VEGETATION CLASSIFICATION OF THE WITSAND NATURE RESERVE, NORTHERN CAPE PROVINCE, SOUTH AFRICA

by

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Declaration

"I Thulani Fanifani Mthombeni declare that the Master's Degree research dissertation that I herewith submit for the Master's Degree qualification Vegetation Classification of the Witsand Nature Reserve, Northern Cape Province, South Africa, at the University of the Free State is my independent work, and that I have not previously submitted it for a qualification at another institution of higher education."

Thulani Fanifani Mthombeni

Signature   15 May 2019

Date

Abstract

Witsand Nature Reserve (WNR) is located in the Northern Cape Province of South Africa on the western side of the Langeberg Mountain range in the triangle between the towns Postmasburg, Olifantshoek and Groblershoop. The study covered the entire reserve of 3 500 ha. The name Witsand is the Afrikaans word for “white sand”. WNR is known for its “roaring” white sand which is a great tourist attraction. These white sand dunes are unique and in strong contrast with the surrounding red Kalahari sand dunes. The occurrence of white sand in the study area is due to the shallow water table under the white dunes. Percolating water has bleached the sand over millions of years. Through this process, red iron oxide, which usually coats sand grains, is leached through water, rendering sand grains white. WNR was established in April 1994, with the primary aim of conserving the unique white sand dune ecosystem. Prior to its proclamation, Witsand was utilised as a farm. Previous human impacts included water abstraction, overgrazing and 4x4 trails which have disturbed the dune system. No river systems are present at or near WNR, yet the Witsand area was a reliable source of water for local farmers in the past. When inundated, a few small ephemeral pans provide fresh water for the animals in the region. The area has a climate that varies from extremely cold winter nights to extremely hot summer days. Rainfall is low and typically peaks toward the end of summer. Precipitation events are mostly in the form of thunderstorms. The geology is dominated by rocks of the Kalahari Group and Olifantshoek Super Group. The former being formed through sedimentary accumulation, which took place approximately 65 million years ago, while the formation of the younger Olifantshoek Supergroup is estimated at 48 million years ago. WNR falls within the semi-arid savanna biome of the Kalahari bioregion where the dominating vegetation type is the Olifantshoek Plain Thornveld, (SVk 13) characterised by scattered trees and shrubs and a ground layer dominated by grasses. The study of this reserve’s vegetation is important, because it allows for the mapping of its plant communities, understanding the relationships between the plant species distributions and environmental factors. This vegetation study allow us to understand how animal and plant interactions function and what actions need to be implemented to ensure biodiversity conservation and management A total of 120 sample plots were placed within homogenous vegetation units throughout the reserve in various habitats such as pans, rocky outcrops, sand dunes and sandy plains. Vegetation surveys were conducted using the Braun-Blanquet method. A modified TWINSPAN classification was applied and resulted in the classification of four plant communities, four sub-communities and four variants. These vegetation units (communities, sub-communities and variants) were described and ecologically interpreted. Various management practices are recommended, which should be incorporated into the management plan of the Witsand Nature Reserve.

Keywords: Witsand Nature Reserve, vegetation classification, conservation, sustainable use, biodiversity, Braun-Blanquet, environmental management, management plans

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Abbreviations

CARA – Conservation of Agricultural Resources Act, 1983 (Act 43 of 1983)

CDF – Conservation Development Framework

DEA – Department of Environmental Affairs

DWS – Department of Water and Sanitation

EIA – Environmental Impact Assessment

GPS – Global Positioning System

NEMBA – National Environmental Management Biodiversity Act, 2004 (Act No.10 of 2004)

NEM: PAA – National Environmental Management: Protected Areas Act, 2003 (Act No.57 of 2003)

NVFFA – National Veld and Forest Fire Act, 1998 (Act No.101 of 1998)

RNR – Rooipoort Nature Reserve

SANParks – South African National Parks

TWINSPAN – Two-Way Indicator Species Analysis

WNR – Witsand Nature Reserve

CHAPTER 1: INTRODUCTION

Plants are one of the most crucial components of ecosystems (Van As *et al.,* 2012). They provide a wide variety of ecosystem services which include oxygen production, reducing atmospheric carbon dioxide, soil stability, provisioning of food, and shelter (Secretariat of the Convention on Biological Diversity, 2009; Van As *et al.,* 2012, Omar, 2014; Raimondo, 2015). Plant communities form the fundamental units of ecosystems (Brown *et al.,* 2013). The extinction of plant species as well as ecosystem degradation is a global concern (Omar, 2014). Population growth, habitat fragmentation, deforestation, pollution, spreading of invasive alien species and climate change are amongst factors contributing towards extinction of plants (Secretariat of the Convention on Biological Diversity, 2009; Omar, 2014; Raimondo, 2015). Arid and semi-arid environments are vulnerable to degradation, due to overgrazing, bush encroachment and alien plant invasion (Omar, 2014). These dry ecosystems take long to recover from any form of disturbances due to the low rainfall that they receive (Secretariat of the Convention on Biological Diversity, 2009; Davis-Reddy & Vincent 2017). The primary aim of the establishment of conservation areas (private and provincial nature reserves as well as national parks) is to conserve and protect natural resources including flora and fauna.

