the fact that there are no rivers that drain the numerous pans (playas). The soils in the area are mostly dry, clayey, duplex soils (Mucina and Rutherford, 2006).

6.6.2.6 Vaal-Vet Sandy Grassland (Gh 10)

The Vaal-Vet Sandy Grassland (Figure 6.1) is present in both the North-West and Free State Provinces. In the Free State, the unit occurs in the vicinity of Bothaville to Brandfort and areas north of Bloemfontein (Mucina and Rutherford, 2006).

The vegetation occurs at an altitude of around 1 220 m – 1 560 m above mean sea level. The landscape is dominated by plains with irregular undulating plains and hills. The vegetation is dominated by low-tussock grasslands and an abundant karroid element (Mucina and Rutherford, 2006).

Aeolian and colluvial sand overly the sandstone, mudstone and shale of the Ecca Group. There are also some older Ventersdrop andesite and basement gneiss in the north of the vegetation unit. The dominant soil forms in the unit are mostly Avalon, Westleigh and Clovelly (Mucina and Rutherford, 2006).

6.6.3 Savanna Biome

This is one of the world`s major biomes occupying 12% of the global land surface (Scholes, 1997). The Savanna Biome is one of the most widespread (Mucina and Rutherford, 2006) and dominant (Scholes, 1997) vegetation biomes in Africa. The occurrence in South-Africa is the most southern extension if this biome (Mucina and Rutherford, 2006) and cover an area of about 632 000 km^2 (Scholes, 1997). The plant species richness of this biome in southern Africa is relatively high (Scholes, 1997). The vegetation of this biome occurs in all nine the provinces of South Africa. In the provinces of interest, the biome only occurs in the extreme western parts of the Free State as well as the far northern parts of the Northern Cape (Mucina and Rutherford, 2006).

The savannas are mostly associated with old planation surfaces and are, therefore, believed to form part of the vegetation that flourished during the Tertiary. It is believed that the conditions during the Tertiary were hotter and wetter than climatic conditions today (Mucina and Rutherford, 2006).

The macroclimatic traits of the Savanna Biome include the seasonality of precipitation with an alteration between wet summers and dry winters, as well as subtropical thermal regimes. The occurrence of frost is either absent or occurs with low incidences (Mucina and Rutherford, 2006). Scholes (1997) stated that mild frost occurs on a few occasions a year, while severe frost is only experienced every few decades. The areas in which the biome occurs usually have a summer rainfall regime. The altitude at which this biome occur is normally below 1 500 m but may extend up to 1 800 m above mean sea level. Temperatures in the biome are relatively high, reaching 32°C in summer with the winters never being colder than 16°C. The mean annual precipitation varies between 200 mm in the western parts to 1 350 mm in the high lying areas of Swaziland. The precipitation mostly occurs in mid-summer (Mucina and Rutherford, 2006). In contrast to the Grassland Biome, the Savanna Biome has a relatively low frequency of hail and lightning flash density. Surface winds in the Savanna biome is light, however, strong winds may occur on the Polokwane Plateau (Mucina and Rutherford, 2006).

Most savanna areas are composed of herbaceous layers dominated by grass species (0.5 – 2 m) and a sometimes discontinuous crown covered layer of very open trees (2 – 10 m) (Scholes, 1997; Mucina and Rutherford, 2006). In the tree layer, there are sometimes no distinctions between tall shrubs and small trees. Therefore, it can also be called bushveld (Scholes, 1997; Mucina and Rutherford, 2006). Rainfall plays an important role in the distribution of species, but is not the only factor (Mucina and Rutherford, 2006). However, Scholes (1997) stated that the climate in the Savanna Biome has a hot wet season for four to eight months and warm dry for the rest of the year.

Soil fertility of soil can be the distinction between nutrient-poor (moister environment) savanna and nutrient-rich (arid environments) savanna (Scholes, 1997; Mucina and Rutherford, 2006). The distinction between nutrient rich and nutrient poor savanna can be made on the size of leaves (Scholes, 1997; Mucina and Rutherford, 2006) the higher root/shoot ratio, lower grass palatability, greater woody biomass, lower herbaceous water use efficiency and more conspicuous litter (Mucina and Rutherford, 2006). The defence mechanism against damage by herbivores also differs. In the nutrient-poor savanna secondary chemical (Scholes, 1997) substances are being used as defence, while in the nutrient-rich savanna structural defence (thorns) are being used (Mucina and Rutherford, 2006). According to Scholes (1997) the fine-leaved trees in the savanna have thorns or spines as defence mechanisms. The broad-leaved savanna trees are almost thornless, but are hardly browsed due to digestion-retarding substances which include toxins such as alkaloids and tannins.

Vegetation in the savanna has adapted to survive the harsh environmental conditions. During seasonal drought desiccation is prevented by the shedding of leaves. Most of the evergreen and deciduous trees have sclerophyllous leaves. Another adaptation is the spares and sunken stomata which conserve water and limit photosynthesis (Scholes, 1997).

Many of the woody plants that occur in the savanna have shallow root systems, but deeper roots are not excluded. These shallow root systems enable the plants to make use of light showers where water does not penetrate deep into the soil. The evergreen trees in the savanna tend to have a deep root system to have the ability to survive during the dry season (Mucina and Rutherford, 2006).

When looking at the savanna biome from a world's perspective, it contributes largely to the informal and subsistence of economies. This is due to the supply of resources which include grazing, fuelwood, timber and others. This biome also contributes towards the production of livestock and ecotourism. The emission of trace gases from fires, soils, vegetation and animals also have a global impact. Furthermore, the sequestration of carbon in soils and biomass as well as their biological diversity are also important (Scholes, 1997).

6.6.4 Vegetation units of the Savanna Biome

6.6.4.1 Kimberley Thornveld (SVk 4)

This vegetation unit (Figure 6.1) occurs in the North-West, Free State as well as the Northern Cape. The unit mostly occurs in the vicinity of Kimberley, Hartswater, Bloemhof and Hoopstad districts. There are also substantial parts present in the areas of Warrenton, Christiana, Taung, Boshof and even Barkley West (Mucina and Rutherford, 2006).

The Kimberley Thornveld occurs at altitudes of between 1 050 m and 1 400 m above mean sea level. The plains are somewhat irregular with a well-developed tree and shrub layer. The grassy layer is relatively open with much uncovered soil. The geology is dominated by andesitic lavas of the Allanridge Formation as well as fine-grained sediments of the Karoo Supergroup. The soils are mostly deep sandy soils of the Hutton form that occur on slightly undulating plains (Mucina and Rutherford, 2006).

6.6.4.2 Vaalbos Rocky Shrubland (SVk 5)

The Northern Cape and Free State are the provinces in which this vegetation unit (Figure 6.1) occur. The vegetation is found along solitary hills and scattered ridges east of the Orang-Vaal River confluence, mainly in the Kimberley and Herbert Districts. The unit also occurs in the western Free State near the towns of Luckhoff, Petrusburg, Dealesville, Bultfontein and Hertzogville (Mucina and Rutherford, 2006).
This vegetation unit occurs within the Kimberley Thornveld and Northern Upper Karoo units on slopes, elevated hills and ridges. The vegetation is mostly composed

of evergreen shrub communities or trees that occur in sheltered, cool sites. The footslopes of the dolerite hills with calcrete-rich soils are dominated by shrubs and small trees (Mucina and Rutherford, 2006).

In terms of geology, the area is highly fragmented and occurs on Ecca and Dwyka Group sediments as well as Karoo dolerites and Ventersdorp Supergroup lavas. The dolerite sills form ridges and plateaus, slopes of koppies and small escarpments with erosion terraces. The alternating mudstone and sandstone of sedimentary origin is covered by dolerite sills. The soil forms are dominated by the stony Mispah and gravel-rich Glenrosa, with calcrete-rich soils covering the lowlands (Mucina and Rutherford, 2006).

6.6.4.3 Schmidtsdrif Thornveld (SVk 6)

This vegetation unit (Figure 6.1) mostly occurs on the foot- and midslopes to the south-east and below the Ghaap Plateau in the Douglas area. There are also areas of Schmidtsdrif Thornveld in the area of Taung in the north-east. Small areas around Warrenton and Hertzogville also contain vegetation of this unit (Mucina and Rutherford, 2006).

The structure of the vegetation is mostly a closed shrubby thornveld. Grasses, bulbous and annual herbaceous plant species are prominent within the shrubby thornveld. The effects of overgrazing may be visible due to the presence of goats and other browsers (Mucina and Rutherford, 2006).

The geology is dominated by the Karoo Supergroup with Dwyka diamictites and Ecca shales. The Schmidtsdrif Subgroup also occurs in the area in the form of shale and dolomite. The sporadically occurrence of lime is also present in the area. The soils are mostly of the Mispah form and are well drained, shallow, stony soils. Large angular rocks are present on the soil surface (Mucina and Rutherford, 2006).

6.6.5 Inland Azonal Vegetation

6.6.5.1 Highveld Alluvial Vegetation (AZa 5)

This vegetation unit occur in the Free State, North-West, Mpumalanga and Gauteng Provinces of South Africa. Highveld Alluvial vegetation (Figure 6.1) is present along the alluvial drainage lines and floodplains along the rivers within the Grassland and

Savanna Biomes. These rivers include the upper Riet, Harts, upper Modder, upper Caledon, Vet, Sand, Vals, Wilge, Mooi as well as the middle and upper Vaal Rivers. Each of these rivers has numerous tributaries that contribute to the water present in the rivers. The altitude ranges from 1 000 m – 1 500 m above mean sea level (Mucina and Rutherford, 2006).

The topography is mostly flat and support riparian thickets with seasonally flooded grasslands and disturbed herblands. This riparian vegetation is often dominated by alien plant species (Mucina and Rutherford, 2006).

The soils of this unit are mostly deep sandy to clayey soils of alluvial origin from the Quaternary alluvial sediments. The soil forms include: Oakleaf, Dundee, Shortlands, Glenrosa and Mispah in the Vaal River floodplain. The Rivers are mostly in flood during the summer season which is causing riverbank erosion. This contributes towards new fine soil deposits on the alluvium (Mucina and Rutherford, 2006).

6.6.5.2 Highveld Salt Pans (Azi 10)

These salt pans (Figure 6.1) occur in the Northern and Eastern Cape, North West, Free State and Gauteng Provinces. The highest concentration of pans is found around the towns of Dealesville, Bultfontein, Wesselsbron (the centre of the study area), Delareyville and Petrusburg. The average size of the pans is about 0.2 km^2. Pans like Soutpan near Florisbad and Annaspan measure several kilometres across. The altitude of the pans vary between 1 000 m – 1 600 m (Mucina and Rutherford, 2006).

Temporary water bodies occur in the pans that are present on the plateau landscape. The centre part of the pans is often seasonally inundated with some floating macrophyte vegetation. Vegetation in the pans might also form concentric zonation patterns. The edges of the pan might be exposed to the development of grassy dwarf shrublands due to heavy grazing pressure (Mucina and Rutherford, 2006).

The bottom of the pans is mostly comprised of shales from the Ecca Group. The soils in the pans are mostly vertic clays. During the wet seasons, the pans are freshwater systems but during the dry season high evaporation changes the environment, and the pans become saline systems. Wind erosion is a common phenomenon during the dry season when the vegetation on the edge of the pans are short and sparse (Mucina and Rutherford, 2006).

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SECTION II

CHAPTER 7
MATERIALS AND METHODS

7.1 INTRODUCTION

The vegetation of an area is the only natural representative of the current state of the environment, and therefore plays an important role in the climatic changes observed (Clegg and O'Connor, 2012; Brown *et al.*, 2013). This chapter presents the methods used to study the present-day vegetation in the study area (sections 7.2 to 7.3), as well as the methods used for the preliminary reconstruction of the palaeo-environments with data from Baden-Baden spring mount (sections 7.4 to 7.6).

The main aim of vegetation classification is the grouping together of individuals on the basis of their attributes. The individuals in these groupings should be more similar to the individuals within the groups than with any individuals in any other groups (Kent and Coker, 1992). The vegetation assessment of the western Free State was done by using, the Zurich-Montpellier method (Braun-Blanquet method) to assess, classify and describe the natural vegetation in the study area. This method was preferred due to the fact that most of the vegetation analysis of the world was done using the Braun-Blanquet method (Chytrý *et al.*, 2011). Furthermore, Whittaker (1980) and Keddy (2007) mentioned that the system of Braun-Blanquet is widely applied and has been adapted to diverse kinds of communities.

7.2 DATA COLLECTION FOR THE PHYTOSOCIOLOGICAL STUDY

7.2.1 Site selection

The aim of the survey was to sample all the different vegetation types that occurred within the various terrain forms (pans, dolerite outcrops, plains, etc.) within the three different broad transects (zones) which were staked out across the study area. The method of stratified random sampling was used to place plots in the transects (Kooij *et al.*, 1990; Malan *et al*., 1994; Dingaan *et al*., 2001; Malan *et al*., 2001; Janecke *et al.*, 2003). During the process of stratified random sampling the geology formations, topography and the rainfall gradient were used to determine the location of the sample plots. During the field surveys the sample plots were placed within the different homogeneous vegetation units to adhere to the first rule of the Zurich-Montpellier sampling method (Brown *et al.*, 2013).

Due to the fact that the sampling was done along three different transects (zones) across the study area, it happened that some sampling plot numbers, in particular stands of homogenous vegetation, followed chronologically. The result was that the data of these sample plots were also relatively homogenous. Although these sample plots are a representative sample of a particular association, they do not really reflect the plant biodiversity of the region.

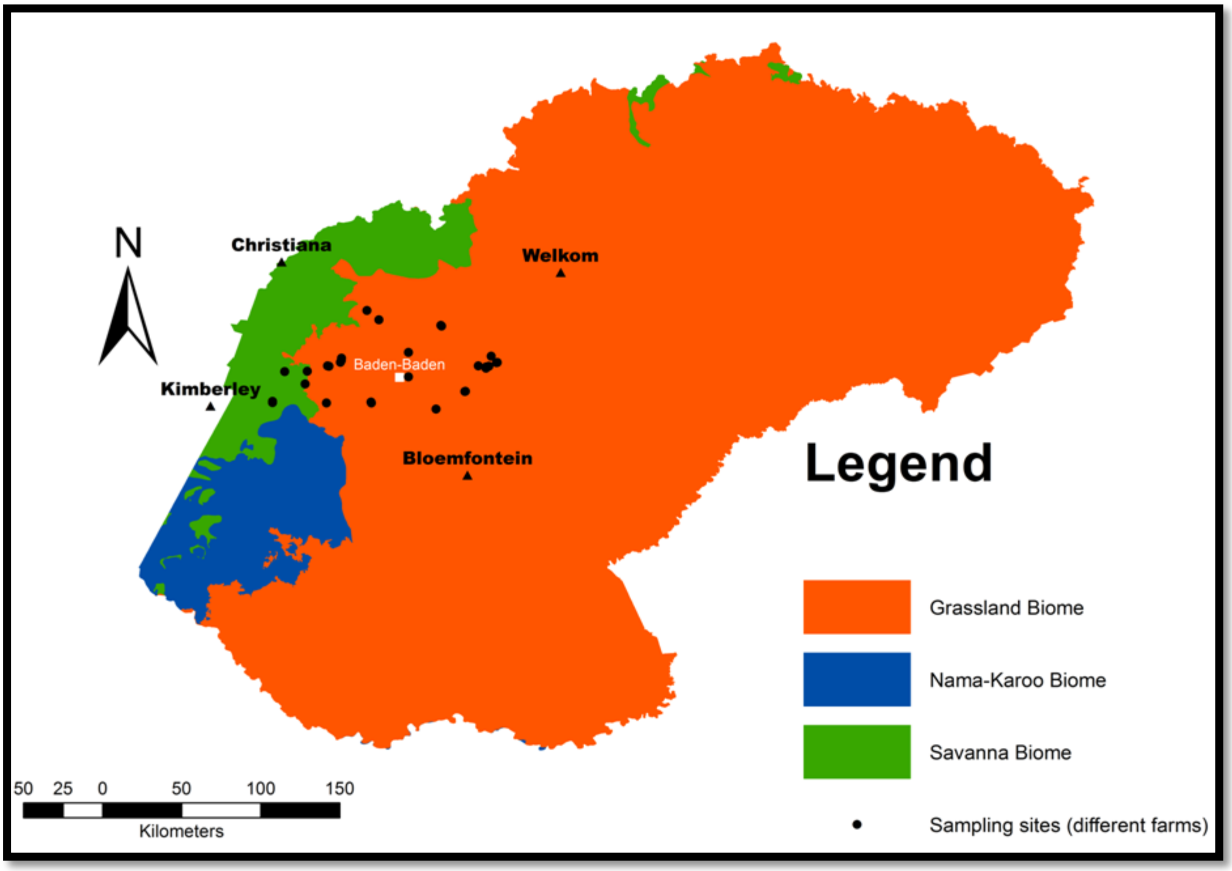

Figure 7.1: Map of the Free State with the different biomes after Mucina and Rutherford (2006), indicating the different sampling sites (different farms).

7.2.2 Number of sample plots

A total number of 410 sample plots were placed in various homogenous vegetation types in the western Free State. The homogeneity of the sample plots is of importance according to Kent and Coker (1992).

7.2.3 Plot sizes

The sample plot sizes for data collection were fixed at 16 m^2 for the herbaceous communities and 100 m^2 for the woody communities (Kooij *et al.*, 1990; Malan *et al.*, 1994; Dingaan *et al.*, 2001; Malan *et al.*, 2001; Janecke *et al.*, 2003).

7.2.4 Taxon names

Plant taxon names used in this study were confirmed as those listed by Germishuizen and Meyer (2003) with updates form Plants of southern Africa an online checklist (SANBI, 2014a). There is however one exception. The use of *Acacia* which was changed in 2013 by Kyalangalilwa *et al.* to *Senegalia* Raf. and *Vachellia* Wight & Arn.

7.2.5 Site assessment

Field work was conducted during the growing season of 2013/2014. The fieldwork was completed during May 2014.

Both the habitat information and the species present in each sample plot were recorded. Cover-abundance values were assigned to each plant species, within the sample plots, using the Braun-Blanquet cover-abundance scale presented in Table 7.1. Values 5 – 2 represents the cover – the vertical crown or shoot-area projected per species in the plot. Values below these are primarily estimates of abundance and therefore, the number of individuals per species.

Table 7.1: Adapted Braun-Blanquet cover-abundance scale (Werger, 1974; Westhoff and Van der Maarel, 1980; Van der Maarel, 2005).

Braun Blanquet value	Abundance category	Cover category
r	Very rare, usually with 1-3 individuals	c≤1%
+	Present but not abundant, with a small cover	c≤1%
1	Numerous but covering less than 1% of the quadrant, or not abundant and covering 1-5% of the quadrant	c≤5%
2a	Not applicable	5<c≤12.5%
2b	“	12.5<c≤25%
3	“	25<c≤50%
4	“	50<c≤75%
5	“	c>75%

During the field survey different environmental variables were also collected. Table 7.2 indicate the different categories of environmental data collected during the study.

Table 7.2: Different categories of environmental data collected during the field analysis.

Environmental factors	Categories
Aspect	N, NE, E, SE, S, SW, W, NW
Slope	flat (0°-3°), gradual (3°-8°), moderate (8°-16°), steep (16°-26°), very steep (26°-45°)
Exposure to the sun	full sun, semi-shade or full-shade
Topography	mountain, hill, ridge, summit, cliff, ravine, valley, plain, donga, vlei, pan, floodplain, dune, river-bed, river-bank
Water saturation	Water saturated, seasonally inundated, poorly drained and well drained
Terrain units	plain, foot slope, mid-slope, shoulder or plateau adapted from the Soil Classification Working Group (1991)
Soil form	soil were sampled using a hand held bucket or spiral auger, thereafter the soil were classified using the Soil Classification: A taxonomic system for South Africa as reference (Soil Classification Working Group (1991))
Size of rock	gravel (<10mm), stones (10-50mm), rocks (50-200mm), boulders (>200mm)
Soil texture	using the texture-by-feel method described by Brady and Weil (2008)
Soil depth	measured with a measuring tape; the augers used to take the samples were limited to a depth of 1.5 m

7.2.6 Data analysis

The collected environmental and floristic data was captured on computer by means of TURBOVEG (Hennekens, 1996; Hennekens and Schaminée, 2001) which served as the database for the information collected during the study. The data could be exported from TURBOVEG to other computer programmes for further analysis.

From TURBOVEG the data was exported to PC-ORD. The data was then tested for normality as a minimum requirement as prescribed by Brown *et al.* (2013) using PC-ORD (McCune and Mefford, 2006). The average skewness of the data was calculated at 12.899. This value is higher than 2, meaning that the data needed to be transformed.

The captured data were exported from TURBOVEG to JUICE (Tichý and Holt 2006). Within the JUICE programme the data can easily be visualised, classified and processed to compile phytosociological tables of various sizes. Furthermore, JUICE is seen as a multifunctional editor with advanced parametrization and classification functions (Tichý, 2002).

The whole data set was classified in JUICE using the options of "Cluster Analysis – PC-ORD. Thereafter, it was decided to split the data set into different units which represented three different sets of data. The three different sets of data were split in terms of habitat and structure: the woody (rocky outcrops),non woody (water saturated and seasonally inundated pans, wetlands and springs) as well as the non woody (well drained, deep sandy soils and the poorly drained, clayey soils).During the analysis of the three different data sets the JUICE programme was used to perform both agglomerative and divisive clustering. During agglomerative cluster analysis different combinations of the distance measures and group linkage methods were used. It was decided that the Cluster Analysis option using PC-ORD was the best to represent the vegetation. The settings that provided the best results were: Relative Euclidean distance measures and the Ward's linkage method.

The primary goal of ordination is to determine ecologically meaningful ordering of relevés based on the abundance of species in the data present at each site (Wartenberg *et al.,* 1987). Due to the complexity of a very large data set, CANOCO (Ter Braak and Smilauer, 2002) was used to interpret the data and determine outliers. The long gradients of the data and "the arch effect" resulted in the analysis using DCA ordination. DCA are known to remove "the arch effect" (Gauch, 1982; Wartenberg *et al.*, 1987; Pee t*et al*., 1988) and furthermore, DCA are a better choice of ordination when long gradients are present (Hill and Gauch, 1980; Gauch, 1982; Peet *et al.*, 1988). Eilertsen *et al.* (1990) mentioned that DCA provides non-linear rescaling of the ordination axes and ordinate sample plots and species. The rescaling is presented in standard deviation units of species turnover which is shown to be reliable. Furthermore, Wartenberg *et al.* (1987) noted that several scientists claimed that DCA describes the data gathered in a more meaningful and interpretable way. In this study the ordination of data by means of DCA gave better and more interpretable results than the CA ordination method. The summary of the variation present in the communities might in some instances be better with the use of detrending and rescaling, thus the interpretability is improved (Peet *et al.,* 1988). This might be due to the fact that DCA removes most of the same variation (Wartenberg *et al.,* 1987).

Problems with DCA are that important ecological information may be lost (Peet *et al.*, 1988). Although Peet *et al.* (1988) mentioned the problems present in DCA they further mentioned that DCA are one of the most powerful multivariate tools used to interpret communities composed of species along a gradient. The effectiveness of DCA as an analytical method for the analysis of community data is further supported by Gauch (1982) which noted that DCA ordinates samples and species simultaneously, objectively, efficiently and effectively. Kent (2012) noted that all methods used for ordination have its advantages and disadvantages, thus the knowledge of the field is important when using ordination to analyse the data.

7.3 PHYTOSOCIOLOGICAL TABLE

Werger (1974) noted that the arrangement of the species and relevés in a phytosociological table should not be seen as the end, but rather as the basis for further studies in ecology. The classification of vegetation is aimed at the grouping of individuals on the basis of their floristic composition (Kent and Coker, 1992). The aim of sampling vegetation with similar species composition and arranging these units into hierarchical systems is to define vegetation units (Chytrý *et al.*, 2011).

The phytosociological table for this study was compiled according the guidelines recommended by Brown *et al.* (2013). The diagnostic species of a plant community is above the diagnostic groups of sub-associations and variants. The species groups were labelled alphabetically indicating the diagnostic groups for easy reference. Species shared between communities were placed towards the bottom of the table. The description of the plant communities was done using the guidelines as proposed by Brown *et al.* (2013). Kent and Coker (1992) noted that the presence or absence of species in a community is of primary importance. The amount or abundance of the species present in a community is also of interest.

During the description of the different communities, sub-communities and variants the ‘Analysis of Columns of Synoptic Tables’ a function in JUICE were used to determine the diagnostic, constant and dominant species. The description of the clusters was done using the diagnostic, constant and dominant species as recommended by Brown *et al.*, (2013). The lower threshold was set at 75, 60 and 50 respectively. Species exceeding the lower threshold were all listed. The upper threshold was set at 80, 80 and 60. Species that exceed this threshold were printed in bold, e.g.

Diagnostic species: ***Cynodontransvaalensis 100***

Constant species: ***Cynodontransvaalensis 100***

Dominant species: ***Cynodontransvaalensis 100,*** *Cyperusdifformis 29, Leptochloafusca 14*

The diagnostic species is seen as a combination of character species (species mostly restricted to a certain community) and differential species (species of medium to low consistency which occur together in a series of relevés and can be used as characteristic groups (Kent and Coker, 1992)) (Brown *et al*., 2013). The diagnostic species is followed by a value, indicating the measure of the strength of its fidelity to the cluster; thus a higher fidelity value indicates the uniqueness of the species to that specific cluster (Collins, 2011). The constant species is determined by looking at the number of relevés in which each species occur (Kent and Coker, 1992). The percentage of relevés of the cluster in which the species was recorded is indicated after the constant species' name. The dominant species can be seen as species that are abundant (Tilman and May, 1997) and thus, occur with a high cover-abundance within clusters. The percentages of relevés that represents the cluster/s in which the species exceed the minimum cover value are indicated in the values after the species.

7.4 BACKGROUND ON THE POLLEN ANALYSIS AT BADEN-BADEN SPRING MOUNT

Palynology or pollen analysis is based on the analysis of the male gametophyte (pollen) of both angiosperms and gymnosperms together with spores. Erdtman (1966) demonstrated how palynology deals with the walls of pollen grains and spores and not with their live interior. Pollen analysis as science begun in 1916 and was used in the reconstruction of Late-Quaternary vegetation changes. Thus, today palynology is applied in the reconstruction of vegetation history (Faegri and Iversen, 1964; Traverse, 1988; Faegri and Iversen, 1989; Moore *et al.,* 1991; Bradley, 1999; Lawrence, 2000; Benton and Harper, 2009).

Pollen grains are very small in size and vary from 10 to 100 μm in size. Flowering plants and cryptogams disperse numerous spores and pollen into the atmosphere each season (Bradley, 1999). The identification of the grains to the lowest taxonomic level (family, genus or even some times species level) is important in pollen analysis. The unique identification is due to the variation in form and sculpture of the resistant coat (the outermost layer (exine) of the pollen) (Faegri and Iversen, 1964; Jacobson JR, 1988; Faegri and Iversen, 1989; Moore *et al.*, 1991; Hedberg, 1988; McCarthy and Rubidge, 2005). The success of the pollen grain is dependent on the arrival at the stigma of a plant of the same species for fertilization of an egg (Faegri and Iversen, 1964; Moore *et al.*, 1991). Pollen that does not find a female receptacle will fall to the ground, accumulate in sediment and might be preserved as fossils under ideal conditions. These pollen fossils make it useful for reconstruction of past vegetation and climatic conditions at sites where it is preserved (Faegri and Iversen, 1964; Traverse, 1988; McCarthy and Rubidge, 2005).

Sporomorphs can be used for the reconstruction of palaeo-climates (Bradley, 1999) and vegetation history (Hedberg, 1988) due to:

- the resilient nature of the pollen – found in deposits where other fossil types have been destroyed;
- pollen grains are produced in large numbers;
- the distribution being much wider than macrofossils – thus less dependent on the mother plant;
- large quantities of pollen can be retrieved (Faegri and Iversen, 1989; Moore *et al.*, 1991; Benton and Harper, 2009).

Several studies (Van Zinderen Bakker, 1967a; Scott, 1982; Scott, 1999; Scott *et al.*, 2008), more recently Scott *et al.* (2012) and Nash and Meadows (2012) demonstrate that radio-metrically dated pollen, plant macrofossils and phytoliths are important in the compilation of the vegetation history in Africa – especially the late Pleistocene (Jacobson JR, 1988). Another contributor to the vegetation analysis is: microscopic fragments of burned plant matter (microscopic charcoal or charred particles). These microscopic or macroscopic fragments can be indicators of past fire regimes (Jacobson JR, 1988; Clark *et al.*, 1998; Scott, 2002a; Duffin, 2008; Duffin *et al.,* 2008) and local fire frequencies (Tinner *et al.*, 2006). These fire regimes can either be the result of natural burning, climatic factors or human activity. It is difficult to distinguish between climate and human induced fires (Scott, 2002a) but high concentrations of charcoal in the upper 6 m of the Tswaing Crater, for instance, might be indicative of human induced fires (Middle and Later Stone Age humans) (Metwalley *et al.*, 2014).

Pollen is mostly preserved in lakes, bogs, estuaries and other wet environments (peats, wetlands and lakes) (Faegri and Iversen, 1964; Deacon and Lancaster, 1988). In above mentioned wet environments most other organic matter is decomposed. The corrosion effect of peat can damage the pollen and only occurs in aerated peats – above the water level. Acidity of the substrate is also important for pollen preservation, as alkaline deposits have badly corroded pollen (Feagri and Iversen, 1964; Traverse, 1988). Well-drained alkaline soils are one of the least suitable environments for pollen preservation in South Africa (Coetzee, 1967; Deacon and Lancaster, 1988). Factors such as abrasion, oxidation or bacterial actions can destroy the pollen (Faegri and Iversen, 1964; Jacobson JR, 1988). The pollen plays an important part in preserving records of the vegetation changes of the past due to climatic change (Traverse, 1988). In these suitable environments pollen can be preserved for hundreds of millions of years. The radiocarbon-dating method, which is most often used in late younger pollen analysis is, however, only reliable for the last 40 000 years (Libby, 1955; Brink, 1994; Brink, 1997) and dating of older deposits or deposits with too little carbon will have to rely on other methods like OSL dating (using signals in mineral grains) (Rhodes, 2011). Pollen analyses further play an important part in providing additional information on the information derived from marine sediments and ice cores (Bradley, 1999) in developing models of global environmental change.

Climate change is not the only factor affecting long-term natural vegetation changes. Other factors that need to be taken into account include: fire, insects infestation, plant successional changes and the interference of humans (Traverse, 1988). Furthermore, accumulation and preservation of the fossil material can have an influence on the interpretation of the pollen record (Bradley, 1999). With the interpretation in mind, pans and swamps (wetlands) trap pollen from a wider geographic range, but water plants or local swamp vegetation may be over-represented (Scott, 1982; Scott, 1999). Springs and peats may accumulate pollen in spurts of activity thus, being less reliable and accurate for the changes in vegetation in comparison with gradual accumulation in lakes (Deacon and Lancaster, 1988).

7.5 THE BASIS FOR POLLEN ANALYSIS

The reconstruction of palaeo-climates is possible due to four basic attributes of pollen grains:

- the morphological characters of pollen are specific to a particular genus or species level of plants;
- vast quantities of pollen are produced by wind-pollinated plants – widely distributed from their sources;
- in certain sedimentary environments, pollen are extremely resistant to decay; and
- although biased by several factors, such as differences in pollen production, dispersal mechanisms of species, and preservation quality, the deposited pollen, reflect the natural vegetation of that time and therefore, provide information on the past climatic conditions (Moore *et al.*, 1991; Bradley, 1999).

7.5.1 Pollen "rain": production and dispersal

Pollen is then dispersed by various mechanisms to reach and fertilize the female reproductive organs of other plants. The amount of pollen produced is determined by the dispersal agent. Thus, wind pollinated species produce more pollen than species pollinated by insects or animals (Coetzee, 1955; Hamilton and Perrott, 1980; Deacon and Lancaster, 1988; Bradley, 1999). This is the reason why pollen at any site will be dominated by species that use wind as dispersal agent (Bradley, 1999). The weight of pollen grains should also be taken into account as lighter pollen travel much longer distances than e.g. insect pollinated pollen or pollen tetrads or polyads e.g. *Acacia* [*Vachellia*or *Senegalia*] pollen (Coetzee and Van Zinderen Bakker, 1952; Coetzee, 1955; Scott, 1982; Cooremans, 1989).

Caution should therefore be taken when reconstructing vegetation compositions using pollen. In a deposit the abundance of pollen grains cannot be directly interpreted in terms of the abundance of species in the area. The reason being: difference in pollen productivity and dispersal rates (Bradley, 1999).

7.5.2 Sources of Fossil Pollen

Pollen forms part of the stratigraphic record as it is aeolian sediment, falling on sites with organic or inorganic sediments. Pollen can be isolated from peat, lake sediments, alluvial deposits, estuarine and marine sediments, glacial ice, archaeological sites, rat middens and coprolites by means of special methods (Erdtman, 1966; Traverse, 1988).

7.6 MATERIALS AND METHODS OF POLLEN EXTRACTION

7.6.1 Field collection

Samples from three excavation areas were obtained previously from Baden-Baden for pollen analysis by L. Scott (UFS) and stored. One of the pits was the archaeological excavation of one meter in Holocene layers of the Central Block by C.B. Bousman (Texas State University, San Marcos, Texas) and J.S. Brink (National Museum Bloemfontein that revealed alternating layers of sandy and peaty deposits (Van Aardt *et al.,* 2015). Another was a deeper excavation, Trench 3 of three meters, made by an excavator in predominantly sandy deposits as a test pot for the observation of the older Pleistocene levels. The third was a one meter deep Pollen Pit in *Phragmites* covered peaty deposits excavated by L. Scott. Within these pits organic and peaty layers were previously sampled at different depths for pollen analysis, radiocarbon and optically simulated luminescence (OSL) dating by different laboratories (Van Aardt *et al.,* 2015).

7.6.2 Laboratory preparation

The pollen samples were transferred to sealed plastic bags to prevent contamination with modern day pollen. On these bags the number of the sample, the depth and the name of the pit were added. Samples from pollen containing peats were digested in 10% KOH and HCL and heavy liquid mineral separation with $ZnCl_2$ with a density of 2 (Scott, 1982; Scott *et al.*, 2005) was applied to separate the organic fraction with pollen. Some slides were washed with 40% HF to remove the remaining minerals. Exotic palynomorphs (*Lycopodium*) in the form of tablets were added to the samples in order to determine the pollen concentration (Stockmarr, 1971). The treated material was mounted onto microscope slides using glycerine jelly.

7.6.3 Pollen identification

The microscope slides containing the mounted specimens were studied under the 16X objective to scan the slides. The 100X objective were used for identifying the pollen grains. The pollen was identified using the reference collection present at the palynological laboratory at the University of the Free State. The identification and photography of the pollen were done on a Zeiss photomicroscope, using the 100X oil immersion objective (Scott, 1982) and a Dino-Lite (Dino-Lite Digital Microscope) electronic camera.

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SECTION III

CHAPTER 8
THE WETLAND COMMUNITIES OF THE STUDY AREA

8.1 OVERVIEW

When assessing the DCA ordinationof all the relevés in the study area (Figure 8.1) three distinct different groups can be noted. The blue dots represent the water-related communities present in the study area. The five blue dots on the far left of the graph (red circle) represent pan vegetation which are seasonally dry and mostly degraded (Community 9). The brown dots represent the woody vegetation whilethe green dots represent the grassland and karroid vegetation. It must also be mentioned that grassland and karroid vegetation (green and brown dots) occur away from the water-related communities which is an indication that these communities are present in well-drained areas.

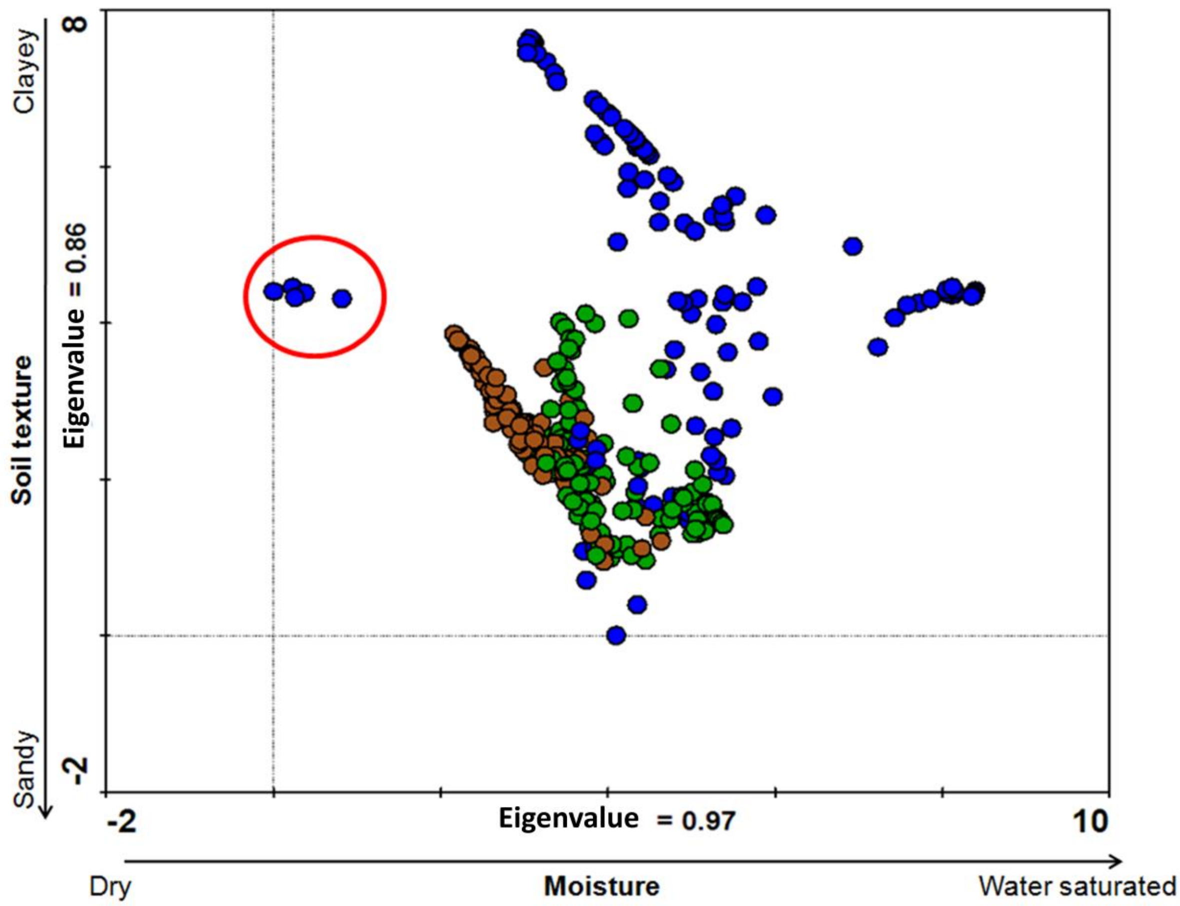

Figure 8.1: Ordination diagram of all the relevés present in the area of study. The blue relevés dots represent the water-related communities, the green dots represent the karroid and grassland communities and the brown dots represent the woody communities.

This ordination corresponds to the phytosociological classification (Table 8.1) of the vegetation which also cristalised into three main vegetation units. In this chapter only the water-related communities (blue) will be described.

8.2 CLASSIFICATION

Table 8.1 represents the phytosociological classification of the wetland communities in the western Free State, South Africa. The wetland communities can be divided into nine communities, 18 sub-communities and 11 variants.

1. *Cynodon transvaalensis – Cyperus difformis* Community
2. *Leptochloa fusca*Community
    - 2.1 *Leptochloa fusca – Panicum schinzii*Sub-community
    - *2.2* *Leptochloa fusca – Eragrostis biflora* Sub-community
    - *2.3* *Leptochloa fusca – Echinochloa holubii* Sub-community
    - 2.4 *Leptochloa fusca – Sporobolus ludwigii* Sub-community
    - 2.5 *Leptochloa fusca – Sporobolus virginicus* Sub-community
        - 2.5.1 *Juncus rigidus* Variant
    - 2.6 *Leptochloa fusca – Salsola glabrescens* Sub-community
3. *Suaeda merxmuelleri – Salsola glabrescens* Community
    - 3.1 *Suaeda merxmuelleri – Salsola glabrescens – Leptochloa fusca* Sub-community
    - 3.2 *Suaeda merxmuelleri – Salsola glabrescens – Sporobolus ioclados* Sub-community
        - 3.2.1 *Tragus berteronianus* Variant
        - 3.2.2 *Leptochloa fusca* Variant
4. *Berula erecta – Eleocharis limosa* Community
    - 4.1 *Berula erecta – Eleocharis limosa – Typha capensis* Sub-community
        - 4.1.1 *Limosella africana* Variant
        - 4.1.2 *Lemna gibba* Variant
    - 4.2 *Berula erecta – Eleocharis limosa – Cyperus longus* Sub-community
5. *Marsilea burchellii – Isolepis cernua* Community
6. *Limosella longiflora – Cynodon dactylon* Community
7. *Juncus rigidus*Community
    - 7.1 *Juncus rigidus – Cynodon dactylon* Sub-community
    - 7.2 *Juncus rigidus – Finicia nodosa* Sub-community

7.2.1 *[2]*Cirsium vulgare* Variant

7.2.2 *Salvia runcinata*Variant

7.3 *Juncus rigidus – Cyperus marginatus* Sub-community

8. *Eragrostis lehmanniana* Community

8.1 *Eragrostis lehmanniana – *Phyla nodiflora* Sub-community

8.2 *Eragrostis lehmanniana – Salsola aphylla* Sub-community

8.2.1 *Eragrostis trichophora* Variant

8.2.2 *Thesium costatum* Variant

8.3 *Eragrostis lehmanniana – Panicum coloratum* Sub-community

8.3.1 *Lycium horridum*Variant

8.3.2 *Digitaria eriantha* Variant

8.4 *Eragrostis lehmanniana – Sporobolus fimbriatus* Sub-community

9. *Cynodon hirsutus* Community

9.1 *Cynodon hirsutus –Tragus berteronianus* Sub-community

8.3 DESCRIPTION OF THE WETLAND COMMUNITIES

1. *Cynodon transvaalensis – Cyperus difformis*Community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Katspruit and Kroonstad
Soil depth:	>1.5 m
Hydrology:	Seasonally inundated
Exposure:	Full sun
Disturbance:	None

Species

Average number of species in the community: 7

Number of relevés in the community:4

Diagnostic species:	***Cynodon transvaalensis 100***
Constant species:	***Cynodon transvaalensis 100***
Dominant species:	***Cynodon transvaalensis 100,*** *Cyperus difformis 29, Leptochloa fusca 14*

[2] * indicate alien species

Discussion: Species from species group A (*Cynodon transvalensis, Cyperus difformis* and *Isolepis diabolicus*) defines this community. This community occurs on the floor of pans (Figure 8.2 A) as well as along the edges of pans (Figure 8.2 B). In the pan basin the community usually occur in small patches (1m x 1m). It is mainly dominated by the grass *Cynodon transvaalensis* (Species group A). The communities present along the edges of the pans are mostly dominated by the sedge *Cyperus difformis* (Species group A) (Figure 8.2 B).