The primary objective of conservation is to achieve the sustainable use of natural resources (Van Rooyen & Van Rooyen, 2017). In order to manage wildlife effectively, a good knowledge of the plant communities, their species composition and ecological condition of the veld is essential. Thus protected areas must be managed properly to protect ecosystem services and promote sustainability of biological resources (flora and fauna) (South African National Parks, 2017). This creates a need to develop strategies which will enhance conservation of biodiversity, with great focus on the conservation of habitats which support the flora and fauna of a particular area.

When developing strategies for the conservation of biodiversity, baseline information is needed. This includes understanding the ecological aspects of nature by among others conducting vegetation studies in order to identify management units of which plant communities form the basics. Floristic classification of areas is a crucial tool that simplifies complex ecosystems (Brown *et al.,* 2013). The South African National Parks (SANParks) recommended continuous vegetation surveys and monitoring in protected areas (South African National Parks, 2017). This recommendation was also confirmed by Masubelele *et al*. (2014). According to Masubelele *et al*. (2014), vegetation surveys assist conservation managers to determine the changes occurring in the ecosystem that they manage.

Before this study, the flora at WNR was not extensively studied and properly classified. Vegetation surveys have been conducted to determine the suitability for game introduction (Veldsman, 2008). This means that no proper management plan could be compiled for this nature reserve. The aim of this study is to provide a detailed description of the different plant communities present within the Witsand Nature Reserve.

The objectives of the study are to:

- Assess, classify and describe the indigenous vegetation of Witsand Nature Reserve.
- Compile a vegetation map for the area.
- Make possible recommendations that can improve the management plan of the reserve.
- Compile a plant species list of the study area.

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CHAPTER 2: Description of the study area

2.1. Background

The Witsand Nature Reserve (WNR) is a provincial nature reserve of approximately 3 500 hectares, located in the Northern Cape and managed by the Northern Cape Provincial Government. This portion of land was purchased by the Government in 1993 and proclaimed to be a nature reserve in April 1994 (Van den Berg *et al.,* 2007; Witsand Nature Reserve, 2015). Prior to its proclamation as a nature reserve, the WNR have been used by farmers as grazing land for livestock (Witsand Nature Reserve, 2015). Over the years, human activities such as farming activities (grazing), recreation (4x4 drives in the dunes, etc.) and water extraction had an impact on the area. The Witsand area is unique as it houses a reliable groundwater source in the arid Kalahari (Van den Berg *et al.,* 2007; Witsand Nature Reserve, 2015). Human activities such as driving with off-road vehicles on the sand dunes have disturbed the dune system and destroyed the vegetation cover in places (Terblanche & Taylor, 2000).

Witsand is the Afrikaans word meaning “white sand” and the name of the reserve was given due to the presence of a massive island of white sand dunes (Figure 2.1) surrounded by the typical red dunes of the Kalahari. Some of the dunes are up to 60 metres high. These dunes also got the name of “brulsand” because the sand makes a “roaring sound” when you walk on it (Witsand Nature Reserve, 2015). The roaring sound can be heard from January to April.

Figure 2.1: White sand dunes in the central parts of the Witsand Nature Reserve are visible in the background.

Being a protected area, the WNR is important for conservation of unique ecosystems and biodiversity (flora and fauna). This unique ecosystem consists of distinct plant communities which, according to Anderson (1996) are in need of conservation. The WNR has been considered as an area of possible plant endemism (Anderson, 1996; Witsand Nature Reserve, 2015; Frisby, 2016) with endemic plant species such as *Brachiaria dura* var. *pilosa, Amphiglossa tecta* and *Justicia thymifolia* (Frisby, 2016). *Amphiglossa tecta* is a critically endangered species (South African National Biodiversity Institute, 2018).

2.2. Locality

The WNR is situated in the south-eastern parts of the Kalahari region (Veldsman, 2008), approximately 65 kilometres south-west of Postmasburg and 80 kilometres south of Olifantshoek. The local authority is Siyancuma Local Municipality, which falls within the jurisdiction of Pixley Ka Seme District Municipality, in the Northern Cape Province. The WNR lies within the geographical co-ordinates: Latitude 28º 33' 99” (S); Longitude 22º 29' 25” (E). The Langberg mountain range, along the east of the reserve forms part of the geographical landscape of the area (Anderson, 1996).

2.3. Topography and geology

2.3.1 Topography

Topography is one of the factors determining the level of exposure of vegetation to solar radiation. North facing slopes have greater exposure to the sun, as opposed to south facing slopes in the southern hemisphere. Topography can also influence the local distribution of plants and their growth form (Muller *et al.*, 2016). Different patterns or structures of vegetation units are driven by topography and geomorphology (Godron & Forman, 1983). The shape of landforms is given by the geological characteristics of that particular region (Holmes, 2012). Hills occurring on the plains usually create distinct vegetation patterns (Muller *et al.*, 2016). This phenomenon occurs mostly in the grassland and savanna ecosystems, where trees are dominant in the low-lying area and shrubs in the high-lying areas. In semi-arid regions, drainage lines support the occurrence of woody vegetation due to the availability of water. High-lying areas are subject to low temperatures and occurrence of frost is possible in some areas (Muller *et al.*, 2016). Frost in winter is a limiting factor for the development of tree communities (Daubenmire, 1974) since frost restricts vegetation development.