Cynodon transvaalensis which dominate this community has relatively wide ecological amplitude and occursunder various environmental conditions. Furthermore, *Cynodon transvaalensis* are associated with different communities (Janecke *et al.*, 2003; Collins, 2011). Although the communities identified by Janecke *et al.* (2003) and Collins (2011) were also dominated by *Cynodon transvaalensis* the species composition differs from community to community.

Figure 8.2: *Cynodon transvaalensis – Cyperus difformis* Community.

2. *Leptochloa fusca* Community

Habitat

<u>Geology:</u> Beaufort and Ecca Groups

<u>Soil form/forms:</u> Katspruit and Kroonstad

<u>Soil depth:</u> >1.5 m

<u>Hydrology:</u> Seasonally inundated

<u>Exposure:</u> Full sun

<u>Disturbance:</u> In some pans there are no disturbances, while others are heavily

grazed by livestock.

Species

Average number of species in the community: 5

Number of relevés in the community:44

Diagnostic species: No diagnostic species

Constant species: ***Leptochloa fusca 86***

Dominant species: *Cynodon dactylon 2, *Dichondra micrantha 2, Eragrostis biflora 5, Finicia nodosa 2, Isolepis costata 2, Juncus rigidus 2, Leptochloa fusca 41, Panicum schinzii 5, Sporobolus ludwigii 5, Sporobolus virginicus 9*

Discussion: *Leptochloa fusca* is the only dominant species in this plant community; therefore, this community has only one name instead of two. This grass, (*Leptochloa fusca)* (Species group B), is a common grass growing in pans as well as, in fresh or brackish water. This grass can even be found in ephemeral pans. *L. fusca*is successful in brackish soils, only if there is sufficient water present (Acocks, 1988; Müller, 2002; Van Oudtshoorn, 2004; Collins, 2011). The grass is furthermore a palatable grass and is grazed by livestock (Van Oudtshoorn, 2004). This grass sometimes forms dense homogenous stands with a high cover. This community is mostly dominated by grasses with some sedges present.

This community occur on clayey soils which are saturated during the rainy season. Although the sodium content of the soil were not analysed, salt crystals were noted on the soil surface in some communities. This is similar to the *Diplachne fusca* sub-community found by Janecke *et al. (2003).* The dry, hot, brackish conditions during the dry season and the fluctuating inundation conditions during the rainy season described by Jancecke *et al.* (2003) are similar to the conditions in the area of study.

This community can be divided into six different sub-communities, namely:

2.1 *Leptochloa fusca – Panicum schinzii*Sub-community

2.2 *Leptochloa fusca – Eragrostis biflora* Sub-community

2.3 *Leptochloa fusca – Echinochloa holubii* Sub-community

2.4 *Leptochloa fusca – Sporobolus ludwigii* Sub-community

2.5 *Leptochloa fusca – Sporobolus virginicus* Sub-community

2.6 *Leptochloa fusca – Salsola glabrescens* Sub-community

2.1 *Leptochloa fusca – Panicum schinzii*Sub-community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Katspruit and Kroonstad
Soil depth:	>1.5m
Hydrology:	Seasonally inundated
Exposure:	Full sun
Disturbance:	Grazed by livestock, but not overgrazed

Species

Average number of species in the sub-community: 5

Number of relevés in the sub-community:3

Diagnostic species:	***Cyperus difformis 82.8***
Constant species:	***Cyperus difformis 100, Leptochloa fusca 100,*** *Panicum schinzii 67*
Dominant species:	***Leptochloa fusca 67, Panicum schinzii 67***

Discussion: This sub-community (Figure 8.3) is distinguished by the presence of *Cyperus difformis* (Species group A) and *Panicumschinzii* (Species group C). Van Oudtshoorn (2004) describes *Panicum schinzii* as a palatable, sweet grass that occurs close to water; in wetlands or river areas. *P. schinzii* also occur in low-lying wetter parts of the pans with clayey soils (Acocks, 1988). This is also true for the area of study. These sub-communities occurred in pans with clayey soils. The presence of grazers was also visible in these areas.

Figure 8.3: *Leptochloa fusca – Panicum schinzii*Sub-community.

2.2 *Leptochloa fusca – Eragrostis biflora* Sub-community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Kroonstad
Soil depth:	± 0.39 m to >1.5 m
Hydrology:	Seasonally inundated
Exposure:	Full sun
Disturbance:	None

Species:

Average number of species in the sub-community: 5

Number of relevés in the sub-community:5

Diagnostic species: ***Eragrostis biflora 88.1***

Constant species: ***Eragrostis biflora 100,*** *Juncus rigidus 80*

Dominant species: *Cynodon dactylon 20, Eragrostis biflora 40, Finicia nodosa 20*

Discussion: The grass (*Eragrostis biflora*) (Species group U) together with *Cynodon dactylon* (Species group X) is seen as pioneer grasses (Van Oudtshoorn, 2004). The presence of *Juncus rigidus* (Species group R) is an indication that this area is saturated with water during the rainy season.

This sub-community is similar to the *Eragrostis bicolor – Diplachne fusca* sub-community described by Janecke *et al.* (2003). Both Janecke *et al.* (2003) and Collins (2011) mentioned that the species that dominates this sub-community occurs on brackish soils in pans.

2.3 Leptochloa fusca – Echinochloa holubii Sub-community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Katspruit
Soil depth:	>1.5 m
Hydrology:	Seasonally inundated
Exposure:	Full sun
Disturbance:	Grazed by livestock

Species

Average number of species in the sub-community: 5

Number of relevés in the sub-community:3

Diagnostic species: ***Dichondra micrantha 100, Echinochloa holubii 95.5***

Constant species: ***Alternanthera sessilis 100,*** ***Dichondra micrantha 67,* ***Echinochloa holubii 100,*** *Euphorbia inaequilatera 67, Isolepis costata 67,* ***Leptochloa fusca 100, *Verbena bonariensis 100***

Dominant species: **Dichondra micrantha 33, Isolepis costata 33*

Discussion: This sub-community (Figure 8.4) is distinguished by the presence of species from species group D (*Echinochloa holubii, Alternanthera sessilis, *Verbena bonariensis, Euphorbia inaequilatera, *Dichondra micrantha* and *Isolepis costata*). *Echinochloa holubii* (Species group D) (which dominates this sub-community) is a grass that occurs in wet areas (wetlands) which are water saturated at least for the rainy season. This grass can withstand severe grazing, although the production of the grass is then limited (Van Oudtshoorn, 2004). Within this variant there are a few alien species which can be an indication of disturbance. In the area of study this sub-community occurred on clay soils in pans.

In the studies done by Bezuidenthout *et al.* (1993) communities similar to this one were found on seasonal inundated environmental conditions associated with the Willowbrook soil form. In contrast to this the community described by Kooij *et al.* (1991) and the community found in this study occur in areas associated with seasonally saturated soils, ofthe Katspruit soil form. The occurrence on Katspruit soils is similar to the results found by Collins (2011) in the description of valley-bottom wetlands.

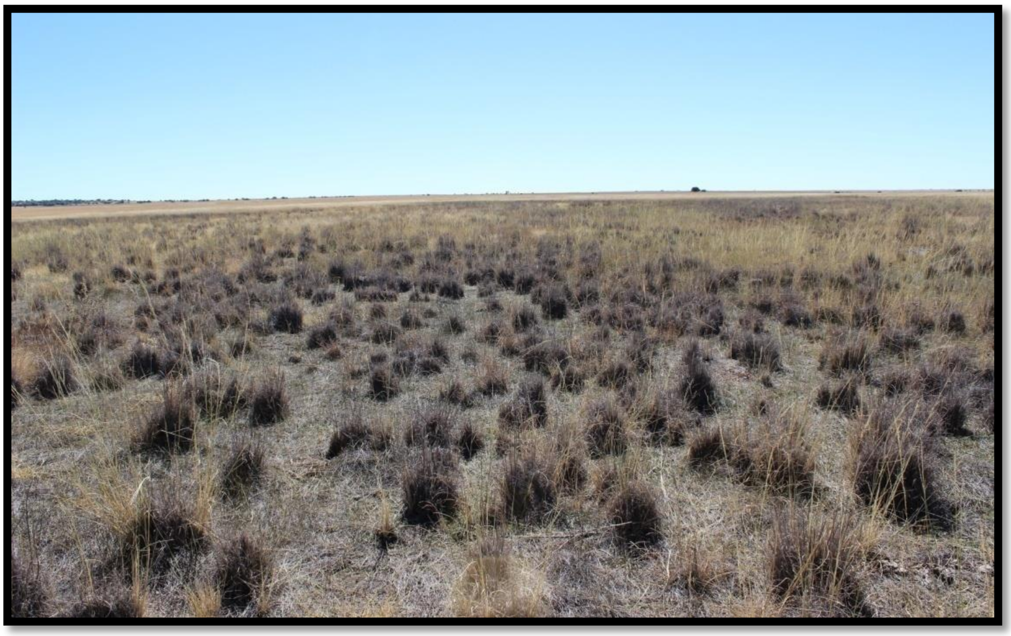

Figure 8.4: *Leptochloa fusca – Echinochloa holubii* Sub-community.

2.4 *Leptochloa fusca – Sporobolus ludwigii* Sub-community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Kroonstad
Soil depth:	>1.5 m
Hydrology:	Seasonally inundated
Exposure:	Full sun
Disturbance:	None

Species

Average number of species in the sub-community: 5

Number of relevés in the sub-community:6

Diagnostic species: ***Frankenia pulverulenta* 90.9, *Sporobolus ludwigii* 100.0**

Constant species: ***Eragrostis lehmanniana* 100, *Frankenia pulverulenta* 83, *Leptochloa fusca* 100, *Sporobolus ioclados* 100, *Sporobolus ludwigii* 100**

Dominant species: *Leptochloa fusca* 50, *Sporobolus ludwigii* 33

Discussion: Species from species group E (*Sporobolus ludwigii* and *Frankenia pulverulenta*) and species group W (*Eragrostis lehmanniana*) characterise this sub-community. This sub-community (Figure 8.5) occurs in pans that are dry except in years with above average rainfall. Within these pans salt crystals are present on the soil surface. In a study done by Müller (2002) *Sporobolus ludwigii* (Species group E) was found to occur as part of the transition zone between the aquatic habitats of pans and the terrestrial areas. In this study this sub-community occur within the pans and not on the rim of the pans as mentioned by Müller (2002).

Collins (2011) describes a sub-community with similar species to be typical of arid regions, which are temporary wet and occur on clayey soils. Furthermore, these areas are prone to grazing by livestock and game (Collins, 2011).

Figure 8.5: *Leptochloa fusca – Sporobolus ludwigii* Sub-community.

2.5 *Leptochloa fusca – Sporobolus virginicus* Sub-community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Katspruit and Kroonstad
Soil depth:	>1.5 m
Hydrology:	Seasonally inundated
Exposure:	Full sun
Disturbance:	None

Species

Average number of species in the sub-community: 5

Number of relevés in the sub-community:16

Diagnostic species: *Sporobolus virginicus 79.2*

Constant species: *Leptochloa fusca 75,* ***Sporobolus virginicus 100***

Dominant species: *Juncus rigidus 6, Leptochloa fusca 12, Sporobolus virginicus 25*

Discussion: This sub-community is defined by the presence of the grass *Sporobolus virginicus* (Species group G). This sub-community occurs on the edge of pans and is therefore seen as the transition between the communities in the pan and the communities of the grassland surrounding the pans. This finding is supported by Müller's (2002) study who found this sub-community on the drier edges of seepage areas. The grass, *Sporobolus virginicus* (Species group G) occurs on dunes, beaches and along tidal streams. This plant can vary in growth form, from delicate plants to large and robust plants (Russell *et al.*, 1990). In the area of study the grasses were mostly delicate plants. Naidoo and Naidoo (1998) noted that *Sporobolus virginicus* is a halophytic (Acocks, 1988), mat-forming, stoloniferous, perennial grass that is widely distributed in South Africa. This grass species has salt glands on both leaf surfaces which effectively maintain the salt levels in the plant (Naidoo and Naidoo, 1988). The large flask-shaped, sunken basal cells and dome-shaped cap cells and adjacent mesophyll cells are very effective in the process of salt secretion (Naidoo and Naidoo, 1998).

This community is mostly dominated by grasses as well as a number of sedges.

This sub-community can be divided into one variant, namely:

2.5.1 *Juncus rigidus* Variant

2.5.1 *Juncus rigidus* Variant

Habitat

Geology:	Beaufort and Ecca groups
Soil form/forms:	Katspruit and Kroonstad
Soil depth:	>1.5m
Hydrology:	Seepage of water to the surface may occur during the rainy season
Exposure:	Full sun
Disturbance:	None

Species

Average number of species in the variant: 4

Number of relevés in the variant:3

Diagnostic species: No diagnostic species

Constant species: ***Cynodon dactylon 100, Juncus rigidus 100,*** *Sporobolus* *fimbriatus 67,* ***Sporobolus ioclados 100, Sporobolus virginicus 100***

Dominant species: *Juncus rigidus 33,* ***Sporobolus virginicus 100***

Discussion: The strong presence of species such as *Sporobolus ioclados* (Species group F), *Juncus rigidus* (Species group R), and *Cynodon dactylon* (Species group X) distinguish this variant. The absence of *Leptochloa fusca* (Species group B) is also notable.

This variant (Figure 8.6) occurs in areas close to wetlands with permanent water. The presence of the grass *Sporobolus ioclados* (Species group F) indicates disturbance in natural veld, however, it occurs along the edges of ephemeral pans on various soil forms. This grass is well adapted to occur in saline and sodic soils (Bezuidenhout, 1995; Van Oudtshoorn, 2004). The sedge *Juncus rigidus* (Species group R) is known as a halophyte that occurs mostly on inland areas in South Africa. This sedge can also occur near saline or alkaline pools and may form large stands (Cook, 2004). Fourie (2013) mentioned that *Juncus rigidus* occurs in areas with lower surface water where the soil is saturated. In this study the soil will only be saturated during the rainy season. In the study done by Janecke *et al.* (2003) the *Juncus rigidus* Community occurs close to a hot spring in the Open *Diplachne* Pan. In this study, this variant was found where *Leptochloa fusca*, was absent.

Figure 8.6: *Juncus rigidus* Variant.

2.6 *Leptochloa fusca – Salsola glabrescens* Sub-community

Habitat

Geology: Beaufort and Ecca Groups

Soil form/forms: Katspruit

Soil depth: >1.5 m

Hydrology: Seasonally inundated

Exposure: Full sun

Disturbance: None

Species

Average number of species in the sub-community: 5

Number of relevés in the sub-community:5

Diagnostic species: No diagnostic species

Constant species: ***Leptochloa fusca 100, Salsola glabrescens 100***

Dominant species: ***Leptochloa fusca 100***

Discussion: *Salsola glabrescens* (Species group H) characterise this sub-community. This sub-community was found to occur towards the middle of the pans where it was sampled. Thus, in this casethis sub-community can be seen as the transition between the grass-dominated middle of the pans and the pan's edge, which is dominated by species from Chenopodiaceae. The soil is a deep clayey soil which cracks when the soil becomes desiccated. Fourie (2013) found *Salsola glabrescens* in variants studied at Florisbad, however, the species present in the variant differs from the ones found in this study. He mentioned that the main environmental factor driving this variant is dry soils. In this study this sub-community is however associated with seasonally inundated soils.

3. *Suaeda merxmuelleri – Salsola glabrescens* Community

Habitat

Geology: Beaufort and Ecca Groups

Soil form/forms: Katspruit

Soil depth: >1.5 m

Hydrology: Seasonally inundated

Exposure: Full sun

Disturbance: Grazing livestock

Species

Average number of species in the community: 4

Number of relevés in the community:21

Diagnostic species: ***Salsola glabrescens 94.0, Suaeda merxmuelleri 94.5***

Constant species: ***Salsola glabrescens 100, Suaeda merxmuelleri 90***

Dominant species: *Leptochloa fusca 24, Malephora cf. crocea 5, Salsola glabrescens 52, Sporobolus ioclados 10*

Discussion: This community (Figure 8.7) occurs towards the edge of the pans on a deep clayey soil which cracks when it becomes desiccated.This pan community is dominated by the presence of two leaf-succulents, members of the family Chenopodiaceae. The presence of this family in dry depressions is a common phenomenon. *Salsola glabrescens* (Species group H) is known as a palatable succulent shrub that is used by farmers as fodder for livestock during the dry periods (Le Roux *et al.*, 1994). The farmers in the area are well aware of the value of *Salsola glabrescens*as fodder. This community or communities similar to this community are absent in all the studies done in and around this study area.

This community can be divided into two sub-communities, namely:

3.1 *Suaeda merxmuelleri – Salsola glabrescens – Leptochloa fusca* Sub-community

3.2 *Suaeda merxmuelleri – Salsola glabrescens – Sporobolus ioclados* Sub-community

Figure 8.7: *Suaeda merxmuelleri – Salsola glabrescens* Community.

3.1 *Suaeda merxmuelleri – Salsola glabrescens – Leptochloa fusca* Sub-community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Katspruit
Soil depth:	>1.5 m
Hydrology:	Seasonally inundated
Exposure:	Full sun
Disturbance:	Grazing livestock

Species

Average number of species in the sub-community: 4

Number of relevés in the sub-community:6

Diagnostic species: No diagnostic species

Constant species: ***Leptochloa fusca 83, Salsola glabrescens 100, Suaeda merxmuelleri 100***

Dominant species: ***Leptochloa fusca 83,*** *Salsola glabrescens 17*

Discussion: This is a karroid sub-community and occurs in pans that have a high salt content which usually forms salt crystals on the soil surface. This sub-community is distinguished by the strong presence of the grass *Leptochloa fusca* (Species group B).

3.2 *Suaeda merxmuelleri – Salsola glabrescens – Sporobolus ioclados* Sub-community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Katspruit
Soil depth:	>1.5 m
Hydrology:	Seasonally inundated
Exposure:	Full sun
Disturbance:	Grazing livestock

Species

Average number of species in the sub-community: 4

Number of relevés in the sub-community:9

Diagnostic species: ***Malephora cf. crocea 87.7***

Constant species: *Malephora cf. crocea 78,* ***Salsola glabrescens 100, Sporobolus ioclados 89, Suaeda merxmuelleri 100,*** *Tragus berteronianus 67*

Dominant species: *Malephora cf. crocea 11, Salsola glabrescens 44, Sporobolus ioclados 22*

Discussion: This sub-community (Figure 8.8) is distinguished by the presence of species from species group J (*Malephora* cf. *crocea* and *Tragus berteronianus*). However, the strong presence of the grass *Sporobolus ioclados* (Species group F) is notable in this sub-community. In studies done in and around the study area, *Sporobolus ioclados* was found to occur associated with grasses and sedges (Müller, 2002; Janecke *et al.,* 2003; Collins, 2011). The above mentioned species distinguishes this sub-community from the *Suaeda merxmuelleri – Salsola glabrescens*sub-community. Species of the genus *Malephora* (Mesembryanthemaceae) grow in areas that usually receive winter and summer rainfall of less than 500 mm per year (Smith *et al.*, 1998). The low rainfall compares well to the area of study.

This sub-community can be divided into two variants, namely:

3.2.1 *Tragus berteronianus* Variant

3.2.2 *Leptochloa fusca* Variant

Figure 8.8: *Suaeda merxmuelleri – Salsola glabrescens – Sporobolus ioclados* Sub-community.

3.2.1 *Tragus berteronianus* Variant

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Katspruit
Soil depth:	>1.5 m
Hydrology:	Seasonally inundated
Exposure:	Full sun
Disturbance:	Grazing livestock

Species

Average number of species in the variant: 4

Number of relevés in the variant:6

Diagnostic species:	No diagnostic species
Constant species:	*Malephora* cf. *crocea 67,* ***Salsola glabrescens 100, Sporobolus ioclados 83, Sporobolus virginicus 83, Suaeda merxmuelleri 100, Tragus berteronianus 100***
Dominant species:	*Malephora* cf. *crocea 17,* ***Salsola glabrescens 67***

Discussion: The presence of the grasses *Tragus berteronianus* (Species group J) and *Sporobolus virginicus* (Species group G) as well as the absence of the grass *Leptochloa fusca* (Species group B) distinguish this variant from variant 3.2.2.

Tragus berteronianus (Species group J) is known to indicate disturbance and can occur on compacted soil (Van Oudtshoorn, 2004). In the area of study the variant occurs on clayey soils which are severely desiccated during the dry season. *T. berteronianus* also indicates disturbances such as trampling and overgrazing (Van Oudtshoorn, 2004) however, in the area of study there were no signs of trampling or overgrazing.

3.2.2 *Leptochloa fusca* Variant

Habitat

Geology: Beaufort and Ecca Groups

Soil form/forms: Katspruit

Soil depth: >1.5 m

Hydrology: Seasonally inundated

Exposure: Full sun

Disturbance: Grazing livestock

Species

Average number of species in the variant: 4

Number of relevés in the variant:3

Diagnostic species: *Malephora* cf. *crocea 77.1*

Constant species: ***Leptochloa fusca 100, Malephora* cf. *crocea 100, Salsola glabrescens 100, Sporobolus ioclados 100, Suaeda merxmuelleri 100***

Dominant species: ***Sporobolus ioclados 67***

Discussion: This variant is distinguished by the presence of the grass *Leptochloa fusca* (Species group B) and the total absence of the grasses *Sporobolus virginicus* (Species group G) and *Tragus berteronianus* (Species group J).

4. *Berula erecta – Eleocharis limosa* Community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Katspruit
Soil depth:	>1.5 m
Hydrology:	Water saturated
Exposure:	Full sun
Disturbance:	None

Species

Average number of species in the community: 9

Number of relevés in the community: 32

Diagnostic species: ***Berula erecta 100, Eleocharis limosa 100, Limosella africana 91.2, Potamogeton sp. 81.9***

Constant species: *Cynodon dactylon 65,* ***Limosella africana 85,*** *Potamogeton* sp. *70*

Dominant species: *Berula erecta 35, cf. Schoenoplectus tabernaemontana 5, Eleocharis dregeana 25, Isolepis cernua 30, Limosella africana 30, Marsilea burchellii 10, Potamogeton* sp. *5*

Discussion: This community is distinguished by the presence of species from species group K (*Berula erecta, Eleocharis limosa, Potamogeton* sp. and *Agrostis lachnantha*). Other species such as the hydrophytic forb, *Limosella africana* (Species group P) and the grass *Cynodon dactylon* (Species group X) also has a strong presence in this community, although they are species that occur in all hydrophytic communities.

This community occurs close to or in permanent water bodies. *Berula erecta* occurs as emergent aquatic plants or sometimes with floating stems. This plant may also occur in areas with flowing water (Cook, 2004).*Eleocharis limosa* occur in shallow standing water (Cook, 2004). In the area of study these plants occur in shallow water close to springs, where the water might be flowing during certain times of the year. In the studies done in and around the study area (Müller, 2002; Janecke *et al.,* 2003; Collins, 2011 and Fourie, 2013) no similar communities to this community occur.

This community can be divided into two sub-communities, namely:

4.1 *Berula erecta – Eleocharis limosa – Typha capensis* Sub-community

4.2 *Berula erecta – Eleocharis limosa – Cyperus longus* Sub-community

4.1 *Berula erecta – Eleocharis limosa – Typha capensis* Sub-community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Katspruit
Soil depth:	>1.5 m
Hydrology:	Water saturated
Exposure:	Full sun
Disturbance:	None

Species

Average number of species in the sub-community: 9

Number of relevés in the sub-community: 6

Diagnostic species:	*Agrostis lachnantha 76.3,* **cf. *Schoenoplectus tabernaemontana 100.0, Typha capensis 100.0***
Constant species:	***Agrostis lachnantha 100, Berula erecta 100, cf. Schoenoplectus tabernaemontana 100, Cynodon dactylon 83, Eleocharis limosa 100, Potamogeton sp 100, Typha capensis 100***
Dominant species:	*Berula erecta 33,* cf. *Schoenoplectus tabernaemontana 17, Limosella africana 17*

Discussion: Water saturation of the soil is the driving factor in this sub-community. The plants present in this sub-community are well adapted to waterlogged or moist conditions (Figure 8.9). Waterfowl was also present in the vicinity of these sub-communities. The plants that define this sub-community are the emergent hydrophytic forb *Typha capensis* and the sedge cf. *Schoenoplectus tabernaemontana* (Species group L).

T. capensis is often dominant in marshes, backwaters, lagoons, pools and along some water courses. The genus *Typha* occurs in large stands in various aquatic habitats. This large stands of *Typha* provide valuable refuge areas for many species of waterfowl and wildlife (Cook, 2004).*Schoenoplectus tabernaemontana* occurs in streams, ditches, pools and swamps. This species often occurs in water and can also tolerate brackish conditions (Cook, 2004). In the study done by Müller (2002) *Typha capensis* was found to be part of a sub-community of the *Paspalum distichum* Community which occurs in water saturated soils or shallow water. The occurrence of *Typha capensis* in this sub-community is also in water saturated soils or shallow water.

This sub-community can be divided into two variants, namely:

4.1.1 *Limosella africana* Variant

4.1.2 *Lemna gibba* Variant

Figure 8.9: *Berula erecta – Eleocharis limosa – Typha capensis* Sub-communityindicated by the red arrow.

4.1.1 *Limosella africana* Variant

Habitat

<u>Geology:</u> Beaufort and Ecca Groups

<u>Soil form/forms:</u> Katspruit

<u>Soil depth:</u> >1.5 m

<u>Hydrology:</u> Water saturated

<u>Exposure:</u> Full sun

<u>Disturbance:</u> None

Species

<u>Average number of species in the variant:</u> 9

<u>Number of relevés in the variant:</u> 3

Diagnostic species: No diagnostic species

Constant species: ***Agrostis lachnantha 100, Berula erecta 100,* cf. *Schoenoplectus tabernaemontana 100,*** *Cynodon dactylon 67,* ***Eleocharis limosa 100, Limosella africana 100, Potamogeton* sp. *100, Typha capensis 100***

Dominant species: *Berula erecta 33, Limosella africana 33*

Discussion: This variant is characterised by the presence of the hydrophytic forb *Limosella africana* (Species group P) and the complete absence of *Lemna gibba, Salix *babylonica* (Species group M) and *Finicia nodosa* (Species group S).

The species in this variant occur towards the edge of wetlands in shallow water. Cook (2004) noted that *Limosella africana* occur in shallow water or on the muddy/sandy edges of pools or marshes.

4.1.2 *Lemna gibba* Variant

Habitat

<u>Geology:</u> Beaufort and Ecca Groups

<u>Soil form/forms:</u> Katspruit

<u>Soil depth:</u> >1.5 m

<u>Hydrology:</u> Water saturated

<u>Exposure:</u> Full sun to semi-shade

Disturbance: None

Species

Number of species in the variant: 8

Number of relevés in the variant: 3

Diagnostic species: ***Lemna gibba 100.0, Salix *babylonica 100.0***

Constant species: ***Agrostis lachnantha 100, Berula erecta 100, cf. Schoenoplectus tabernaemontana 100, Cynodon dactylon 100, Eleocharis limosa 100, Finicia nodosa 100, Lemna gibba 100, Potamogeton sp 100, Salix *babylonica 100, Typha capensis 100***

Dominant species: *Berula erecta 33,* cf. *Schoenoplectus tabernaemontana 33*

Discussion: The presence of species such as; *Lemna gibb,Salix* **babylonica* (Species group M) and *Finicia nodosa* (Species group S) distinguish this variant from variant 4.1.1.

Lemna gibba (Species group M) is a cosmopolitan floating aquatic plant that occurs in warm and Mediterranean climates. This aquatic plant mostly occurs in mesotrophic and eutrophic water (Cook, 2004). In some instances this variant occurs in the shade of *Salix* **babylonica* (Species group M) trees. The water in which this variant occurs was not clear; which could indicate some degree of eutrophication in the water, however, the water was not analysed in a laboratory.

4.2 *Berula erecta – Eleocharis limosa – Cyperus longus* Sub-community

Habitat

Geology: Beaufort and Ecca Groups

Soil form/forms: Katspruit

Soil depth: >1.5 m

Hydrology: Water saturated

Exposure: Full sun

Disturbance: None

Species

Average number of species in the sub-community: 9

Number of relevés in the sub-community: 6

Diagnostic species: ***Cyperus longus 84.9***

Constant species: *Agrostis lachnantha 67,* ***Berula erecta 100, Cyperus longus 100,*** *Eleocharis dregeana 67,* ***Eleocharis limosa 100, Limosella africana 100, Potamogeton sp. 100***

Dominant species: ***Berula erecta 83,*** *Eleocharis dregeana 50, Limosella africana 33, Potamogeton* sp. *17*

Discussion: *Cyperus longus* and *Eleocharis dregeana* (Species group N) (Figure 8.10) are the characteristic species of this sub-community. These speciesare present in this sub-community butare completely absent from sub-community4.1. This sub-community (4.2) occurs in wetlands which are permanently water saturated. The characteristic species in this sub-community *Cyperus longus*and *Eleocharis dregeana*(Species group N) are known to occur in seasonally flooded depression or shallow water (Cook, 2004).

Figure: 8.10: *Berula erecta – Eleocharis limosa – Cyperus longus* Sub-community.

5. *Marsilea burchellii – Isolepis cernua* Community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Katspruit
Soil depth:	>1.5 m
Hydrology:	Seasonally inundated
Exposure:	Full sun
Disturbance:	None

Species

Average number of species in the community: 6

Number of relevés in the community: 8

Diagnostic species: ***Marsilea burchellii 100.0***

Constant species: *Cynodon dactylon 75, Isolepis cernua 75,* ***Limosella africana 100, Marsilea burchellii 100***

Dominant species: *Eleocharis dregeana 25,* ***Isolepis cernua 75,*** *Limosella africana 38, Marsilea burchellii 25*

Discussion: This community (Figure 8.11) is dominated by the hydrophytic fern*Marsilea burchellii* and the sedge *Isolepis cernua* (Species group O). This community occurs in pans that are seasonally wet.

Cook (2004) noted that *I. cernua* is a non-aquatic or wetland species. This sedge is however, found on damp soil or areas that are seasonally wet. The soils of the study area on which these wetlands were present, were moist throughout the profile. No similar communities were found in the studies done by (Müller, 2002; Janecke *et al.,* 2003; Collins, 2011 and Fourie, 2013)

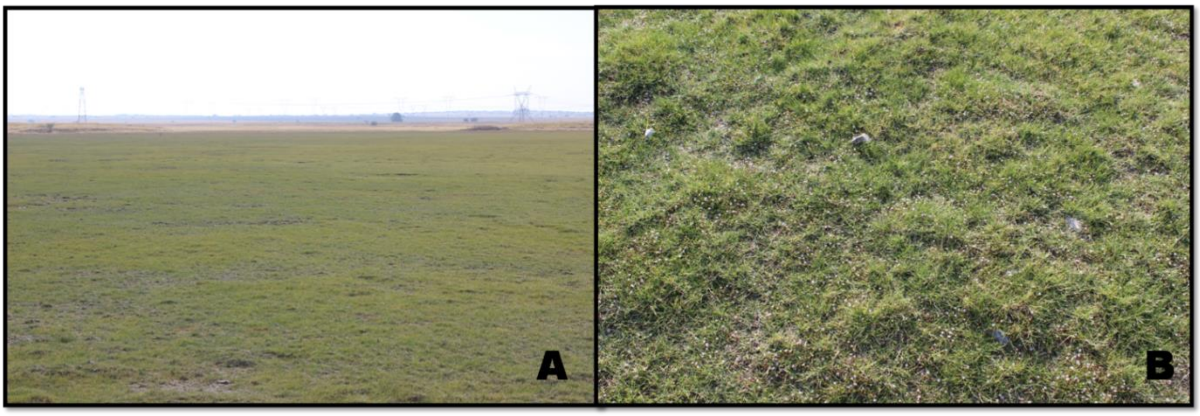

Figure 8.11: *Limosella africana – Marsilea burchellii – Isolepis cernua* Sub-community.

6. *Limosella longiflora – Cynodon dactylon* Community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Katspruit
Soil depth:	>1.5 m
Hydrology:	Seasonally inundated
Exposure:	Full sun
Disturbance:	None

Species

Number of species in the community: 2

Number of relevés in the community:3

Diagnostic species:	***Limosella longiflora 100.0***
Constant species:	*Cynodon dactylon 67,* ***Limosella longiflora 100***
Dominant species:	No dominant species

Discussion: This plant community (Figure 8.12) is limited to the cracks in clayey soils which occur in some of the pans in the study area. These cracks are moist and provide suitable conditions for the growth of the hydrophytic forb *Limosella longiflora* (Species group Q). Cook (2004) mentioned that when *L. longiflora* occurs in terrestrial habitats the plant is much smaller compared to the specimens growing in aquatic habitats. This was the case in the area of study, although the communities formed part of the pans. Although the grass *Cynodon dactylon* (Species group X) also occurs in this community there are only a few individuals present with low cover abundance.

Figure 8.12: *Limosella longiflora – Cynodon dactylon* Community.

7. *Juncus rigidus* Community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Katspruit, Kroonstad and Kinkelbos
Soil depth:	>1.5 m
Hydrology:	Seasonally inundated
Exposure:	Full sun
Disturbance:	None

Species

Average number of species in the community: 7

Number of relevés in the community:14

Diagnostic species:	***Juncus rigidus 91.8***
Constant species:	***Juncus rigidus 100***
Dominant species:	*Cynodon dactylon 6, Cyperus longus 6, Cyperus marginatus 18, Eragrostis biflora 6, Finicia nodosa 12, Juncus rigidus 41*

Discussion: This community is dominated by the presence of the sedge *Juncus rigidus* (Species group R). Furthermore, this community occurs in the floodplain areas of the wetlands or in some of the pan areas that are seasonally inundated. The soils in this community were mostly moist throughout the profile.

The sedge *Juncus rigidus* is known as a robust, tufted perennial sedge with creeping woody rhizomes. This species occur in the inland areas of southern Africa as a halophytic plant. Furthermore, this species can also occur in saline or alkaline wetland areas and marches. Large, dense stands of this sedge are mostly found (Cook, 2004).

Juncus rigidus communities were found in studies done by Janecke *et al.* (2003) and Collins (2011). The community found in this study is similar to the one found by Janecke *et al.* (2003) with is associated with numerous other species. In the study by Janecke *et al.* (2003) the community can be divided into four sub-communities, however, in this study there are only three sub-communities. Furthermore, as mentioned by Janecke *et al.* (2003) the species in this community tend to avoid permanently inundated habitats. This community is not similar to the monospecific community found by Collins (2011).

This community can be divided into three sub-communities, namely:

7.1 *Juncus rigidus – Cynodon dactylon* Sub-community

7.2 *Juncus rigidus – Finicia nodosa* Sub-community

7.3 *Juncus rigidus – Cyperus marginatus* Sub-community

7.1 *Juncus rigidus – Cynodon dactylon* Sub-community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Katspruit and Kinkelbos
Soil depth:	>1.5 m
Hydrology:	Seasonally inundated
Exposure:	Full sun

Disturbance: None

Species

Average number of species in the sub-community: 6

Number of relevés in the sub-community:3

Diagnostic species: No diagnostic species

Constant species: ***Cynodon dactylon 100, Juncus rigidus 100***

Dominant species: *Cynodon dactylon 33, Juncus rigidus 33*

Discussion: The absence of the species from species groups T, U and V distinguishes this sub-community from the others in community 7. The presence of the grass *Cynodon dactylon* (Species group X) is characteristic of this sub-community. This sub-community (Figure 8.13) occurs in dry pan areas with some barren patches among the vegetation.

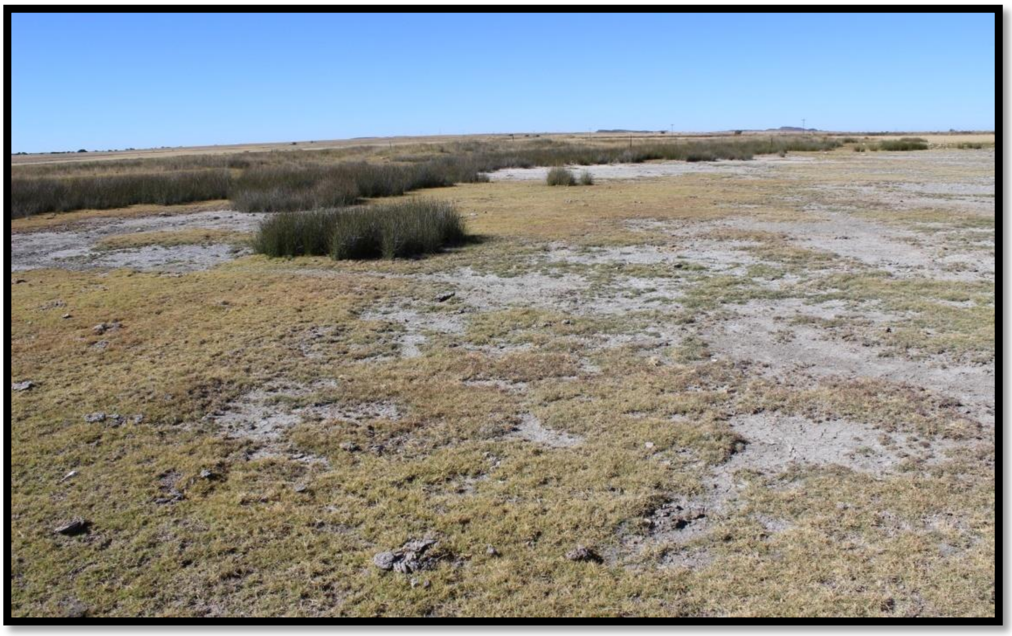

Figure 8.13: *Juncus rigidus – Cynodon dactylon* Sub-community.

7.2 *Juncus rigidus – Finicia nodosa* Sub-community

Habitat

Geology: Beaufort and Ecca Groups

Soil form/forms: Katspruit and Kroonstad

Soil depth: >1.5 m

Hydrology: Seasonally inundated

Exposure: Full sun

Disturbance: None

Species

Average number of species in the sub-community: 6

Number of relevés in the sub-community:11

Diagnostic species: No diagnostic species

Constant species: *Finicia nodosa 73,* ***Juncus rigidus 100***

Dominant species: *Cyperus longus 9, Eragrostis biflora 9, Finicia nodosa 18, Juncus rigidus 45*

Discussion: *Finicia nodosa* (Species group S) distinguish this sub-community form the other sub-communities in this community.

This sub-community can be divided into two variants, namely:

7.2.1 **Cirsium vulgare* Variant

7.2.2 *Salvia runcinata*Variant

7.2.1 **Cirsium vulgare* Variant

Habitat

Geology: Beaufort and Ecca Groups

Soil form/forms: Katspruit

Soil depth: >1.5 m

Hydrology: Seasonally inundated

Exposure: Full sun

Disturbance: None

Species

Average number of species in the variant: 4

Number of relevés in the variant:6

Diagnostic species: ***Cirsium vulgare 100.0,** *Conyza *bonariensis 76.2, *****Oenothera rosea 81.2, Ranunculus *multifidus 81.2***

Constant species: ***Cirsium vulgare 100, Conyza *bonariensis 83, Finicia nodosa 83, Juncus rigidus 100, **Oenothera rosea 67,* *Ranunculus *multifidus 6*

Dominant species: *Cyperus longus 17, Finicia nodosa 33, Juncus rigidus 50*

Discussion: The species form species group T (**Cirsium vulgare, Conyza *bonariensis, *Oenothera* rosea and *Ranunculus *multifidus*)are all diagnostic to this variant and are also the species that defines this variant (Figure 8.14). These forbs defining this variant are all alien invasive species. This variant mostly occurred as areas transitional between the permanently water saturated wetlands and the areas of the wetlands which are only periodically water saturated (during the rainy season).

Figure 8.14: **Cirsium vulgare* Variant.

7.2.2 *Salvia runcinata*Variant

Habitat

Geology: Beaufort and Ecca Groups

Soil form/forms: Kroonstad

Soil depth: ± 0.39 m

Hydrology: Seasonally inundated

Exposure: Full sun

Disturbance: None

Species

Average number of species in the variant: 4

Number of relevés in the variant:5

Diagnostic species: ***Salvia runcinata 89.1***

Constant species: ***Juncus rigidus 100,*** *Salvia runcinata 80, Setaria verticillata 80*

Dominant species: *Eragrostis biflora 20, Juncus rigidus 40*

Discussion: Species of species group U (*Setaria verticillata, Eragrostis biflora* and *Salvia runcinata*) characterise this variant. This variant (Figure 8.15) occurs on the floodplains of permanent wetlands. These wetlands might experience droughts during years of low rainfall. The grass *Setaria verticillata* (Species group U) occurs in shady, disturbed areas on moist soil (Van Oudtshoorn, 2004). However, in the area of study this grass occurs on the floodplain of permanent wet wetlands in full sun and dry soil. The soils in these areas are also relatively shallow as indicated in the habitat information.

Figure 8.15: *Salvia runcinata*Variant.