The topography of the WNR varies greatly and includes an undulating landscape with rocky outcrops towards the south and low-lying areas towards the north (Figure 2.2). The altitude in the Witsand area varies between 1 180 and 1 440 m above sea level (Mucina & Rutherford, 2006; Thomas & Wiggs, 2012). The landscape features of the area include pans, plains, hills and mountains (Witsand Nature Reserve, 2015). The Langeberg mountain range is the longest in the region, with a length of about 160 kilometres (Frisby, 2016). Vast sandy plains occur in the north and extend towards the eastern parts of the reserve. The elevated areas from the central parts of the reserve extend towards the south-west (Figure 2.2). The landscape of the Kalahari region is characterised by the presence of up to 60 m deep cross-bedded aeolian sands (Maud, 2012). Factors such as geological characteristics of the region, weathering and erosion, influenced and shaped the landforms (Holmes, 2012). Topography of the entire Kalahari is also shaped by aeolian sand (Du Toit, 1926b; Thomas & Wiggs, 2012; Frisby, 2016). The Kalahari sand is believed to be the product of rock weathering. During the Pleistocene Epoch’s last ice age (18 000 to 10 000 years ago) the climate became very arid and a vast desert formed in the interior of southern Africa of which the Kalahari Desert is a small remnant (McCarthy & Rubidge 2005, Holmes, 2012; Thomas & Wiggs, 2012). The white sand dunes cover an area of approximately 10 kilometers long and three kilometers wide (Anderson, 1996). At present, sand movement by wind is minimal due to vegetation establishment in the region (Thomas & Wiggs, 2012).

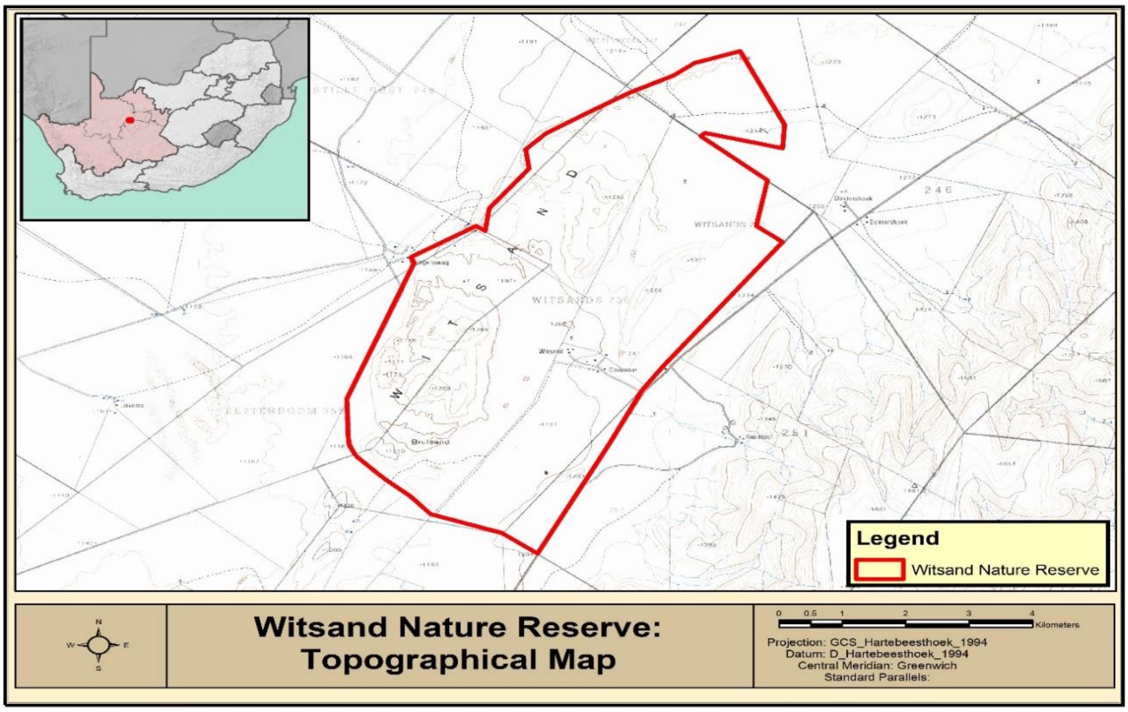

Figure 2.2: Topographical map of the Witsand Nature Reserve (Map provided by the Department of Environment & Nature Conservation, Northern Cape).

2.3.2 Geology

The study area is underlain by the Kalahari Group as well as the Olifantshoek Supergroup (Visser, 1989). The Kalahari Basin stretches from north of the Orange River towards Botswana and into Namibia (Visser, 1989). Karoo rocks and the rocks of the Tertiary Kalahari Group are underlying parts of the region (Visser, 1989). Du Toit (1926a) mentioned the quartzite rocks is continuously occurring as terraces in the upper and lower surfaces of the Kalahari. In certain areas (including the study area) they form rocky outcrops. According to McCarthy & Rubidge (2005) these rocks were formed at the edge of the Kaapvaal Craton in shallow marine environments about 1 900 million years ago. The climate became gradually drier towards the end of the

Pliocene Epoch of the Triassic Period, with evaporation far exceeding precipitation (King, 1963, McCarthy & Rubidge, 2005).

Kalahari Group

The Kalahari Group was formed through sedimentary accumulation which occurred about 65 million years before present (McCarthy & Rubidge, 2005). Kalahari Group includes Quaternary alluvium, terrace gravel, surface limestone silcrete and aeolian sand (King, 1963; Visser, 1989). Four geological formations namely Wessel, Budin, Eden and Gordonia occur in the Kalahari Group (Visser, 1989; Partridge *et al.,* 2006). The Wessel formation is made up of soft, argillaceous gravel of fluviatile origin which was deposited on the basement of the parent rock (Visser, 1989; Partridge *et al.*, 2006). This gravel covers large areas of the region and it becomes thicker in palaeo-valleys (Partridge *et al.,* 2006). The Budin formation was deposited after the Wessel deposits (Visser, 1989). This geological formation is composed of calcareous claystone with gravel in the interbeds (Visser, 1989; Partridge *et al.,* 2006). This claystone have been mentioned by Partridge *et al.* (2006) to have been deposited in shallow saline lakes. Outcrops of Budin formation are visible in areas located north-east of Kuruman (King, 1963; Visser, 1989). Following the Budin deposits, is the Eden formation which is composed of clayey and calcareous sandstone (Visser, 1989). This sandstone is mainly red or brown but in some areas it is yellow (Partridge *et al.,* 2006). Sandstone of the Eden formation is poorly consolidated and shows areas of contact with Budin formation in certain areas (Partridge *et al.*, 2006). According to Partridge e*t al.* (2006) the Eden formation is a result of deposition by braided streams. The Gordonia formation occurred after the Eden and it is composed of aeolian surface sand and fossil dunes (Visser, 1989; Partridge *et al.,* 2006). This red Kalahari sand covers most of the underlying Kalahari Group sediments (Partridge *et al.,* 2006). The thickness of the Gordonia formation is estimated at 30 m and consist of rounded quartz grains covered by thin coating of haematite (Partridge *et al.,* 2006). It lies on the calcrete surface but in some areas it lies on pre-Kalahari bedrock (Partridge *et al.,* 2006). The three formations (Wessel, Budin and Eden formations) make up a combined maximum thickness of 280 m (Visser, 1989). Of all these formations, the Gordonia formation occurred during the Early to Middle Pleistocene (Visser, 1989). The age of Wessel, Budin and Eden is pre-Pleistocene (Visser, 1989). Dry river beds and pans occurring in the region are overlaid by limestone or calcrete deposits (King, 1963; Partridge *et al.,* 2006).

The Olifantshoek Supergroup

The formation of Olifantshoek Supergroup is estimated at approximately 48 million years old (Moen, 2006). Mountain ranges occurring in the region are formed by the Arenaceous sediment of the Olifantshoek Supergroup, which are progressively covered by the sands of the Kalahari Group (Moen, 2006). Interbedded shale, quartzite and lava are present in the Olifantshoek Supergroup (Moen, 2006). Within the Olifantshoek Supergroup, geology of the study area is in the subdivision called Brulsand Subgroup (Meon, 2006). According to Moen (2006) this subgroup consists of four formations namely Verwater, Top Dog as well as Vuilnek and Vryboom. The lithology associated with the Verwater is grey quartzite with haematite nodules and thin pebble layers (Moen, 2006). The Top Dog subgroup is described as having white to light-grey quartzite with interbedded shale (Moen, 2006). Lithology of the Vuilnek and Vryboom formation is made up of light-grey quartzite with scattered layers of pebbles (Moen, 2006).

Kalahari sand dunes

The Kalahari region is vast, covering areas of Botswana, Namibia and extends into the Northern Cape Province of South Africa (Wright, 1978). This region is described by Wright (1978) as sparsely populated, bushy and mantled with sandy soils through which low rocky hills occasionally emerge. The origin of the red Kalahari sands could be linked to the geological activities involving old granites, dating back from 3 800 million years ago (Field, 1996). The appearance of the red Kalahari sand is due to the deposits of the Kalahari sediments into basins situated in the pans of Botswana (Field, 1996). These Kalahari deposits then dried up and left its sediments exposed to wind (Field, 1996). Over time the wind have blown and shaped the sediments into dunes. The wind direction was from east to west (Wright, 1978). This is a geological phenomenon which took place approximately 20 million years ago (Field, 1996). In addition, King (1951) mentioned that the distribution of the sand, occurred at different times and therefore has different ages.