7.3 *Juncus rigidus – Cyperus marginatus* Sub-community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Katspruit and Kroonstad
Soil depth:	>1.5 m
Hydrology:	Seasonally inundated
Exposure:	Full sun
Disturbance:	None

Species

Average number of species in the sub-community: 4

Number of relevés in the sub-community:3

Diagnostic species:	***Cyperus marginatus 100.0***
Constant species:	***Cyperus marginatus 100, Euphorbia inaequilatera 100, Juncus rigidus 100, *Verbena bonariensis 100***
Dominant species:	***Cyperus marginatus 100,*** *Juncus rigidus 33*

Discussion: This sub-community (Figure 8.16) is characterised by the presence of *Cyperus marginatus* (Species group V), which distinguish this sub-community from all the other sub-communities in this community. The vegetation in this sub-community under-go seasonal water saturation.

Figure 8.16: *Juncus rigidus – Cyperus marginatus* Sub-community.

8. *Eragrostis lehmanniana*Community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Katspruit, Kinkelbos, Addo, Knersvlakte, Fernwood and Brandvlei
Soil depth:	>1.5 m
Hydrology:	Seasonally inundated
Exposure:	Full sun
Disturbance:	Occasional grazing by livestock

Species

Average number of species in the community: 10

Number of relevés in the community: 13

Diagnostic species: No diagnostic species

Constant species: *Cynodon dactylon 62,* ***Eragrostis lehmanniana 88***

Dominant species: *Cynodon dactylon 34, Eragrostis lehmanniana 9, Eragrostis obtusa 3, Eragrostis trichophora 3, Panicum schinzii 6, *Phyla nodiflora 38, Salsola aphylla 9, Sporobolus fimbriatus 6*

Discussion: This community is defined by the presence of the grass*Eragrostis lehmanniana* (Species group W). Although, Collins (2011) found a community dominated by the grass *Eragrostis lehmanniana*the community contained autocorrelated relevés and were therefore not discussed. In a study done by Botha (2003) an *Eragrostis lehmanniana* dominated sub-community was found as part of the *Pennisetum sphacelatum – Scirpoides dioecus* Community. This sub-community is similar to the community found in this study. The community in this study also occur as the transition between the grassland and wetland areas – situated on the seepage area of the seasonally inundated pan. The soils in this area are clayey.

This community can be divided into four sub-communities, namely:

8.1 *Eragrostis lehmanniana – *Phyla nodiflora* Sub-community

8.2 *Eragrostis lehmanniana – Salsola aphylla* Sub-community

8.3 *Eragrostis lehmaniniana – Panicum coloratum* Sub-community

8.4 *Eragrostis lehmanniana – Sporobolus fimbriatus* Sub-community

8.1 *Eragrostis lehmanniana – *Phyla nodiflora* Sub-community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Katspruit
Soil depth:	>1.5 m
Hydrology:	Seasonally inundated
Exposure:	Full sun
Disturbance:	Occasional grazing by livestock

Species

Average number of species in the sub-community: 10

Number of relevés in the sub-community: 13

Diagnostic species: No diagnostic species

Constant species: ***Cynodon dactylon* 100, *Eragrostis lehmanniana* 85, **Phyla nodiflora* 100,** **Schkuhria pinnata 62, Sporobolus fimbriatus 69*

Dominant species: ***Cynodon dactylon* 85, **Phyla nodiflora* 62**

Discussion: This sub-community is characterised by the presence of species from species group X (*Cynodon dactylon, *Phyla nodiflora, Chloris virgata, Sporobolus fimbriatus, *Schkuhria pinnata, Eragrosits obtusa, Aristida congesta* and *Senecio burchellii*) (Figure 8.17). This sub-community is present on the edges of pans, between the water saturated areas and the grassland communities.This habitat along the shores of dams and pans is where Janecke *et al.* (2003) also found **Phyla nodiflora* to occur. The soil in this sub-community is deep and occasionally moist.**Phyla nodiflora* is a naturalized exotic in South Africa (SANBI, 2014b).

Figure 8.17: *Cynodon dactylon* – **Phyla nodiflora* Sub-community.

8.2 *Eragrostis lehmanniana* – *Salsola aphylla* Sub-community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Kinkelbos
Soil depth:	>1.5 m
Hydrology:	Seasonally inundated
Exposure:	Full sun
Disturbance:	None

Species

Average number of species in the sub-community: 10

Number of relevés in the sub-community: 8

Diagnostic species: ***Eragrostis trichophora* 100.0, *Salsola aphylla* 84.9**

Constant species: ***Cynodon dactylon* 100, *Eragrostis lehmanniana* 100, *Eragrostis trichophora* 100, *Salsola aphylla* 100**

Dominant species: *Eragrostis trichophora 25, Salsola aphylla 50*

Discussion: This sub-community is characterised by the strong presence of the shrub *Salsola aphylla* (Species group Y). This sub-community occurs on the edge of pans towards the grasslands. In the study done by Collins (2011), *Salsola aphylla* was found to occur on temporary wet soils of channelled endorheic depressions. In this study it was found that *Salsola aphylla* also occurs on the edge of pans. On the other hand Geldenhuys (1982) found that *Salsola aphylla* and *Sueda fruticosa* occur on pan floors.

This sub-community can be divided into two variants, namely:

8.2.1 *Eragrostis trichophora* Variant

8.2.2 *Thesium costatum* Variant

8.2.1 *Eragrostis trichophora* Variant

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Kinkelbos
Soil depth:	>1.5 m
Hydrology:	Seasonally inundated in very good rainfall years
Exposure:	Full sun
Disturbance:	None

Species

Average number of species in the variant: 6

Number of relevés in the variant: 4

Diagnostic species:	***Eragrostis trichophora 100.0***
Constant species:	***Cynodon dactylon 100, Eragrostis lehmanniana 100, Eragrostis trichophora 100, Salsola aphylla 100***
Dominant species:	*Eragrostis trichophora 25, Salsola aphylla 50*

Discussion: This variant (Figure 8.18) occurs on the slopes of the lunette dunes of the pans in the study area. The soil is deep and sandy. The grass *Eragrostis trichophora* (Species group Z) characterises this variant and distinguishes the variant from 8.2.2.

Eragrostis trichophora is known to occur in disturbed areas and on barren patches in the veld. This grass is mostly present on sandy or rocky soils (Van Oudtshoorn, 2004). In the case of this study the grass was present on deep sandy soils. This variant is present in the transitional zones between the pans and the surrounding grasslands.

Figure 8.18: *Eragrostis trichophora*Variant.

8.2.2 *Thesium costatum* Variant

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Kinkelbos
Soil depth:	±0.90 m
Hydrology:	Seasonally inundated in very good rainfall years
Exposure:	Full sun
Disturbance:	Grazing by livestock

Species

Average number of species in the variant: 6

Number of relevés in the variant: 4

Diagnostic species:	***Enneapogon desvauxii 100.0, Thesium costatum 86.2***
Constant species:	***Enneapogon desvauxii 100, Eragrostis lehmanniana 100, Eragrostis obtusa 100, Felicia muricata 100, Salsola aphylla 100,*** *Thesium costatum 75,* ***Tragus berteronianus 100***
Dominant species:	*Eragrostis lehmanniana 25, Eragrostis obtusa 25, Salsola aphylla 25*

Discussion: This variant (Figure 8.19) occurs on very dry soils on the top of lunette dunes in the study area. The vegetation is relatively sparsely distributed in this variant. This variant is characterised by the presence of *Thesium costatum* and *Enneapogon desvauxii* (Species group AA).

Figure 8.19: *Thesium costatum* Variant.

8.3 *Eragrostis lehmanniana – Panicum coloratum* Sub-community

Habitat

Geology: Beaufort and Ecca Groups

Soil form/forms: Katspruit, Addo and Knersvlakte

Soil depth: >1.5 m

Hydrology: Seasonally inundated

Exposure: Full sun

Disturbance: Grazing by livestock

Species

Average number of species in the sub-community: 10

Number of relevés in the sub-community: 3

Diagnostic species: *Eragrostis obtusa 78.9, Felicia muricata 79.1*

Constant species: ***Eragrostis lehmanniana 100, Eragrostis obtusa 91,*** *Felicia muricata 64, Panicum coloratum 64, Tragus* *berteronianus 64*

Dominant species: *Eragrostis lehmanniana 27, Eragrostis obtusa 9, Salsola aphylla 9*

Discussion: This sub-community is characterised by the grass*Panicum coloratum* (Species group AC). This grass is known to occur in clay and other fertile soils, especially in areas where water accumulates during the rainy season (Van Oudtshoorn, 2004). In the area of study this sub-community occurred on sloping, low lying areas surrounded by grasslands dominated by *Themeda triandra.*

This sub-community can be divided into two variants, namely:

8.3.1 *Lycium horridum*Variant

8.3.2 *Digitaria eriantha*Variant

8.3.1 *Lycium horridum*Variant

Habitat

Geology: Beaufort and Ecca Groups

Soil form/forms: Katspruit and Addo

Soil depth: >1.5 m

Hydrology: Seasonally inundated

Exposure: Full sun

Disturbance: Grazing by livestock

Species

Average number of species in the variant: 9

Number of relevés in the variant: 4

Diagnostic species: ***Cyperus rupestris 86.2***

Constant species: *Aristida congesta 75, Chloris virgata 75, Cyperus rupestris 75,* ***Eragrostis lehmanniana 100, Eragrostis obtusa 100,*** *Felicia muricata 75, Lycium horridum 75,* ***Panicum coloratum 100,*** *Tragus berteronianus 75*

Dominant species: No dominant species

Discussion: This variant (Figure 8.20) occurs as a mosaic in patches surrounded by stands of *Themeda triandra*. The soil is deeper than 1.5 m and very dry. This variant is dominated by the species from species group AD (*Lycium horridum* and *Cyperus rupestris*). Although *Cyperus rupestris* is the diagnostic species in this variant, the cover abundance values of *Lycium horridum* are higher and therefore used as the species to name the variant.

Cyperus rupestris is widespread in southern Africa and mostly occur in rocky areas (Van der Walt, 2009). In the study area this species occurs on deep soil.

Figure 8.20: *Lycium horridum*Variant.

8.3.2 *Digitaria eriantha*Variant

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Knersvlakte
Soil depth:	±0.26 m
Hydrology:	Seasonally inundated
Exposure:	Full sun
Disturbance:	Occasional grazing by livestock

Species

Average number of species in the variant: 9

Number of relevés in the variant: 3

Diagnostic species: ***Digitaria eriantha 100.0, Pseudognaphalium *luteo-album 100.0, Selago densiflora 100.0, Sutera caerulea 100.0***

Constant species: *Cynodon dactylon 67,* ***Digitaria eriantha 100, Eragrostis lehmanniana 100,*** *Eragrostis obtusa 67,* ***Panicum coloratum 100, Pseudognaphalium *luteo-album 100, Selago densiflora 100, Sutera caerulea 100***

Dominant species: ***Eragrostis lehmanniana 67***

Discussion: This variant (Figure 8.21) occurs on rocky shallow soils on the plains of the western Free State. It is characterised by the presence of the species *Digitaria eriantha, Pseudognaphalium *luteo-album*, *Sutera caerulea* and *Selago densiflora* (Species group AE). Although the cover abundance of these species is low, these species are only present in this sub-community.

The grass (*Digitaria eriantha*) that distinguishes this variant can be seen as a generalist that grows in a wide range of habitat types (Van Oudtshoorn, 2004). *Pseudognaphalium *luteo-album* is widely distributed in South Africa. This species occurs in grasslands mostly on disturbed and moist areas (Van Wyk and Malan, 1988).

Figure 8.21: *Digitaria eriantha* Variant.

8.4 *Eragrostis lehmanniana – Sporobolus fimbriatus* Sub-community

Habitat

<u>Geology:</u>	Beaufort and Ecca Groups
<u>Soil form/forms:</u>	Fernwood and Brandvlei
<u>Soil depth:</u>	±1.3 m
<u>Hydrology:</u>	Seasonally inundated
<u>Exposure:</u>	Full sun
<u>Disturbance:</u>	Occasional grazing by livestock

Species

<u>Average number of species in the sub-community:</u> 10

<u>Number of relevés in the sub-community:</u> 4

Diagnostic species: ***Bidens *pilosa 86.2***

Constant species: *Alternanthera sessilis 75, Bidens *pilosa 75, Finicia nodosa 75, ****Phyla nodiflora 100, *Schkuhria pinnata 100,*** *Setaria verticillata 75,* ***Sporobolus fimbriatus 100***

Dominant species: *Panicum schinzii 50, ****Phyla nodiflora 100,*** *Sporobolus fimbriatus 50*

Discussion: The presence of various species such as: *Ficinia nodosa* (species group S), *Setaria verticillata* (Species group U), **Phyla nodiflora, Sporobolus fimbriatus* and **Schkuhria pinnata* (species group X) and *Bidens *pilosa* (Species group AF) characterise this sub-community (Figure 8.22). From a hydrological perspective this sub-community occurs close to the edge of pans where the soils become periodically water saturated. Thus, the area around the pan is moist and therefore, favourable for the growth of vegetation.

**Phyla nodiflora* is a naturalized exotic in South Africa (SANBI, 2014b). In a study done by Janecke *et al.* (2003) **Phyla nodiflora* was also found on the zone next to the edge of the water. This is also the case in the study area.

Figure 8.22: *Eragrostis lehmanniana – Sporobolus fimbriatus* sub-community.

9. *Cynodon hirsutus* Community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Kroonstad
Soil depth:	>1.5 m
Hydrology:	Seasonally inundated
Exposure:	Full sun
Disturbance:	Grazed by livestock

Species

Average number of species in the community: 2

Number of relevés in the community:6

Diagnostic species:	***Cynodon hirsutus 100***
Constant species:	***Cynodon hirsutus 100***
Dominant species:	***Cynodon hirsutus 100***

Discussion: This community (Figure 8.23) is dominated by the grass *Cynodon hirsutus* (Species group AG). The high cover abundance value of this grass makes this a community dominated by *C. hirsutus.* The grass *C. hirsutus* mostly occur in well-drained loam soils and is known to control erosion (Russell *et al.* 1990). However, similar to the study done by Collins (2011) the community in this study was found to occur on the temporary or seasonally wet soils of the Kroonstad soil form. This community was present on clayey soils in pans in the area of study. The vegetation in this community can be seasonally flooded.

This community can be divided into one sub-community, namely:

9.1 *Cynodon hirsutus – Tragus berteronianus* Sub-community

Figure 8.23: *Cynodon hirsutus* Community.

9.1 *Cynodon hirsutus – Tragus berteronianus* Sub-community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Kroonstad
Soil depth:	>1.5 m
Hydrology:	Seasonally inundated
Exposure:	Full sun
Disturbance:	Grazed by livestock

Species

Average number of species in the sub-community: 2

Number of relevés in the sub-community:3

Diagnostic species: No diagnostic species

Constant species: ***Cynodon hirsutus 100, Tragus berteronianus 100***

Dominant species: ***Cynodon hirsutus 100***

Discussion: This sub-community is distinguished by the strong presence of the grass *Tragus berteronianus* (Species group J). This sub-community is present on dry, deep, clayey soils which can be water saturated during the rainy season. According to Van Oudtshoorn (2004) the grass *T. berteronianus,* which characterise this sub-community, indicate disturbance.

8.4 DCA ORDINATION OF THE WETLAND COMMUNITIES

A DCA ordination (Ter Braak and Smilauer, 2002) (Figure 8.24) was performed on data of the wetland communities in the area of study. The vegetation classification and ordination complement each other. From the ordination it is clear that on axes one the *Cynodon dactylon* Community (Community 1) and the *Cynodon hirsutus* Community (Community 9) differ significantly from the *Berula erecta – Eleocharis limosa* Community (Community 4) and the *Marsilea burchellii – Isolepis cernua* Community (Community 5). The significant difference between these communities is indicated by the relative high Eigen value of the first axes. Communities 1 and 9 occur in areas that are very dry and only become inundated during high rainfall years. In contrast to these communities 4 and 5 occur in water saturated conditions and are also dominated by hydrophytic vegetation. The *Leptochloa fusca* Community (Community 2), *Limosella* longiflora – *Cynodon dactylon* Community (Community 6), *Juncus rigidus* Community (Community 7) and *Eragrostis lehmanniana* Community (Community 8) occur in wetlands which are seasonally inundated.

By observing the impact of livestock and game farming it is clear that on axis two the *Cynodon dactylon* Community (Community 1) and the *Cynodon hirsutus* Community (Community 9) are moderately to severely grazed. In contrast to this the *Suaeda merxmuelleri – Salsola glabrescens* Community (Community 3) is in a good condition and not degraded because these species are not browsed by animals.

The difference between these communities is confirmed by the relative high Eigen value on axis two.

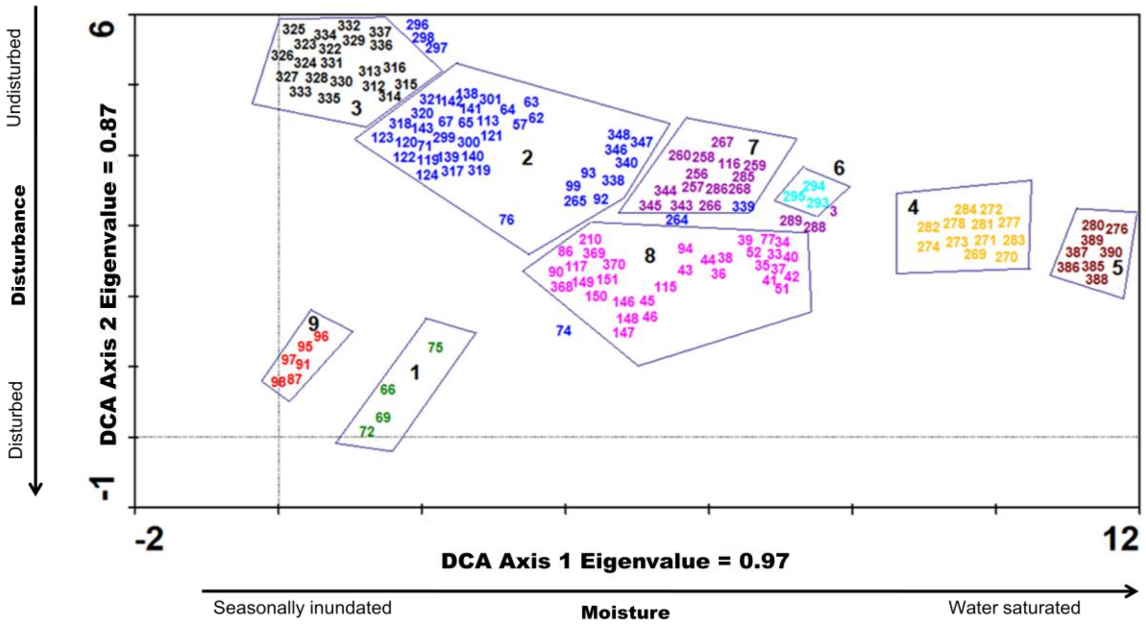

Figure 8.24: Ordination diagram of the wetland communities in the study area. Community 1 – *Cynodon transvaalensis – Cyperus difformis* Community (green); Community 2 – *Leptochloa fusca*Community (blue); Community 3 – *Suaeda merxmuelleri – Salsola glabrescens* Community(black); Community 4 – *Berula erecta – Eleocharis limosa* Community (yellow); Community 5 – *Marsilea burchellii – Isolepis cernua* Community (brown); Community 6 – *Limosella longiflora – Cynodon dactylon* Community (light blue); Community 7 – *Juncus rigidus* Community (purple); Community 8 – *Eragrostis lehmanniana* Community (pienk); Community 9 – *Cynodon hirsutus* Community (red).

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CHAPTER 9

THE KARROID AND GRASSLAND COMMUNITIES OF THE STUDY AREA

9.1 OVERVIEW

A DCA ordination was performed on all thedata from the relevés in the area of study. This ordination indicates three different groups of vegetation types visible. The blue dots represent the water related communities found in the study area. The brown dots represent the woody vegetation and the green dots represent the karroid and grassland vegetation. The green and brown dots represent the terrestrial communities which occur away from the water-related habitats. This ordination indicates that the classification of the vegetation into three main vegetation units is relatively effective. In this chapter the karroid and grassland communities will be described.

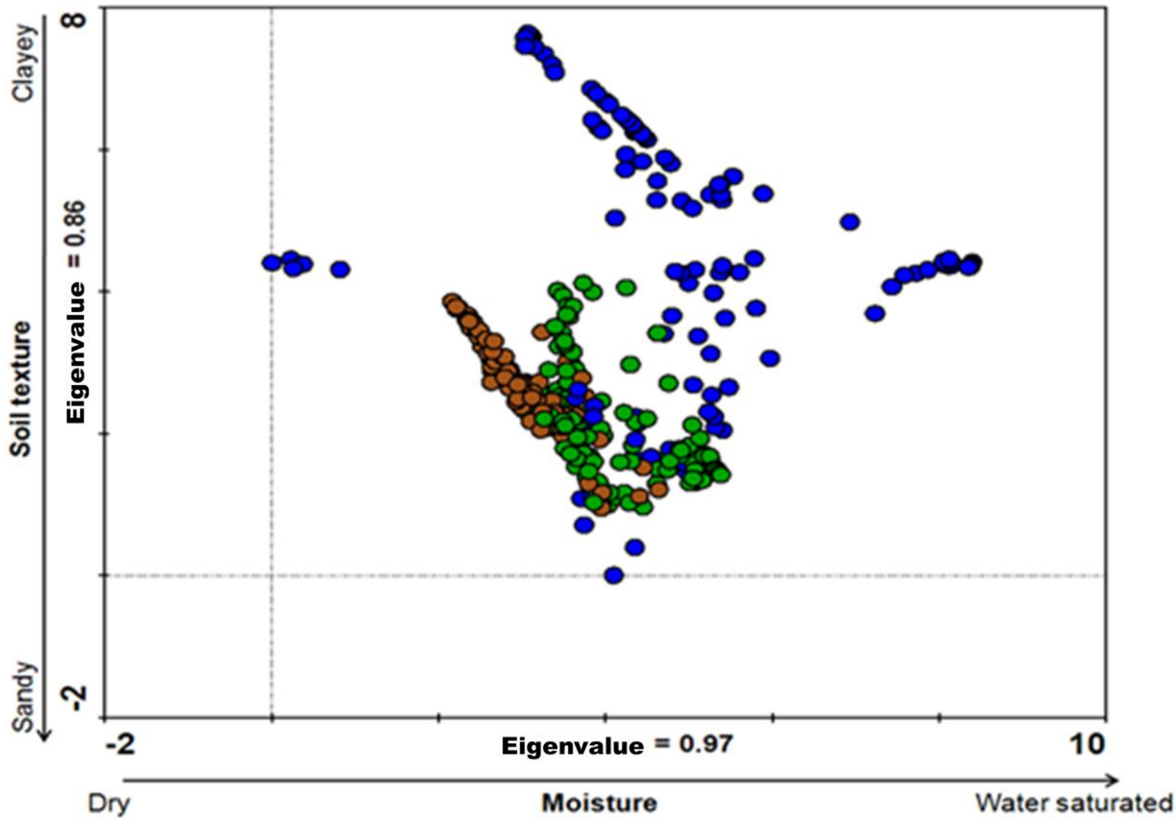

Figure 9.1: Ordination diagram of all the relevés present in the area of study. The blue relevés are the water related relevés, the green relevés are the karroid and grassland relevés and the brown relevés are the woody relevés.

9.2 CLASSIFICATION

Table 9.1 represents the phytosociological classification of the karroid and grassland communities in the catchments of the palaeo-Kimberley and palaeo-Modder Rivers in the western Free State. The karroid and grassland vegetation can be divided into ten communities, fourteen sub-communities and nine variants.

1. *Themeda triandra – Berkheya pinnatifida* Community
    - 1.1 *Themeda triandra – Berkheya pinnatifida – Digitaria eriantha* Sub-community
        - 1.1.1 *Aristida diffusa* Variant
        - 1.1.2 *Eragrostis curvula* Variant
    - 1.2 *Themeda triandra – Berkheya pinnatifida – Rosenia humilis* Sub-community
    - 1.3 *Themeda triandra – Berkheya pinnatifida – Eragrostis superba*Sub-community
        - 1.3.1 *Nenax microphylla* Variant
        - 1.3.2 *Digitaria argyrograpta* Variant
2. *Enneapogon desvauxii – Zygophyllum microcarpum* Community
3. *Stachys spathulata– Pentzia globosa*Community
    - 3.1 *Stachys spathulata– Pentzia globosa – Eragrostis chloromelas* – Sub-Community
    - 3.2 *Stachys spathulata – Pentzia globosa – Eragrostis lehmanniana* Sub-community
4. *Rosenia humilis – Tragus koelerioides* Community
5. *Sporobolus fimbriatus – Pentzia globosa* Community
    - 5.1 *Sporobolus fimbriatus – Pentzia globosa – Eragrostis gummiflua* Sub-community
    - 5.2 *Sporobolus fimbriatus – Pentzia globosa – Amaranthus thunbergii* Sub-community
6. *Ennaepogon desvauxii – Aristida canescens* Community
7. *Eragrostis biflora – Eragrostis lehmanniana* Community
8. *Heteropogon contortus – Selago densiflora* Community
9. *Chloris virgata – Aristida congesta* Community
    - 9.1 *Chloris virgata – Aristida congesta – Pentzia globosa* Sub-community
        - 9.1.1 **Schkuhria pinnata* Variant

9.1.2 *Tragus berteronianus* Variant

9.2 *Chloris virgata – Aristida congesta– Brachiaria eruciformis* Sub-community

9.2.1 *Eragrostis obtusa* Variant

9.2.2 *Lycium cinereum* Variant

9.2.3 *Ennaepogon desvauxii* Variant

10. *Cynodon dactylon*Community

10.1 *Cynodon dactylon – Eragrostis superba* Sub-community

10.2 *Cynodon dactylon – Frankenia pulverulenta* Sub-community

10.3 *Cynodon dactylon – Brachiaria eruciformis* Sub-community

10.4 *Cynodon dactylon – Panicum coloratum* Sub-community

10.5 *Cynodon dactylon – Tragus berteronianus* Sub-community

9.3 DESCRIPTION OF THE KARROID AND GRASSLAND COMMUNITIES

1. *Themeda triandra – Berkheya pinnatifida* Community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Pinedine, Avalon, Hutton, Bloemdal, Sepane, Glenco, Garries, Etosha and Mispha
Soil depth:	Between 0.5 m and >1.5 m
Hydrology:	Well drained
Exposure:	Full sun
Disturbance:	None

Species

Number of species in the community: 43

Number of relevés in the community:25

Diagnostic species:	No diagnostic species
Constant species:	***Themeda triandra 88***
Dominant species:	*Digitaria eriantha 4, Eragrostis chloromelas 4, Eragrostis curvula 4, Eragrostis lehmanniana 4, *Schkuhria pinnata 4, Sporobolus fimbriatus 20, Themeda triandra 48*

Discussion: This community is defined by the presence of species from species group A (*Themeda triandra, Berkheya pinnatifida* and *Hyparrhenia hirta*). The grass *Themeda triandra* that dominates this community is known to occur in undisturbed areas with an average to high rainfall with a mean elevation of between 1 300 and 3 000 m a.m.s.l. *T. triandra* occurs in any soil type, but are mostly present in clay soils. This is true for the area of study as the community were present in different soil types, mostly with soils having high clay content. This grass is an indicator of veld in a good condition (Van Oudtshoorn, 2004).

Similar to the *Themeda triandra – Aristida congesta* Community found by Botha (2003) this community is also dominated by grasses although the species composition differ. Furthermore, the soils of this community also vary in depth from shallow to deep.

However, the strongpresence of the grass *Themeda triandra*and the dominance of other grass speciescan be misleading. Upon closer investigation different karroidspecies were found among the grasses. This was also the case in the study by Botha (2003). The karroid species usually have lower cover-abundance values.

This community can be divided into three sub-communities, namely:

1.1 *Themeda triandra – Berkheya pinnatifida – Digitaria eriantha*Sub-community
1.2 *Themeda triandra – Berkheya pinnatifida – Rosenia humilis* Sub-community
1.3 *Themeda triandra – Berkheya pinnatifida – Eragrostis superba*Sub-community

1.1 Themeda triandra – Berkheya pinnatifida – Digitaria eriantha Sub-community

Habitat

Geology: Beaufort and Ecca Groups

Soil form/forms: Pinedine, Avalon, Bloemdal and Hutton

Soil depth: >1.5 m

Hydrology: Well drained

Exposure: Full sun

Disturbance: None

Species

Number of species in the sub-community: 33

Number of relevés in the sub-community:9

Diagnostic species: No diagnostic species

Constant species: ***Digitaria eriantha 89,*** *Hyparrhenia hirta 67, *Schkuhria pinnata 67, Selago densiflora 67,* ***Sporobolus fimbriatus 89,*** *Themeda triandra 67*

Dominant species: *Digitaria eriantha 11, Eragrostis curvula 11, Eragrostis lehmanniana 11, *Schkuhria pinnata 11, Sporobolus fimbriatus 56*

Discussion: The presence of the grass *Digitaria eriantha* (Species group B) and *Sporobolus fimbriatus* (Species group Q) discerns this sub-community from the other sub-communities. *Digitaria eriantha* occurs in moist areas with high rainfall in sandy and rocky soils. The grass *Sporobolus fimbriatus* is a grass that occurs in well-drained soils and mostly occurs in the shade of trees (Van Oudtshoorn, 2004). However, in the area of study this sub-community did not occur in shady areas. This sub-community is present in open grasslands on clayey soils which are poorly drained.

This sub-community can be divided into two variants, namely:

1.1.1 *Aristida diffusa* Variant

1.1.2 *Eragrostis curvula* Variant

1.1.1 *Aristida diffusa* Variant

Habitat

Geology: Beaufort and Ecca Groups

Soil form/forms: Pinedine

Soil depth: ± 0.52m

Hydrology: Well drained

Exposure: Full sun

Disturbance: None

Species

Number of species in the variant: 22

Number of relevés in the variant:3

Diagnostic species: *Elionurus muticus 78.9,* ***Ipomoea bathycolpos 81.1, Pentzia incana 100.0, Amphiglossa triflora*** **(*Pterothrix* spinescens) 81*.1***

Constant species: *Aptosium procumbens 67,* ***Aristida diffusa 100, Berkheya pinnatifida 100, Digitaria eriantha 100, Elionurus muticus 100,*** *Eragrostis lehmanniana 67, Helichrysum dregeanum 67,* ***Heteropogon contortus 100,*** *Hyparrhenia hirta 67, Ipomoea bathycolpos 67,* ***Pentzia incana 100,*** *Amphiglossa triflora* (*Pterothrix spinescens*) *67,* ***Selago densiflora 100,*** *Sporobolus fimbriatus 67, Stachys spathulata 67,* ***Themeda triandra 100***

Dominant species: No dominant species

Discussion: Species from species group C (*Aristida diffusa, Elionurus muticus, Pentzia incana, Setaria verticillata, Amphiglossa triflora* and *Ipomoea bathycolpos*) dominate this variant and is also the species that distinguishes this variant from the other variants in this sub-community. This variant occurs on the edge or on the upper slope of pans before the grassland communities' start. This variant is dominated by dwarf shrubs (<0.5 m high) and graminoids. Although it might seem from Figure 9.2 that the grasses are dominant; the karroid shrubs are more prominent amongst the grasses.

The karroid shrub *Pentzia incana* (Species group C) is a very palatable plant depending on the area in which the species is occurring. Due to the palatability of this species it is also economic important as fodder for sheep (Le Roux *et al.*, 1994). Although this plant can be fodder for sheep. Müller (2002) noted that *Pentzia incana* can be an indication of grassland being invaded by dwarf karroid shrubs. The presence of the grass *Elionurus muticus* (Species group C) is seen as an indication of overgrazing and selective grazing in the past (Van Oudtshoorn, 2004).

Figure 9.2: *Aristida diffusa* Variant.

1.1.2 *Eragrostis curvula* Variant

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Hutton, Avalon and Bloemdal
Soil depth:	0.50 m to >1.5 m
Hydrology:	Well drained
Exposure:	Full sun
Disturbance:	Occasional grazing by livestock

Species

Number of species in the variant: 21

Number of relevés in the variant: 6

Diagnostic species:	No diagnostic species
Constant species:	***Digitaria eriantha 83, Eragrostis curvula 83,*** *Hyparrhenia hirta 67, Monsonia angustifolia 67, Oxalis *corniculata 67,* ****Schkuhria pinnata 100, Sporobolus fimbriatus 100***
Dominant species:	*Digitaria eriantha 17, Eragrostis curvula 17, Eragrostis lehmanniana 17, *Schkuhria pinnata 17,* ***Sporobolus fimbriatus 83***

Discussion: Species group D (*Schkuhria pinnata, Eragrosits curvula* and *Oxalis *corniculata*) characterise this variant. This variant (Figure 9.3) occur on the plains of the study area. The soil in these variants was moist and clayey. These variants might occasionally be used for grazing by livestock as *Sporobolus fimbriatus* (Species group Q) and *Eragrostis curvula* (Species group D) are palatable grasses (Van Oudtshoorn, 2004). Due to the palatability of the grasses in this variant, this variant will make good pastures for livestock farmers. This can in return cause disturbance in the area.

Figure 9.3: *Eragrostis curvula*Variant.

1.2 *Themeda triandra – Berkheya pinnatifida – Rosenia humilis* Sub-community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Sepane
Soil depth:	>0.30 m to >1.5 m
Hydrology:	Well drained
Exposure:	Full sun
Disturbance:	Occasional grazing by livestock

Species

<u>Number of species in the sub-community:</u> 17

<u>Number of relevés in the sub-community:</u> 5

Diagnostic species: No diagnostic species

Constant species: *Aristida congesta 80, Brachiaria eruciformis 80, Lycium horridum 80, Pentzia globosa 80,* ***Rosenia humilis 100, Themeda triandra 100***

Dominant species: ***Themeda triandra 80***

Discussion: Species form species group E (*Lycium horridum*and *Salsola aphylla*)distinguish this sub-community form the other sub-communities. This sub-community (Figure 9.4) is characterised by the strong presence of the shrubs *Rosenia humilis* (Species group K), *Salsola aphylla*, *Lycium horridum* (Species group E) and the grass *Brachiaria eruciformis* (Species group V), which are totally absent from sub-communities 1.1 and 1.3.

This sub-community occurs on the plains and pan edges of the study area. Although this sub-community seems to be completely dominated by a monospecific stand of *Themeda triandra,* upon closer investigation the other species are present. *Rosenia humilis* is widely distributed in southern Africa. This plant is drought resistant and provides good food for animals (Shearing, 1994).

Figure 9.4: *Themeda triandra – Berkheya pinnatifida – Rosenia humilis* Sub-community.

1.3 *Themeda triandra – Berkheya pinnatifida – Eragrostis superba* Sub-community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Sepane
Soil depth:	>0.55 m to >1.5 m
Hydrology:	Well drained
Exposure:	Full sun
Disturbance:	Occasional grazing by livestock

Species

Number of species in the sub-community: 44

Number of relevés in the sub-community: 32

Diagnostic species: No diagnostic species

Constant species: *Berkheya pinnatifida 73,* ***Eragrostis superba 82, Themeda triandra 100***

Dominant species: *Eragrostis chloromelas 9,* ***Themeda triandra 73***

Discussion: This sub-community occurs on the plains and hills of the study area. The soil varies from very deep (>1.5 m) to very shallow (<0.55 m). This sub-community is characterised by the strong presence of the graminoid *Eragrostis superba* (Species group P).

Eragrostis superba (Species group P) is known to occur on disturbed areas and in barren patches in the veld. This grass also occurs on almost all soil types, but does not prefer clay (Van Oudtshoorn, 2004). Van Oudtshoorn (2004) mentioned that this grass does not commonly occur in natural veld, while in the area of study this grass did occur in natural veld.

This sub-community can be divided into two variants, namely:

1.3.1*Nenax microphylla* Variant

1.3.2*Digitaria argyrograpta* Variant

1.3.1 *Nenax microphylla* Variant

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Etocha, Sepane, Mispah and Glenco
Soil depth:	Between 0.10 m and 1.5 m
Hydrology:	Well drained
Exposure:	Full sun
Disturbance:	Occasional grazing by livestock

Species

Number of species in the variant: 23

Number of relevés in the variant: 5

Diagnostic species: ***Nenax microphylla 86.0***

Constant species: ***Nenax microphylla 100, Themeda triandra 100***

Dominant species: ***Themeda triandra 80***

Discussion: The presence of species from species group F (*Nenax microphylla*)distinguishes this variant (Figure 9.5) from the other two variants in this sub-community. Characteristic is the presence of the dwarf shrub, *Nenax microphylla,* which is absent from the other variants in this community.

Nenax microphylla grows almost anywhere, however rocky soils and hills are preferred habitats (Le Roux *et al.*, 1994). In the area of study this species occurred on the plains among well-established stands of *Themeda triandra*. *N. microphylla* is known to be adapted to occur in dry environments and has the ability to withstand drought (Le Roux *et al.*, 1994). Thus, *Nenax microphylla* fit well into the area of study, due to the low rainfall.

Figure 9.5: *Nenax microphylla* Variant.

1.3.2 *Digitaria argyrograpta* Variant

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Pindine, Garies, Mispah, Valsrivier and Bloemdal
Soil depth:	±0.49 m to 1.1 m
Hydrology:	Poorly drained
Exposure:	Full sun
Disturbance:	Occasional grazing by livestock

Species

Number of species in the variant: 24

Number of relevés in the variant: 6

Diagnostic species:	No diagnostic species
Constant species:	*Aristida congesta 67,* ***Berkheya pinnatifida 83,*** *Digitaria argyrograpta 67, Digitaria eriantha 67,* ***Eragrostis superba 100,*** *Helichrysum dregeanum 67, Hyparrhenia hirta 67,* ***Themeda triandra 100***
Dominant species:	*Eragrostis chloromelas 17,* ***Themeda triandra 67***

Discussion: This variant (Figure 9.6) is distinguished by the presence of the grass *Digitaria argyrograpta* and the dwarf shrub *Helichrysum dregeanum* (Species group G). The absence of species from species group F is also visible on table 9.1.

The grass *Digitaria argyrograpta* mostly occurs in grasslands and open areas of the bushveld. *D. argyrograpta* mostly occurs on rocky soils or soils with lots of clay (Van Oudtshoorn, 2004). In the area of study this variant occurred on clayey soils with no rocks which are poorly drained. This variant also occurred in areas sloping towards wetlands

Figure 9.6: *Digitaria argyrograpta* Variant.

2. *Enneapogon desvauxii – Zygophyllum microcarpum* Community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Knersvlakte
Soil depth:	<0.30m
Hydrology:	Well drained
Exposure:	Full sun
Disturbance:	Occasional grazing by livestock

Species

<u>Number of species in the community:</u> 18

<u>Number of relevés in the community:</u> 6

Diagnostic species: ***Stachys hyssopoides 89.3, Zygophyllum microcarpum 100.0***

Constant species: **Alternanthera pungens 67,* ***Asparagus suaveolens 83, Cynodon dactylon 100, Enneapogon desvauxii 100, Eragrostis lehmanniana 83, Eragrostis obtusa 100, Hertia pallens 83,*** *Lycium pilifolium 67,* ***Pentzia globosa 100, Salsola glabrescens 83, Stachys hyssopoides 100, Zygophyllum microcarpum 100***

Dominant species: *Cynodon dactylon 33, Enneapogon desvauxii 33, Hertia pallens 17,* ***Pentzia globosa 100***

Discussion: This community (Figure 9.7) occurs on gentle slopes of the plains. At the surface of this community there are some calcrete rocks present (Figure 9.7). Furthermore, the soil in this sub-community is also very shallow. Species group H (*Enneapogon desvauxii, Zygophyllum microcarpum, Stachys hyssopoides, Asparagus suaveolens, Hertia pallens, Lycium pilifolium, *Alternanthera pungens* and *Salsola glabrescens*) have all the species that characterise and distinguish this community from all the other communities. This community is mostly a shrubby community, dominated by shrubs of about 1 m tall.

The shrub, *Zygophyllum microcarpum* (Species group H), is a karroid shrub that occurs in low areas and brackish veld. These shrubs grow to a height of about 1 m and are present in the southern and western parts of the Free State Province (Le Roux *et al.*, 1994). Another succulent shrub that occurs in this community is *Hertia pallens* (Species group H). This shrub indicates overgrazing if present in natural veld (Le Roux *et al.*, 1994).

Figure 9.7: *Enneapogon desvauxii – Zygophyllum microcarpum* Community.

3. *Stachys spathulata – Pentzia globosa* Community

Habitat

Geology:	Ecca Group
Soil form/forms:	Prieska, Knersvlakte and Bloemdal
Soil depth:	± 1.03 m
Hydrology:	Well drained
Exposure:	Full sun
Disturbance:	None

Species

Number of species in the community: 29

Number of relevés in the community:7

Diagnostic species:	***Stachys spathulata 84.3***
Constant species:	***Aristida congesta 86,*** *Cynodon dactylon 71,* ***Eragrostis obtusa 100, Pentzia globosa 100, Stachys spathulata 100***
Dominant species:	*Aptosium procumbens 29, Pentzia globosa 57, Sporobolus ioclados 43*

Discussion: This community is characterised by the presence of the species *Stachys spathulata* (Species group I). *Stachys spathulata* is a widespread species and occurs in the Free State, KwaZulu-Natal, Limpopo, Northern Cape and North West (Le Roux *et al.*, 1994). *Pentzia globosa* (Species group W) also occurs with high cover abundance in this community; however this dwarf shrub is common all over the area of study. Kooji *et al.* (1990) mentioned that the dwarf shrub *Pentzia globosa* can indicate poor conditions in the grassland. This species together with species such as *Aristida congesta, Cynodon dactylon, Stachys spatulata* and *Eragrostis obtusa,* which occur in this community, indicate overgrazing or selective grazing by livestock. This community occur in sandy, rocky soils with a good drainage.