In his study, Wright (1978) described the Kalahari sand as red to reddish-brown, commonly with a thin surface layer of bleached coating. The effect of water could result in colour changing from red to grey or white (King, 1951). Red Kalahari sand were trapped among the narrow quartzite rocky outcrops. Due to leaching by the perennial aquifer, underlying the sands, the red iron oxide coating of the sand was removed (Anderson, 1996). This leached sand has a strong contrast with the surrounding red sand-plains. The particle size of the sand dunes within the WNR is coarser as compared to the surrounding plains (King, 1963; Frisby, 2016). The white sands of the WNR occurred due to the Kalahari sand blown in from the north and trapped by the isolated quartzite outcrops (Anderson, 1996). According to Anderson (1996) these sands piled up and were bleached by water, resulting in the white dunes of Witsand. The white sand at Witsand might be a result of iron leaching by water and deposited in deeper layers. Water at Witsand originates from the perennial aquifers, just below the surface of the sand (Anderson, 1996). The southern dunes make a roaring sound (brulsand) when disturbed. Disturbance such as walking or sliding down the sand dunes may produce the 'roaring sound' (Witsand Nature Reserve, 2015). According to Anderson (1996) this 'roaring sound' occur as a result of the friction between sand particles. The sound is favoured by the conditions of dryness, as less sound is produced by dunes during rainy months (King, 1951).

Aeolian sands are a remarkable feature in the Kalahari region (Du Toit, 1926b; Maud, 2012). The nature of their arrangement is described as linear, long and lies almost parallel to one another (Leistner & Werger, 1973; Wright, 1978). Fusing and diverging at intervals is a common phenomenon in their arrangement (Leistner & Werger, 1973). These dunes resemble ripples when viewed from far at higher elevated areas. Other longitudinal sand dunes, similar to the Kalahari dunes occur in regions such as Australia (Hesse *et al.,* 2017) and Antarctica (Bourke *et al.,* 2009). Leistner & Werger (1973) mention the average height of the dunes as approximately 12 metres with a mean distance of about 230 metres from crest to crest. The thickness of the sand dunes is estimated to range from 20 – 30 metres (Wright, 1978). According to Leistner & Werger (1973) these red sand dunes cover much of the Kalahari region. To a large extent, the vegetation has covered and stabilized the Kalahari sands. King (1951) mentions the absence of vegetation in some crest-lines of the dunes as a factor causing sand instability. The patterns of the sand dunes have to a certain degree been influenced by the valley trends (Wright, 1978). The valley winds have been found to cause mobility of similar sand dunes in Antarctica (Bourke *et al.,* 2009). In the dunes of Antarctica, movement of the dunes begin at the dune crest which could at a later stage result in the shifting of the entire dune (Bourke *et al.,* 2009). In certain areas of Witsand, movement of sand dunes due to wind erosion have left some quartzite rocks exposed to the surface (Figure 2.3).

Figure 2.3: Exposed quartzite from the central sand dunes of the Witsand Nature Reserve.

2.4 Soils

Soil is the living medium forming a link between the atmosphere and lithosphere; in which plants and animals obtain water and nutrients (Ellis & Amellor, 1995; Van Aardt, 2010). Soil act as a substrate for vegetation establishment and development. Organic and inorganic materials are the components of the soil (Barbour *et al.,* 1987). Organic substances include decomposed plant and animal residues as well as living soil organisms (Barbour *et al.,* 1987). Mineral grains, water and air defines the inorganic nature of the soil (Barbour *et al.,* 1987). Soil properties determine the medium in which plants can grow. It is the medium for plant growth and establishment. Soils of this region are mainly derived from the rocks of the Tertiary Kalahari Group through the process of weathering (Du Toit, 1926a). Two types of weathering namely chemical and mechanical occur under different environmental conditions (King, 1963).

Chemical weathering involves chemical reactions which take place within the constituents of rocks (King, 1963). Mechanical weathering occur as rocks break and disintegrate to form new particles of different sizes (King, 1963).

Arenosol soils have been mentioned by Schwiede *et al.* (2005) as the most dominant soil type in the Kalahari region. This soil type is described as deep and similar across the horizons (Schwiede *et al.,* 2005). However, among the sand dunes there are variations in terms of colour, texture and depth (Du Toit, 1926; Frisby, 2016). Soil colour determines the presence of certain soil components such as organic matter and minerals (Ellis & Amellor, 1995). Red coloured soils are an indication of iron oxides and grey/yellow colours indicate reduced iron content (Ellis & Amellor, 1995). The Hutton soil form is the dominant soil form in the study area (Mucina & Rutherford, 2006). This soil form is described as fine sandy loam (Soil Classification Working Group, 1991). Plains of the WNR are composed of reddish and yellowish sand, whilst the white sand makes up the dunes. Soils with a high clay content is restricted to pans with a greater potential to hold water as opposed to sandy soils. The pans are reported to be dominated by saline soil (Schwiede *et al.,* 2005). In the Kalahari region, calcrete, silcrete and ferricrete crusts, are reported to be widely distributed (Schwiede *et al.,* 2005).