This community can be divided into two sub-communities, namely:

3.1 *Stachys spathulata– Pentzia globosa – Eragrostis chloromelas* Sub-Community

3.2 *Stachys spathulata – Pentzia globosa – Eragrostis lehmanniana* Sub-community

3.1 *Stachys spathulata– Pentzia globosa – Eragrostis chloromelas* – Sub-Community

Habitat

Geology:	Ecca Group
Soil form/forms:	Prieska
Soil depth:	± 1.03 m
Hydrology:	Well drained
Exposure:	Full sun
Disturbance:	None

Species

Number of species in the sub-community: 16

Number of relevés in the sub-community:3

Diagnostic species: *Aristida diffusa 78.2, Eragrostis chloromelas 76.4,* ***Finicia nodosa 94.6***

Constant species: ***Aptosium procumbens 100, Aristida canescens 100, Aristida congesta 100, Aristida diffusa 100, Cynodon dactylon 100, Eragrostis chloromelas 100, Eragrostis obtusa 100, Finicia nodosa 100, Hyparrhenia hirta 100, Panicum coloratum 100, Pentzia globosa 100,*** *Rosenia humilis 67,* ***Sporobolus ioclados 100, Stachys spathulata 100,*** *Themeda triandra 67*

Dominant species: ***Aptosium procumbens 67, Pentzia globosa 100, Sporobolus ioclados 100***

Discussion: This sub-community (Figure 9.8) occurs on the edge or slope of pans before the grassland communities' start. Furthermore, this sub-community is mostly dominated by grasses although there are also some small shrubs present. This sub-community is defined by the presence of species from species group J (*Sporobolus ioclados, Eragrostis chloromelas* and *Finicia nodosa*). Other species such as *Aristida canescens* (Species group N) and *Aptosium procumbens* (Species group P) also occur with high cover abundance values in this sub-community.

Sporobolus ioclados (Species group J) is a grass that occurs on ephemeral pans and disturbed areas of natural veld. This grass mostly occurs on brackish soils. The grass *Eragrostis chloromelas* (Species group J) which is one of the diagnostic species in this community is known for being present on rocky slopes in sandy or loamy soil (Van Oudtshoorn, 2004). In this study the grasses were found on a clayey soil (>55%). *Aristida canascens* (Species group N) which is also a diagnostic species in this sub-community is known to occur on disturbed and eroded areas. Furthermore, Van Oudtshoorn (2004) also noted that this grass occurs in poor, shallow rocky soils which are usually hard and barren. In this sub-community the soils were not that shallow, but can become hard during the dry winter months as the clay can lose water and also form cracks.

Figure 9.8: *Stachys spathulata* – *Pentzia globosa* – *Eragrostis chloromelas* – Sub-Community.

3.2 *Stachys spathulata* – *Pentzia globosa* – *Eragrostis lehmanniana* Sub-community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Knersvlakte and Bloemdal
Soil depth:	±0.40 m to >1.5 m
Hydrology:	Well drained
Exposure:	Full sun
Disturbance:	Occasional grazing by livestock

Species

Number of species in the sub-community: 19

Number of relevés in the sub-community: 4

Diagnostic species:	No diagnostic species
Constant species:	***Aristida congesta 83,*** *Eragrostis lehmanniana 67,* ***Eragrostis obtusa 100, Pentzia globosa 100, Stachys spathulata 100,*** *Thesium hystrix 67*
Dominant species:	*Pentzia globosa 17*

Discussion: This sub-community (Figure 9.9) occurs on shallow to very deep soils, on hill slopes and plains close to pans. The herb, *Stachys spathulata* (Species group I) that defines the community also has very high cover abundance in this sub-community compared to 3.1. *Eragrostis lehmanniana* (Species group X) only occurs in this sub-community and is absent from 3.1. Van Oudtshoorn (2004) noted that *E. lehmanniana* is an indication of disturbance.

Figure 9.9: *Stachys spathulata – Pentzia globosa – Eragrostis lehmanniana* Sub-community.

4. *Rosenia humilis – Tragus koelerioides* Community

Habitat

Geology: Beaufort and Ecca Groups

Soil form/forms: Prieska, Kimberley, Mispah and Knersvlakte

Soil depth: Between 0.30 and 0.88 m

Hydrology: Well drained

Exposure: Full sun

Disturbance: Occasional grazing by livestock

Species

Number of species in the community: 32

Number of relevés in the community: 9

Diagnostic species: *Rosenia humilis 76.9,* ***Tragus koelerioides 83.2***

Constant species: *Cynodon dactylon 67, Eragrostis lehmanniana 78,* ***Eragrostis obtusa 100, Pentzia globosa 100, Rosenia humilis 100,*** *Themeda triandra 78, Thesium hystrix 67,* *Tragus koelerioides 78*

Dominant species: *Eragrostis lehmanniana 22, Pentzia globosa 33, Themeda triandra 22*

Discussion: This community occurs on shallow soils on the plains of the study area. The species from species group K (*Rosenia humilis, Tragus koelerioides* and *Thesium hystrix*) characterise this community. Although this community is mostly dominated by grasses a few dwarf shrubs are also present in the form of *Rosenia humilis* (Species group K) and *Pentzia globosa* (Species group W). The grass, *Themeda triandra* (Species group A) also shows a strong presence in this community.

Rosenia humilis (Species group K) is widely distributed in the dry areas of southern Africa with the exception of Namaqualand. This plant is also drought resistant and provides food for livestock and game during times when other plants are already grazed (Shearing, 1994). Although Figure 9.10 only indicates grasses, *Rosenia humilis* are present among these grasses.

The presence of both *Rosenia humilis* and *Tragus koelerioides* indicate the invasion by karroid vegetation (Acocks, 1988). Botha (2003) in her study mentioned that *Tragus koeleroides* occurs in disturbed areas such as roads and around troughs used for the feeding of animals.

Figure 9.10: *Rosenia humilis – Tragus koelerioides* Community.

5. *Sporobolus fimbriatus – Pentzia globosa* Community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Clovely and Knersvlakte
Soil depth:	±0.40 m to 1.5 m
Hydrology:	Well drained
Exposure:	Full sun
Disturbance:	Occasionally grazed by livestock

Species

Number of species in the community: 11

Number of relevés in the community: 8

Diagnostic species: No diagnostic species

Constant species: *Amaranthus thunbergii 62, Berkheya pinnatifida 62, Cynodon dactylon 62,* ***Eragrostis lehmanniana 100, Pentzia globosa 100, Sporobolus fimbriatus 100***

Dominant species: *Cynodon dactylon 38, Sporobolus fimbriatus 38*

Discussion: The presence of the grass *Sporobolus fimbriatus* (Species group Q) discerns this community. This grass is known as a palatable grass with a high production of palatable parts for grazing animals (Van Oudtshoorn, 2004). This community occur in a relatively dry area. Müller (2002) mentioned that the presence of species such as

Pentzia globosa, Berkheya pinnatifida and *Amaranthus thunbergii* is indicative of the karoo invasion in the grassland. This community occur in sandy, rocky soils on the plains of the study area.

This community can be divided into two sub-communities, namely:

5.1 *Sporobolus fimbriatus – Pentzia globosa – Eragrostis gummiflua* Sub-community

5.2 *Sporobolus fimbriatus – Pentzia globosa – Amaranthus thunbergii* Sub-community

5.1 *Sporobolus fimbriatus – Pentzia globosa – Eragrostis gummiflua* Sub-community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Clovely
Soil depth:	>1.5 m
Hydrology:	Well drained
Exposure:	Full sun
Disturbance:	Occasionally grazed by livestock

Species

Number of species in the sub-community: 9

Number of relevés in the sub-community: 3

Diagnostic species: ***Eragrostis gummiflua 82.9***

Constant species: ***Aristida congesta 100, Eragrostis gummiflua 100, Eragrostis lehmanniana 100, Eragrostis superba 100, Heteropogon contortus 100, Pentzia globosa 100, Sporobolus fimbriatus 100, Themeda triandra 100***

Dominant species: ***Sporobolus fimbriatus 100***

Discussion: The presence of species such as *Eragrostis gummiflua* (Species group L), *Heteropogon contortus* and *Eragrostis superba* (Species group P) and *Aristida congesta* (Species group X) distinguish this sub-community from 5.2.

The *Eragrostis gummiflua* (Species group L) sub-community (Figure 9.11) occurs on the plains of the study area in deep soils. *Eragrostis gummiflua* is known to occur in open grassland and bushveld where disturbance has occurred in the past. Furthermore, this grass can also occur in moist areas and prefer sandy or rocky soils (Van Oudtshoorn, 2004). In the study area this sub-community is limited to sandy, rocky soils.

Figure 9.11: *Sporobolus fimbriatus – Pentzia globosa – Eragrostis gummiflua* Sub-community.

5.2 *Sporobolus fimbriatus – Pentzia globosa – Amaranthus thunbergii* Sub-community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Knersvlakte
Soil depth:	>1.5 m
Hydrology:	Well drained
Exposure:	Full sun
Disturbance:	Occasional grazing by livestock

Species

Number of species in the sub-community: 6

Number of relevés in the sub-community: 5

Diagnostic species: ***Amaranthus thunbergii 85.8***

Constant species: ***Amaranthus thunbergii 100,*** *Berkheya pinnatifida 80,*

Cynodon dactylon 100, Eragrostis lehmanniana 100, Pentzia globosa 100, Sporobolus fimbriatus 100

Dominant species: *Cynodon dactylon 60*

Discussion: This sub-community (Figure 9.12) occurs on top of lunette dunes in the study area. The soil in this sub-community is deep, with sandy topsoil's. Although *Amaranthus thunbergii* (Species group M) characterise this sub-community, *Cynodon dactylon* (Species group Y) also has high cover abundance in this sub-community.

The grass *Cynodon dactylon* (Species group Y) occurs on all soil types, but is mostly present on disturbed, moist areas (Van Oudtshoorn, 2004). This is not the case in the study area. Here the grass occurred on sandy, rocky soils.

Figure 9.12: *Sporobolus fimbriatus – Pentzia globosa – Amaranthus thunbergii* Sub-community.

6. *Enneapogon desvauxii – Aristida canescens* Community

Habitat

Geology: Beaufort and Ecca Groups

Soil form/forms: Mispah

Soil depth: <0.15 m

Hydrology: Well drained

Exposure: Full sun

Disturbance: None

Species

Number of species in the community: 19

Number of relevés in the community: 6

Diagnostic species: *Amaranthus *caudatus 77.9,* ***Eragrostis nindensis 90.5,*** *Hypertelis salsoloides 76.9,* ***Lotononis burchellii 90.5, Oropetium capense 87.3***

Constant species: ***Amaranthus *caudatus 83, Aristida canescens 83, Aristida congesta 83, Berkheya pinnatifida 83, Brachiaria eruciformis 100, Enneapogon desvauxii 100, Eragrostis lehmanniana 100, Eragrostis nindensis 83, Eragrostis obtusa 100, Hertia pallens 83,*** *Hypertelis salsoloides 67,* ***Lotononis burchellii 83, Oropetium capense 100, Pentzia globosa 100, Thesium hystrix 83***

Dominant species: *Aristida canescens 50,* ***Eragrostis lehmanniana 83,*** *Eragrostis obtusa 17, Hertia pallens 33, Pentzia globosa 17*

Discussion: This community is dominated by species from species group N (*Aristida canescens, Oropetium capense, Eragrostis nindensis, Lotononis burchellii, Amaranthus *caudatus, Sesamum triphyllum* and *Hypertelis salsoloides*). However species such as *Enneapogon desvauxii* and *Hertia pallens* (Species group H), *Thesium hystrix* (Species group K) and *Brachiaria eruciformis* (Species group V) also have high cover abundance values in this community. The strong presence of *Aristida canescens* and the visibility thereof (Figure 9.13) were used to define this community.

The soil in this sub-community is very shallow as indicated in the habitat description; this might be the reason for the occurrence of species that indicate disturbance or overgrazing.

Enneapogon desvauxii (Species group H) is a grass that favours shallow calcareous soils, however are also present in other soil types. This grass is abundant in overgrazed veld. *Oropetium capense* (Species group N) is a pioneer grass that occurs in shallow soils that are not well drained. The grass *Aristida canescens* (Species group N) occurs in poor, shallow, rocky soils or barren patches of soil. This is a grass that commonly occurs on disturbed and eroded areas (Van Oudtshoorn, 2004). The information gathered from the habitat descriptions of the grasses present in this community confirms the shallow soil and the disturbance in this community.

In a study done by Botha (2003) the species *Oropetium capense* and *Eragrostis nindensis* found in this community were found in the *Oropetium capense – Eragrostis nindensis* sub-community. Although the species from this sub-community differs from the species present in this community, the sub-community were also present on shallow soils. In the study by Botha (2003) the sub-community occurred in depressions on the plateau of dolerite hills. In contrast to this, the community in this study occurs on the plains of the western parts of the Free State.

Figure 9.13: *Enneapogon desvauxii – Aristida canescens* Community.

7. *Eragrostis biflora – Eragrostis lehmanniana* Community

Habitat

Geology:	Beaufort and Ecca groups
Soil form/forms:	Hutton
Soil depth:	>1.5 m
Hydrology:	Well drained
Exposure:	Full sun to semi-shade
Disturbance:	Occasional grazing by livestock

Species

Number of species in the community: 8

Number of relevés in the community: 4

Diagnostic species: ***Eragrostis biflora 92.8***

Constant species: ***Aristida congesta 100, Eragrostis biflora 100, Eragrostis lehmanniana 100,*** *Pentzia globosa 75*

Dominant species: *Aristida congesta 25, Eragrostis lehmanniana 50*

Discussion: This community is distinguished from the other communities by the presence of the grass *Eragrostis biflora* (Species group O). This community occur on deep, sandy soils with good drainage.

8. *Heteropogon contortus – Selago densiflora* Community

Habitat

Geology:	Dolerite outcrops
Soil form/forms:	Hutton
Soil depth:	±0.63 m
Hydrology:	Well drained
Exposure:	Full sun
Disturbance:	Grazing by livestock

Species

Number of species in the community: 14

Number of relevés in the community: 4

Diagnostic species: *Aptosium procumbens 76.4,* ***Chrysocoma ciliata 84.3, Pseudognaphalium oligandrum 100.0, Selago***

densiflora 81.5

Constant species: ***Aptosium procumbens 100, Aristida congesta 100,*** *Berkheya pinnatifida 75,* ***Chrysocoma ciliata 100, Eragrostis lehmanniana 100, Eragrostis superba 100, Heteropogon contortus 100, Hyparrhenia hirta 100, Panicum coloratum 100, Pentzia globosa 100, Pseudognaphalium oligandrum 100, Selago densiflora 100, Themeda triandra***

Dominant species: *Aristida congesta 25, Themeda triandra 25*

Discussion: This community (Figure 9.14) is defined by the presence of species from species group P (*Heteropogon contortus, Selago densiflora, Eragrostis superba, Aptosium procumbens, Pseudognaphalium oligandrum, Chrysocoma ciliata* and *Monsonia angustifolia*). This community occurs on sandy soils of medium depth on the dolerite outcrops in the study area. This community have an absence of trees that might provide shade. Species from species group A are also prominent in this community. The grass *Panicum coloratum* (Species group X) also occurs with a high abundance in this community.

Heteropogoncontortus (Species group P) is a sub-climax grass that co-occurs with *Themeda triandra* (Species group A); a climax grass (Van Oudtshoorn, 2004). The occurrence of these two species might be an indication that this is a climax community in the area of study.

Figure 9.14: *Heteropogon contortus – Selago densiflora* Community.

9. *Chloris virgata – Aristida congesta* Community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Hutton, Sepane and Longlands
Soil depth:	±0.59 m to >1.5 m
Hydrology:	Well drained
Exposure:	Full sun
Disturbance:	Occasional grazing by game and livestock

Species

Number of species in the community: 31

Number of relevés in the community: 32

Diagnostic species: No diagnostic species

Constant species: ***Aristida congesta* 84,** *Brachiaria eruciformis 62,* ***Chloris virgata* 84,** *Tragus berteronianus 78*

Dominant species: *Aristida bipartita 3, Aristida congesta 31, Brachiaria eruciformis 16, Chloris virgata 9, Eragrostis obtusa 3, Hertia pallens 3, Lycium cinerium 12, Tragus berteronianus 6*

Discussion: This community mostly occurs on the plains of the study area and is dominated by the grasses (*Aristida congesta* (Species group X), *Chloris virgata* (Species group R) and *Tragus berteronianus* (Species group T)) which are all indicators of disturbance in some way. These grasses are also present on barren patches in the veld and are therefore seen as pioneers (Van Oudtshoorn, 2004). In the study done by Müller (2002) she also mentioned that the occurrence of *Tragus berteronianus* is an indication of overgrazing and trampling; thus disturbance.

This community can be divided into two sub-communities, namely:

9.1 *Chloris virgata – Aristida congesta – Pentzia globosa* Sub-community

9.2 *Chloris virgata – Aristida congesta– Brachiaria eruciformis* Sub-community

9.1 *Chloris virgata – Aristida congesta – Pentzia globosa* Sub-community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Hutton
Soil depth:	±0.59 m to >1.5 m
Hydrology:	Well drained
Exposure:	Full sun
Disturbance:	Occasional grazing by game and livestock

Species

Number of species in the sub-community: 22

Number of relevés in the sub-community: 12

Diagnostic species: No diagnostic species

Constant species: ***Aristida congesta* 100, *Chloris virgata* 100**

Dominant species: ***Aristida congesta* 75,** *Chloris virgata 17*

Discussion: This sub-community is distinguished by the strong presence of the grass *Aristida congesta*(Species group X) with high cover abundance values. The absence of *Brachiaria eruciformis* (Species group V) from this sub-community is also important.

This sub-community can be divided into two variants, namely:

9.1.1 **Schkuhria pinnata* Variant

9.1.2 *Tragus berteronianus* Variant

9.1.1 **Schkuhria pinnata* Variant

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Hutton
Soil depth:	>1.5 m
Hydrology:	Well drained
Exposure:	Full sun
Disturbance:	Occasional grazing by livestock and game

Species

<u>Number of species in the variant:</u> 13

<u>Number of relevés in the variant:</u> 6

Diagnostic species: *Salvia verbenaca 79.9*

Constant species: **Alternanthera pungens 67,* ***Aristida congesta 100, Chloris virgata 100, Salvia verbenaca 100, *Schkuhria pinnata 100***

Dominant species: ***Aristida congesta 67***

Discussion: This variant (Figure 9.15) occurs on deep Hutton soils with a sandy-loamy texture, which is well drained. The species that characterise this variant are **Schkuhria pinnata* (Species group D), **Alternanthera pungens* (Species group H) and *Salvia verbenaca* (Species group S).

Salvia verbenaca (Species group S) is widespread in South Africa and is common in the Eastern Cape, Free State, Northern Cape, North West and Western Cape (SANBI, 2014b). **Alternanthera pungens* (Species group H) is widely distributed in southern Africa (Bromilow, 2010).

Figure 9.15: *Salvia verbenaca*Variant.

9.1.2 *Tragus berteronianus* Variant

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Augrabies
Soil depth:	±0.59 m
Hydrology:	Poorly drained
Exposure:	Full sun
Disturbance:	Occasional grazing by livestock and game

Species

Number of species in the variant: 13

Number of relevés in the variant: 6

Diagnostic species:	***Eriocephalus spinescens 81.1***
Constant species:	***Aristida congesta 100, Chloris virgata 100,*** *Eragrostis obtusa 67, Eriocephalus spinescens 67, Lycium pilifolium 67,* ***Tragus berteronianus 100***
Dominant species:	***Aristida congesta 83,*** *Chloris virgata 33*

Discussion: This variant (Figure 9.16) occurs on shallow soil with higher clay content which might be the reason for hard soil surfaces during drought conditions. This sub-community occur on the plains of the study area, among *Vachellia tortillis* [*Acacia tortillis*] trees, in the patches of veld not covered with trees. As previously mentioned the dominant grasses (*Aristida congesta* (Species group X) and *Chloris virgata* (Species group R)) indicate disturbance.

Tragus berteronianus (Species group T) which distinguish this variant from 9.1.1. This grass can also occur on compacted soils. Although this grass has no grazing potential, it is a grass that is very resistant and can occur on hard, barren soils where other grasses are absent. This grass protects the soil and enhances growing conditions for other perennial grasses (Van Oudtshoorn, 2004).

Figure 9.16: *Tragus berteronianus* Variant.

9.2 *Chloris virgata – Aristida congesta– Brachiaria eruciformis* Sub-community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Sepane and Longlands
Soil depth:	>1.5 m
Hydrology:	Poorly drained
Exposure:	Full sun
Disturbance:	Occasional grazing by livestock

Species

Number of species in the sub-community: 18

Number of relevés in the sub-community: 20

Diagnostic species: No diagnostic species

Constant species: *Aristida congesta 75,* ***Brachiaria eruciformis 90,*** *Chloris virgata 75, Lycium cinerium 70,* ***Tragus berteronianus 95***

Dominant species: *Aristida bipartita 5, Aristida congesta 5, Brachiaria eruciformis 25, Chloris virgata 5, Eragrostis obtusa 5, Hertia pallens 5, Lycium cinerium 20, Tragus berteronianus 10*

Discussion: This sub-community is discerned by the presence of the grass *Brachiaria eruciformis*(Species group V). This grass occurs on soils with higher clay content and in moist, disturbed areas (Van

Oudtshoorn, 2004). This sub-community occur on deep soils of the plains of the study area.

This sub-community can be divided into three variants, namely:

9.2.1 *Eragrostis obtusa* Variant
9.2.2 *Lycium cinereum* Variant
9.2.3 *Enneapogon desvauxii* Variant

9.2.1 *Eragrostis obtusa* Variant

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Sepane
Soil depth:	>1.5 m
Hydrology:	Poorly drained
Exposure:	Full sun
Disturbance:	Occasional grazing by livestock

Species

Number of species in the variant: 13

Number of relevés in the variant: 6

Diagnostic species: No diagnostic species

Constant species: *Aristida congesta 67,* ***Brachiaria eruciformis 100, Eragrostis obtusa 100, Tragus berteronianus 100***

Dominant species: *Aristida bipartita 17, Brachiaria eruciformis 17, Eragrostis obtusa 17, Hertia pallens 17, Tragus berteronianus 33*

Discussion: This variant occurs on deep soils on the plains of the study area, among *Vachellia tortillis* [*Acacia tortillis*] trees. The trees however, do not form part of this variant. This variant is discerned by the presence of the grass *Eragrostis obtusa* (Species group X) which is not that dominant in the other variants. The grasses in this variant are indicators of disturbed areas. The grass *Aristida bipartita* (Species group X) occurs in moist areas such as wetland areas as well as in disturbed or overgrazed areas. This grass mostly occurs on clay soils. If dominant in the field, this grass indicates overgrazing (Van Oudtshoorn, 2004). In the area of study this grass occurs in dry areas where there is no water present, even during seasonal rainfall events.

9.2.2 *Lycium cinereum* Variant

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Longlands
Soil depth:	>1.5 m
Hydrology:	Poorly drained
Exposure:	Full sun
Disturbance:	Grazing by livestock

Species

Number of species in the variant: 12

Number of relevés in the variant: 5

Diagnostic species: No diagnostic species

Constant species: *Brachiaria eruciformis 80*, ***Lycium cinereum 100, Tragus berteronianus 100***

Dominant species: *Brachiaria eruciformis 40, Chloris virgata 20, Lycium cinereum 20*

Discussion: This variant contains some of the species present in the pans found in previous communities. The soil in this sub-community is blocky and form deep cracks in the dry state. The vegetation cover is low, although several species are present in this sub-community. The dwarf shrub *Lycium cinereum* (Species group X) defines this variant. Kok (1999) mentioned that *Lycium cinereum* is widely distributed in South Africa, Namibia, Lesotho and Botswana. This plant is common in the "bossieveld" of the southern Free State. In this study area this variant occurs on the plains in areas that might be seasonally inundated if the rainfall is sufficient.

9.2.3 *Enneapogon desvauxii* Variant

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Longlands
Soil depth:	>1.5 m
Hydrology:	Poorly drained
Exposure:	Full sun
Disturbance:	Grazing by livestock

Species

Number of species in the variant: 12

Number of relevés in the variant: 9

Diagnostic species: No diagnostic species

Constant species: ***Aristida congesta 89, Brachiaria eruciformis 89, Chloris virgata 100,*** *Cyperus rupestris 67,* ***Enneapogon desvauxii 100, Lycium cinerium 100, Tragus berteronianus 89***

Dominant species: *Aristida congesta 11, Brachiaria eruciformis 22, Lycium cinereum 33*

Discussion: This variant (Figure 9.17) is characterised by the presence of the grass *Enneapogon desvauxii* (Species group H) which is absent from all the other variants in this sub-community. *E. desvauxii* is known to occur in shallow calcareous soils, but also in other habitat and soil types. This grass is common in overgrazed veld and can be dominant where severe overgrazing occurred (Van Oudtshoorn, 2004). This variant has various barren patches among the vegetation and occurs on deep, loamy-clay soils.

Figure 9.17: *Enneapogon desvauxii* Variant.

10. *Cynodon dactylon* Community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Augrabies, Clovely, Hutton, Garies, Pindineand Kinkelbos
Soil depth:	±0.85 m to >1.5 m
Hydrology:	Poorly drained
Exposure:	Full sun
Disturbance:	Grazing by livestock

Species

Number of species in the community: 37

Number of relevés in the community: 40

Diagnostic species: No diagnostic species

Constant species: ***Cynodon dactylon 92***

Dominant species: *Aristida congesta 2,* ***Cynodon dactylon 78,*** *Eragrostis lehmanniana 2, Hypertelis salsoloides 2*

Discussion: This community is dominated by the grass *Cynodon dactylon* (Species group Y). This grass occurs on all soil types, but is mostly present on disturbed, moist areas. The rhizomes make this grass very suitable as a soil stabilizer. *C. dactylon* also provides some grazing potential in the natural veld during winter (Van Oudtshoorn, 2004). In the study area this community is not always present in moist areas; however, the areas might be wet during seasons of extreme high rainfall.

This community can be divided into five sub-communities, namely:

10.1 *Cynodon dactylon – Eragrostis superba* Sub-community
10.2 *Cynodon dactylon – Frankenia pulverulenta* Sub-community
10.3 *Cynodon dactylon – Brachiaria eruciformis* Sub-community
10.4 *Cynodon dactylon – Panicum coloratum* Sub-community
10.5 *Cynodon dactylon – Tragus berteronianus* Sub-community

10.1 *Cynodon dactylon – Eragrostis superba* Sub-community

Habitat

Geology: Beaufort and Ecca Groups
Soil form/forms: Hutton, Clovely, Garies, Pindene and Augrabies
Soil depth: Between 1 m and 1.5 m
Hydrology: Well drained
Exposure: Full sun
Disturbance: Occasional grazing by livestock

Species

Number of species in the sub-community: 27
Number of relevés in the sub-community: 13

Diagnostic species: No diagnostic species

Constant species: *Aristida congesta 77, Cynodon dactylon 77, Eragrostis lehmanniana 69, Eragrostis superba 62,* ***Pentzia globosa 100***

Dominant species: *Aristida congesta 8,* ***Cynodon dactylon 69,*** *Eragrostis lehmanniana 8*

Discussion: This sub-community (Figure 9.18) mostly occurs on shallow soils in the area of study. Patches occur within grassland communities as much shorter vegetation units, mostly dominated by the grass *Cynocon dactylon* (Species group Y). Several other species (27) are present in this sub-community, mostly with low cover-abundance values.

The grass *Eragrostis superba* (Species group P), which distinguishes this sub-community from the other sub-communities in this community, are mostly present on disturbed areas or barren patches in any soil type. This species is palatable in the early growth stages and become unpalatable when older. *E. superba* is not common in natural veld and is known to be a sub-climax grass – colonizing barren patches (Van Oudtshoorn, 2004). This might be the reason that the vegetation in the area of study shows these barren patches.

Figure 9.18: *Cynodon dactylon – Eragrostis superba* Sub-community.

10.2 *Cynodon dactylon – Frankenia pulverulenta* Sub-community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Katspruit
Soil depth:	>1.5 m
Hydrology:	Poorly drained
Exposure:	Full sun
Disturbance:	Grazed by livestock

Species

Number of species in the sub-community: 2

Number of relevés in the sub-community: 4

Diagnostic species: ***Frankenia pulverulenta 85.3***

Constant species: ***Cynodon dactylon 100, Frankenia pulverulenta 100***

Dominant species: No dominant species

Discussion: Two species are present in this sub-community namely: *Cynodon dactylon* (Species group Y) and *Frankenia pulverulenta* (Species group X). *Frankenia pulverulenta* distinguishes this sub-community from all the other sub-communities in this community. This sub-community occurs on the edges of some pans in deep, clayey soils as indicated in figure 9.19.

Although this community has wetland soil types, this area is only flooded in areas with above average rainfall. Thus this sub-community dominated by *Frankenia pulverulenta* is seen as a grassland/karroid sub-community.

Figure 9.19: *Cynodon dactylon – Frankenia pulverulenta*Sub-community indicated between the yellow lines.

10.3 *Cynodon dactylon – Brachiaria eruciformis* Sub-community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Katspruit
Soil depth:	>1.5 m
Hydrology:	Poorly drained
Exposure:	Full sun
Disturbance:	Occasional grazing by livestock

Species

Number of species in the sub-community: 2

Number of relevés in the sub-community: 4

Diagnostic species: No diagnostic species

Constant species: ***Brachiaria eruciformis 100, Cynodon dactylon 100***

Dominant species: ***Cynodon dactylon 100***

Discussion: The grass *Brachiaria eruciformis* (Species group V) defines this sub-community and distinguishes it from all the other sub-communities. This sub-community occurs on the edges of pans in a deep soil.

Brachiaria eruciformis mostly occurs on clayey soils on moist, disturbed areas or areas that have been trampled (Russell *et al*., 1990; Van Oudtshoorn, 2004). This grass is seen as a useful pioneer on clay soils and is an indicator of poor drainage (Van Oudtshoorn, 2004). In the study area this grass is present on clay soils which form cracks when dry.

10.4 *Cynodon dactylon – Panicum coloratum* Sub-community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Kinkelbos
Soil depth:	<0.5 m to >1.5 m
Hydrology:	Well drained
Exposure:	Full sun
Disturbance:	Occasional grazing by livestock

Species

Number of species in the sub-community: 9

Number of relevés in the sub-community: 6

Diagnostic species:	No diagnostic species
Constant species:	*Chloris virgata 67,* ***Cynodon dactylon 100,*** *Eragrostis lehmanniana 67,* ***Panicum coloratum 100,*** *Sporobolus ioclados 67*
Dominant species:	***Cynodon dactylon 100***

Discussion: This sub-community occurs on deep, loamy-clay soils. The grass *Panicum coloratum* (Species group X) characterises this sub-community. This grass is absent from all the other sub-communities of this community or occurs with low cover-abundance values.

Panicum coloratum is mostly present in clayey, fertile soils but can also occur on other soil types (such as in the area of study). Furthermore, this grass has the ability to survive in both saturated and very dry conditions (Van Oudtshoorn, 2004).

This sub-community is similar to the *Panicum coloratum – Eragrostis lehmanniana* sub-community identified by Müller (2002). This sub-community is also in a degraded state and therefore, dominated by the pioneer grass *Cynodon dactylon* (Van Oudtshoorn, 2004).

10.5 *Cynodon dactylon – Tragus berteronianus* Sub-community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Pinedene and Augrabies
Soil depth:	Between 1m and 1.5 m
Hydrology:	Well drained
Exposure:	Full sun
Disturbance:	Occasional grazing by livestock

Species

<u>Number of species in the sub-community:</u> 15

<u>Number of relevés in the sub-community:</u> 8

Diagnostic species: No diagnostic species

Constant species: *Aristida congesta 75,* ***Cynodon dactylon 100, Tragus berteronianus 100***

Dominant species: ***Cynodon dactylon 88,*** *Hypertelis salsoloides 12*

Discussion: This sub-community (Figure 9.20) occurs on deep, dry soils. The vegetation in this variant has low cover-abundance with a lot of barren soil present. The grass *Tragus berteronianus* (Species group T) defines this sub-community. Müller (2002) noted that the presence of *Tragus berteronianus* indicates overgrazing and trampling however, this is not the case in this study.

Tragus berteronianus is a common grass in the Savanna, Grassland, Nama-Karoo and Desert Biomes (Russell *et al*., 1990). The grass is mostly present on disturbed areas occurring on hard, barren soil. The soil is mostly sandy or loamy (Russell *et al*., 1990; Van Oudtshoorn, 2004). This is also true for the study area, where this sub-community occur with barren patches in between on loamy soils.

Figure 9.20: *Cynodon dactylon – Tragus berteronianus* Sub-community.

9.4 DCA ORDINATION OF THE KARROID AND GRASSLAND COMMUNITIES

The DCA ordination (a package in CANOCO (Ter Braak and Smilauer, 2002)) performed on the data of the karroid and grass-related communities in the area of study reveal that the phytosociological classification and ordination complement each other. From the ordination (Figure 9.21) it is clear that on axis one the high Eigen values indicate a remarkable difference between communities 5, 10 and community 9. This difference is due to the difference in drainage of these communities. The *Sporobolus fimbriatus – Pentzia globosa* Community (Community 5, grey) and the *Cynodon dactylon* Community (Community 10, Purple) occur on poorly drained soils – mostly in pans or on the edges of pans. In contrast to this the *Chloris virgata – Aristida congesta* Community (Community 9, red) occur on well-drained soil on the plains of the study area. The communities in between occur on soils that show some extent of drainage.

When looking at axis two: the high Eigen value also suggests a significant discontinuity between the *Themeda triandra – Berkheya pinnatifida* Community (Community 1, green) and the *Enneapogon desvauxii – Zygophyllum microcarpum* Community (Community 2, brown), *Ennaepogon desvauxii – Aristida canescens* Community (Community 6, orange) and the *Eragrostis biflora – Eragrostis lehmanniana* Community (Community 7, dark blue). Communities 2, 6 and 7 did not form clear cluster which might be ascribed to the small size of these communities. These communities occur in rocky sandy soils in contrast to Community 1 which occur in clayey soils where no rocks are present. The other communities in the ordination diagram occur in soils with different textures and different sizes of rocks.

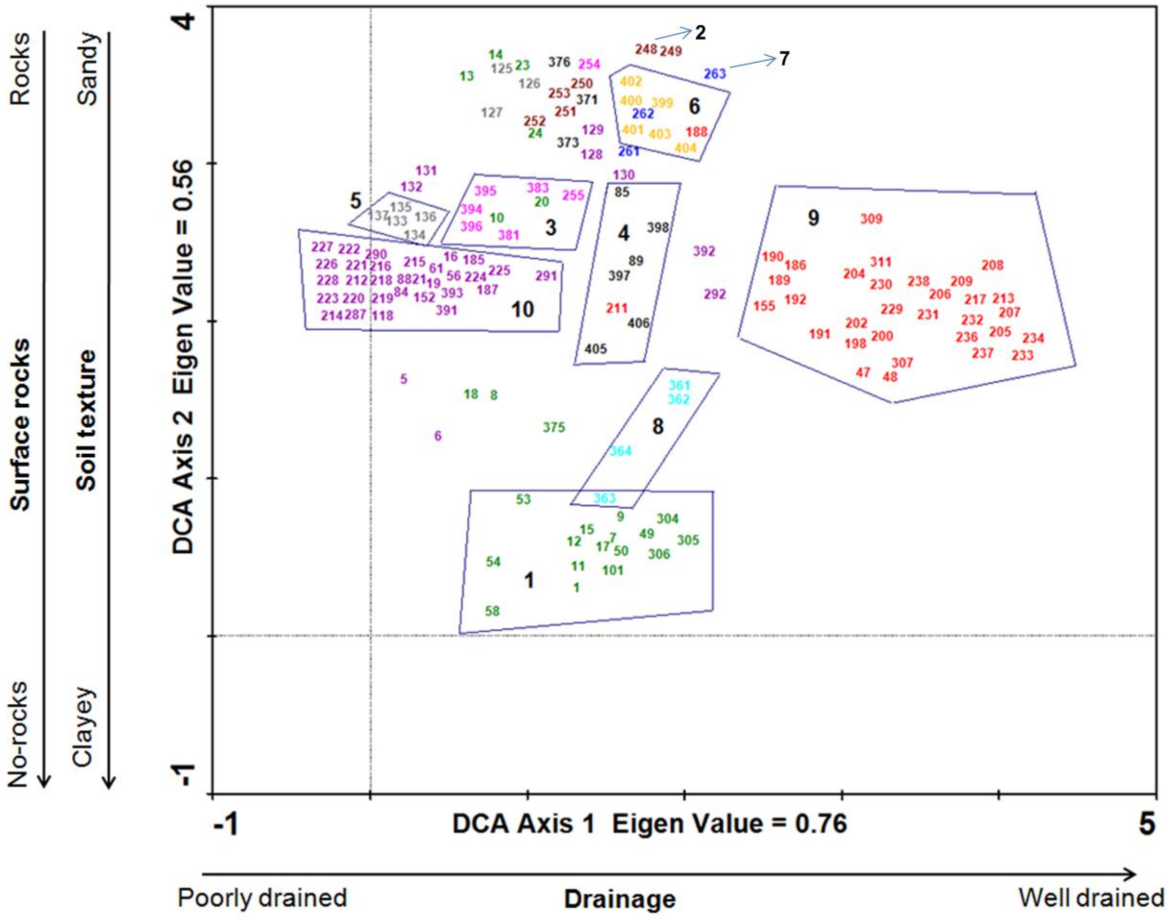

Figure 9.21: Ordination diagram of the karroid and grassland communities in the study area. Community 1 – *Themeda triandra – Berkheya pinnatifida* Community (green); Community 2 – *Enneapogon desvauxii – Zygophyllum microcarpum* Community (brown); Community 3 – *Stachys spathulata – Pentzia globosa* Community (pienk); Community 4 – *Rosenia humilis – Tragus koelerioides* Community (black); Community 5 – *Sporobolus fimbriatus – Pentzia globosa* Community (grey); Community 6 – *Ennaepogon desvauxii – Aristida canescens* Community (yellow); Community 7 – *Eragrostis biflora – Eragrostis lehmanniana* Community (dark blue); Community 8 – *Heteropogon contortus – Selago densiflora* Community (light blue); Community 9 – *Chloris virgata – Aristida congesta* Community (red); Community 10 – *Cynodon dactylon* Community (purple).

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CHAPTER 10

THE WOODY COMMUNITIES OF THE STUDY AREA

10.1 OVERVIEW

The DCA ordination (Figure 10.1), of the data collected in the study area indicates three different groups of vegetation types. This is to distinguish between various major communities present in the study area. The water-related communities found in the area of study are indicated by blue dots. The woody vegetation is represented by the brown dots and the grassland and karroid vegetation is represented by the green dots.

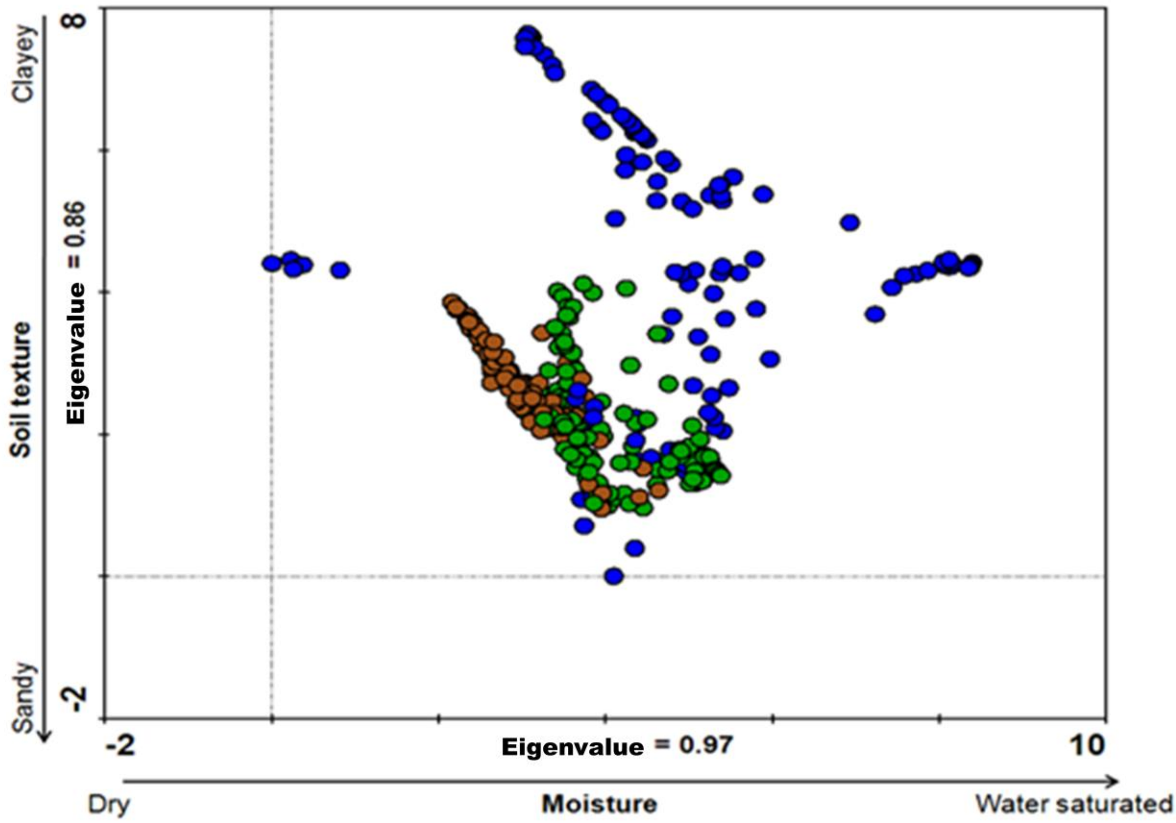

Figure 10.1: Ordination diagram of all the relevés present in the area of study. The blue relevés are the water-related relevés, the green relevés are the karroid and grassland relevés and the brown relevés are the woody relevés.

On the ordination diagram there is a separation between the terrestrial communities (woody, grassland and karroid communities) and the wetland and aquatic communities. This ordination indicates that the classification of the vegetation into three major vegetation units was relatively successful.The woody communities will be discussed in this chapter.

10.2 CLASSIFICATION

Table 10.1 is a phytosociological table of the woody communities in the palaeo-Kimberley and palaeo-Modder River catchments of the western Free State. The woody vegetation can be divided into five communities, eleven sub-communities and nine variants.

1. *Vachellia hebeclada – Ehretia rigida* Community
   - 1.1 *Vachellia hebeclada – Ehretia rigida – Melolobium candicans* Sub-community
   - 1.2 *Vachellia hebeclada – Ehretia rigida – Triraphis andropogonoides* Sub-community
2. *Searsia cilliata – Digitaria eriantha* Community
   - 2.1 *Searsia cilliata – Digitaria eriantha – Eragrostis superba* Sub-community
   - 2.2 *Searsia cilliata – Digitaria eriantha – Olea europaea* subsp. *africana* Sub-community
     - 2.2.1 *Heteropogon contortus* Variant
     - 2.2.2 *Aristida canescens* Variant
     - 2.2.3 *Hermannia cuneifolia* Variant
   - 2.3 *Searsia cilliata – Digitaria eriantha – Enneapogon scoparius* Sub-community
     - 2.3.1 *Tarchonanthus camphoratus* Variant
     - 2.3.2 *Cenchrus ciliaris* Variant
   - 2.4 *Searsia cilliata – Digitaria eriantha – Euclea crispa* subsp. *ovata* Sub-community
3. *Ziziphus mucronata – Asparagus africanus* Community
   - 3.1 *Ziziphus mucronata – Asparagus africanus – Digitaria argyrograpta* Sub-community
   - 3.2 *Ziziphus mucronata – Asparagus africanus – Chenopodium *murale*[3] Sub-community
     - 3.2.1 *Cynodon dactylon* Variant
     - 3.2.2 *Vachellia erioloba* Variant
4. *Vachellia tortilis – Pentzia globosa* Community
   - 4.1 *Vachellia tortilis – Pentzia globosa – Chloris virgata* Sub-community
   - 4.2 *Vachellia tortilis – Pentzia globosa – Cynodon dactylon* Sub-community

[3] * indicate alien invasive species

4.3 *Vachellia tortilis – Pentzia globosa – Chrysocoma ciliata* Sub-community

4.3.1 *Helichrysum dregeanum* Variant

4.3.2 *Eragrostis trichophora* Variant

5. *Searsia lancea – Sporobolus fimbriatus* Community

10.3 DESCRIPTION OF THE WOODY COMMUNITIES

1. *Vachellia hebeclada – Ehretia rigida* Community

Habitat

Geology:	Dolerite outcrops
Soil form/forms:	Mispah
Soil depth:	>0.32 m
Hydrology:	Well-drained
Exposure:	Full sun
Disturbance:	Occasional grazing by game and livestock

Species

Average number of species in the community: 17

Number of relevés in the community: 6

Diagnostic species: ***Vachellia hebeclada 91.7, Dicoma schinzii 100.0, Searsia burchellii 82.8***

Constant species: ***Vachellia hebeclada 100, Dicoma schinzii 100, Ehretia rigida 100, Eragrostis lehmanniana 100, Eragrostis superba 100,*** *Gymnosporia karooica 67,* ***Searsia burchellii 100, Themeda triandra 100***

Dominant species: *Olea europaea* subsp. *africana 17, Stipagrostis uniplumis 33*

Discussion: *Vachellia hebeclada*, *Ehretia rigida* and *Dicoma schinzii* (Species group A) are the species characterising this community.

In the research done by Viljoen (1979) *Vachellia hebeclada*was mostly found as a shrub present in communities dominated by the Camel Thorn tree (*Vachellia erioloba)*. In this study *Vachellia hebeclada* is present as dominant shrub among a few trees and grasses on loamy-sandy soils with a low clay content (15% clay).

This community is present on dolerite outcrops in the western parts of the study area.

This community can be divided into two sub-communities, namely:

1.1 *Vachellia hebeclada – Ehretia rigida – Melolobium candicans* Sub-community
1.2 *Vachellia hebeclada – Ehretia rigida – Triraphis andropogonoides* Sub-community

1.1 *Vachellia hebeclada – Ehretia rigida – Melolobium candicans* Sub-community

Habitat

Geology:	Beaufort and Ecca Groups as well as Dolerite outcrops
Soil form/forms:	Mispah
Soil depth:	<0.32 m
Hydrology:	Well-drained
Exposure:	Full sun
Disturbance:	Occasional grazing by livestock

Species

Number of species in the sub-community: 17

Number of relevés in the sub-community:3

Diagnostic species:	*Vachellia erioloba 77.5,* ***Melolobium candicans 84.6, Rhynchosia totta 92.9***
Constant species:	***Vachellia erioloba 100, Vachellia hebeclada 100, Asparagus africanus 100, Asparagus suaveolens 100, Dicoma schinzii 100, Ehretia rigida 100, Eragrostis lehmanniana 100, Eragrostis superba 100,*** *Gymnosporia karooica 67,* ***Melolobium candicans 100, ****Opuntia ficus-indica 67,* ***Rhynchosia totta 100, Searsia burchellii 100, Searsia ciliata 100,*** *Sporobolus fimbriatus 67,* ***Themeda triandra 100, Ziziphus mucronata 100***
Dominant species:	No dominant species

Discussion: This sub-community (Figure 10.2) occurs in open grassland on dolerite outcrops among rocks and boulders. The vegetation in this sub-community is characterised by species of species group B (*Melolobium candicans, Vachellia erioloba, *Opuntia ficus-indica* and *Rhynchosia totta*). This sub-community is distinguished by the absence of species from species group C. *Searsia ciliata* (Species group D), *Ziziphus mucronata* and *Asparagus africanus* (Species group P) only occurs in this sub-community and is absent from 1.2. The soils in this sub-community are relatively shallow with a sandy-loam texture.

Figure 10.2: *Vachellia hebeclada – Ehretia rigida – Melolobium candicans* Sub-community.

1.2 *Vachellia hebeclada – Ehretia rigida – Triraphis andropogonoides* Sub-community

Habitat

Geology:	Dolerite Outcrops
Soil form/forms:	Mispah
Soil depth:	>0.32 m
Hydrology:	Well-drained
Exposure:	Full sun to semi-shade
Disturbance:	Occasional grazing by livestock and game

Species

Number of species in the sub-community: 17

Number of relevés in the sub-community:3

Diagnostic species: ***Aloe grandidentata 97.1, Aristida diffusa 84.9, Triraphis andropogonoides 88.3***

Constant species: ***Vachellia hebeclada 100, Aloe grandidentata 100, Aristida congesta 100, Aristida diffusa 100, Dicoma schinzii 100, Ehretia rigida 100, Eragrostis lehmanniana 100, Eragrostis superba 100,*** *Gymnosporia karooica 67,* ***Olea europaea* subsp. *africana 100, *Schkuhria pinnata 100, Searsia burchellii 100, Stipagrostis uniplumis 100, Tarchonanthus camphoratus 100, Themeda triandra 100, Triraphis andropogonoides 100***

Dominant species: *Olea europaea* subsp. *africana 33,* ***Stipagrostis uniplumis 67***

Discussion: This sub-community occurs on dolerite outcrops with shallow soils. On these outcrops there are areas where the vegetation grows among boulders and in cracks and crevices. Species form species group C (*Triraphis andropogonoides, Aristida diffusa* and *Aloe grandidentata*)define this sub-community. Other species that are present in this sub-community and absent from 1.1 are: *Stipagrostis uniplumis* (Species group S), *Tarchonanthus camphoratus* (Species group U), **Schkuhria pinnata* and *Aristida congesta* (Species group AB).

Aloe grandidentata (Figure 10.3) which is a diagnostic species in this sub-community grows on the shoulders of the plateau areas in cracks in the dolerite (Botha, 2003). This coincides with the findings of this study where the plants present in this sub-community grow among boulders on the shoulder areas of the dolerite outcrops in the study area.

Figure 10.3: *Aloe grandidentata* present in the *Vachellia hebeclada – Ehretia rigida – Triraphis andropogonoides* Sub-community.

2. *Searsia cilliata – Digitaria eriantha* Community

Habitat

Geology:	Beaufort and Ecca Groups as well as Dolerite outcrops
Soil form/forms:	Mispah and Garies
Soil depth:	<0.50 m
Hydrology:	Well drained soil
Exposure:	Full sun to semi-shade
Disturbance:	Occasional grazing by livestock

Species

Average number of species in the community: 29

Number of relevés in the community:41

Diagnostic species:	No diagnostic species
Constant species:	*Aristida congesta 64, Digitaria eriantha 69, Searsia ciliata 62, Sporobolus fimbriatus 67*
Dominant species:	*Vachellia karroo 2, Aristida canescens 10, Aristida congesta 2, Buddleja saligna 21, Digitaria eriantha 10, Melolobium candicans 2, Olea europaea* subsp. *africana 14, Searsia ciliata 26, Sporobolus fimbriatus 2, Tarchonanthus camphoratus 2*

Discussion: This community occurs on shallow, sandy soils in the area of study. The vegetation is characterised by the presence of species from species group D (*Searsia ciliata, Digitaria eriantha, Buddleja saligna* and *Eustachys paspaloides*). *Searsia ciliata* (Species group D)is a multi-stemmed shrub occurring on the plains in the Free State.

This community with the sub-communities and variants is similar to the *Rhus cilliata – Olea europapea* Community described by Müller (2002). However, there are some differences in the species composition. The community in this study also occurs on slopes of dolerite hills and ridges. In contrast to the relatively deep soils found by Müller (2002) the soils found in this study are relatively shallow, although also a gravelly and well-drained type of the Mispah soil form. Rocks and boulders – forming part of the dolerite sills are also present at the surface. The soil depth in this community is determined by the state of weathering of the dolerite sheets.

This community can be divided into four sub-communities, namely:

2.1 *Searsia ciliata – Digitaria eriantha – Eragrostis superba* Sub-community
2.2 *Searsia cilliata – Digitaria eriantha – Olea europaea* subsp. *africana* Sub-community.
2.3 *Searsia cilliata – Digitaria eriantha – Enneapogon scoparius* Sub-community.
2.4 *Searsia cilliata – Digitaria eriantha – Aristida bipartita* Sub-community.

2.1 *Searsia ciliata – Digitaria eriantha – Eragrostis superba* Sub-community

Habitat

Geology: Beaufort and Ecca Groups
Soil form/forms: Mispah and Garies
Soil depth: 0.22 to 0.55 m
Hydrology: Well-drained
Exposure: Full sun to semi-shade
Disturbance: Occasional grazing by livestock

Species

Average number of species in the variant: 32

Number of relevés in the variant:5

Diagnostic species: No diagnostic species

Constant species: *Vachellia karroo 80, Bidens *pilosa 80, Eragrostis superba 80, Monsonia angustifolia 80, Ruschia hamata 80, Searsia ciliata 80, Selago densiflora 80, Sporobolus fimbriatus 80, Themeda triandra 80*

Dominant species: *Buddleja saligna 20, Searsia ciliata 40*

Discussion: The grass *Eragrostis superba* (Species group E) defines this sub-community. This sub-community (Figure 10.4) is distinguished by the absence of species of species group F, K and N which dominate the other sub-communities in this community. *Ruschia hamata* (Species group Q) *Monsonia angustifolia* (Species group AB) are the characteristic species of this sub-community. This sub-community occurs on the foot slopes of the dolerite outcrops in the area of study on medium depth (0.5 m to 1 m), sandy soils.

Figure 10.4: *Searsia ciliata – Digitaria eriantha – Eragrostis superba* Sub-community.

2.2 *Searsia cilliata – Digitaria eriantha – Olea europaea* subsp. *africana* Sub-community

Habitat

Geology:	Beaufort and Ecca Groups as well as Dolerite outcrops
Soil form/forms:	Mispah and Garies
Soil depth:	0.22 to 0.55 m
Hydrology:	Well-drained
Exposure:	Full sun to semi-shade
Disturbance:	Occasional grazing by livestock

Species

Average number of species in the sub-community: 32

Number of relevés in the sub-community:18

Diagnostic species: No diagnostic species

Constant species: *Aristida congesta 61, Hyparrhenia hirta 67, Olea europaea* subsp. *africana 67, Searsia ciliata 67, Sporobolus fimbriatus 67, Themeda triandra 61*

Dominant species: *Vachellia karroo 6, Aristida canescens 22, Aristida congesta 6, Buddleja saligna 17, Melolobium candicans 6, Olea europaea* subsp*. africana 33, Searsia ciliata 17*

Discussion: This sub-community is distinguished by the presence of species of species group F: *Olea europaea* subsp. *africana, Searsia burchellii* and *Asparagus suaveolens.*

This sub-community can be divided into three variants, namely:

2.2.1 *Heteropogon contortus* Variant

2.2.2 *Aristida canescens* Variant

2.2.3 *Hermannia cuneifolia* Variant

2.2.1 *Heteropogon contortus* Variant

Habitat

Geology:	Dolerite outcrop
Soil form/forms:	Mispah
Soil depth:	<0.42 m

<u>Hydrology:</u> Well drained

<u>Exposure:</u> Full sun to semi-shade

<u>Disturbance:</u> Occasional grazing by livestock

Species

<u>Number of species in the variant:</u> 37

<u>Number of relevés in the variant:</u>4

Diagnostic species: No diagnostic species

Constant species: *Vachellia karroo 75, Eragrostis lehmanniana 75, Felicia muricata 75, Hyparrhenia hirta 75,* ***Olea europaea*** **subsp.** ***africana 100, Searsia ciliata 100, Sporobolus fimbriatus 100,*** *Themeda triandra 75*

Dominant species: *Vachellia karroo 25, Aristida congesta 25, Melolobium candicans 25, Olea europaea* subsp. *africana 25, Searsia ciliata 25*

Discussion: This variant (Figure 10.5) is dominated and distinguished by species from species group G (*Felicia muricata, Euphorbia rectirama, Gnaphalium declinatum, Diospyros austro-africana* and *Barleria macrostegia*). *Heteropogon contortus* (Species group AB) is chosen as the species that defines this variant due to the high cover abundance values.

In contrast to the findings of Müller (2002), in this study *Diospyros austro-africana* is mostly found on rocky outcrops with shallow soils of the Mispah form. In Müller’s study *Diospyros austro-africana* was found on clayey footslopes of the dolerite hills and ridges. *Heteropogon contortus* occur in a more closed shrub community in contrast to the shrub communities found by Müller (2002). In the area of study this variant occurs on rocky dolerite outcrops with well drained, shallow soils.

Figure 10.5: *Heteropogon contortus* Variant.

2.2.2 *Aristida canescens* Variant

Habitat

Geology:	Dolerite outcrops
Soil form/forms:	Mispah
Soil depth:	>0.20 m
Hydrology:	Well drained
Exposure:	Full sun to semi-shade
Disturbance:	Grazing by livestock

Species

Number of species in the variant: 30

Number of relevés in the variant: 4

Diagnostic species: ***Aristida canescens* 88.7, *Cussonia paniculata* 100.0**

Constant species: ***Aristida canescens* 100,** *Asparagus suaveolens 75, Buddleja saligna 75,* ***Cussonia paniculata* 100, *Enneapogon scoparius* 100,** *Hyparrhenia hirta 75, Olea europaea* subsp. *africana 75,* ***Pellaea calomelanos* var. *calomelanos* 100,** *Searsia burchellii 75*

Dominant species: ***Aristida canescens* 100,** *Buddleja saligna 50, Olea europaea* subsp. *africana 25*

Discussion: This variant (Figure 10.6) is dominated by the presence of species from species group H (*Aristida canescens, Pellaea calomelanos* var. *calomelanos, Cussonia paniculata* and *Grewia occidentalis*) which if present in other variants, have a low cover abundance value. This variant occurs on dolerite outcrops with shallow soils, among rocks and boulders.

This variant is similar to the *Cussonia paniculata* – *Olea europaea* Sub-community found in the study of Botha (2003). Similar to the study of Botha (2003) this variant is also found on the steep slopes of dolerite hills and ridges. However in contrast to the deep soils found by Botha (2003) the soils in this study are relatively shallow. The soils are however also well drained and of the Mispah form. This variant also has large rocks and boulders similar to that found by Botha (2003).

Figure 10.6: *Aristida canescens* Variant.

2.2.3 *Hermannia cuneifolia* Variant

Habitat

Geology: Dolerite outcrops

Soil form/forms: Mispah

Soil depth: <0.20 m

Hydrology: Well-drained

Exposure: Full sun to semi-shade

Disturbance: Grazing by livestock

Species

Number of species in the variant: 27

Number of relevés in the variant:5

Diagnostic species: **Datura stramonium 76.5, Haemanthus humilis 76.7,* ***Hermannia cuneifolia 100.0***

Constant species: ***Aristida congesta 100,*** *Cheilanthes hirta* var. *hirta 80, Commelina africana 80, Digitaria eriantha 80, Haemanthus humilis 80,* ***Hermannia cuneifolia 100,*** *Hyparrhenia hirta 80,* ***Olea europaea* subsp*. africana 100, Setaria verticillata 100***

Dominant species: ***Olea europaea* subsp. *africana 80***

Discussion: This variant (Figure 10.7) is dominated by species from species group I which are absent from or occur with low cover abundance values in other variants of this sub-community. The species are: *Hermannia cuneifolia, Commelina africana, Haemanthus humilis, *Datura stramonium* (Species group I), *Cheilanthes hirta* var. *hirta* (Species group L)and *Setaria verticillata* (Species group AB). This variant occurs in shallow soils or the vegetation occurs in cracks and crevices in the dolerite outcrops.

Figure 10.7: *Hermannia cuneifolia* Variant.

2.3 *Searsia cilliata – Digitaria eriantha – Enneapogon scoparius* Sub-community

Habitat

Geology:	Dolerite outcrops
Soil form/forms:	Mispah
Soil depth:	<0.15 m
Hydrology:	Well-drained
Exposure:	Full sun to semi-shade
Disturbance:	None

Species

Average number of species in the sub-community: 26

Number of relevés in the sub-community:16

Diagnostic species: ***Cleome rubella 81.6***

Constant species: *Buddleja saligna 75, Cleome rubella 69,* ***Digitaria eriantha 94,*** *Enneapogon scoparius 75,* ***Searsia ciliata 88,*** *Tarchonanthus camphoratus 75*

Dominant species: *Buddleja saligna 31, Digitaria eriantha 25, Searsia ciliata 50*

Discussion: This sub-community (Figure 10.8), characterised by the species of species group K (*Enneapogon scoparius* and *Cleome rubella),* occurs on the mid-slopes and crests of the dolerite outcrops in the savanna parts of the study area. The soil in this sub-community is very shallow and sometimes even absent. There are areas where the vegetation grows in organic matter present on and among the rocks. In some instances the vegetation is confined to cracks and crevices in the rocks.

This sub-community can be divided into two variants, namely:

2.3.1 *Tarchonanthus camphoratus* Variant

2.3.2 *Cenchrus ciliaris* Variant

Figure 10.8: *Searsia cilliata – Digitaria eriantha – Enneapogon scoparius* Sub-community.

2.3.1 *Tarchonanthus camphoratus* Variant

Habitat

Geology:	Dolerite outcrops
Soil form/forms:	Mispah, organic matter on rock, cracks and crevices
Soil depth:	<0.15 m
Hydrology:	Well-drained
Exposure:	Full sun to semi-shade
Disturbance:	None

Species

Average number of species in the variant: 26

Number of relevés in the variant:10

Diagnostic species: No diagnostic species

Constant species: *Buddleja saligna 70,* Cheilanthes *hirta* var. *hirta 80,* ***Digitaria eriantha 100,*** *Enneapogon scoparius 70, Searsia ciliata 80,* ***Tarchonanthus camphoratus 100***

Dominant species: *Buddleja saligna 40, Digitaria eriantha 30, Searsia ciliata 40*

Discussion: This variant occurs on shallow soils with a sandy texture. The vegetation is dominated by species from species group L, with *Cheilanthes hirta* var. *hirta, Pollichia campestris*and *Sida dregei as* the species that define this variant. Although *Trachonanthus* *camphoratus* (Species group U) shows a strong presence in this variant, the species also has a strong presence in other sub-communities.

In Müller's study (2002) *Tarchonanthus camphoratus* occurred mostly on dolerite outcrops and most of the other geological formation in the western Free State, Northern Cape and North West Province. The soils on which *Tarchonanthus camphoratus* occurs are mostly relatively shallow soils such as the Mispah and Glenrosa soil forms (Müller. 2002). Furthermore, *Tarchonanthus camphoratus* also occurs in other communities and sub-communities described by Müller (2002).

The findings of this study correlate well with those findings of Müller (2002) as this variant also occurs on shallow soils of the Mispah form on dolerite outcrops. Malan *et al.* (1998) also mentioned that *Tarchonanthus camphoratus* found in their study occur on hills and ridges. In this study area *Tarchonanthus camphoratus* is mostly limited to the Vaalbos Rocky Shrubland (SVk5) and the Schmidtsdrift Thornveld (SVk6) vegetation types (Mucina and Rutherford, 2006) which belong to the Savanna biome part of the study area.

2.3.2 *Cenchrus ciliaris* Variant

Habitat

Geology:	Dolerite outcrops
Soil form/forms:	Mispah, organic matter on rock, cracks and crevices
Soil depth:	<0.15m
Hydrology:	Dry
Exposure:	Full sun to semi-shade
Disturbance:	None

Species

Average number of species in the variant: 26

Number of relevés in the variant:6

Diagnostic species: ***Cenchrus ciliaris 90.8***

Constant species: ***Aristida congesta 83, Buddleja saligna 83, Cenchrus ciliaris 83, Cleome rubella 83, Digitaria eriantha 83, Enneapogon scoparius 83, Eragrostis lehmanniana 100, Heteropogon contortus 83, Searsia ciliata 100***

Dominant species: *Buddleja saligna 17, Digitaria eriantha 17,* ***Searsia ciliata 67***

Discussion: This variant is distinguished from the other variants by the presence of species from species group M (*Cenchrus ciliaris*). The strong presence of the grasses *Cenchrus ciliaris* (Species group M) and *Heteropogon contortus* (Species group AB) distinguishes this variant from variant 2.3.1. In the study area this variant occurs on slopes with sandy, well drained soils.

2.4 *Searsia cilliata – Digitaria eriantha – Euclea crispa* subsp. *ovata* Sub-community

Habitat

Geology: Dolerite outcrops

Soil form/forms: Mispah

Soil depth: <0.15 m

Hydrology: Well-drained

Exposure: Full sun to semi-shade

Disturbance: None

Species

Number of species in the sub-community: 27

Number of relevés in the sub-community:8

Diagnostic species: No diagnostic species

Constant species: ***Aristida bipartita 100, Aristida congesta 100,*** *Buddleja saligna 75,* ***Digitaria eriantha 100,*** *Euclea crispa* subsp. *ovata 75, Heteropogon contortus 62,* ***Sporobolus***

	***fimbriatus* 100, *Tarchonanthus camphoratus* 100, *Themeda triandra* 100**
Dominant species:	*Buddleja saligna 12, Sporobolus fimbriatus 12, Tarchonanthus camphoratus 12*

Discussion: The dominance of the grass, *Aristida bipartita* (Species group O), distinguishes this sub-community (Figure 10.9) from the other sub-communities within this community. This sub-community occurs on the foot slopes of the hills present in the Savanna biome. The soil is relatively shallow with a sandy texture.

The grass *Aristida bipartita* (Species group O) is known to occur in disturbed areas that are moist. This grass is also very unpalatable and indicates overgrazing if it dominates the veld (Van Oudtshoorn, 2004). Although this grass has a high occurrence in the study area, the grass does not dominate the veld.

Figure 10.9: *Searsia cilliata – Digitaria eriantha – Euclea crispa* subsp. *ovata*Sub-community.

3. *Ziziphus mucronata – Asparagus africanus* Community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Mispah and Hutton
Soil depth:	<0.20 m to >1.5 m
Hydrology:	Well-drained

Exposure: Full sun

Disturbance: Occasionally grazed by livestock

Species

Average number of species in the community: 33

Number of relevés in the community:10

Diagnostic species: No diagnostic species

Constant species: *Aristida congesta 80,* ***Asparagus africanus 90,*** *Asparagus suaveolens 80, Chenopodium *murale 70, Eragrostis lehmanniana 80, Setaria verticillata 70,* ***Ziziphus mucronata 90***

Dominant species: *Vachellia erioloba 10, Vachellia hebeclada 10, Vachellia karroo 10, Asparagus suaveolens 10, Digitaria argyrograpta 10, Searsia lancea 10, Tarchonanthus camphoratus 40, Tragus koelerioides 10, Ziziphus mucronata 10*

Discussion: This community is characterised by the presence of the tree *Ziziphus mucronata* and the climber *Asparagus africanus* (Species group P) as well as *Asparagus suaveolens* (Species group F). In the studies by Müller (2002) and Botha (2003) there are no communities which are dominated by *Ziziphus mucronata* and *Asparagus africanus* (Species group P). Venter and Venter (2005) noted that *Ziziphus mucronata* occurs in almost all “ecological cases”, however in this study is limited to the dolerite outcrops and the associated slopes.

This community occurs in soils with a loamy to loamy-clay texture and are not very deep. Furthermore, this community is limited to the dolerite outcrops in the area of study.

This community can be divided into two sub-communities, namely:

3.1 *Ziziphus mucronata – Asparagus africanus – Digitaria argyrograpta* Sub-community

3.2 *Ziziphus mucronata – Asparagus africanus – Chenopodium *murale* Sub-community

3.1 *Ziziphus mucronata – Asparagus africanus – Digitaria argyrograpta* Sub-community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Mispah
Soil depth:	<0.20 m
Hydrology:	Well-drained
Exposure:	Full sun
Disturbance:	Occasionally grazed by livestock

Species

Average number of species in the sub-community: 33

Number of relevés in the variant:3

Diagnostic species: ***Brachiaria eruciformis* 81.9, *Cyperus capensis* 100.0,** *Digitaria argyrograpta 78.7,* ***Eragrostis nindensis* 88.3, *Grewia flava* 97.1,** *Kyphocarpa angustifolia 76.3,* ***Ruschia hamata* 84.0, *Thesium costatum* 96.7**

Constant species: ***Vachellia tortilis* 100, *Aristida bipartita* 100, *Aristida congesta* 100, *Asparagus africanus* 100,** *Asparagus suaveolens 67,* ***Brachiaria eruciformis* 100, *Cyperus capensis* 100,** *Cyperus rupestris 67,* ***Digitaria argyrograpta* 100, *Diospyros lycioides* 100, *Eragrostis lehmanniana* 100, *Eragrostis nindensis* 100, *Eragrostis superba* 100, *Eriocephalus spinescens* 100, *Grewia flava* 100, *Gymnosporia karooica*100,** *Hertia pallens 67,* ***Heteropogon contortus* 100, *Kyphocarpa angustifolia* 100, *Lotononis burchellii* 100, *Lycium cinerium* 100, *Pentzia globosa* 100, *Ruschia hamata* 100, *Thesium costatum* 100,** *Tragus koelerioides 67, Tribulus terrestris 67,* ***Ziziphus mucronata* 100**

Dominant species: *Asparagus suaveolens 33, Digitaria argyrograpta 33, Searsia lancea 33, Tragus koelerioides 33*

Discussion: This sub-community (Figure 10.10) is distinguished from sub-community 3.2 by the presence of species of species group Q (*Digitaria argyrograpta, Eragrostis nindensis, Hertia pallens, Cyperus rupestris, Tribulus terrestris, Grewia flava, Cyperus capensis, Kyphocarpa angustifolia, Gymnosporia karooica, Thesium costatum, Ruschia hamata*). These species are completely absent from sub-community 3.2, except for *Tribilus terrestris*. Other species that are also restricted to this sub-community are *Eragrosits superba* (Species group E), *Aristida bipartita* (Species group O), *Vachellia tortilis, Pentzia globosa* (Species group V) and *Eriocephalus spinescens* (Species group W).

Although the research done by Müller (2002) and Botha (2003) describe communities with some similar species, none are as diverse as the sub-community found in this study. This sub-community is present on the shallow, sandy Mispah soils found on the elevated area where no dolerite outcrops are visible. This sub-community is mostly occurring in the western parts of the study area.

Figure 10.10: *Ziziphus mucronata – Asparagus africanus – Digitaria argyrograpta* Sub-community.

3.2 *Ziziphus mucronata – Asparagus africanus – Chenopodium *murale* Sub-community

Habitat

Geology:	Ecca Group
Soil form/forms:	Hutton
Soil depth:	>1.5 m
Hydrology:	Well-drained
Exposure:	Full sun to semi-shade
Disturbance:	None

Species

Number of species in the sub-community: 33

Number of relevés in the sub-community:8

Diagnostic species: No diagnostic species

Constant species: *Vachellia karroo 71, Aristida congesta 71,* ***Asparagus africanus 86, Asparagus suaveolens 86, Chenopodium *murale 100,*** *Cynodon dactylon 71, Eragrostis lehmanniana 71, Oxalis *corniculata 71,* ***Setaria verticillata 86,*** *Stipagrostis uniplumis 71,* ***Tarchonanthus camphoratus 86, Ziziphus mucronata 86***

Dominant species: *Vachellia erioloba 14, Vachellia hebeclada 14, Vachellia karroo 14, Tarchonanthus camphoratus 57, Ziziphus mucronata 14*

Discussion: This sub-community (Figure 10.11) is defined by the species form species group S (*Chenopodium *murale, Oxalis *corniculata, Stipagrostis uniplumis, Heliophila carnosa* and *Eragrostis obtusa*), which are completely absent from sub-community 3.1.

This sub-community can be divided into two variants, namely:

3.2.1 *Cynodon dactylon* Variant

3.2.2 *Vachellia erioloba* Variant

Figure 10.11: *Ziziphus mucronata – Asparagus africanus – Chenopodium *murale* Sub-community.

3.2.1 *Cynodon dactylon* Variant

Habitat

Geology:	Ecca Group
Soil form/forms:	Hutton
Soil depth:	>1.5 m
Hydrology:	Well-drained
Exposure:	Full sun to semi-shade
Disturbance:	None

Species

Number of species in the variant: 29

Number of relevés in the variant:3

Diagnostic species: No diagnostic species

Constant species: *Vachellia karroo 67, Aristida bipartita 67, Aristida congesta 67,* ***Asparagus africanus 100, Asparagus suaveolens 100,*** *Bidens *pilosa 67,* ***Brachiaria eruciformis 100, Chenopodium *murale 100,*** *Chloris virgata 67,* ***Cynodon dactylon 100, Diospyros lycioides 100,*** *Eragrostis lehmanniana 67, Eragrostis obtusa 67, Heliophila carnosa 67, Lotononis burchellii 67, Lycium cinerium 67,* ***Oxalis***

corniculata 100,** *Schkuhria pinnata 67, Setaria verticillata 67, Sporobolus fimbriatus 67, Tarchonanthus camphoratus 67,* ***Themeda triandra 100, Tragus berteronianus 100, *Ziziphus mucronata 67*

Dominant species: *Vachellia hebeclada 33, Vachellia karroo 33,* ***Tarchonanthus camphoratus 67,*** *Ziziphus mucronata 33*

Discussion: The soils in the variant have a loamy texture, are well-drained and are relatively deep. This variant is distinguished from 3.2.2 by the absence of species from species group R (*Lycium cinerium, Diospyros lycioides, Lotononis burchellii* and *Brachiaria eruciformis*). These species are however not characteristic, as these species also occur in sub-community 3.1. Other species that occur in this variant and is absent from 3.2.2 are: *Cynodon dactylon* (Species group V), *Chloris virgata* and *Tragus berteronianus* (Species group W), **Schkuhria pinnata* and *Themda triandra* (Species group AB).

3.2.2 *Vachellia erioloba* Variant

Habitat

Geology:	Ecca Group
Soil form/forms:	Hutton
Soil depth:	>1.5 m
Hydrology:	Well-drained
Exposure:	Full sun to semi-shade
Disturbance:	None

Species

Number of species in the variant: 37

Number of relevés in the variant:4

Diagnostic species: ***Cyathula uncinulata 85.9, Pentzia sphaerocephala 85.9, Pogonarthria squarrosa 85.9, Schmidtia pappophoroides 88.7,*** *Tephrosia capensis 75.5*

Constant species: ***Vachellia erioloba 100,*** *Vachellia karroo 75, Aristida congesta 75, Asparagus africanus 75, Asparagus suaveolens 75,* ***Chenopodium *murale 100,*** *Cyathula* *uncinulata 75, Ehretia rigida 75, Eragrostis lehmanniana 75, Pentzia sphaerocephala 75, Pogonarthria squarrosa 75,* ***Schmidtia pappophoroides 100, Setaria verticillata 100, Stipagrostis uniplumis 100, Tarchonanthus camphoratus 100,*** *Tephrosia capensis 75,* ***Ziziphus mucronata 100***

Dominant species: *Vachellia erioloba 25, Tarchonanthus camphoratus 50*

Discussion: Species from species group T (*Schmidtia pappophoroides, Cyathula uncinulata, Tephrosia capensis, Pogonarthria squarrosa* and *Pentzia sphaerocephala*) distinguish this variant from variant 3.2.1. Other species that are prominent in this variant and that is absent from 3.2.1 include: *Ehretia rigida* (Species group A) and *Vachellia erioloba* (Species group B).

This variant is similar to the *Acacia* (*Vachellia*) *erioloba – Stipagrostis uniplumis* Community (Viljoen, 1979) and *Schmidtia pappophoroides – Aristida stipitata* variant (Müller, 2002). Although *Aristida stipitata* is absent from this study most of the other species present in the variant are similar. Müller (2002) did not mention anysoil forms in the study, while Viljoen (1979) mentioned that the community occurred on yellow-brown, sandy soils. In contrast to Viljoen (1979) this variant is present on red, sandy soils of the Hutton form.

4. *Vachellia tortilis – Pentzia globosa* Community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Bloemdal, Augrabies, Mispah, Sepane, Fernwood and Hutton
Soil depth:	<0.10 m to >1.5 m
Hydrology:	Well drained
Exposure:	Full sun
Disturbance:	Occasional grazing by livestock and game

Species

Average number of species in the community: 25

Number of relevés in the community: 28

Diagnostic species: No diagnostic species

Constant species: *Vachellia tortilis 71, Aristida congesta 64, Eragrostis lehmanniana 75, Pentzia globosa 68*

Dominant species: *Vachellia tortilis 7, Aristida congesta 25, Bidens *pilosa 4, Cynodon dactylon 11, Olea europaea* subsp. *africana 4, Osteospermum muricata 4, Pentzia globosa 7, Searsia burchellii 4, Searsia lancea 14, Sporobolus fimbriatus 4, *Tagetes minuta 4, Tragus berteronianus 7*

Discussion: This community is characterised by the presence of species of species group V (*Vachellia tortilis, Pentzia globosa* and *Cynodon dactylon*). The environmental factor that distinguish this community form the others are the presence of soils with higher clay content.

This community is similar to the *Acacia tortilis (Vachellia tortilis*) – *Eragrosits obtusa* Community described by Müller (2002). Müller (2002) stated that this community is present on deep, sandy soils with a red colour and a high base status. In this study the *Vachellia tortilis – Pentzia globosa* Community was found on deep and shallow sandy soils as well as clayey soils. The presence on clayey soils was mostly restricted to the most western parts of the study area.

This community can be divided into three sub-communities, namely:

4.1 *Vachellia tortilis – Pentzia globosa – Chloris virgata* Sub-community

4.2 *Vachellia tortilis – Pentzia globosa – Cynodon dactylon* Sub-community

4.3 *Vachellia tortilis – Pentzia globosa – Chrysocoma ciliata* Sub-community

4.1 *Vachellia tortilis – Pentzia globosa – Chloris virgata* Sub-community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Augrabies
Soil depth:	±0.59 m
Hydrology:	Dry
Exposure:	Full sun
Disturbance:	Occasional grazing by livestock and game

Species

Average number of species in the sub-community: 25

Number of relevés in the sub-community: 4

Diagnostic species: *Chloris virgata 78.9,* ***Enneapogon desvauxii 85.5, Lycium pilifolium 85.5***

Constant species: ***Vachellia tortilis 100, Aristida congesta 100, Chloris virgata 100,*** *Enneapogon desvauxii 75, Enneapogon scoparius 75, Eragrostis lehmanniana 75,* ***Eragrostis obtusa 100, Eriocephalus spinescens 100,*** *Lycium pilifolium 75,* ***Pentzia globosa 100, Setaria verticillata 100,*** *Tragus berteronianus 75*

Dominant species: *Aristida congesta 25, Tragus berteronianus 50*

Discussion: This sub-community (Figure 10.12) occurs on shallow soils with very high clay content which might be the reason for hard soil surfaces during drought conditions. This sub-community occurs on the plains of the study area, among *Vachellia tortilis* shrubs. The species that characterise this sub-community are: *Chloris virgata, Tragus berteronianus, Enneapogon desvauxii, Lycium pilifolium*and *Eriocephalus spinescens* (Species group W). Other species that are prominent in this sub-community are: *Enneapogon scoparius* (Species group K), *Eragrostis obtusa* (Species group S) and *Setaria verticillata* (Species group AB). The presence of the grasses *Aristida congesta* (Species group AB) and *Chloris virgata* (Species group W) indicate disturbance.

Figure 10.12: *Vachellia tortilis – Pentzia globosa – Chloris virgata* Sub-community.

4.2 *Vachellia tortilis – Pentzia globosa – Cynodon dactylon* Sub-community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Bloemdal, Sepane and Mispah
Soil depth:	<0.10 m to >1.5 m
Hydrology:	Well-drained
Exposure:	Full sun to semi-shade
Disturbance:	Grazing by livestock

Species

Average number of species in the sub-community: 25

Number of relevés in the sub-community: 9

Diagnostic species: No diagnostic species

Constant species: ***Vachellia tortilis* 100,** *Cynodon dactylon 78, Eragrostis lehmanniana 78, Pentzia globosa 67*

Dominant species: *Vachellia tortilis 22, Aristida congesta 22, Cynodon dactylon 33, Pentzia globosa 22, *Tagetes minuta 11*

Discussion: This sub-community is distinguished from the other sub-communities in this community by the absence of species from species group W, X, Y and Z. In the area of study this sub-community occurs on small hills in shallow and deep soils. The soil is mostly covered by the grass *Eragrostis lehmanniana* (Species group AB) with some dwarf shrubs such as *Pentzia globosa* (Species group V). The tree layer is dominated by *Vachellia tortilis* (Species group V) (Figure 10.13).

Figure 10.13: *Vachellia tortilis – Pentzia globosa – Cynodon dactylon* Sub-community.

4.3 *Vachellia tortilis – Pentzia globosa – Chrysocoma ciliata* Sub-community

Habitat

Geology:	Beaufort and Ecca Groups as well as Dolerite outcrops
Soil form/forms:	Hutton and Fernwood
Soil depth:	>1.50 m
Hydrology:	Well-drained
Exposure:	Full sun
Disturbance:	None to occasional grazing by livestock

Species

Average number of species in the sub-community: 25

Number of relevés in the sub-community: 7

Diagnostic species: ***Aptosium procumbens 94.3, Chrysocoma ciliata 97.1, Osteospermum muricata 91.9***

Constant species: ***Vachellia tortilis 86, Aptosium procumbens 100, Aristida congesta 100, Chrysocoma ciliata 100, Cynodon dactylon 86, Eragrostis lehmanniana 100,***

Hyparrhenia hirta 71, ***Osteospermum muricatum 86, Pentzia globosa 86, Themeda triandra 100***

Dominant species: *Aristida congesta 43, Osteospermum muricata 14, Searsia lancea 14*

Discussion: This sub-community is defined by the presence of species from species group X (*Chrysocoma ciliata, Osteospermum muricatum* and *Aptosium procumbens*). Le Roux *et al.* (1994) mentioned that the presence of *Chrysocoma ciliata* is an indication of overgrazing, deterioration of the veld as well as karoo encroachment.

This sub-community can be divided into two variants, namely:

4.3.1 *Helichrysum dregeanum* Variant

4.3.2 *Eragrostis trichophora* Variant

4.3.1 *Helichrysum dregeanum* Variant

Habitat

Geology:	Dolerite outcrops
Soil form/forms:	Hutton
Soil depth:	±0.63 m
Hydrology:	Well-drained
Exposure:	Full sun to semi-shade
Disturbance:	Grazing by livestock

Species

Average number of species in the variant: 25

Number of relevés in the variant: 3

Diagnostic species: ***Helichrysum dregeanum 86.0***

Constant species: ***Vachellia tortilis 100, Aptosium procumbens 100, Aristida congesta 100, Chrysocoma ciliata 100,*** *Cynodon dactylon 67,* ***Eragrostis lehmanniana 100, Eragrostis superba 100, Helichrysum dregeanum 100, Hertia pallens 100, Heteropogon contortus 100, Hyparrhenia hirta 100, Lotononis burchellii 100, Monsonia angustifolia 100, Osteospermum muricata***

100, Pentzia globosa 100, Themeda triandra 100

Dominant species: ***Aristida congesta 67,*** *Osteospermum muricata 33*

Discussion: This variant (Figure 10.14) occurs on dolerite outcrops in the area of study. Some trees and shrubs are present in this variant; however, the cover abundance is low. These trees and shrubs provide shade for some of the species growing underneath them. The soils in this variant have a clayey-loam texture.

This variant is defined by the strong presence of the dwarf shrub *Helichrysum dregeanum* (Species group Y). This is also the species that distinguishes this variant from variant 4.3.2. However, *Eragrostis superba* (Species group E), *Hertia pallens* (Species group Q), *Lotononis burchellii* (Species group R), *Monsonia angustifolia* and *Heteropogon contortus* (Species group AB) is only present in this variant of the sub-community.

Figure 10.14: *Helichrysum dregeanum* Variant.