2.5 Climate

Vegetation establishment and development largely depends on climatic conditions of the region. Climate directly influences vegetation at both local and regional scales (Schulze, 1997). In South Africa, there are wet and dry regions in which vegetation patterns vary. Among climatic factors, temperature, light and moisture largely influence vegetation establishment and development (Schulze, 1997). These climatic thresholds greatly determine distribution of plant species and to a large extent, they can be used to predict the impacts of climate change (Schulze, 1997). The distribution of South African biomes is mainly due to climate, geology and soil (Muller *et al.,* 2016).

Climate includes all aspect of precipitation, temperature, wind, evaporation rate and amount of solar radiation in a particular geographical region. Schulze (1997) mention light, temperature and moisture as the most important climatic factors in vegetation development. Schulze (1965) stated that the climate of any place is determined by its latitude, distance from the sea and height above sea level. The climate within the study area could be described as hot and dry during summer with daily temperature reaching above 35°C (Figures 2.4 & 2.5). Winters are extremely cold with average temperatures dropping below 5°C during June and July (Figures 2.4 & 2.5). In terms of the Köppen climatic classification of South Africa (1961 – 1990), the climatic region of the study area is classified as Steppe (semi-arid), (Schulze, 1965; Kruger, 2004). The study area is located in the inland region, where influence of oceans is minimal (Schulze, 1997; Mucina & Rutherford, 2006). Schulze (1965) and Erasmus (1996) described the Kalahari region as extremely hot during summer and cold during winter nights with occasional frost. Conditions of severe drought form part of the precipitation cycle (Schulze, 1965; Erasmus, 1996). The hot and dry climatic conditions supports the establishment of arid-adapted flora and fauna. The southern parts of the region have a high evaporation rate (Schulze, 1965; Erasmus, 1996). There is no weather station located in the study area thus, climatic data was obtained from the weather stations situated in the towns of Upington (to the west of the study area) and Postmasburg (to the east of the study area).

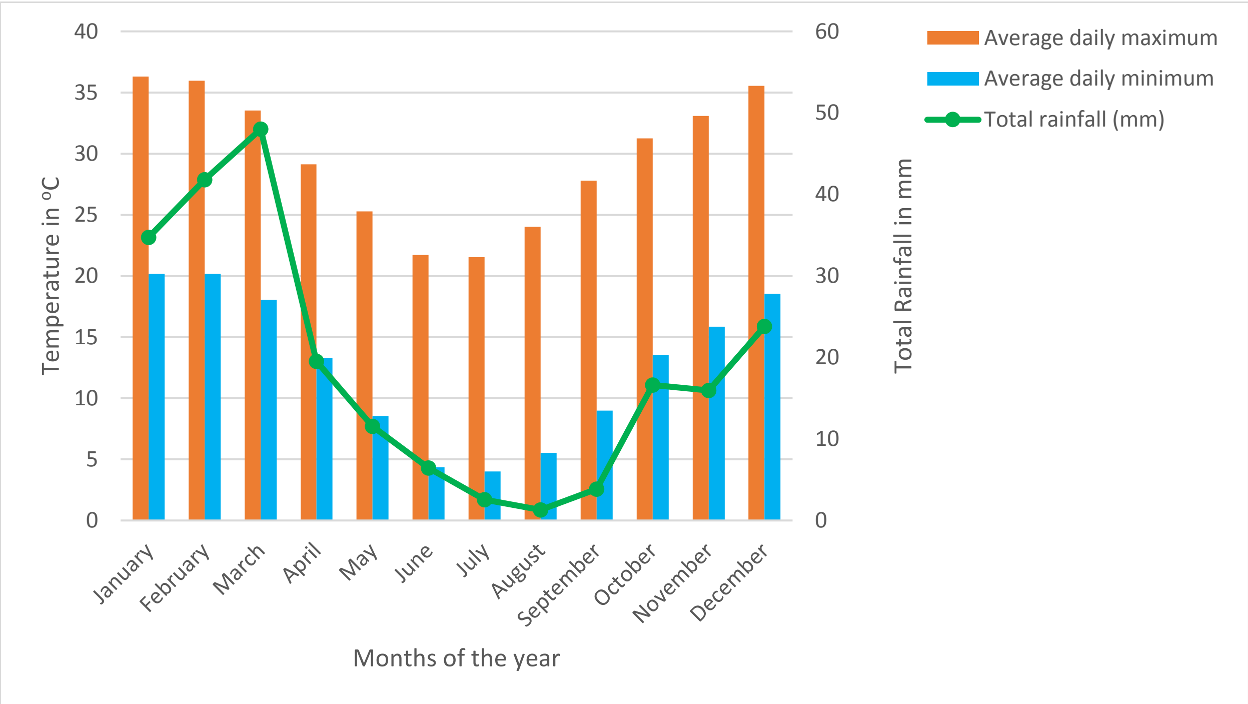

Figure 2.4: Average daily minimum, maximum temperature and average rainfall for Postmasburg for the period 1997 – 2017 (South African Weather Services-Station 0317475A8).