4.3.2 *Eragrostis trichophora* Variant

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Hutton and Fernwood
Soil depth:	±0.05 m to ±0.50 m
Hydrology:	Well-drained
Exposure:	Full sun
Disturbance:	Occasional grazing by livestock

Species

Average number of species in the variant: 25

Number of relevés in the variant: 4

Diagnostic species: No diagnostic species

Constant species: ***Vachellia karroo 100,*** *Vachellia tortilis 75,* ***Aptosium procumbens 100, Aristida congesta 100, Asparagus africanus 100,*** *Barleria macrostegia 75,* ***Bidens *pilosa 100,*** *Chenopodium *murale 75,* ***Chrysocoma ciliata 100, Cynodon dactylon 100,*** *Dicoma macrocephala 75, Eragrostis biflora 75,* ***Eragrostis lehmanniana 100, Eragrostis obtusa 100,*** *Eragrostis trichophora 75, Osteospermum muricata 75, Pentzia globosa 75, Pollichia campestris 75, *Schkuhria pinnata 75, Searsia lancea 75, Selago densiflora 75,* ***Themeda triandra 100***

Dominant species: *Aristida congesta 25, Searsia lancea 25*

Discussion: This variant (Figure 10.15) is distinguished from others in this sub-community by the presence of species from species group Z (*Eragrostis trichophora, Eragrostis biflora* and *Dicoma macrocephala*). Other species that also occur in this variant with high cover abundance include: *Asparagus africanus* (Species group P), *Eragrostis obtusa*(Species group S), **Schkuhria pinnata* and *Vachellia karroo* (Species group AB).

Eragrostis trichophora (Species group Z) is known to occur on barren patches in the field as well as in disturbed areas. Mostly in shallow sandy or rocky soil (Van Oudtshoorn, 2004). The soils present in this variant in the study area have a more loamy-clay texture.

Figure 10.15: *Eragrostis trichophora* Variant.

5. *Searsia lancea* – *Sporobolus fimbriatus* Community

Habitat

Geology:	Beaufort and Ecca Groups
Soil form/forms:	Hutton and Mispah
Soil depth:	< 0.20 m to ±0.96 m
Hydrology:	Well-drained
Exposure:	Full sun to semi-shade
Disturbance:	Occasional grazing by livestock

Species

Number of species in the sub-community: 25

Number of relevés in the sub-community: 8

Diagnostic species: No diagnostic species

Constant species: *Asparagus africanus 75, Bidens *pilosa 75,* ***Searsia lancea 100,*** *Sporobolus fimbriatus 75,* ***Themeda triandra 88***

Dominant species: *Aristida congesta 12, Bidens *pilosa 12, Olea europaea* subsp. *africana 12, Searsia burchellii 12, Searsia lancea 38, Sporobolus fimbriatus 12*

Discussion: This community (Figure 10.16) is defined by the strong presence of the tree *Searsia lancea* (Species group AA) and the grass *Sporobolus fimbriatus* (Species group AB). This community occurs on the plains in the area of study in deep soils of the Hutton form or on dolerite hills with shallow soils of the Mispah form. The annual forb, **Tagetes minuta* (Species group AA) is also prominent in this community.

This community is similar to the *Rhus lancea* (*Searsia lancea*) – *Olea europaea* Variant described by Müller (2002). There is however differences between the communities in the study of Müller (2002) and the community found in this study. The variant described by Müller occurs close to streams and in sheltered valleys. The community in this study is restricted to open plains and dolerite outcrops in shallow to deep soils which are relatively well-drained.

Figure 10.16: *Searsia lancea – Sporobolus fimbriatus*Community.

10.4 DCA ORDINATION OF THE WOODY COMMUNITIES

The DCA ordination (Figure 10.17)(Ter Braak and Smilauer, 2002) of the woody communities in the study area indicates discontinuities between some of the communities. The high Eigenvalues of the first axis indicate that there is a relatively strong difference between the *Searsia cilliata* – *Digitaria eriantha* Community (Community 2, red) and the *Vachellia tortilis* – *Pentzia globosa* Community (Community 4, black) these differences occur along a soil texture gradient. Community 2 occur in soils with a sandy to loamy-sandy texture, while community 4 occur in soils with a clay texture. The topography of these two communities also differs. The *Searsia* cilliata – *Digitaria eriantha* Community mostly occur on rocky outcrops, while the *Acacia tortilis* – *Pentzia globosa* Community occur on the plains in the area of study. The *Vachellia hebeclada* – *Ehretia rigida* Community (Community 1, blue), *Ziziphus mucronata* – *Asparagus africanus* Community (Community 3, green) and *Searsia lancea* – *Sporobolus fimbriatus* Community (Community 5, brown) occur in soils with a sandy-loam to loamy-clay texture. These communities are present on the foot slopes in the area of study.

When interpreting axis two (Figure 10.17), there is also a significant seperation between the vegetation units in terms of soil depth. The relevés present at the bottom of the graph occur in very shallow soil in contrast to the relevés at the top of the graph which occur in soils deeper than 1.5 m.

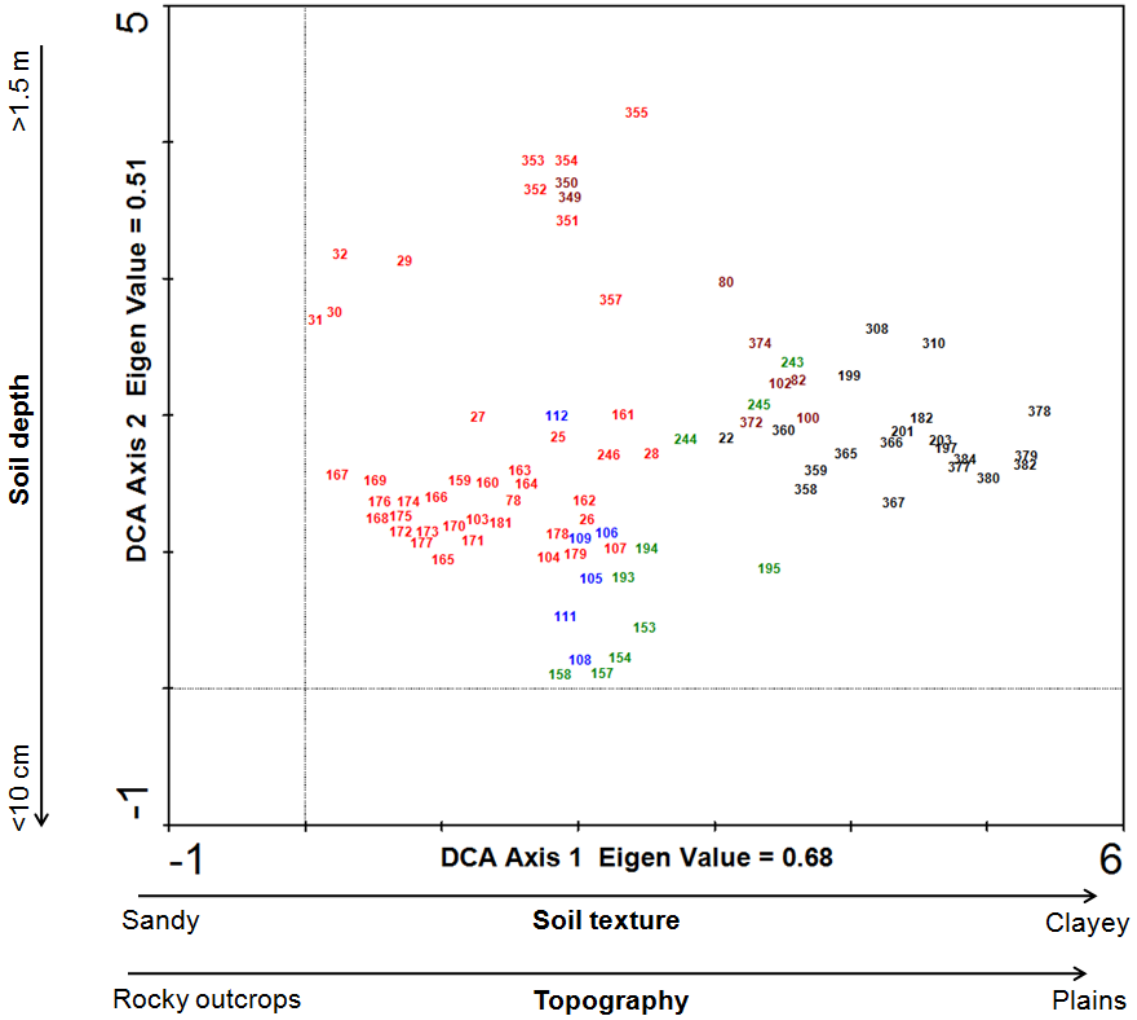

Figure 10.17: Ordination diagram of the wetland communities in the study area. Community 1 – *Vachellia hebeclada* – *Ehretia rigida* Community (blue); Community 2 – *Searsia cilliata* – *Digitaria eriantha* Community (red); Community 3 – *Ziziphus mucronata* – *Asparagus africanus* Community (green); Community 4 – *Vachellia tortilis* – *Pentzia globosa* Community (black); Community 5 – *Searsia lancea* – *Sporobolus fimbriatus* Community (brown).

The following interpretations about the different woody communities can thus be made from the DCA analysis: The *Vachellia hebeclada* – *Ehretia rigida* Communities (one, blue) occur in soils with a depth of between 0.10 m to more or less 1 m; the *Searsia cilliata* – *Digitaria eriantha* Communities (two, red) occur in soils with a depth of between 0.5 m to deeper than 1.5 m; the *Ziziphus mucronata* – *Asparagus africanus* Communties (three, green) occur in soils with a depth of between 0.10 m up to more or less 1 m; the *Vachellia tortilis* – *Pentzia globosa* Communities occur in soils with a depth of around 1 m; the *Searsia lancea* – *Sporobolus fimbriatus* Communities occur in soils with a depth of between 1 m and more than 1.5 m.

The ordination (Figure 10.17) coincide well with the phytosociological classification (Table 10.1), except for the occurrence of relevés 31, 31, 32, 29, 353, 352, 349, 351, 350, 354 and 355 towards the top left of the DCA ordination diagram. The results of the classification were accepted. The reason: the strong presence of species group F in Community 2. Relevés 350 and 349 from Community 5 which also occur in this section only have the strong presence of *Olea europaea* subsp. *africana* and *Searsia burchellii* (Species group F), however these relevés fit better in with the relevés of Community 5 than with Community 2. Although the ordination indicates the close correlation between communities 1 and 3, it was decided to keep these communities separated because Community 1 is strongly dominated by the presence of *Vachellia hebeclada* (Species group A) which are absent in Community 3. The close correlation can be due to the presence of species such as *Ehretia rigida* (Species group A), *Vachellia erioloba* (Species group B), *Ziziphus mucronata*, *Asparagus africanus* (Species group P), *Stipagrostis uniplumis* (Species group S) and *Tarchonanthus camphorathus* (Species group U) which is common in both these communities.

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CHAPTER 11
BADEN-BADEN POLLEN ANALYSIS

11.1 INTRODUCTION

The purpose of this chapter is to gain insights in the vegetation history in the study area and to briefly investigate the potential of reconstructing it. The reconstruction of the vegetation will contribute towards the understanding of environmental changes. Africa experienced high amplitude environmental changes during the Quaternary Period that affected the wide range of present-day climates (Nash and Meadows, 2012). The climate changes have not only influenced the environment, but also played a major part in the development of humans in the grassland (Van Aardt *et al.,* 2015). The environmental changes can be studied using fossil pollen. Pollen records that shed light on this history in Africa are restricted due to the relatively few studies attempted and the environmental conditions that are rarely beneficial for the preservation of pollen.

Pollen-containing organic sediments are rare in arid and semi-arid regions such as southern Africa (Nash and Meadows, 2012). Coetzee (1978; 1980; 1983) and Coetzee and Muller (1984) did several studies on the vegetation history of the south-western Cape region using pollen analysis of organic coastal deposits. The results obtained indicated alternations of cool-wet conifer forests with palm-dominated sub-tropical vegetation during the Late Oligocene to the Pliocene. The time interval at one of the sites, viz., Noordhoek is now believed to represent a much shorter period in the early Miocene than previously assumed (Roberts *et al.*, 2013). At the end of the Miocene the climate started to become more arid – leading to the development of the present Namib Desert (Van Zinderen Bakker, 1984). This information gained from the south-western Cape raised questions about the vegetation history of the Highveld. The question is pertinent in view of the lack of suitable deposits with plant fossil preservation in the Free State and most of the central interior of southern Africa.

However, the lack of basins and erosion towards the Atlantic Ocean is the reason for extremely few palaeontological sites of Neogene age that might shed light on the early history of the Grassland Biome in the Free State. A mammoth's (*Mammuthus* sp.) molar, ulna and partial tusk were recovered from a railway cutting near Virginia

(Butzer, 1973). The deposits are of Pliocene origin, the first in the Free State. Further investigation at the site indicated that the outcrops in the area were covered by deeply weathered aeolian sands and the valley bottoms filled with silt form the late Pleistocene to Holocene. No organic layers preserving pollen were present at this site (Butzer, 1973). Another site is Erfkroon situated in the valley of the Modder River with large exposures of well-stratified Middle to Late Pleistocene and Holocene alluvial terrace deposits. The fossil-bearing deposits at Erfkroon are present in exposed erosional gullies (dongas) with river channel gravels, overbank silts and clays. These deposits are of MSA (*c*. 240-25 kyr) and LSA (*c.* 25 kyr) age. Pollen bearing sediment is also absent from Erfkroon however hyena coprolites at the site promised to have pollen for analysis (Churchill *et al.*, 2000). Investigation revealed that the coprolites were not containing any pollen (L. Scott, pers comm.)[4].

With the above mentioned in mind, it is clear the older deposits in the Free State lack preserved pollen. Thus, to reconstruct the vegetation history of the central interior of South Africa, only the younger deposits are available for pollen analysis. These younger deposits are present at Florisbad, a well known archaeological site (Van Zinderen Bakker, 1955; 1989; Henderson, 1992; 1995; Brink 1997) and Baden-Baden a newly discovered archaeological site (Van Aardt *et al.,* 2015).

To contribute to the reconstruction of vegetation history in the region a palynological study was done at Baden-Baden, one of the very rare pollen bearing deposits in the arid western Free State. Thus, this study promises to increase the 270 records present in the African Pollen Database (Nash and Meadows, 2012).

11.2 PREVIOUS PALYNOLOGICAL WORK IN THE WESTERN FREE STATE

After the discovery of the Florisbad skull in deposits of a thermal spring in 1932 by Professor T.F. Dreyer, it became a world famous archaeological site (Henderson, 1992; 1995; Brink 1997). Florisbad is situated 48 km north-northwest of Bloemfontein on the edge of a large playa (Soutpan). Florisbad spring deposits have distinctive layers of sands, loam, clays and organic material which contain paleontological, archaeological and palynological elements. This site is a well known research site for both local and international researchers (Van Zinderen Bakker, 1955; Rubidge and Brink, 1985; Brink, 1987a; Van Zinderen Bakker, 1989; Joubert

[4] Prof. Louis Scott, Department of Plant Sciences, University of the Free State, Bloemfontein.

et al., 1991; Scott and Brink, 1992; Van Zinderen Bakker, 1995; Grün *et* al., 1996; Scott and Rossouw, 2005).

Although Florisbad is a well known research site, there are still uncertainties about the age of the deposits. On the basis of the first radiocarbon dates, which are now known to be inaccurate, the Florisbad deposits were originally thought to be older than 48 000 years (Van Zinderen Bakker 1955; 1967a; 1995). Apart from Holocene spring layers (Scott and Nyakale, 2002), the latest radiocarbon and ESR dating reveal that the older parts of the sequence is between 100 000 and 300 000 years old (Kuman and Clarke, 1986; Grün *et al*., 1996).

The present-day grassland surrounding Florisbad receive around 400-500 mm of rainfall annually. In contrast to this, fossil pollen from the Pleistocene indicated semi-desert, Karoo type vegetation with annual rainfall between 125-250 mm (Van Zinderen Bakker 1955; 1967a; 1989; Scott and Rossouw, 2005).

The type of grasslands represented by pollen in the deposits is difficult to determine. However, the occurrence of rare Ericaceae and Restionaceae in some of the oldest levels led van Zinderen Bakker to assume that the grassland can be similar to some cold alpine type of grassland (Van Zinderen Bakker 1955; 1967a; 1989). This cold alpine type of grassland is presently found in the Drakensberg, which currently includes a high portion of C_3 grasses (Vogel *et al.*, 1978; Scott and Rossouw, 2005). Otherwise marked fluctuations on pollen composition between dry pan floor elements (Chenopodiaceae), karroid vegetation (Asteraceae) and mesic conditions (grasses) indicate that major cycles of moisture change occurred. For the Holocene pollen section, Van Zinderen Bakker’s dating was improved by Scott and Nyakale (2002) using radiocarbon dating. This pollen sequence is ranging in age between 1 700 BP to 8 200 BP, suggesting an accumulation rate of approximately 23 cm for each 1 000 years (Scott and Nyakale, 2002). Scott and Nyakale (2002) further indicated that conditions in this part of the Free State were not always dry during the Holocene and that the climate alternated between wetter and drier periods.

In terms of macro-plant fossils; wood of a *Zanthoxylum chalybeam* tree were found at Florisbad (Middle Stone Age layers) by Bamford and Henderson (2003); possibly as a transported object from a woodland environment. This tree is mostly found several hundred miles north in the warmer savanna and its presence near Florisbad could indicate either long distance transportation or a major climate shift towards warmer, wetter conditions than at present during an interglacial phase (Scott and Rossouw, 2005). Thus one can conclude that through time Florisbad experienced major climatic changes.

Other indications for major climate shifts are reported by Butzer *et al.* (1973) who proposed that the evaporation pans present at Alexandersfontein once were a lake of around 19 m deep with a surface area of approximately 44 km^2 during the late Pleistocene at >16 000 yr BP. Thus, the climate at the time was around 6°C cooler than today with rainfall almost twice what is experienced at present. Pollen analysis of younger spring deposits post-dating the lake deposits at Alexandersfontein were conducted by Scott (1976). Indications from the pollen sequence that was < 5 000 yr BP old (late Holocene) are not that clear, but a more humid environment might be suggested including pollen from the Lactucoideae (Asteraceae) that suggest a different local spring environment (Scott, 1976; 1988).

Another site with Holocene environmental data is at Deelpan, a pan of around 6.5 km^2 without any vegetation but with spring deposits and lunette dunes (Butzer 1984a, 1948b; Scott, 1988; Scott and Brink, 1992; Scott *et al.*, 2012). The silts of this pan are rich in carbonates and other salts. Vegetation present on the shores of this pan is dominated by halophytes from the Amaranthaceae family. Although springs are present on the south-western portion of the pan; this pan is dry most of the time. During years with above average rainfall, this pan can contain water of several meters deep. Therefore, there is reason to assume that the pan represented a lake environment during the wetter phases of the Quaternary. The pollen sampled at Deelpan indicate prominent Poaceae and Asteraceae values at around *c.* 4 000 yr BP and *c.* 2 000 yr BP. This indicates a good karroid vegetation cover (mostly dominated by grasses (Scott, 1988; Scott and Brink, 1992)) in the immediate surroundings of the pan. After *c.* 2 000 yr BP the high numbers of Amaranthaceae (Cheno/Ams) pollen at *c.* 820 yr BP (uncalibrated) are indicative of dry pan shore conditions (Scott, 1988). After 820 yr BP the local vegetation around the pan were dominated by sedges (Scott and Brink, 1992). Indications are that the area to the south of the spring eye at Deelpan was generally drier than the spring eye itself.

The bones found in the hyena den (at Deelpan) imply a small carnivore component and the dominance of grazers among the herbivores (Scott and Brink, 1992). This further implies that the surroundings were mostly dominated by open grasslands. The presence of the Cape clawless otter represents the aquatic element – indicating that for some time permanent water was present at the pan (Scott and Brink, 1992).

11.3 STUDY SITE

Baden-Baden is situated 70 km north-west of Bloemfontein. The site is similar to Florisbad, also consisting of a spring mound with Pleistocene deposits. A pre-Boer War bath house (Figure 11.1) is situated close to a series of mineral springs as featured in Culna, a newsletter of the National Museum, Bloemfontein (Dreyer, 1993). Information about the history of the bath house is given in a letter from Dr. Albert Wessels (Nel, *pers comm.,* 2014).[5] The deposits present at the spring mounds found at Baden-Baden has the potential to complement studies done at Florisbad and Deelpan to expand the palaeo-environmental records of the Late Pleistocene, which is absent at Florisbad.

The present-day vegetation at Baden-Baden occurs on aeolian dune deposits from the close by Annaspan. The primary mound and the dry parts of the secondary mounds are covered with grasses such as *Cynodon dactylon, Eragrostis lehmanniana, Digitaria eriantha* and *Aristida congesta.* The karroid shrub, *Chrysocoma ciliata,* is also present on these mounds. Elevated parts of the mounds with deep, well-drained and leached sandy soils, are disturbed by the burrowing actions of aardvarks (*Orycteropus afer*) and suricates (*Suricata suricatta*) (Van Aardt *et al*., 2015)

In seepage areas at Baden-Baden, the vegetation is dominated by *Phragmites australis* and *Ranunculus multifidus.* Salt concentrations, soil texture, the availability of surface water, leaching and disturbance affect the valley-bottom communities. In the areas with high salt concentrations and a high pH, *Limonium dregeanum* is the dominant plant species (Van Aardt *et al*., 2015). *Juncus rigidus* and *Sporobolus virginicus* occur in areas where the seeping water evaporates and the soil contain high concentrations of salts. Most parts of the valley floor are bare, covered with red sand with a few *Suaeda fruticosa* and *Salsola aphyla* plants. The deep water along

[5] Mr Nellis Nel, Baden-Baden, Dealesville.

the fringes of an impoundment is dominated by the sedge, *Schoenoplectus triqueter,* and the bulrush, *Typha capensis* (Van Aardt *et al.,* 2015).

Figure 11.1: The primary spring mound and the bath house at Baden-Baden.

Topographical analysis of the site indicated that the primary mound (Figure 11.2) is bi-lobed oval – thus, two large mounds merged into a single mound. Two streams drained the numerous springs. The largest drainage on the eastern side of the primary mound is where the bathhouse was constructed, over a strong spring eye. From the bath house, the stream flows in a northward direction and then turns north-west draining towards the nearby Annaspan. Secondary mounds occur on the eastern side contributing to the flow of the eastern stream (on the western side of the secondary mounds) also draining to Annaspan. These small mounds appear to be coalescing into a new mound complex, merging with a large dune deposit to the east and south. This suggests a complex pattern of mound genesis (Van Aardt *et al.,* 2015).

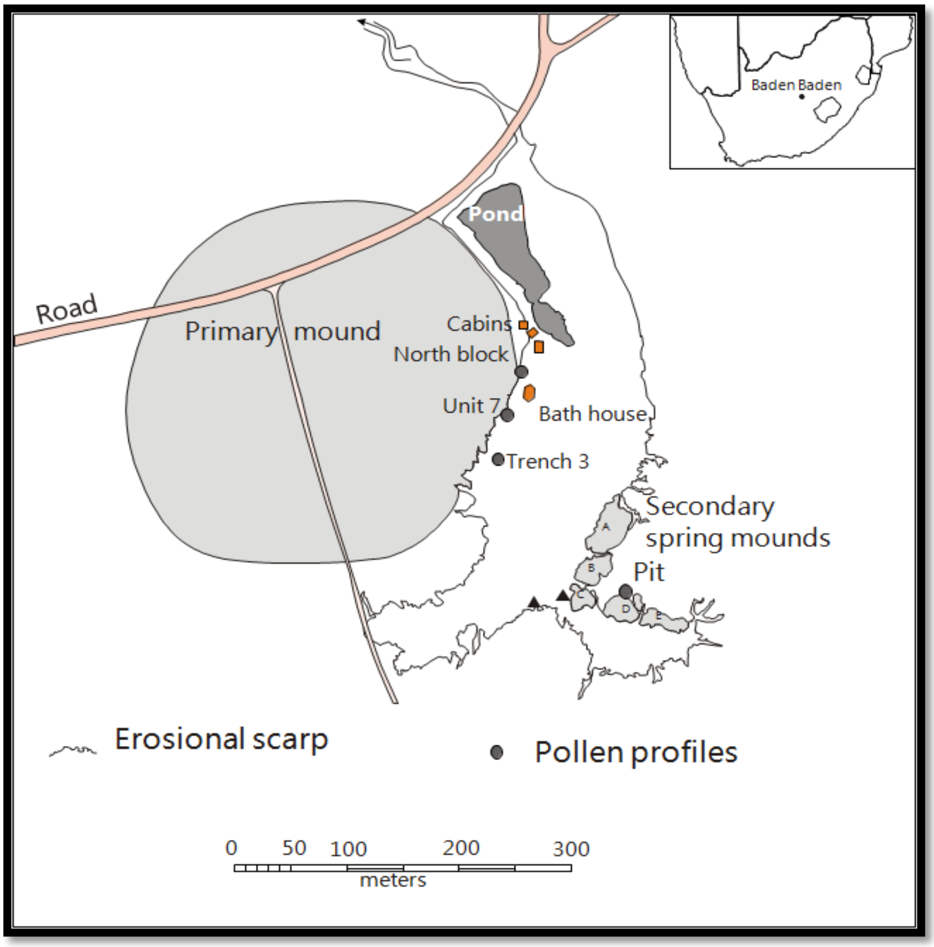

Figure 11.2: Map of the study site and its layout (adapted from Bousman *et al.*, undated).

Excavations units (1 x 1 m) at Baden-Baden were dug on the edges and at the base of the primary mound (Figure 11.2) by Bousman and his team (Van Aardt *et al.*, 2015). These excavations revealed that over time the springs trapped aeolian sand which gave rise to mounds where numerous heavily weathered Stone Age artifacts were found (Bousman *et al.*, undated). The fossil fauna found at Baden-Baden included remains of tortoises, zebra, warthog, black wildebeest and Bondi's springbok (*Antidorcas bondi*) (Van Aardt *et al.*, 2015). The presence of *Antidorcas bondi,* a type of springbok, and the different size of the wildebeest remains are indications that the layers date back to the Late Pleistocene (Bousman *et al.,* undated).

11.4 MATERIALS AND METHODS

The materials and methods used for the pollen analysis were described in Chapter 7 from section 7.6.

11.5 RESULTS AND DISCUSSIONS

The pollen analysed during this study were extracted from deposits of three different areas around the Baden-Baden spring mounds. The first set of samples was removed from an exploratory pit of organic deposits in one of the secondary spring mounds between the depths of 0 cm and 80 cm (Figure 11.3). Radiocarbon dating of two levels by Beta Analytical were however, problematic because two fractions were isolated in each that gave different ages, viz. small plant remains and amorphous organic material. At the 10-20 cm level they date to 680 ± 30 and 1 870 ± 30 yr BP respectively and at the 73-78 cm level to 3 380 ± 30 and 6 810 ± 30 yr BP (uncalibrated). We assume the younger fraction of plant remains in each case is due to the presence of root material within the samples. Thus the material sampled for dating in future should be taken with care to eliminate and remove small rootlets.

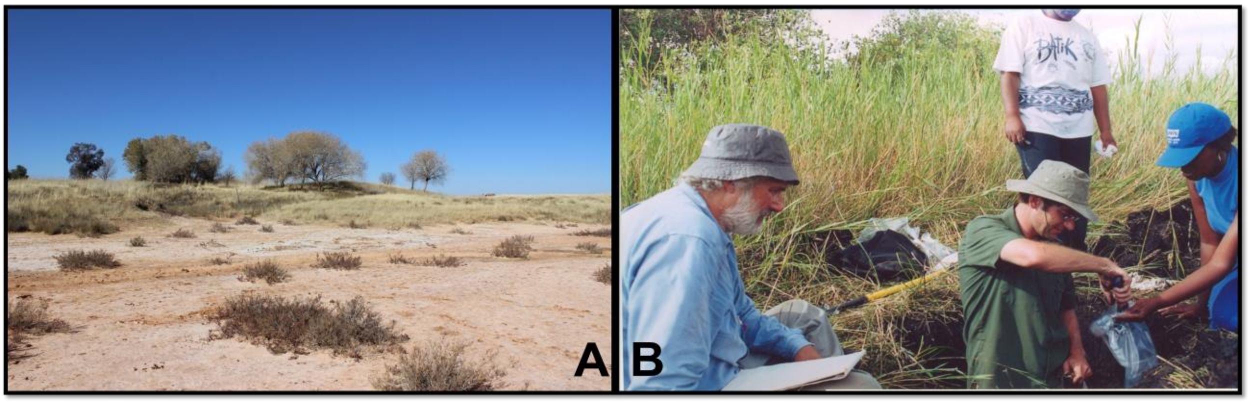

Figure 11.3: A) The secondary spring mounds at Baden-Baden. B) Collecting samples for analysis at the pit in the secondary spring mound (L. Scott, L. Rossouw, B. Theko and L. Nyenye).

Pollen of Asteraceae and Aizoaceae (Figure 11.4) in the spring mound deposit is more likely to represent the surrounding vegetation rather than the spring itself. The high percentage of Poaceae could also be from the wider grassy environment but might include pollen grains of *Phragmites* growing on the spring mound. As this is an exploratory study, these groups have not been distinguished but should be separated in future pollen analysis by identifying the smaller grass grains of less than 20 μm. This promised to give a better estimate of changes in the grassiness of the surroundings in comparison with shrub ratio (Asteraceae). Except for the grassy component; Apiaceae and Cyperaceae pollen are indicative of hydrophytic vegetation types that were derived from the spring area indicating shallow water or

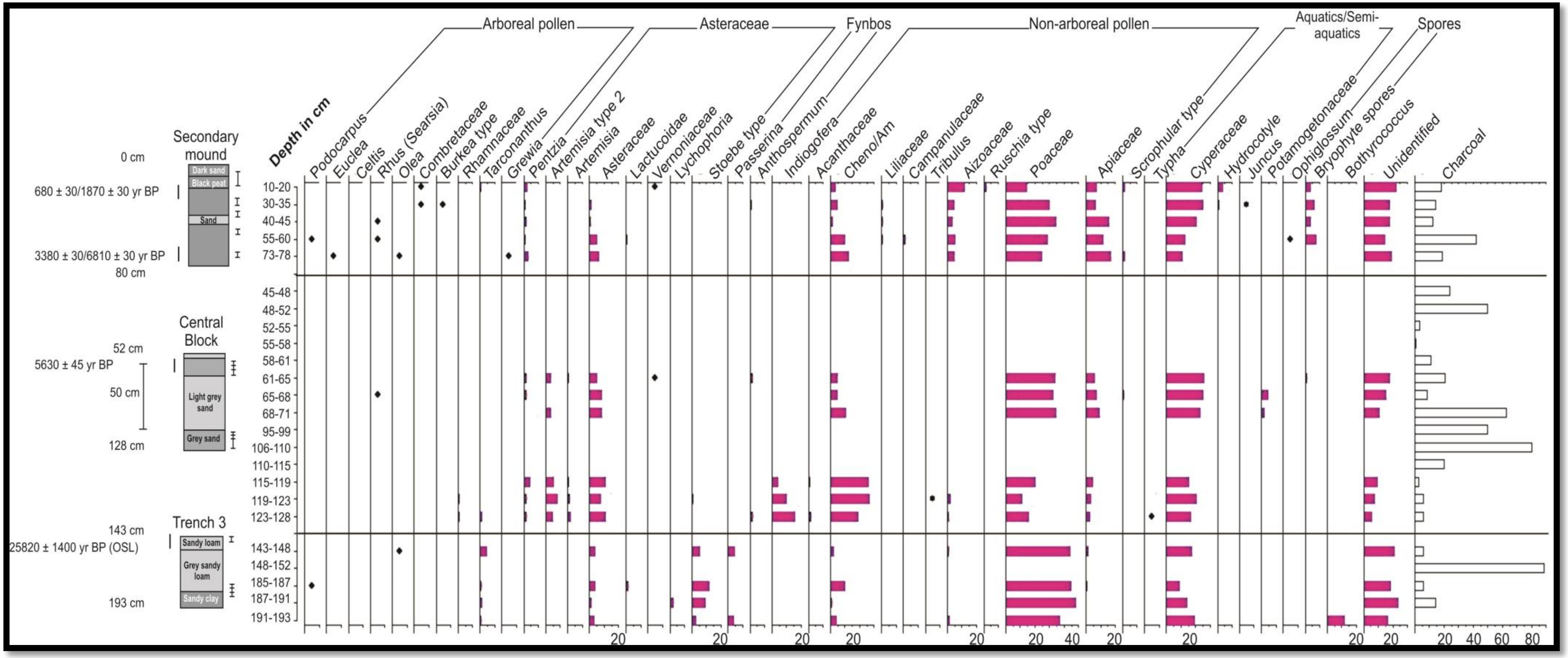

Figure 11.4: Graph of the different pollen and charcoal percentages at the different sites found at Baden-Baden.

damp soils (Scott and Nyakale, 2002). This might indicate a wetland environment surrounded by grasslands.

The overall pollen sequence provisionally seems to indicate slightly drier conditions in the early Holocene with more Asteraceae and Chenopodiaceae. The pollen from the grasses showed a peak in the middle Holocene, a more accurate interpretation will depend on the distinction of the ratio between local *Phragmitis* and regional grass. The high proportion of charcoal is an indication that fire was an important factor during the early Holocene that appeared to decline in more recent times. Interpretation of this charcoal presence will require further research due to the fact that drier karroid veld have less fuel to favour fires. Bond (1997) noted that the availability of fuel is an important characteristic in the determining of fire frequency. Therefore, the high proportion of charcoal could also have an anthropogenic origin. Furthermore, one will also have to determine whether the fires were regional or local. The presence of grazers and their grazing intensity also play a role in the availability of grass present and thus the frequency of fire.

At the second site (Central Block (Figure 11.5)) analysed at Baden-Baden pollen was only analysed from a depth of 61 cm – 128 cm. The section above this that provided a radiocarbon date of ca. 2 420 ± 70 ^{14}C BP was previously reported by Theko *et al*. (2003) but will have to be re-analysed to link it with the current work. The profile was radiocarbon dated in 2003 as middle-Holocene in age (5 630 ± 45 yr BP) by the Groningen (Netherlands) dating laboratory via the Quaternary Dating Research Unit (QUADRU) at the CSIR in Pretoria.

According to Bousman *et al.* (undated) the fauna was represented by tortoise, zebra, warthog, black wildebeest and Bondi's springbok. As suggested by pollen, the vegetation during this time was dominated by Poaceae. The high presence of Poaceae can be indicative of regional humid conditions. Some pollen of Asteraceae, Chenopodiaceae, Amaranthaceae (Cheno/Ams) and Apiaceae were also present (Figure 11.4) but with a lower percentage than at the secondary spring mounds. According to Koekemoer *et al.*, (2014) most members of the Chenopodiaceae family occur in soils containing high concentrations of inorganic salts. In the area of study the present-day vegetation that occur in salt containing soils are mostly restricted to seasonal pans – where water evaporate during the dry season. The presence of

Cyperaceae pollen indicates a good stand of hydrophytic vegetation at the spring. Although the presence of Poaceae and Asteraceae dominating environments can be indicative of summer rainfall, a ratio change might indicate a change in overall rainfall or seasonality (Scott and Nyakale, 2002). In the case of the Central Block, the Cyperaceae pollen is much more prominent than the Asteraceae. This might be indicative of a wetter habitat containing more sedges. Some hygrophilous grass species are also adapted to occur in water saturated habitats. The co-occurrence of these two families might indicate a wetter environment.

Figure 11.5: Excavation of the Central block at Baden-Baden.

When comparing the results form Florisbad (Scott and Nyakale, 2002) with the results found at Baden-Baden (Figure 11.4) it is clear that the trend between the two sites are similar. Although the Asteraceae and Cheno/Ams percentages are much higher at Florisbad than at Baden-Baden. This is important in interpreting the results where the similar trend at both the sites seems to support the occurrence of dry times during the early Holocene.

The second part of the Central block (Figure 11.4) (containing pollen) with a depth of between 115 cm to 128 cm is not dated but is older than 5 800 yr BP. This zone might tentatively represent the transition between isotope stage 2 (glacial periods) and the Holocene. During this time the pollen analysis revealed a decline in the Cyperaceae, Poaceae and Apiaceae. The presences of the Cheno/Ams during his time show a remarkable increase. In this section *Indiogofera* pollen appears for the first time. A very low percentage (<2-3%) of *Tribulus* indicate disturbance in this section of the profile (Coetzee, 1967).

Within the samples of the Central Block there are two sections present where pollen are completely absent and only high numbers of charcoal occur (Figure11.4). The first section (45 cm – 61 cm) overlaps with the samples from the Secondary mound in terms of depth. Thus, the high presence of charcoal might indicate that fire during this time played a significant role in shaping the vegetation. The light grey sand (95 cm – 119 cm) from the central block Figure 11.4 had no pollen, but abundant numbers of charcoal are present in the samples perhaps as result of selective preservation.

When looking at the pollen section described above it is clear that the pollen percentage of Poaceae decrease and that Asteraceae and Cheno/Ams increase (115 – 128 cm with an age of early Holocene/late Pleistocene). When Cheno/Ams are abundant, both the relative proportion of Asteraceae and Poaceae may decrease but this does not necessarily reflect change in their actual cover in the vegetation because Cheno/Ams may reflect local disturbance or increase in salinity. However, in the case of Baden-Baden only the Poaceae decreased. The strong presence of Cheno/Ams in this section may be indicative of dry pan shore conditions (Scott, 1988; Scott and Nyakale, 2002), strong evaporative environments (Holmgren *et al.*, 2003; Scott *et al.*, 2012), dry pan floor elements (Scott and Rossouw, 2005) or dry regions with saline habitats (Coetzee, 1967; Koekemoer *et al.*, 2014). The increase in Asteraceae pollen in grasslands should be interpreted as evenly distributed seasonal moisture or cooler growth season under dry conditions (Scott and Nyakale, 2002; Scott *et al.*, 2005). Thus, the environment during this time was dry but might have been the result of a different seasonal moisture distribution with the growth seasons shifted towards winter.

Figure 11.6: Trench 3 being excavated.

The last site was Trench 3, (Figure 11.6) the pollen was dated to be older than 25 820 ± 14 00 yrs, thus isotope stage 2 (Figure 11.4). This site was dated using OSL dating at the Quaternary Dating Research Unit (QUADRU) at the CSIR in Pretoria. This pollen is present in the special trench at a depth of between 143 cm and 193 cm.

The Poaceae have the highest occurrence during this time. During this time fynbos vegetation components such as *Passerina* and *Stoebe* type pollen occurred in the pollen diagram. *Passerina* is mostly present in the highlands in the eastern parts of southern Africa in association with C_3 grasses (Scott, 2002b). Pollen from *Stoebe*-type which are absent from Florisbad's pollen diagrams indicate cooler, wetter conditions (Scott and Rossouw, 2005; Scott *et al.,* 2012). These cooler conditions can be confirmed by results from the Wonderkrater and Tswaing Crater, where Scott (1999) found *Artemisia, Stoebe* and *Passerina* and Ericaceae to occur together during cooler times. During isotope stage 2 there is also a marked decrease in the Cheno/Ams pollen. The presence of Cyperaceae and Apiaceae were low during this time, which might be indicative of a less local small spring due to the moist conditions of the surrounding environment. The presence of greenish grey sediment layers in Trench 3 is indicative of standing water present during this time (Van Aardt *et al*., 2015). Isotope stage 2 is thus represented for the first time in the western parts of the Free State with the presence of speciesof the genera *Stoebe*, *Passerina* and the high percentage of grasses.

The charcoal percentage of Trench 3 was low in the samples where pollen was present. This might further indicate a cool wet climate where fire did not play a significant role.

When looking at the pollen diagram (Figure 11.4) the charcoal shows relative high percentage values. However, when calculating the concentrations of pollen and charcoal it is clear that the pollen concentration is much higher than the charcoal concentrations. The concentrations from the secondary spring mounds show the same trends, although the pollen concentration is much higher than the charcoal concentration. From figure 11.7 it is also clear that the pollen decline towards the surface of the secondary spring mounds.

The Central block (Figure 11.7) section again starts with charcoal present in the absence of pollen, however in low concentrations. This may be an indication of selective preservation where pollen was removed by oxidation while some microscopic charcoal still remain. This is also the case for the grey sand with a depth of between 95 cm and 119 cm. Between the two charcoal containing depths and towards the end of the profile; the pollen and charcoal show similar patterns.

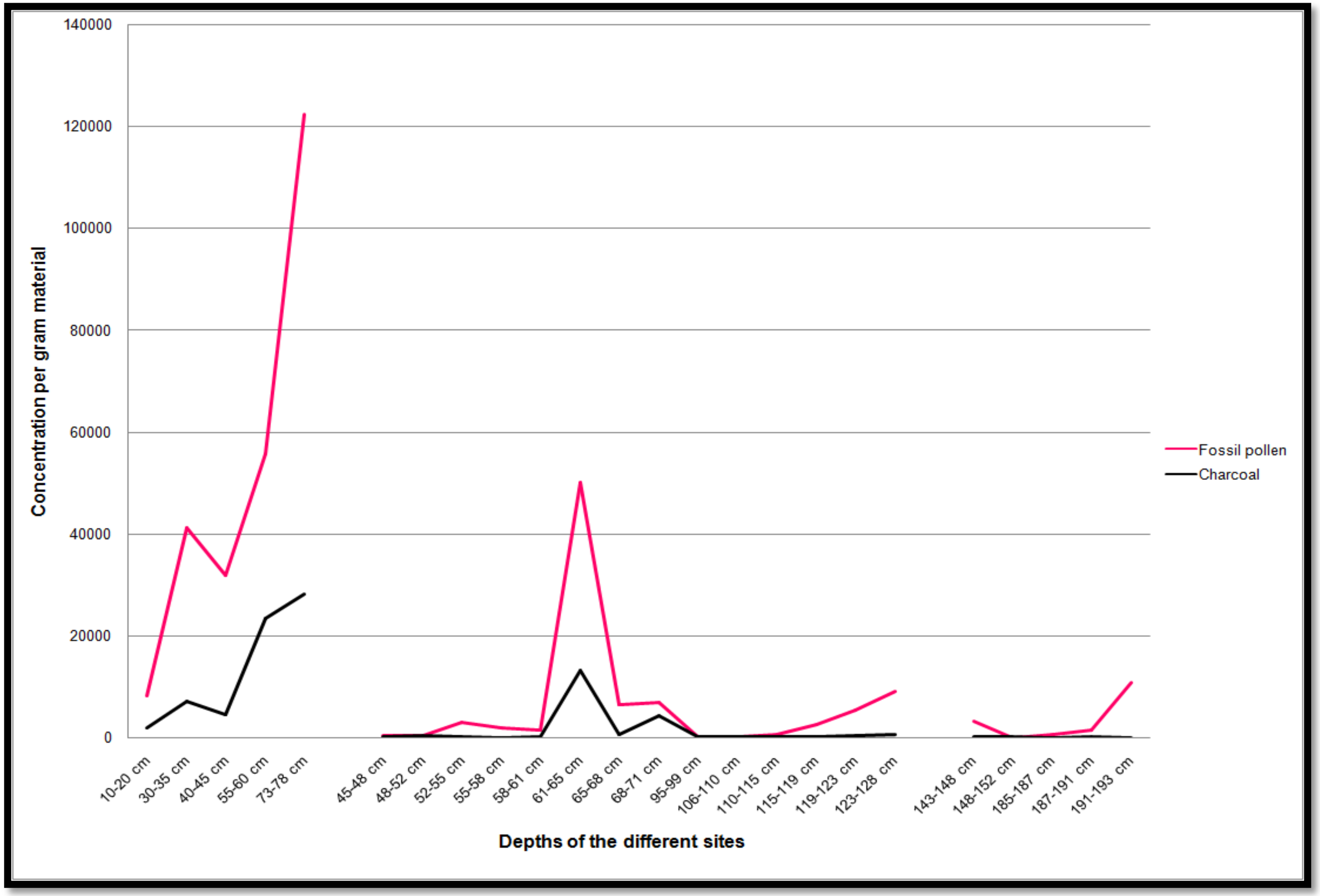

Figure 11.7: Graph of the fossil pollen and charcoal concentrations per gram in the different samples of the different sites.

The pollen concentration in Trench 3 (Figure 11.6) is the lowest of all the sites present at Baden-Baden. The trend of the pollen and the charcoal (Figure 11.7) are again the same. When the pollen concentration increases, the charcoal also increases.

11.6 CONCLUSION

Sites such as Baden-Baden are rare in the semi-arid to arid climates. Baden-Baden therefore, contributes valuable information to the difficulty in the reconstruction of palaeo-environmental histories (Scott *et al.*, 1997). An alternative is to look for hyrax dung deposits that trap fossil pollen (Scott, 1996; Gil-Romera *et al.*, 2007) but the right kind of rocky outcrops are scarce in the western Free State.

The preliminary results indicate alternating dry and wet periods at Baden-Baden. This pattern is also observed at Florisbad (Scott and Nyakale, 2002) and in older sequences from that site (Van Zinderen Bakker, 1989). Baden-Baden deposits also provide indications of vegetation from the last glacial period (isotope stage 2; older than 25 820 yr BP). Future work at this site will thus, make a valuable contribution towards the understanding of palaeo-environmental conditions in the central parts of South Africa; filling in gaps in the South African palaeoenvironmental records because, for instance, data from Florisbad only provide insights into the last 8 170 yr BP (Scott and Nyakale, 2002) but shows a major gap for the late and Middle Pleistocene (Van Zinderen Bakker, 1989; Grün *et al*., 1996); Deelpan can only contribute data for the last 4 000 yr BP; data from the Tswaing Crater more or less 550 kilometres north of the study areab (north of Pretoria), has a gap between 7 200 and 31 000 yr BP which is partially filled by data from 7 000 to 14 000 and 20 000 to 25 000 yr BP obtained from the Wonderkrater (Scott 1999). Thus, future research on the sediments found at Baden-Baden promise to fill gaps in the palaeo-environmental records of the above mentioned sites. The sedimentary deposits at Baden-Baden will contribute towards information to complete the picture of environmental changes in the interior of South Africa.

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SECTION IV




CHAPTER 12
GENERAL DISCUSSION AND CONCLUSIONS

Due to human impacts as well as the cycles of nature, it is important to keep track of on-going changes in the western Free State's ecosystems and environment as part of the global system. This study lays the foundation for describing the current situation in terms of the vegetation and to assess the potential for investigating past vegetation changes that could eventually give us a predictive ability for what to expect in future, either as a result of climate change or anthropological activities.

From the literature (Section I) it is clear that the geological changes prior and during the fragmentation of Gondwana, left its imprints on the geology and climate of southern Africa. To some extent, the geology influenced the changes in climate, which in turn influenced the evolution of the vegetation of the continent. Locally the vegetation can also have an influence on the micro-climate of an area. The literature review indicated that palaeo-ontological and palynological information about long-term vegetation change that extends into the Neogene is mostly limited to regions close to or at the coastal areas of South Africa. However, only a few sites for the reconstruction of long-term vegetation changes are present in the interior parts of South Africa. This is due to the fact that the environmental conditions in the interior (especially) the western Free State are not favourable for the preservation of macro- and micro-plant fossils. Not only is it difficult to find sites, which are useful for the reconstruction of the vegetation history in the area, but there is also uncertainty about the development of the landscape in the western Free State. The western Free State landscape, with its numerous pans as a characteristic feature, is still poorly understood and to date has not been properly resolved. The proposal for the existence of two putative palaeo-rivers, the Palaeo-Kimberley and Palaeo-Modder Rivers (Marshall, 1988) is an interesting proposal that needs to be investigated further. This proposal by Marshall (1988) is based on morphotectonic analysis and the interpretation of LANDSAT images (Chapter 4).

With the proposed existence of these two palaeo-rivers in mind this research was intended to find sedimentary evidence of the palaeo-rivers that might contain evidence of the history of the natural vegetation during that time that the rivers might have existed. It was, however, found that it is highly unlikely that any Neogene or older Cainozoic deposits, containing fossil plant material from that time, will be found. This is, due to long-term processes of erosion that would have removed them. Some rare, younger pollen-bearing deposits that post-date the rivers are, however, available for providing evidence of more recent late-Pleistocene environmental conditions that could have led to the current situation. It was proposed that the Baden-Baden spring site can contribute towards the understanding of the more recent history of the study area. The aims of this study are presented in Chapter 1.

The assessment, classification and description of the natural vegetation is given in chapters 8, 9 and 10 and a summary of the vegetation communities of the western Free State are presented in Table 12.1. The vegetation can be divided into wetland, grassland and karroid communities as well as woody communities. This division of the communities is confirmed by the DCA ordination diagram (Figure 12.1).

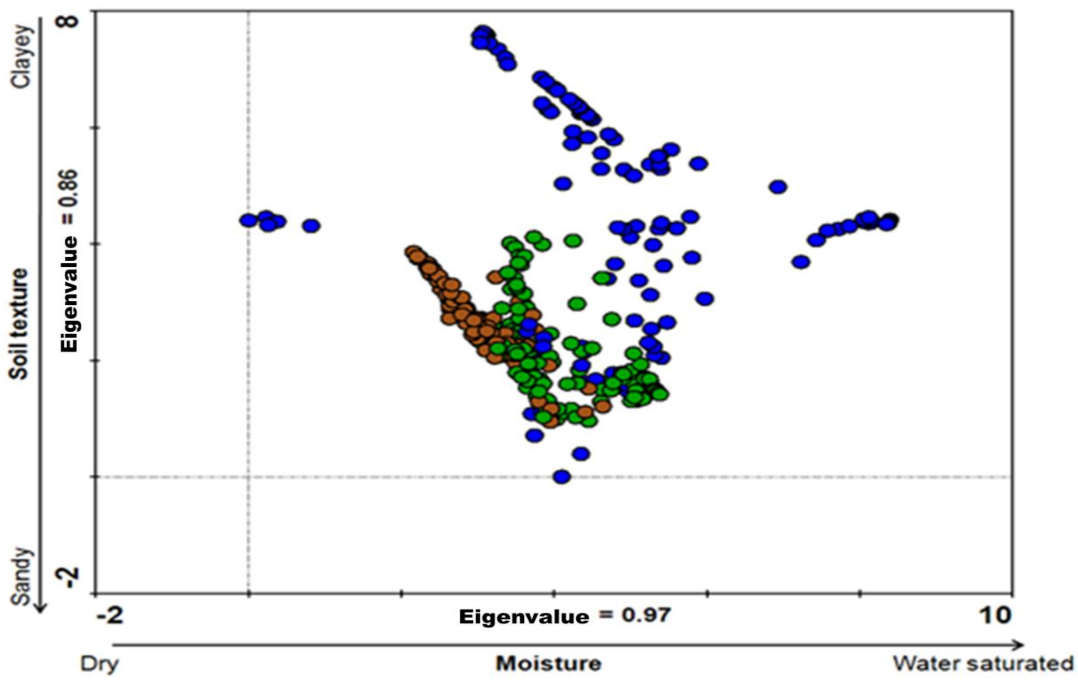

Figure 12.1: Ordination diagram of all the relevés present in the area of study. The blue dots are the water related relevés, the green dots are the karroid and grassland relevés and the brown dots are the woody relevés.

The wetland related communities can be divided into nine communities mostly dominated by grasses, sedges, forbs and hydrophytic or aquatic vegetation. The nine communities can be divided according to the moisture content of the soil and the disturbance as described in Chapter 8. Communities 1, 3 and 9 occur in areas that are mostly dry, only with saturated condition during years with above average rainfall. The species that dominate these communities are: *Cynodon transvaalensis* (Species group A), *Suaeda merxmuelleri* (Species group E) and **Phyla nodiflora* (Species group P). Between these three communities, communities 1 and 9 are severely degraded, mostly dominated by pioneer grasses such as *Cynodon transvaalensis* (Species group A), *Cynodon dactylon* and *Tragus berteronianus* (Species group AX). Community 3 is relatively undisturbed. Communities 2, 6, 7 and 8 occur in areas close to water or areas which are inundated during the rainy season. These communities are exposed to moist soil conditions for large parts of the year, and will be flooded during the rainy season or even during years with above average rainfall. These communities are dominated by *Sporobolus ludwigi* (Species group B), and *Leptochloa fusca* (Species group F), *Cynodon hirsutus* (Species group K), *Limosella longiflora* (Species group L), *Juncus rigidus* (Species group O). The disturbance in these communities is moderately as these communities are mostly used for winter grazing by livestock. Communities 4 and 5 occur in water saturated conditions, thus water are present throughout the year. In the area of study these communities occur around natural springs. The species that dominate these communities are; *Berula erecta, Eleocharis limosa, Agrostis lachnantha* (Species group G), *Marsilea burchellii* (Species group I) and *Potamogeton* sp (Species group H). These communities are moderately disturbed as animals graze in these areas. From this it is clear that the water-related communities in the study area are mostly defined in terms of the amount of moisture present. Water can thus be seen as the determining factor affecting the distribution of these communities.

The grassland and karroid communities can be divided into ten different communities. The plants in these communities are mostly grasses, shrubs and forbs occurring on the edges of pans, the plains and lunette dunes in the area of study. The soil texture mostly influenced the grassland and karroid communities. The degree of drainage also affected the distribution of the different communities.

The communities found on the plains and lunette dunes were well drained in contrast to the communities on the edges of the pans. Communities 10 and 12-19 can be seen as Grassland/Karroid communities because they are mostly dominated by grasses with the presence of shrubs in between. When considering the overall study area they look like pure grasslands, but with closer inspection it can be seen that the shrubby components present reveal some karroid characteristics. The dominant species in the different grassland/karroid communities are: (10) *Elionurus muticus* and *Eragrostis curvula* (Species group R); (12) *Stachys spathulata* and *Eragrostis chloromelas* (Species group V); (13) *Rosenia humilis* (Species group V) and *Tragus koelerioides* (Species group AV); (14) *Amaranthus thunbergii* (Species group AW); (15) *Sesamum triphyllum* (Species group W) as well as *Oropetium capense* and *Amaranthus *caudatus* (Species group X); (16) *Eragrostis biflora* (Species group AY); (17) *Chrysocoma ciliata, Aptosimum procumbens, Selago densiflora* and *Hyparrhenia hirta* (Species group AU); (18) *Eriocephalus spinescens* (Species group AO), *Enneapogon desvauxii* (Species group AT) and *Chloris virgata* (Species group AW) and (19) *Cynodon dactylon* (Species group AX). The different grassland/karroid communities occur on soils with various textures, amounts of rocks and drainage ranging from poor to well-drained.

The only karroid community on Table 12.1 is community 11 because of the dominance of shrubs. This community occur in the most western parts of the study area. The dominate plants in this community are the shrub *Zygophyllum microcarpum* (Species group S) and the forb *Stachys hyssopoides* (Species group T). *Zygophyllum microcarpum* occur with 100% fidelity, exclusively in this community. This karroid community occur on sandy soils with a relative good drainage.

The grasslands on the plains are mostly used for agricultural purposes (cultivation and grazing of either livestock or game). Few areas in the grasslands are completely covered with the climax grass *Themeda triandra*, which are known to be an indication of good veld conditions. The occurrence of grasses such as *Cynodon dactylon, Chloris virgata* and *Tragus* species are much more prominent. This might be due to the dry climate of the western Free State which goes hand in hand with a low rainfall. There are however, small patches dominated by *T.triandra*, mostly occurring on clayey soils which might indicate that *T.triandra* occur in areas where water are abundant.

The woody communities were mostly restricted to the dolerite outcrops of the study area. However, some woody communities occur on the foot-slopes as well as on the plains in the most western parts of the study area. The woody communities can be divided into five different communities. Community 20 is dominated by *Dicoma schinzii* (Species group AD) and *Vachellia hebeclada* (Species group AI). It occurs in the most western parts of the study area on soils with a medium depth with a loamy texture. Community 21 occurs on shallow to deep sandy to loamy soils. Community 21 is distinguished by the presence of species from species group AF. Community 22 occurs in shallow soils with a loamy texture on dolerite outcrops. This community is dominated by species from species groups AG and AH. Community 23 is dominated by *Vachellia tortilis* (Species group AO) and mostly occur on shallow clayey soils in the area of study. This community is restricted to the plains of the study area and does not occur on the dolerite outcrops. Community 24 occurs on sandy to loamy soils with a medium depth (1 – 1.5 m) in the study area and is distinguished by the strong presence of the tree *Searsia lancea* (Species group AQ).

Thus the vegetation in the north-western Free State can be divided into definite units by looking at the different terrain units as mentioned above. The different terrain units in the study area support different plant communities. From this study it is also clear that the soil texture affects the grassland and karroid communities as well as the woody communities. The different wetland communities are affected by the degree of wetness.

For further research it is suggested that a more detailed soil texture analysis as well as chemical analysis of the soil need to be done to help interpret the phytosociological classification. This study then provides new information, in terms of the vegetation, regarding the whole of the north-western Free State in contrast to the sections done by previous researchers as mentioned in Chapter 1. However, some of the communities show resemblance to the Veld Types described by Acocks (1988). These resemblances were discussed in the description of the different communities.

With the present-day vegetation described above, this study also attempted to investigate the nature and influence of vegetation that existed in the past. The preliminary results at this site indicate the potential to fill gaps in the data from sites in the vicinity such as Erfkroon, Florisbad and Alexandersfontein (Figure 12.2). The presence of fynbos elements (*Stoebe*-type and *Passerina*) in the palynological records at Baden-Baden during the late Quaternary (*c.* 25 000 years ago) reveals a striking difference in the vegetation composition. At present the nearest fynbos vegetation elements occur in the eastern Free State. This palynological result reveals a change from cooler climates to the current warmer conditions at Baden-Baden. Previous palynological work from diverse areas such as Aliwal North (Coetzee, 1967) and from Naboomspruit (Scott, 1982; Scott *et al.,* 2012) mentioned that the presence of fynbos elements e.g. *Stoebe*-type indicates cooler and more humid conditions than at present. The species in this pollen type cannot be identified and might include *Elytropappus*, from sites including Wonderkrater near Naboomspruit (Scott, 1982), Wonderwerk Cave near Kuruman (Brooke *et al*., 2010), Equus Cave near Taung (Scott, 1987) and even at the Brandberg in Namibia (Scott *et al.*, 2004), indicated that Asteraceae producing this pollen type were regionally prominent during the cool phases of the Last Glacial Maximum. In drier areas like Baden-Baden and further to the west, this pollen was accompanied by *Passerina* and in the wetter areas to the east by more diverse fynbos that included Ericaceae and *Cliffortia* (Scott, 1987). Although rare fynbos elements such as Restionaceae, Ericaceae and high numbers of Asteraceae pollen (Van Zinderen Bakker, 1955) were present in the Florisbad sequence, the ages thereof is uncertain (Scott and Rossouw, 2005). Scott and Rossouw (2005) mentioned that the high number of Asteraceae pollen present at Florisbad might include *Stoebe*-type (a fynbos element) which was not specified by Van Zinderen Bakker. The presence of *Stoebe*-type at Florisbad can only be confirmed in new research, which will then indicate that *Stoebe*-type was present in the Free State. The preliminary results found at Baden-Baden and the results from the phytosociological study indicate that there must have been remarkable changes in the vegetation since the Quaternary.

The preliminary palynological data from Baden-Baden only represent certain plant families or some genera present during the past and therefore one cannot determine the different plant communities present at the late Pleistocene/early Holocene.

Furthermore, it is difficult to separate the pollen that was blown in from a distance or whether it is of local origin, although one can form an idea from the amounts of aquatics (Apiaceae and Cyperaceae) or pan-floor elements (Chenopodiaceae (nowadays included in Amaranthaceae), Amaranthaceae, etc.). Comparing palynology and phytosociology is possible; however, the comparison is not that accurate due to the undiagnostic nature of pollen taxonomy. One can only attempt to use the palynological data to reconstruct the palaeo-climatic conditions that prevailed in the past on the basis of the pollen deposition and bring that into perspective with the existence of present-day genus or family distributions and the climatic conditions under which the families prevail. The additional information gathered from disciplines (archaeology, geology, geochemistry and palaeontology) can contribute towards the reconstruction of the palaeo-environments.

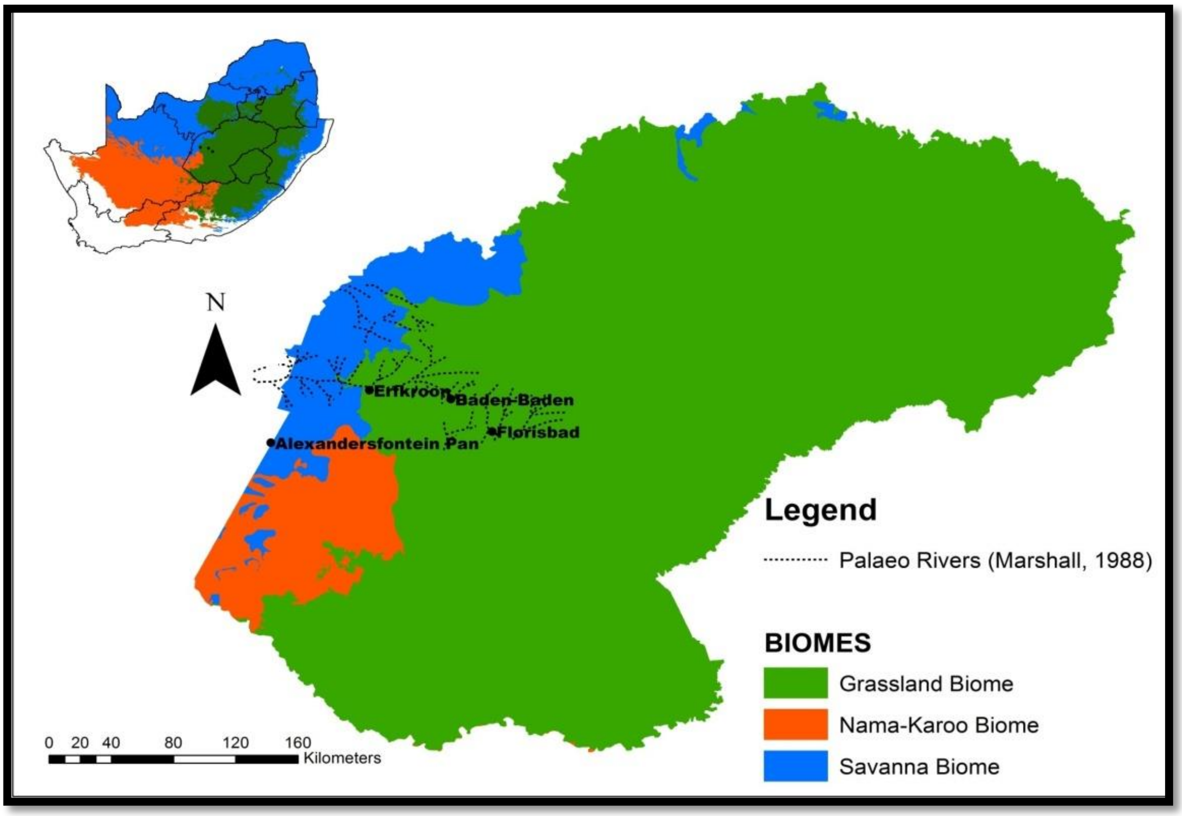

Figure 12.2: Map of the Free State showing the sites in the western Free State as well as the palaeo-rivers with the present-day biomes as the background.

When looking at the putative palaeo-rivers proposed by Marshall (1988) in Figure 12.2, her suggestions for the existence of the rivers might not be unrealistic. The springs found at Florisbad and Baden-Baden occurs on the edges of tributaries of these putative palaeo-rivers. If the continent was tilted towards the north-west then these springs could have added water to these rivers. However, Marshall (1988) proposed that the continent tilted towards the south-east due to the upliftment along the Griqualand-Transvaal Axis. During this time communities similar to the wetland communities, found in the phytosociological study, could have been more numerous during wetter periods such as proposed by Butzer *et al.* (1973) due to the presence of more standing water along the drainage lines and thus, different riparian habitats. The water bodies could have been either flowing or stagnant with plants adapted to the different conditions around them. Palynological data from the south-western Cape indicate the existence of sub-tropical vegetation (conifer forests and palm-dominated forests) during the early Miocene to the early Pliocene (Coetzee, 1978; 1983).

This study is unique due to the fact that palynology and phytosociology both contributed towards the understanding of vegetation development in the western Free State. However, the palynological results are only preliminary and research at Baden-Baden will continue in future. Baden-Baden will be useful in determining the development of the Grassland Biome in the central and western parts of the Free State. By using both palynological and phytosociological knowledge one might be able to understand the changes in climate during the past to make predictions for the future.

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APPENDIX A

Adapted geological timescale as presented by McCarthy and Rubidge (2005) and Johnson *et al.* (2006)

Mya	EPOCH (SERIES)	PERIOD		ERA	EON
1.8	Holocene, Pleistocene	Quaternary		Cenozoic	Phanerozoic
5	Pliocene	Neogene*	Tertiary	Cenozoic	Phanerozoic
23	Miocene	Neogene*	Tertiary	Cenozoic	Phanerozoic
34	Oligocene	Palaeogene*	Tertiary	Cenozoic	Phanerozoic
56	Eocene	Palaeogene*	Tertiary	Cenozoic	Phanerozoic
65	Palaeocene	Palaeogene*	Tertiary	Cenozoic	Phanerozoic
145		Cretaceous		Mesozoic	Phanerozoic
200		Jurassic		Mesozoic	Phanerozoic
250		Triassic		Mesozoic	Phanerozoic
300		Permian		Palaeozoic	Phanerozoic
360		Carboniferous		Palaeozoic	Phanerozoic
416		Devonian		Palaeozoic	Phanerozoic
444		Silurian		Palaeozoic	Phanerozoic
490		Ordovician		Palaeozoic	Phanerozoic
545		Cambrian		Palaeozoic	Phanerozoic
1000				Neo-Proterozoic	Proterozoic
1600				Meso-Proterozoic	Proterozoic
2050 2500				Palaeo-Proterozoic	Proterozoic
					Archaean

* Indicate sub-periods

APPENDIX B
SPECIES LIST

PTERIDOPHYTA

Marsileaceae

Marsilea L.

M. burchellii (Kunze) A.Braun

Sinopteridaceae (Pteridaceae)

Cheilanthes Sw.

C. eckloniana (Kunze) Mett.

C. hirta Sw. var. *hirta*

Pellaea Link

P. calomelanos (Sw.) Link var. *calomelanos*

GYMNOSPERMS

Cupressaceae

**Cupressus* L.

*C. *arizonica* Greene var. *arizonica*

EUDICOTS

Acanthaceae

Barleria L.

B. macrostegia Nees

Crabbea Harv.

C. acaulis N.E.Br.

Aizoaceae

Plinthus Fenzl

P. karooicus I.Verd.

Amaranthaceae

Alternanthera Forssk.

*A. *pungens* Kunth

*A. *sessilis* (L.) DC.

Alternanthera sp.

Amaranthus L.

*A. *caudatus* L.

A. thunbergii Moq.

Cyathula Blume

C. uncinulata (Schrad.) Schinz

Gomphrena L.

*G. *celosioides* Mart.

Guilleminea Kunth

G. densa (Willd. ex Roem. & Schult.) Moq.

Kyphocarpa (Fenzl) Lopr.

K. angustifolia (Moq.) Lopr.

Pupalia Juss.

P. lappacea (L.) A.Juss.

Anacardiaceae

Schinus L.

*S. *molle* L.

Searsia F.A.Barkley

S. burchellii (Sond. ex Engl.) Moffett (*Rhus burchellii*)

S. ciliata (Licht. ex Schult.) A.J.Mill. (*Rhus ciliata*)

S. lancea (L.f.) F.A.Barkley (*Rhus lancea*)

Apiaceae

Berula W.D.J.Koch

B. erecta (Huds.) Coville

Bupleurum L.

B. mundii Cham. & Schltdl.

Apocynaceae

Gomphocarpus R.Br.

G. fruticosus (L.) Aiton f.

Pachypodium Lindl.

P. succulentum (Jacq.) Sweet

Sarcostemma R.Br.

S. viminale (L.) R.Br.

Araliaceae

Cussonia Thunb.

C. paniculata Eckl. & Zeyh.

Asteraceae

Amphiglossa DC.

A. triflora DC. (*Pterothrix spinescens/Helichryxum armatum*)

Berkheya Ehrh.

B. pinnatifida (Thunb.) Thell.

Bidens L.

*B. *pilosa* L.

Chrysocoma L.

C. ciliata L.

Conyza Less.
*C. *bonariensis* (L.) Cronquist
C. podocephala DC.

**Cirsium* Mill. emend. Scop
*C. *vulgare* (Savi) Ten.

Dicoma Cass.
D. anomala Sond.
D. macrocephala DC.
D. schinzii O.Hoffm.

Eriocephalus L.
E. spinescens Burch.

Felicia Cass.
F. muricata (Thunb.) Nees
F. ovata (Thunb.) Compton

Geigeria Griess.
G. filifolia Mattf.
G. ornativa O.Hoffm.

Gnaphalium L.
G. declinatum L.f.

Helichrysum Mill.
H. dregeanum Sond. & Harv.
H. lineare DC.

Hertia Less.
H. pallens (DC.) Kuntze (*Othonna albicaulis*)

Kleinia Mill.
K. longiflora DC. (*Senecio longiflorus*)

Lactuca L.
L. inermis Forssk.
L. **serriola* L.

Nidorella Cass.
N. hottentotica DC.

Nolletia Cass.
N. ciliaris (DC.) Steetz

Osteospermum L.
O. muricatum E.Mey. ex DC.

Pentzia Thunb.
P. globosa Less.
P. incana (Thunb.) Kuntze
P. sphaerocephala DC.

Pseudognaphalium Kirp.
P. **luteo-album* (L.) Hilliard & B.L.Burtt
P. oligandrum (DC.) Hilliard & B.L.Burtt

Rosenia Thunb. emend. K.Bremer
R. humilis (Less.) K.Bremer

**Schkuhria* Roth
S. **pinnata* (Lam.) Kuntze ex Thell.

Senecio L.
S. burchellii DC.
S. hastatus L.

Sonchus L.
*S. *asper* (L.) Hill

**Tagetes* L.
*T. *minuta* L.

**Taraxacum* F.H.Wigg.
*T. *officinale* Weber

Tarchonanthus L.
T. camphoratus L.

Tripteris Less.
T. auriculata S.Moore (*Osteospermum auriculatum*)

**Xanthium* L.
*X. *spinosum* L.

Basellaceae
**Anredera* Juss.
*A. *cordifolia* (Ten.) Steenis

Bignoniaceae
Rhigozum Burch.
R. obovatum Burch.

Boraginaceae
Ehretia P.Browne
E. rigida (Thunb.) Druce

Heliotropium L.
H. lineare (A.DC.) Gürke

Brassicaceae

Heliophila L.

H. carnosa (Thunb.) Steud.

H. dregeana Sond.

Sisymbrium L.

S. burchellii DC.

Buddlejaceae

Buddleja L.

B. saligna Willd.

Cactaceae

**Opuntia* Mill.

*O. *ficus-indica* (L.) Mill.

Campanulaceae

Wahlenbergia Schrad. ex Roth

W. androsacea A.DC.

W. nodosa (H.Buek) Lammers

Capparaceae

Cleome L.

C. rubella Burch.

Caryophyllaceae

Dianthus L.

D. basuticus Burtt Davy

Pollichia Aiton

P. campestris Aiton

Silene L.

S. undulata Aiton

Celastraceae

Gymnosporia (Wight & Arn.) Hook.f.

G. karooica M.Jordaan

Chenopodiaceae

Atriplex L.

A. semibaccata R.Br.

Chenopodium L.

C. **album* L.

C. **murale* L.

Salsola L.

S. aphylla L.f.

S. glabrescens Burtt Davy

Suaeda Forssk. ex J.F.Gmel.

S. merxmuelleri Aellen

Convolvulaceae

**Dichondra* J.R. & G.Forst.

D. **micrantha* Urb. (*Dichondra repens*)

Ipomoea L.

I. bathycolpos Hallier f.

I. oenotheroides (L.f.) Raf. ex Hallier f.

Crassulaceae

Crassula L.

C. setulosa Harv.

C. **vaillantii* (Willd.) Roth

Cucurbitaceae

Coccinia Wight & Arn.

C. sessilifolia (Sond.) Cogn.

Kedrostis Medik.

K. africana (L.) Cogn.

Dipsacaceae

Scabiosa L.

S. columbaria L.

Ebenaceae

Diospyros L.

D. austro-africana De Winter

D. lycioides Desf.

Euclea Murray

E. crispa (Thunb.) Gürke subsp. *ovata* (Burch.) F.White

Euphorbiaceae

Euphorbia L.

E. inaequilatera Sond. (*Chamaesyce inaequilatera*)

E. spartaria N.E.Br

Fabaceae

Elephantorrhiza Benth.

E. elephantina (Burch.) Skeels

Indigofera L.

I. alternans DC.

I. filipes Benth. ex Harv.

I. rhytidocarpa Benth. ex Harv.

Lessertia DC.
L. pauciflora Harv.

Lotononis (DC.) Eckl. & Zeyh.
L. burchellii Benth.
L. eriantha Benth.
L. laxa Eckl. & Zeyh.

Medicago L.
*M. *laciniata* (L.) Mill.

Melolobium Eckl. & Zeyh.
M. candicans (E.Mey.) Eckl. & Zeyh.

**Prosopis* L.
*P. *velutina* Wooton

Rhynchosia Lour.
R. totta (Thunb.) DC.

Senegalia Raf.
S. mellifera (Vahl) Seigler & Ebinger (*Acacia mellifera*)

Tephrosia Pers.
T. capensis (Jacq.) Pers.

Vachellia Wight & Arn.
V. erioloba (E.Mey.) P.J.H.Hurter (*Acacia erioloba*)
V. hebeclada (DC.) Kyal. & Boatwr. (*Acacia hebeclada*)
V. karroo (Hayne) Banfi & Galasso (*Acacia karroo*)
V. tortilis (Forssk.) Galasso & Banfi (*Acacia tortilis*)

Frankeniaceae

Frankenia L.

F. pulverulenta L.

Geraniaceae

Monsonia L.

M. angustifolia E.Mey. ex A.Rich.

Pelargonium L'Hér ex Aiton

P. myrrhifolium (L.) L'Hér.

Lamiaceae

Mentha L.

M. longifolia (L.) Huds.

Salvia L.

S. runcinata L.f.

S. verbenaca L.

Stachys L.

S. burchelliana Launert

S. hyssopoides Burch. ex Benth.

S. linearis Burch. ex Benth.

S. spathulata Burch. ex Benth.

Lobeliaceae

Lobelia L.

L. thermalis Thunb.

Malvaceae

Grewia L.

G. flava DC.

G. occidentalis L.

Hermannia L.
H. cuneifolia Jacq.
H. depressa N.E.Br
H. jacobeifolia (Turcz.) R.A.Dyer

Hibiscus L.
H. pusillus Thunb.
*H. *trionum* L.

Pavonia Cav.
P. burchellii (DC.) R.A.Dyer

Sida L.
S. dregei Burtt Davy

Meliaceae
**Melia* L.
*M. *azedarach* L.

Mesembryanthemaceae
Malephora N.E.Br.
M. cf. *crocea* (Jacq.) Schwantes

Mestoklema N.E.Br. ex Glen
M. arboriforme (Burch.) N.E.Br. ex Glen

Nananthus N.E.Br.
N. aloides (Haw.) Schwantes
N. vittatus (N.E.Br.) Schwantes

Ruschia Schwantes
R. hamata (L.Bolus) Schwantes

Molluginaceae

Hypertelis E.Mey. ex Fenzl

H. salsoloides (Burch.) Adamson

Limeum L.

L. aethiopicum Burm.

L. africanum L.

Myrtaceae

**Eucalyptus* L'Hér.

*E. *camaldulensis* Dehnh.

Oleaceae

Olea L.

O. europaea L. subsp. *africana* (Mill.) P.S.Green

Onagraceae

**Oenothera* L.

*O. *rosea* L'Hér. ex Aiton

Oxalidaceae

Oxalis L.

*O. *corniculata* L.

Pedaliaceae

Sesamum L.

S. triphyllum Welw. ex Asch.

Phyllanthaceae

Phyllanthus L.

P. parvulus Sond.

Plantaginaceae

Plantago L.

*P. *major* L.

Polygonaceae

Persicaria L. Mill

*P. *lapathifolia* (L.) Gray

Polygonum L.

*P. *aviculare* L.

Ranunculaceae

Ranunculus L.

*R. *multifidus* Forssk.

Resedaceae

Reseda L.

R. lutea L.

Rhamnaceae

Ziziphus Mill.

Z. mucronata Willd.

Rubiaceae

Galium L.

G. capense Thunb.

Kohautia Cham. & Schltdl.

K. amatymbica Eckl. & Zeyh.

Nenax Gaertn.

N. microphylla (Sond.) T.M.Salter

Salicaceae

**Populus* L.

P. x **canescens* (Aiton) Sm.

Salix L.

*S. *babylonica* L.

Santalaceae

Osyris L.

O. lanceolata Hochst. & Steud.

Thesium L.

T. costatum A.W.Hill

T. hystrix A.W.Hill

Scrophulariaceae

Aptosimum Burch. ex Benth.

A. procumbens (Lehm.) Steud.

Chaenostoma Benth.

C. caeruleum (L.F.) Kornhall (*Sutera caerulea*)

Jamesbrittenia Kuntze

J. aurantiaca (Burch.) Hilliard

Limosella L.

L. africana Glück

L. longiflora Kuntze

Selago L.

S. albida Choisy

S. densiflora Rolfe

Solanaceae

**Datura* L.

*D. *stramonium* L.

Lycium L.

L. cinereum Thunb.

L. hirsutum Dunal

L. horridum Thunb.

L. pilifolium C.H. Wright

**Physalis* L.

P. **angulata* L.

Solanum L.

S. lichtensteinii Willd.

S. **nigrum* L.

S. **pseudocapsicum* L.

S. retroflexum Dunal

S. supinum Dunal

Vahliaceae

Vahlia Thunb.

V. capensis (L.f.) Thunb.

Verbenaceae

Chascanum E.Mey.

C. hederaceum (Sond.) Moldenke

C. pinnatifidum (L.f.) E.Mey

Lantana L.

L. rugosa Thunb.

**Phyla* Lour.

P. **nodiflora* (L.) Greene

**Verbena* L.

V. **bonariensis* L.

V. **brasiliensis* Vell.

Zygophyllaceae

Tribulus L.

T. terrestris L.

Zygophyllum L.

Z. microcarpum Licht. ex Cham. & Schltdl

<u>MONOCOTS</u>

***Agavaceae**

**Agave* L.

*A. * americana* L.

Amaryllidaceae

Haemanthus L.

H. humilis Jacq.

Asparagaceae

Asparagus L.

A. africanus Lam.

A. cooperi Baker

A. glaucus Kies

A. suaveolens Burch.

Asphodelaceae

Aloe L.

A. grandidentata Salm-Dyck

Trachyandra Kunth

T. asperata Kunth

Commelinaceae

Commelina L.

C. africana L.

Cyperaceae

Bulbostylis Kunth

B. humilis (Kunth) C.B.Clarke

Cyperus L.

C. atriceps (Kük.) C.Archer & Goetgh.

C. capensis (Steud.) Endl.

C. denudatus L.f.

C. difformis L.

C. esculentus L.

C. longus L.

C. marginatus Thunb.

C. rupestris Kunth

C. usitatus Burch.

Eleocharis R.Br.

E. dregeana Steud.

E. limosa (Schrad.) Schult.

Ficinia Schrad.

F. nodosa (Rottb.) Goetgh., Muasya & D.A. Simpson

Isolepis R.Br.

I. cernua (Vahl) Roem. & Schult.

I. costata Hochst. ex A.Rich.

I. diabolica (Steud.) Schard.

Kyllinga Rottb.

K. alba Nees

Kyllinga sp.

Pycreus P.Beauv.
Pycreus sp.

Schoenoplectus (Rchb.) Palla
S. muricinux (C.B.Clarke) J.Raynal
cf. *S. *tabernaemontani* (C.C.Gmel.) Palla

Scirpoides Ség.
S. dioecus (Kunth) Browning

Scirpus L.
Scirpus sp.

Eriospermaceae
Eriospermum Jacq. ex Willd.
E. cooperi Baker

Hyacinthaceae
Albuca L.
A. setose Jacq.
A. shawii Baker

Dipcadi Medik.
D. viride (L.) Moench

Drimia Jacq. ex Willd
D. angustifolia Baker

Iridaceae
Duthieastrum M.P.de Vos
D. linifolium (E.Phillips) M.P.de Vos

Moraea Mill.
M. pallida (Baker) Goldblatt

Juncaceae

Juncus L.

J. rigidus Desf.

Lemnaceae

Lemna L.

L. gibba L.

Poaceae

Agrostis L.

A. lachnantha Nees

Aristida *L.*

A. bipartita (Nees) Trin. & Rupr.

A. canescens Henrard

A. congesta Roem. & Schult.

A. diffusa Trin.

Brachiaria (Trin.) Griseb.

B. eruciformis (Sm.) Griseb.

Cenchrus L.

C. ciliaris L.

Chloris Sw.

C. virgata Sw.

Cymbopogon Spreng.

*C. *pospischilii* (K.Schum.) C.E. Hubb.

Cynodon Rich.

C. dactylon (L.) Pers.

C. hirsutus Stent

C. transvaalensis Burtt Davy

Digitaria Haller
D. argyrograpta (Nees) Stapf
D. eriantha Steud.

Echinochloa P.Beauv.
E. holubii (Stapf) Stapf

Eleusine Gaertn.
E. coracana (L.) Gaertn.

Elionurus Kunth ex Willd.
E. muticus (Spreng.) Kuntze

Enneapogon P.Beauv.
E. desvauxii P. Beauv.
E. scaber Lehm.
E. scoparius Stapf

Eragrostis Wolf
E. biflora Hack. ex Schinz
E. chloromelas Steud.
E. curvula (Schrad.) Nees
E. echinochloidea Stapf
E. gummiflua Nees
E. lehmanniana Nees
E. micrantha Hack.
E. nindensis Ficalho & Hiern
E. obtusa Munro ex Ficalho & Hiern
E. plana Nees
E. superba Peyr.
E. trichophora Coss. & Durieu

Eustachys Desv.
E. paspaloides (Vahl) Lanza & Mattei

Fingerhuthia Nees
F. africana Lehm.

Helictotrichon Besser
H. turgidulum (Stapf) Schweick.

Hemarthria R.Br
H. altissima (Poir.) Stapf & C.E.Hubb

Heteropogon Pers.
H. contortus (L.) Roem. & Schult.

Hyparrhenia E.Fourn.
H. hirta (L.) Stapf

Leptochloa P.Beauv.
L. fusca (L.) Kunth (*Diplachne fusca*)

Melinis P.Beauv.
M. repens (Willd.) Zizka

Microchloa R.Br.
M. caffra Nees

Oropetium Trin.
O. capense Stapf

Panicum L.
P. coloratum L.
P. maximum Jacq.
P. schinzii Hack.

Paspalum L.
P. **dilatatum* Poir.
P. distichum L.

Pennisetum Rich.
P. sphacelatum (Nees) T.Durand & Schinz

Phragmites Adans.
P. australis (Cav.) Steud.

Pogonarthria Stapf
P. squarrosa (Roem. & Schult.) Pilg.

Schmidtia Steud. ex J.A.Schmidt
S. pappophoroides Steud.

Setaria P.Beauv
S. pumila (Poir.) Roem. & Schult.
S. sphacelata (Schumach.) Stapf & C.E.Hubb. ex M.B.Moss
S. verticillata (L.) P.Beauv.

Sporobolus R.Br.
S. discosporus Nees
S. fimbriatus (Trin.) Nees
S. ioclados (Trin.) Nees
S. ludwigii Hochst.
S. virginicus (L.) Kunth

Stipagrostis Nees
S. uniplumis (Licht.) De Winter

Themeda Forssk.
T. triandra Forssk.

Tragus Haller
T. berteronianus Schult.
T. koelerioides Asch.

Trichoneura Andersson
T. grandiglumis (Nees) Ekman

Triraphis R.Br.
T. andropogonoides (Steud.) E. Phillips

Urochloa P.Beauv.
U. panicoides P.Beauv.

Potamogetonaceae
Potamogeton L.
Potamogeton sp.

Typhaceae
Typha L.
T. capensis (Rohrb.) N.E.Br.

Table 8.1: Phytosociological classification of the wetland communities in the palaeo-river catchments of the western Free State, South Africa.