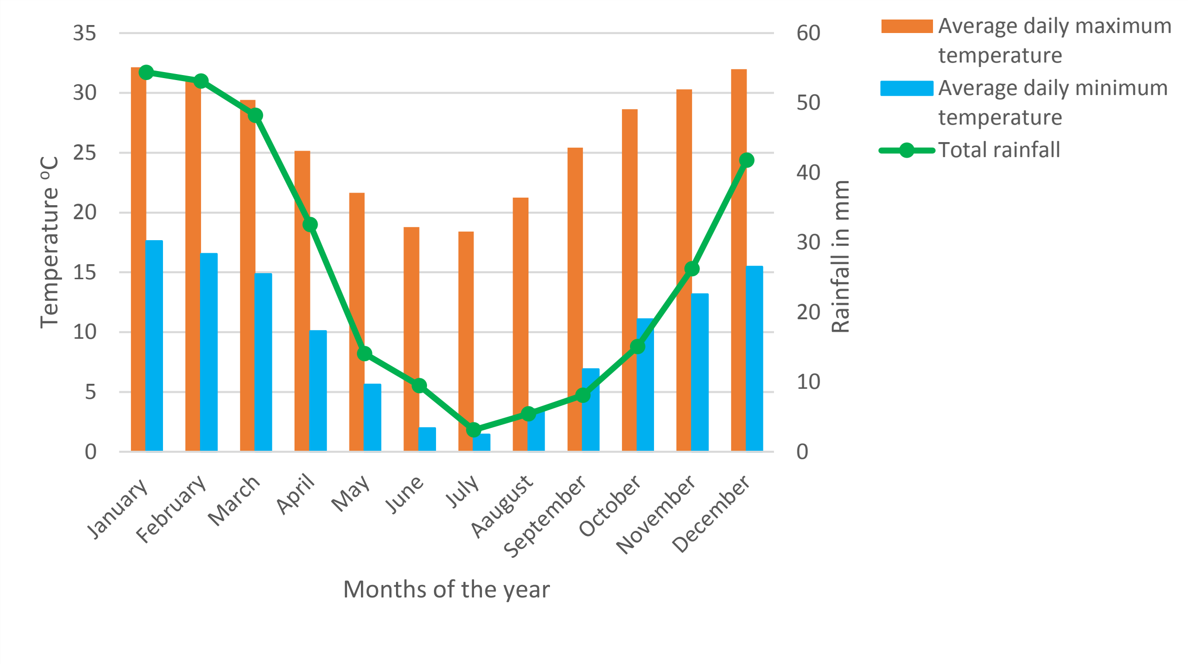

Figure 2.5: Average daily minimum, maximum temperature and average rainfall for Upington for the period 1997 – 2017 (South African Weather Services-Station 0317475A8).

2.5.1 Temperature

Temperature generally refers to the degree of hotness and coldness, of the surrounding environment (in this context). In the study area, the lowest and highest temperatures ever recorded were -8°C and 42°C respectively (Van den Berg *et al.*, 2007). Van Zyl (2003) stated that during the hot season (summer) ground surface temperatures could reach 70ºC in the Kalahari. In most parts of the region the daily temperature exceeds 30°C for approximately 120 – 150 days of the year, whilst winter nights drop below 0°C (Erasmus, 1996). The hottest months are November – March, whilst June and July are the coldest (Figure 2.4 & 2.5). Schulze (1965), mentioned that altitude is the most influential factor affecting temperature in the area. Frisby (2016) stated that the elevated areas, including mountains have cooler temperatures as opposed to low lying areas in both summer and winter. Certain plant species are adapted to tolerate freezing temperatures, whilst some could survive in extremely hot temperatures. The ability of plants to survive extremely cold or extremely hot temperatures is due to physiological adaptations of that particular plant species. Low temperatures and frost are critical in survival of plants and their distribution (Schulze, 1997). Frost destroys the plant tissues and consequently the exposed part of the plant or whole plant would eventually die (Muller *et al.,* 2016).

2.5.2 Rainfall

Rain is described by Van Zyl (2003) as precipitation which reaches the ground in a form of liquid droplets, regardless of the state of its origin. Different forms of precipitation recognised by Van Zyl (2003) includes rain (droplets) and ice particles (snow, hail). Rainfall is the most common form of precipitation occurring in the study area. The study area is semi-arid and receives late summer and autumn rainfall (December to April) (Schulze, 1965; Rowntree, 2013). The mean annual precipitation for the region is very low, ranging between 250 mm to 350 mm (Schulze, 1997; Mucina & Rutherford, 2006; Van den Berg *et al.,* 2007). Rainfall is mainly in the form of scattered showers and thunderstorms (Schulze, 1965; Veldsman, 2008). Factors such as distance from the ocean and rain-bearing winds influences the average amount of rainfall in this region (Schulze, 1965). Precipitation provides water, which is essential in maintaining all physiological and chemical processes within plants (Schulze, 1997). Physiological and chemical process may involve exchange of energy and nutrient transport.