Communities	Sub-communities	Variants	Number of relevés	Number of species
1			4	7
2			6	1
2	2.1		3	3
2	2.2		5	10
2	2.3		3	9
2	2.4		6	6
2	2.5		13	3
2	2.5	2.5.1	3	5
2	2.6		5	2
3			6	3
3	3.1		6	3
3	3.2	3.2.1	6	6
3	3.2	3.2.2	3	5
4	4.1	4.1.1	3	8
4	4.1	4.1.2	3	10
4	4.2		6	8
5			8	6
6			3	2
7	7.1		3	3
7	7.2	7.2.1	6	9
7	7.2	7.2.2	5	6
7	7.3		3	6
8	8.1		13	12
8	8.2	8.2.1	4	6
8	8.2	8.2.2	4	7
8	8.3	8.3.1	4	9
8	8.3	8.3.2	3	9
8	8.4		4	14
9			3	2
9	9.1		3	2

Species	Growth form
Species Group A	
Cynodon transvalensis	Grass
Cyperus difformis	Sedge
Isolepis diabolicus	Sedge
Species Group B	
Leptochloa fusca	Grass
Species Group C	
Panicum schinzii	Grass
Species Group D	
Echinochloa holubii	Grass
Alternanthera sessilis	Annual forb
**Verbena bonariensis*	Forb
Euphorbia inaequilatera	Annual forb
**Dichondra micrantha (D. repens)*	Prostrate herb
Isolepis costata	Sedge
Species Group E	
Sporobolus ludwigii	Grass
Frankenia pulverulenta	Dwarf shrub
Species Group F	
Sporobolus ioclados	Grass
Species Group G	
Sporobolus virginicus	Grass
Species Group H	
Salsola glabrescens	Dwarf shrub
Species Group I	
Suaeda merxmuelleri	Dwarf shrub
Species Group J	
Malephora cf. crocea	Succulent
Tragus berteronianus	Grass
Species Group K	
Berula erecta	Aquatic forb
Eleocharis limosa	Sedge
Potamogeton sp.	Submergent hydrophytic forb
Agrostis lachnantha	Grass
Species Group L	
Typha capensis	Emergent hydrophytic forb
cf. Schoenoplectus tabernaemontana	Sedge
Species Group M	
Lemna gibba	Floating hydrophyte
*Salix *babylonica*	Tree
Species Group N	
Cyperus longus	Sedge
Eleocharis dregeana	Sedge
Species Group O	
Marsilea burchellii	Hydrophytic forb
Isolepis cernua	Sedge
Species Group P	
Limosella africana	Hydrophytic forb
Species Group Q	
Limosella longiflora	Hydrophytic forb
Species Group R	
Juncus rigidus	Sedge
Species Group S	
Finicia nodosa	Sedge
Species Group T	
**Cirsium vulgare*	Forb
*Conyza *bonariensis*	Forb
**Oenothera rosea*	Forb
*Ranunculus *multifidus*	Forb
Species Group U	
Setaria verticillata	Grass
Eragrostis biflora	Grass
Salvia runcinata	Forb
Species Group V	
Cyperus marginatus	Sedge
Species Group W	
Eragrostis lehmanniana	Grass
Species Group X	
Cynodon dactylon	Grass
**Phyla nodiflora*	Perennial Forb
Chloris virgata	Grass
Sporobolus fimbriatus	Grass
**Schkuhria pinnata*	Annual forb
Eragrostis obtusa	Grass
Aristida congesta	Grass
Senecio burchellii	Annual forb
Species Group Y	
Salsola aphylla	Dwarf shrub
Species Group Z	
Eragrostis trichophora	Grass
Species Group AA	
Thesium costatum	Parasitic dwarf shrub
Enneapogon desvauxii	Grass
Species Group AB	
Felicia muricata	Dwarf shrub
Species Group AC	
Panicum coloratum	Grass
Species Group AD	
Lycium horridum	Dwarf shrub
Cyperus rupestris	Sedge
Species Group AE	
Digitaria eriantha	Grass
*Pseudognaphalium *luteo-album*	Herb
Sutera caerulea	Annual forb
Selago densiflora	Perennial forb
Species Group AF	
*Bidens *pilosa*	Annual forb
Species Group AG	
Cynodon hirsutus	Grass

Table 9.1: Phytosociological classification of the karroid- and grass-related communities in the palaeo-river catchments of the western Free State, South Africa.

Community	Growth form	1	
Sub-community		1.1	
Variants		1.1.1	1.1.2
Number of relevés		3	6
Number of species		22	21
Relevé numbers		54 53 58	20 13 14 24 23 10
Species Group A			
Themeda triandra	Graminoid	r + r	. r . + r .
Berkheya pinnatifida	Bienial forb	+ + r	2a . . + . .
Hyparrhenia hirta	Graminoid	r r .	r . . r + r
Species Group B			
Digitaria eriantha	Graminoid	+ r +	2a r . r r 4
Species Group C			
Aristida diffusa	Graminoid	3 3 3	. . . . . .
Elionurus muticus	Graminoid	2a 2a r	. . . . . .
Pentzia incana	Dwarf shrub	r 2a r	. . . . . .
Setaria verticillata	Graminoid	. 3 r	. . . + . r
Amphiglossa triflora (Pterothrix spinescens)	Dwarf shrub	. 2a r	. . . . . .
Ipomoea bathycolpos	Geophytic forb	. + +	. . . . . .
Species Group D			
**Schkuhria pinnata*	Annual forb	. . .	r 2a 3 3 4 2a
Eragrostis curvula	Graminoid	. . .	5 r 2a 2b 2a .
*Oxalis *corniculata*	Forb	. . .	r + . r r .
Species Group E			
Lycium horridum	Dwarf shrub	. . .	. . . . . .
Salsola aphylla	Dwarf shrub	. . .	. . . . . .
Species Group F			
Nenax microphylla	Dwarf shrub	. . .	. . . . . .
Species Group G			
Helichrysum dregeanum	Dwarf shrub	. r +	. . . . . .
Digitaria argyrograpta	Graminoid	. . .	. . . . . .
Species Group H			
Enneapogon desvauxii	Graminoid	. . .	. . . . . .
Zygophyllum microcarpum	Shrub	. . .	. . . . . .
Stachys hyssopoides	Forb	. . .	. . . . . .
Asparagus suaveolens	Dwarf shrub	. . .	. . . . . .
Hertia pallens	Shrub	. . .	. . . . . .
Lycium pilifolium	Dwarf shrub	. . .	. . . . . .
**Alternanthera pungens*	Annual forb	. . .	. . . . . .
Salsola glabrescens	Dwarf shrub	. . .	. . . . . .
Species Group I			
Stachys spathulata	Perennial forb	r 2a .	. . . . . .
Species Group J			
Sporobolus ioclados	Graminoid	. . .	. . . . . .
Eragrostis chloromelas	Graminoid	. . .	. . . . . .
Finicia nodosa	Cyperoid	r . .	. . . . . .
Species Group K			
Rosenia humilis	Dwarf shrub	+ . .	. . . . . .
Tragus koelerioides	Graminoid	. . .	. . . . . .
Thesium hystrix	Parasitic dwarf shrub	. . .	. . . . . .
Species Group L			
Eragrostis gummiflua	Graminoid	. . .	3 . . 2a 3 .
Species Group M			
Amaranthus thunbergii	Annual forb	. . .	. . . . . .
Species Group N			
Aristida canescens	Graminoid	. . .	. . . . . .
Oropetium capense	Graminoid	. . .	. . . . . .
Eragrostis nindensis	Graminoid	. . .	. . . . . .
Lotononis burchellii	Perennial forb	. . .	. . . . . .
*Amaranthus *caudatus*	Annual forb	. . .	. . . . . .
Sesamum triphyllum	Annual forb	. . .	. . . . . .
Hypertelis salsoloides	Annual forb	. . .	. . . . . .
Species Group O			
Eragrostis biflora	Graminoid	. . .	. . . . . .
Species Group P			
Heteropogon contortus	Graminoid	+ r +	. . . . . .
Selago densiflora	Perennial forb	3 2a 2b	2b . r . . r
Eragrostis superba	Graminoid	. . .	r . . 2a . .
Aptosium procumbens	Dwarf shrub	2a r .	. . . . . .
Pseudognaphalium oligandrum	Annual forb	. . .	. . . . . .
Chrysocoma ciliata	Dwarf shrub	+ . .	. . . . . .
Monsonia angustifolia	Annual forb	. . .	+ . . + r +
Species Group Q			
Sporobolus fimbriatus	Graminoid	+ r .	r 5 5 4 5 4
Species Group R			
Chloris virgata	Graminoid	. . .	. . . 2a + r
Species Group S			
Salvia verbenaca	Perennial forb	. . .	. . . . . .
Species Group T			
Tragus berteronianus	Graminoid	. . .	r . . . . .
Species Group U			
*Polygonum *aviculare*	Aquatic forb	. . .	. . . . . .
Eriocephalus spinescens	Dwarf shrub	. . .	. . . . . .
Species Group V			
Brachiaria eruciformis	Graminoid	. . .	. . . . . .
Species Group W			
Pentzia globosa	Dwarf shrub	. r .	. . . . . 2a
Species Group X			
Lycium cinerium	Dwarf shrub	. . .	. . . . . .
Frankenia pulverulenta	Dwarf shrub	. . .	. . . . . .
Cyperus rupestris	Cyperoid	. . .	r . . . r .
**Dichondra micrantha (D. repens)*	Prostrate forb	. . .	. . . . . .
Aristida bipartita	Graminoid	. . .	. . . . . .
Panicum coloratum	Graminoid	. . .	. . . . . .
Eragrostis obtusa	Graminoid	. . .	. r . . . .
Eragrostis lehmanniana	Graminoid	. 3 r	5 . . . . .
Aristida congesta	Graminoid	. . .	r . . . . .
Species Group Y			
Cynodon dactylon	Graminoid	r . .	. 2a . . . r

Table 10.1: Phytosociological classification of the woody communities in the palaeo-river catchments of the western Free State, South Africa.

Community		1		2							3			4				5
Sub-community		1.1	1.2	2.1	2.2			2.3		2.4	3.1	3.2		4.1	4.2	4.3		
Variants					2.2.1	2.2.2	2.2.3	2.3.1	2.3.2			3.2.1	3.2.2			4.3.1	4.3.2	
Number of relevés		3	3	5	4	4	5	10	6	8	3	3	4	4	9	3	4	8
Number of species		17	17	33	37	30	27	22	30	27	34	29	37	15	20	16	33	42
Relevé numbers	Growth form	11 08 05	09 06 12	78 28 26 25 27	46 04 57 07	32 30 31 29	52 53 55 54 51	80 70 68 71 67 69 75 77 81 73	78 79 76 03 74 72	60 59 62 66 61 63 64 65	44 45 43	95 94 93	58 54 53 57	97 99 01 03	77 80 79 84 82 78 08 82 10	66 67 65	60 59 22 58	72 74 02 00 50 49 82 80
Species Group A																		
Vachellia hebeclada	Shrub	2b 3 2a	3 2a 3									5 . .						. . . r . . . .
Ehretia rigida	Shrub	+ 2a r	2a r 2a		3 . . .	r . . .		. . . . + r	r		+ . .		2a 2b 2a .					
Dicoma schinzii	Perennial forb	r r +	r + +															
Species Group B																		
Melolobium candicans	Dwarf shrub	3 3 2a		. . . + +	. 3 . 4				r r									
Vachellia erioloba	Tree	3 3 2a											5 3 2b 3					
**Opuntia ficus-indica*	Succulent	r . +	. + .						. . . r . .			. r .						
Rhynchosia totta	Prostrate forb	r r +											+ . . .					
Species Group C																		
Triraphis andropogonoides	Grass		3 2a r							. . . . . r r .								
Aristida diffusa	Grass		2a r +	+									. r 2a .					
Aloe grandidentata	Succulent		2a + r			. 2a . .												
Species Group D																		
Searsia ciliata	Shrub	3 3 2a		5 3 4 . r	4 3 3 2a	. . r 2a	3 . . . 2a	. 3 4 3 2a 4 5 4 . 3	3 4 3 4 5 4		3 . .							3 . . . .
Digitaria eriantha	Grass			. . 2a 3 .			+ r . r r	3 r r 2a 2a 4 3 4 4	3 4 + . 3 2a	r r r r r 2a r 2b			+ r . .				. . r r	
Buddleia saligna	Shrub			. . . 2a 4		. 4 4 3		. 4 . 4 4 4 3 2a 2a	+ r 4 . 3 2a	3 3 . 4 . r 2a 3			. r r .					
Eustachys paspaloides	Grass				. r . +	2a r . .	. . . . +	. . r . r	. . . . r +	r + . r . . . r							. . . r	r . . . .
Species Group E																		
Eragrostis superba	Grass	r r +	+ r 2a	. 3 2a 2a 2a	r + . .	r . . .				r r	r + r					+ 2a r	. . . r	r r r r . . . .
Species Group F																		
Olea europaea subsp. *africana*	Tree		3 2a 4		r r 4 2a	2a . 2a 4	4 5 r 5 4											. . . . 4 3 . .
Searsia burchellii	Shrub	2a + r	r 2a 3	. . . 2a .	. . 2a .	r . 2a 2a	. 2a . 3 .										. . r .	. . r . 4 3 . .
Asparagus suaveolens	Dwarf shrub	+ r r		. . . 2a .	r . r .	r r . 2a	. 2a . 3 .	. . . . . . r + . +			3 4 .	r 2a r	r . r r	r r . .	. . . . + .		. . r .	
Species Group G																		
Felicia muricata	Dwarf shrub			. . + . .	+ r . r								. . . +					
Euphorbia spartaria (*E. rectirama*)	Succulent				. r . +													
Gnaphalium declinatum	Biennual forb				. r . +													
Diospyros austro-africana	Shrub				. r . 2a		3 . . . 2a											. . + ...
Barleria macrostegia	Perennial forb				. + . r												+ r . +	+ r . . . . . .
Species Group H																		
Aristida canescens	Grass				. + . .	4 4 5 4												
Pellaea calomelanos var. *calomelanos*	Fern			. . r . .		r 2a r r	r . . . +	. . r . r		. . . r . . . +								
Cussonia paniculata	Tree					r r r r												
Grewia occidentalis	Shrub					. 2a . r												
Species Group I																		
Hermannia cuneifolia	Dwarf shrub						2a 2a 2a 3 r											
Commelina africana	Perennial forb					. . . r	+ + . r r						. + . .					. . . . + r . .
Haemanthus humilis	Geophyte					. + . .	r + . r +											
**Datura stramonium*	Annual forb						. + 3 r .											
Species Group J																		
Hyparrhenia hirta	Grass			. r . r .	r + . r	r r . r	3 r . 2a 2a			. . . . . r r .						+ + r	. . r r	2a 3 r + ...
Species Group K																		
Enneapogon scoparius	Grass					r r r r	. . . . +	. 3 2a 2a 2a 2a . r . +	2a 2b 2a . r 2a	. . . . . + r .				r . r r				
Cleome rubella	Annual forb							+ + . + . + . . + r	r + r . 2a r									
Species Group L																		
Cheilanthes hirta var. *hirta*	Fern						r + . r +	+ + + r r + . + . +		. . . + . . . +								
Pollichia campestris	Fern							+ + . + . + ...					r . . .				r r . r	. . . . . . r .
Sida dregei	Perennial forb							. + r + + r										
Species Group M																		
Cenchrus ciliaris	Grass								r 2a 2a . r r									
Species Group N																		
Euclea crispa subsp. *ovata*	Shrub							. . r . 2a	. . r . r r	. . 2a r r r + r								
Species Group O																		
Aristida bipartita	Grass				3 . . .				. . . . 2a r	r r r 2a 2a + 2a 2a	3 2a 2a	. r +			. . . . r .			
Tragus koelerioides	Grass								. 2a	r r r . + . . .	3 4 .							r 2a . . . . . .
Species Group P																		
Ziziphus mucronata	Tree	2a 2a r		. . 2a . r	2a . r .	. . r .					r 2a 2a	. 4 2a	2a 2b 2a 2a		3 . 2a			. . + . . . 3 2a
Asparagus africanus	Scrambler	r r +					r . . . 2a				2a 3 2a	3 2a r	. r r +		2a 2a . . . 2a . . .		3 2a r r	. . r + 2a r r r
Species Group Q																		
Digitaria argyrograpta	Grass			. r 2a . r	2a . . .	. . . 2a					3 4 r							r 2a . . . . . .
Eragrostis nindensis	Grass								2a r		r 2a r							. . . r . . . .
Hertia pallens	Shrub										2a 3 .				. . . 2a 2a	r 2a r		. . + ...
Cyperus rupestris	Cyperoid			. . . + +		. . . r					2a 3 .						. . + .	
Tribulus terrestris	Annual forb								+		2a 3 .	+ . .	. . r .					
Grewia flava	Shrub				+ . . .						+ r +							
Cyperus capensis	Cyperoid										+ r r							
Kyphocarpa angustifolia	Forb								2a 3	r + ...	r + r				. . . . + .			+ . . . .
Gymnosporia karooica	Dwarf shrub	r . +	. + r		2a . . .	. . r .					+ r +							. . . . 2a 3 . .
Thesium costatum	Parasitic dwarf shrub							. . . . + .			r r r							
Ruschia hamata	Succulent			. r + + r							r r +						. . + .	
Species Group R																		
Lycium cinerium	Dwarf shrub						3 . . . 2a				2a 3 2a	2a r .	r . . .					. . . . 3 2a . .
Diospyros lycioides	Shrub			. . . r .		. 3 . .					+ + +	r 2a r						. . . . 3 2a . r
Lotononis burchellii	Perennial forb										r + r	. + r				+ r r		
Brachiaria eruciformis	Grass										r r r	3 + r						
Species Group S																		
*Chenopodium *murale*	Annual forb								2a 3			r 3 2a	r + r 2b		. . . . r .		r + . r	
*Oxalis *corniculata*	Perennial forb						r + . . 2a	. . . . . . + + . +				r r +	5 . . r					. . . . + r . .
Stipagrostis uniplumis	Grass		4 3 4		. + . r							r . .	r + r 3					
Heliophila carnosa	Dwarf shrub											. + r	. r + .					
Eragrostis obtusa	Grass			+ . . r .	r . . .	r . . r			r r			. r r	. . + .	+ + r +			3 2a 2a 2a	. . r r . . . .
Species Group T																		
Schmidtia pappophoroides	Grass				+ . . .								2a 3 2a 3					
Cyathula uncinulata	Forb												r r 2a .					
Tephrosia capensis	Perennial forb						. . . . +						. r r +					
Pogonarthria squarrosa	Grass												. 3 r r					
Pentzia sphaerocephala	Perennial forb												. + r +					
Species Group U																		
Tarchonanthus camphoratus	Shrub		2a r r					2b 2b 2b 2b r r 2a 3 2a 2a	r + ...	2a 2a r 3 r r 2a 4		. 5 5	4 4 3 2a	r . . +				
Species Group V																		
Vachellia tortilis	Tree								2a r		r 2a 3			2a 2a 2a 3	4 3 3 r 2a 5 2a 3 3	+ r r	r 2a . 2a	. 3 . . . . . .
Pentzia globosa	Dwarf shrub			. r 2a . r	. r . 2a						2a 2b 2a		. + r .	2a r r 3	3 2a 4 4 3 3 . . .	3 2a 2a	2a r . 2a	3 2a . . . r . .
Cynodon dactylon	Grass								+ + ...			2a 2b 2a	. . r r	. . . .	2a 4 4 2a 4 2a . 3 .	. r +	+ r r r	. . . . . + 3 .
Species Group W																		
Chloris virgata	Grass			. . . r r								r . r		2a r 2a 2a				. . . + ...
Tragus berteronianus	Grass			. . 2a . .					r			3 r +		4 . 3 5				
Enneapogon desvauxii	Grass													3 . r 3				
Lycium pilifolium	Dwarf shrub													r . r r				
Eriocephalus spinescens	Dwarf shrub										r 2a 2a			r r r r				
Species Group X																		
Chrysocoma ciliata	Dwarf shrub			r											3 r 2a	2a r + r	
Osteospermum muricata	Dwarf shrub															2a 4 3	r r . 2a	
Aptosium procumbens	Prostrate forb				. + . r											r 2a r	+ r + r	
Species Group Y																		
Helichrysum dregeanum	Dwarf shrub			r											3 3 2a		. . . + ...
Species Group Z																		
Eragrostis trichophora	Grass				. + . .		2a . . . r			r 2a		2a . .	2a r . .				3 2a . 2a	
Eragrostis biflora	Grass						. r . 2a .						. . . r		. . . . r .		2a 2a . r	
Dicoma macrocephala	Perennial forb																r + . r	+ r . . . . . .
Species Group AA																		
Searsia lancea	Tree				3 . . .	. 2a . .					. . 4						4 + . +	2a 3 2a r 4 3 5 5
**Tagetes minuta*	Annual forb			. . r + r			r + . . 2b						. . . +		. . . . . . 4 . 3		. r . r	3 . . + . r r .
Species Group AB																		
Monsonia angustifolia	Annual forb			. + r r +		r . . r								. + + .			2a + r	. . r .	r r . . . . . .
**Schkuhria pinnata*	Annual forb		r r 2a	. . . r .	+ . . .							. r 2a			. . r		. 2a + 2a	. . + r . . . .
Selago densiflora	Perennial forb			. r r r +	. r . 2a										. . . 3 2a		2a r . r	2a r r . . . . .
*Bidens *pilosa*	Annual forb			+ . 2a r r	3 . . .	r + . .	. r r + .	. r . r . r	+ r		. . r	. r +					2a r + r	3 4 . . r r + r
Heteropogon contortus	Grass				. 2a . 2b			+ . . . . 3 .	r r r . r +	. . . 2b 2b r r r	r + r				. . . . r .	2b r 3	. . r .	2a 3 + r . . . .
Setaria verticillata	Grass			2a r . . .	. . 2a .	. . r +	3 2a 3 3 2a	. r . r . r	+ + ...	. . . . r	. . r	. 3 2a	r 2a r 2a	2a 2a 2a 3			. 2a . .	. . . + . . . +
Aristida congesta	Grass		2a 2a r	. 3 r . r	r . 4 .	. . . r	+ r 2a 2a r	. . . . . . + r . +	2a 3 r . + +	+ r r r r + r r	2a 3 2a	r . r	+ 2b 2a .	3 4 3 2a	. . . . . . 4 4 3	5 3 4	4 3 3 3	3 2a 3 4 . . . .
Eragrostis lehmanniana	Grass	2a 2a r	2a 2a r	. . . r .	2a 2a . r			. . . . . . r + . r	2a 3 r + r +	. . 2a . . 3 . r	2a 2a 2a	. 2a r	. 3 3 r	2a . r 3	2a 3 2a r 2a r . r .	r 3 2a	4 3 2a 3	3 r r 2a . . . .
Vachellia karroo	Tree			. + 3 3 2a	r 2a . 4				+ r	. . + 2a + . . r		. 4 2a	r 2a . r	. + + .	. . . . r .		+ r 2a r	. . . . + r . .
Themeda triandra	Grass	r r +	2a r 2a	+ 2a r . r	r 2a . 3	. . + .	r + . . r		. . . r r +	3 2a + r + 2a r r	. . r	r r +	. + . .		. . . 2a	r r r	+ r 3 r	3 2a r r 2a r . r
Sporobolus fimbriatus	Grass	r . +		. 2a 2a 3 3	r + 2a r	. . . +	. r . r +	r . r . + . r . . r	r r . + . .	+ r 2a 2a 4 r 2a r	. . 2a	. + r	+ . . .		. . . . + .			r + . . 3 4 2a r

Table 12.1: Synoptic table with fidelity values of the different communities found in the catchment of the palaeo-rivers in the western Free State, South Africa.

Communities	Growth form	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Species Group A																									
Cynodon transvaalensis	Grass	100	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Isolepis diabolicus	Sedge	53	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Species Group B																									
Sporobolus ludwigi	Grass	.	36	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Species Group C																									
Cyperus difformis	Sedge	60	7	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Species Group D																									
Sporobolus virginicus	Grass	.	45	28	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Species Group E																									
Suaeda merxmuelleri	Dwarf shrub	.	.	95	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Malephora cf. *crocea*	Succulent	.	.	57	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Species Group F																									
Leptocloa fusca	Grass	38	60	31	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Species Group G																									
Berula erecta	Aquatic forb	.	.	.	100	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Eleocharis limosa	Sedge	.	.	.	100	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Agrostis lachnantha	Grass	.	.	.	91	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Typha capensis	Emergent hydrophytic forb	.	.	.	70	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
cf. *Schoenoplectus tabernaemontana*	Sedge	.	.	.	70	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
*Salix *babylonica*	Tree	.	.	.	49	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Lemna gibba	Floating hydrophyte	.	.	.	49	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Species Group H																									
Limosella africana	Hydrophytic forb	.	.	.	54	74	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Potamogeton sp.	Submergent hydrophytic forb	.	.	.	89	19	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Eleocharis dregeana	Sedge	.	.	.	42	31	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Species Group I																									
Marsilea burchellii	Hydrophytic forb	.	.	.	.	100	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Species Group J																									
Isolepis cernua	Sedge	25	.	.	.	73	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Species Group K																									
Cynodon hirsutus	Grass	.	.	.	.	.	100	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Species Group L																									
Limosella longiflora	Hydrophytic forb	.	.	.	.	.	.	100	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Species Group M																									
**Oenothera rosea*	Forb	.	.	.	.	.	.	.	48	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
*Ranunculus *multifidus*	Forb	.	.	.	.	.	.	.	48	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
**Cirsium vulgare*	Forb	.	.	.	.	.	.	.	59	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
*Conyza *bonariensis*	Forb	.	.	.	.	.	.	.	59	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Salvia runcinata	Forb	.	.	.	.	.	.	.	48	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cyperus marginatus	Sedge	.	.	.	.	.	.	.	41	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Species Group N																									
Cyperus longus	Sedge	.	.	.	57	.	.	.	25	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Species Group O																									
Juncus rigidus	Sedge	.	11	.	.	.	.	.	93	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Echinochloa holubii	Grass	.	18	.	.	.	.	.	15	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
**Verbena bonariensis*	Forb	.	12	.	.	.	.	.	35	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Species Group P																									
**Phyla nodiflora*	Perennial forb	.	.	.	.	.	.	.	.	72	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Senecio burchellii	Annual forb	20	.	.	.	.	.	.	.	42	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Felicia muricata	Dwarf shrub	.	.	.	.	.	.	.	.	32	.	.	.	.	.	.	.	.	.	.	.	13	13	.	.
*Pseudognaphalium *luteo-album*	Herb	.	.	.	.	.	.	.	.	30	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sutera caerulea	Annual forb	.	.	.	.	.	.	.	.	30	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Species Group Q																									
Euphorbia inaequilatera	Annual forb	.	7.1	.	.	.	.	.	34	4.2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Isolepis costata	Sedge	.	9.1	.	.	.	26	.	.	19	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Alternanthera sessilis	Annual forb	.	19	.	.	.	.	.	.	33	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Panicum schinzii	Grass	.	13	.	.	.	.	.	.	18	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Species Group R																									
Elionurus muticus	Grass	.	.	.	.	.	.	.	.	.	48	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Eragrostis curvula	Grass	.	.	.	.	.	.	.	.	.	48	.	.	.	.	.	.	.	.	6.5	.	.	.	.	.
Pentzia incana	Dwarf shrub	.	.	.	.	.	.	.	.	.	34	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Amphiglossa triflora (Pterothrix spinescens)	Dwarf shrub	.	.	.	.	.	.	.	.	.	28	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ipomoea bathycolpos	Geophytic herb	.	.	.	.	.	.	.	.	.	28	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Species Group S																									
Zygophyllum microcarpum	Shrub	.	.	.	.	.	.	.	.	.	.	100	.	.	.	.	.	.	.	.	.	.	.	.	.
Species Group T																									
Stachys hyssopoides	Forb	.	.	.	.	.	.	.	.	.	.	90	.	16	.	.	.	.	.	.	.	.	.	.	.
Species Group U																									
Finicia nodosa	Sedge	.	.	.	18	.	.	.	38	3.5	.	.	34	.	.	.	.	.	.	.	.	.	.	.	.
Species Group V																									
Stachys spathulata	Perennial forb	.	.	.	.	.	.	.	.	.	2.1	.	85	15	.	.	.	.	.	.	.	.	.	.	.
Eragrostis chloromelas	Grass	.	.	.	.	.	.	.	.	.	5.6	.	47	22	.	.	.	.	.	2.1	.	.	.	.	.
Rosenia humilis	Dwarf shrub	.	.	.	.	.	.	.	.	.	15	.	19	79	.	.	.	.	.	.	.	.	.	.	.
Species Group W																									
Sesamum triphyllum	Annual forb	.	.	.	.	.	.	.	.	.	.	.	.	.	.	70	.	.	.	.	.	.	.	.	.
Species Group X																									
Oropetium capense	Grass	.	.	.	.	.	.	.	.	.	.	.	.	16	.	88	.	.	.	.	.	.	.	.	.
*Amaranthus *caudatus*	Annual forb	.	.	.	.	.	.	.	.	.	.	.	.	18	.	79	.	.	.	.	.	.	.	.	.
Species Group Y																									
Pseudognaphalium oligandrum	Annual forb	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	100	.	.	.	.	.	.	.
Species Group Z																									
Berkheya pinnatifida	Biannual forb	.	.	.	.	.	.	.	.	.	25	1.4	0	4.7	29	41	.	36	.	.	.	.	.	.	.
Species Group AA																									
Frankenia pulverulenta	Dwarf shrub	.	15	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	32	13	.	.	.	.	.
*Polygonum *aviculare*	Aquatic forb	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	14	24	.	.	.	.	.
Species Group AB																									
Salsola aphylla	Dwarf shrub	.	.	.	.	.	.	.	.	29	12	.	.	25	.	.	.	.	.	3	.	.	.	.	.
Lycium horridum	Dwarf shrub	.	.	.	.	.	.	.	.	17	29	.	.	.	.	.	.	.	7.3	1.3	.	.	.	.	.
Species Group AC																									
Sporobolus ioclados	Grass	.	16	30	.	.	.	.	.	.	.	.	35	.	.	.	.	.	9.5	4.3	.	.	.	.	.
Salsola glabrescens	Dwarf shrub	.	1.3	64	.	.	.	.	.	.	.	53	3.4	.	.	.	.	.	6.6	.	.	.	.	.	.
Species Group AD																									
Dicoma schinzii	Perennial forb	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	100	.	.	.	.
Species Group AE																									
Triraphis andropogonoides	Grass	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	67	3.5	.	.	.
Melolobium candicans	Dwarf shrub	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	61	15	.	.	.
Species Group AF																									
Cheilanthes hirta var. *hirta*	Fern	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	57	.	.	.
Cleome rubella	Annual forb	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	50	.	.	.
Euclea crispa subsp. *ovata*	Shrub	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	50	.	.	.
Pellaea calomelanos var. *calomelanos*	Fern	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	50	.	.	.
Hermannia cuneifolia	Dwarf shrub	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	34	.	.	.
Cussonia paniculata	Tree	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	30	.	.	.
Haemanthus humilis	Geophte	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	34	.	.	.
Sida dregei	Perennial forb	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	34	.	.	.
Cenchrus ciliaris	Grass	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	34	.	.	.
Euphorbia spartaria	Succulent	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	21	.	.	.
Gnaphalium declinatum	Biannual forb	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	21	.	.	.
Grewia occidentalis	Shrub	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	21	.	.	.
**Datura stramonium*	Annual forb	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	26	.	.	.
Species Group AG																									
Buddleja saligna	Shrub	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	62	20	.	.
Aristida bipartita	Grass	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	6.1	.	.	25	51	1.3	.
Tribulus terrestris	Annual forb	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	61	.	.
Schmidtia pappophoroides	Grass	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	61	.	.
Grewia flava	Shrub	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1.9	52	.	.
Tephrosia capensis	Perennial forb	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1.9	52	.	.
Thesium costatum	Parasitic dwarf shrub	.	.	.	.	.	.	.	.	12	.	.	.	.	.	.	.	.	.	.	.	1	45	.	.
Species Group AH																									
Heliophila carnosa	Dwarf shrub	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	62	.	.
Cyperus capensis	Sedge	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	54	.	.
Cyathula uncinulata	Forb	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	54	.	.
Pogonarthria squarrosa	Grass	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	54	.	.
Pentzia sphaerocephala	Perennial forb	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	54	.	.
Species Group AI																									
Vachellia hebeclada	Shrub	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	90	.	4.6	.	7
Aloe grandidentata	Succulent	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	68	0.3	.	.	.
Rhynchosia totta	Prostrate forb	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	63	.	10	.	.
**Opuntia ficus-indica*	Succulent	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	62	.	9.7	.	.
Stipagrostis uniplumis	Grass	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	47	0.4	47	.	.
Vachellia erioloba	Tree	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	51	.	40	.	.
Species Group AJ																									
Ehretia rigida	Shrub	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	81	2.8	29	.	.
Tarchonanthus camphoratus	Shrub	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	35	33	43	2.5	.
Searsia ciliata	Shrub	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	40	51	4	.	6.3
Species Group AK																									
Lycium cinerium	Dwarf shrub	.	.	.	.	.	.	.	.	.	.	.	4.7	.	.	6.5	13	.	27	.	.	.	40	.	13
Species Group AL																									
Brachiaria eruciformis	Grass	.	.	.	.	.	.	.	.	.	3.5	.	.	0.2	.	60	.	.	35	.	.	.	33	.	.
Aristida canescens	Grass	.	.	.	.	.	.	.	.	.	.	.	29	21	.	61	.	.	.	.	.	3.7	.	.	.
Thesium hystrix	Parasitic dwarf shrub	.	.	.	.	.	.	.	.	.	.	18	15	43	.	55	.	.	.	.	.	.	.	.	.
Species Group AM																									
Digitaria eriantha	Grass	.	.	.	.	.	.	.	.	0.9	36	.	.	11	.	.	.	.	.	1.4	.	46	9	1.4	.
Cyperus rupestris	Sedge	.	.	.	.	.	.	.	.	4.5	15	.	.	17	.	.	.	.	20	0.3	.	2.4	15	0.3	.
Panicum coloratum	Grass	.	.	.	.	.	.	.	.	9.8	.	13	28	13	.	.	.	55	2	7.9	.	.	.	.	.
Species Group AN																									
Osteospermum muricata	Dwarf shrub	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	54	.
Dicoma macrocephala	Perennial forb	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	22	38
Species Group AO																									
Eriocephalus spinescens	Dwarf shrub	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	13	.	.	.	36	23	.
Vachellia tortilis	Tree	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	21	79	5.8
Asparagus africanus	Scrambler	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	27	.	54	17	44
Species Group AP																									
Diospyros austro-africana	Shrub	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	19	.	.	25
Eustachys paspaloides	Grass	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	43	.	4.4	16
Enneapogon scoparius	Grass	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	57	.	17	.
Species Group AQ																									
Commelina africana	Perennial forb	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	15	12	.	35
*Chenopodium *murale*	Annual forb	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.9	71	17	.
Barleria macrostegia	Perennial forb	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4.5	.	20	36
Pollichia campestris	Fern	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	11	12	20	16
Vachellia karroo	Tree	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	22	39	26	17
Ruschia hamata	Succulent	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	12	44	4.9	.
Searsia lancea	Tree	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4.2	8.8	87
**Tagetes minuta*	Annual forb	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	11	6.5	17	49
Kyphocarpa angustifolia	Forb	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	9.8	38	3.6	14
Species Group AR																									
Searsia burchellii	Shrub	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	78	8.4	.	.	26
Olea europaea subsp. *africana*	Tree	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	47	25	.	.	21
Gymnosporia karooica	Dwarf shrub	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	57	.	23	.	18
Species Group AS																									
Hypertelis salsoloides	Annual forb	.	.	.	.	.	.	.	.	.	.	.	.	.	.	78	.	.	.	2.5	.	.	.	.	.
Eragrostis nindensis	Grass	.	.	.	.	.	.	.	.	.	.	.	.	.	.	72	.	.	.	.	.	.	23	.	6.5
Lotononis burchellii	Perennial forb	.	.	.	.	.	.	.	.	.	.	.	.	.	.	67	.	.	.	.	.	.	38	7.6	.
Species Group AT																									
Lycium pilifolium	Dwarf shrub	.	.	.	.	.	.	.	.	.	.	62	9.8	.	.	.	.	.	8	.	.	.	.	11	.
Enneapogon desvauxii	Grass	.	.	.	.	.	.	.	.	.	.	55	1	6	.	55	.	.	16	.	.	.	.	1.5	.
Hertia pallens	Shrub	.	.	.	.	.	.	.	.	.	.	46	1.6	14	.	46	.	.	.	.	.	.	5.3	8.6	0.5
Species Group AU																									
Helichrysum dregeanum	Dwarf shrub	.	.	.	.	.	.	.	.	.	27	.	28	.	.	.	.	.	.	.	.	.	.	13	10
Chrysocoma ciliata	Dwarf shrub	.	.	.	.	.	.	.	.	.	0.7	.	.	12	.	.	.	75	.	.	.	.	.	22	.
Aptosium procumbens	Prostrate forb	.	.	.	.	.	.	.	.	.	2.8	.	26	.	.	.	.	69	.	.	.	.	.	20	.
Selago densiflora	Perennial forb	.	.	.	.	.	.	.	.	.	16	.	.	.	.	.	.	64	.	.	.	3.4	.	11	20
Hyparrhenia hirta	Grass	.	.	.	.	.	.	.	.	.	25	.	19	.	.	.	.	55	.	.	.	13	.	7.8	24
Species Group AV																									
Asparagus suaveolens	Dwarf shrub	.	.	.	.	.	.	.	.	.	.	45	1.1	.	.	2.6	.	.	.	.	24	8.6	42	4.7	.
Monsonia angustifolia	Annual forb	.	.	.	.	.	.	.	.	.	17	.	.	.	.	.	.	35	.	0.3	.	5.8	10	10	15
Ziziphus mucronata	Tree	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	32	2.7	62	1.3	22
Diospyros lycioides	Shrub	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.5	58	.	34
Setaria verticillata	Grass	.	.	.	.	.	.	.	24	0.6	.	.	.	.	.	.	.	.	.	.	.	20	46	12	12
*Oxalis *corniculata*	Perennial forb	.	.	.	.	.	.	.	.	.	15	.	.	.	.	.	.	.	1.3	.	.	9	44	.	19
Eragrostis trichophora	Grass	.	.	.	.	.	.	.	.	12	.	.	.	.	.	.	.	.	.	.	.	11	34	15	.
Tragus koelerioides	Grass	.	.	.	.	.	.	.	.	.	.	.	.	64	.	.	.	.	.	.	.	5.3	13	.	17
Digitaria argyrograpta	Grass	.	.	.	.	.	.	.	.	.	9.4	.	7.8	25	.	.	.	.	.	.	.	5.7	22	.	18
*Bidens *pilosa*	Annual forb	.	.	.	.	.	.	.	.	1.9	.	.	.	.	.	.	.	.	.	.	.	23	19	11	55
Species Group AW																									
**Alternanthera pungens*	Annual forb	.	.	.	.	.	.	.	.	.	.	73	.	.	.	.	.	.	11	.	.	.	.	.	.
Chloris virgata	Grass	.	.	.	.	.	.	.	.	18	7.7	.	.	.	.	.	.	.	54	11	.	.	7.7	7.7	2.3
Eragrostis gummiflua	Grass	.	.	.	.	.	.	.	.	.	20	.	.	.	50	.	.	.	.	.	.	.	.	.	.
**Schkuhria pinnata*	Annual forb	.	.	.	.	.	.	.	.	22	22	.	.	.	.	.	.	.	6.5	0.3	29	.	7.4	7.4	11
Salvia verbenaca	Perennial forb	.	.	.	.	.	.	.	.	.	.	.	.	29	.	.	.	.	24	11	.	.	.	.	.
Heteropogon contortus	Grass	.	.	.	.	.	.	.	.	.	0.5	.	.	17	13	0.9	.	49	.	.	.	11	8.7	5.7	20
Amaranthus thunbergii	Annual forb	.	.	.	.	.	.	.	.	.	.	15	.	.	66	.	.	.	3	.	.	.	.	.	.
Aristida congesta	Grass	.	.	.	.	.	.	.	.	.	1.2	.	19	6.1	.	18	25	25	18	1.7	3.8	9.8	17	12	3.8
Aristida diffusa	Grass	.	.	.	.	.	.	.	.	.	4.8	.	31	.	.	.	16	.	.	.	37	.	12	.	.
Eragrostis superba	Grass	.	.	.	.	.	.	.	.	.	11	.	3.6	6	8.1	.	1.8	40	.	.	40	.	4.3	.	15
Themeda triandra	Grass	.	.	.	.	.	.	.	.	.	27	.	.	22	3.8	.	.	33	.	.	33	11	9.6	5	27
Nenax microphylla	Dwarf shrub	.	.	.	.	.	.	.	.	.	25	.	.	44	.	.	.	.	.	.	.	.	.	.	.
Sporobolus fimbriatus	Grass	.	.	.	.	.	.	.	.	9.4	11	14	.	5.7	39	.	.	.	.	.	5.7	23	9.1	.	27
Eragrostis obtusa	Grass	.	.	.	.	.	.	.	.	9	0.2	34	34	34	.	34	.	.	9	.	.	.	1.1	5.8	.
Pentzia globosa	Dwarf shrub	.	.	.	.	.	.	.	.	.	.	26	26	26	26	26	15	26	.	.	.	.	4.6	17	.
**Dichondra micrantha (D. repens)*	Prostrate forb	.	11	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	24	.	.	.	.	.	.
Eragrostis lehmanniana	Grass	.	.	.	.	.	.	.	.	15	.	14	2.8	11	21	21	21	21	.	.	21	.	12	14	.
Species Group AX																									
Cynodon dactylon	Grass	.	.	.	9.5	17	.	13	.	11	.	28	15	13	11	.	.	.	.	24	.	.	5.9	12	.
Tragus berteronianus	Grass	.	.	9.1	.	.	22	.	.	11	1.4	.	.	19	.	.	.	.	39	5.4	.	.	9.9	0.8	.
Species Group AY																									
Eragrostis biflora	Grass	.	3.1	.	.	.	.	.	8.1	.	.	.	5.5	.	.	.	74	.	.	.	.	.	2.1	10	.