2.5.3 Solar radiation

Solar radiation refers to the light energy from the sun, needed by plants for survival. All ecosystems on earth largely depend on incoming solar radiation as a source of energy (Schulze, 1997). The amount of solar radiation reaching the earth's surface is mainly influenced by cloud cover (Kruger & Esterhuyse, 2005). Cloud cover reduces the amount of sunshine and most areas in the western interior of the country have clear skies (Kruger & Esterhuyse, 2005). The study area and surrounding areas have high percentages of solar radiation with an average of more than 80% in most areas (Schulze, 1965; Kruger & Esterhuyse, 2005). The distribution of solar radiation varies with seasonal changes. According to Schulze (1997), summers receive more solar radiation, whilst winters receive lower solar radiation in the arid areas of the Cape. The variations of solar radiation may influence the distribution of plant species. In the region of the Witsand Nature Reserve, the amount of solar radiation range from 16 – 18 MJ m^{-2} d^{-1} (Schulze, 1997). Slope is another factor influencing the amount of solar radiation, where north/east facing slopes receive most solar radiation in the southern hemisphere (Schulze, 1997). Light is essential for the survival and development of most plants as it supports photosynthetic processes. It is the energy source in all ecosystem (Schulze, 1997). The availability of light to plants is restricted by seasonal changes and cloud cover (Schulze, 1965).

2.5.4 Wind

Van Zyl (2003) mentioned that wind is a major climatic force with the potential to reshape the earth's surface. Wind-blown sand occurring in the study area is an example of this phenomenon. The most crucial aspects of wind are velocity and direction. Wind direction and speed varies from region to region. Major variations in winds have been reported in the coastal regions and they differ with seasons, as opposed to the inland areas of South Africa (Schulze, 1965). In the inland regions (including the study area), northerly winds are common (Schulze, 1965; Kruger, 2004).

The Kalahari region comprises of the semi-arid to arid vegetation types, which has adapted to hot and dry conditions (Leistner & Werger, 1973). Du Toit (1926a) noted that during the past, Kalahari sands covered vast parts of the region but over time, erosion have reduced them to limited areas. Climatic conditions of hot and dry winds have resulted in this phenomenon. Apart from the climatic conditions, the dunes also influence the growth of different life forms of plants, by stabilizing sand and thus preventing erosion by wind. Although the basal parts of the dunes are stable; the crests are frequently reshaped by wind (Leistner & Werger, 1973). These unstable conditions, involving shifting of the dunes due to wind mainly occur during hot and dry conditions (Leistner & Werger, 1973). He-Qiang & Zhang (2012) stated that wind-blown sand is a serious threat to arid ecosystems. This phenomenon, could to a certain extent, affect the vegetation stability on the crests of the dunes. The north-easterly wind of the Kalahari resulted in the steep south-western slopes of the dunes (Leistner & Werger, 1973). Alvarez-Mozos *et al.* (2014) reveals that steep slopes negatively affect the vegetation growth and establishment. According to Alvarez-Mozos *et al.* (2014) the soil erosion due to heavy rains could wash away the seeds of plants and this could result in poor vegetation establishment. In the dune system erosion by heavy rains could be less practical since most of the rain water infiltrates the coarse sand. Although certain parts of the dunes may be unstable and possess no vegetation, Wright (1978) describes the Kalahari sand dunes as generally being fixed by vegetation.

2.5.5 Evaporation

Potential evaporation refers to the total loss of water through evaporation from plants and the soil surface (Schulze, 1997). Evaporation may also occur from the surface of a water body. Factors influencing evaporation include net radiation, wind and vapour pressure (Schulze, 1997). Schulze (1965) studied evaporation of various regions in the country. In southern Africa, the overall estimation of evaporation is 91% from surface water (Schulze, 1997). The evaporation rate in the Northern Cape is the highest when compared to other regions in the country (Schulze, 1997). The average annual evaporation in the vicinity of the study area range between 2 500 – 2 750 mm (Schulze, 1997). In the study area and surrounding areas, evaporation is high during spring and low during autumn and winter (Schulze, 1965).

2.6 Surface Water

The surface water in the study area is limited, as in other semi-arid regions (Anderson, 1996). Two pans with standing water are present in the Witsand Nature Reserve. The standing water in these pans is a result of the shallow water table that is being replenished after good rainfall events (Anderson, 1996; Terblanche & Taylor, 2000). These pans refill in the event of heavy rainfall mostly during the months of December to April. Dry pans are also visible in low lying areas of the reserve (Figure 2.6). These pans may hold water for a limited period of time more or less three weeks and eventually dry up. Pans are described by Thomas & Shaw (2012) as essentially endorheic (systems with enclosed basins), which vary in sizes. They are widespread throughout the Kalahari region and they mostly occur as dry pans, while some have the potential to temporarily hold water (Thomas & Shaw, 2012). Distribution and density of the pans largely depend on factors such as climate and lithology (Thomas & Shaw, 2012). Dominant winds have to a large extent shaped these pans (Thomas & Shaw, 2012). The WNR is relatively flat with no drainage systems. The nearest river is the Orange River, situated approximately 50 km south of the reserve (Anderson, 1996). Small drainage lines may occur in certain areas within the reserve but they usually drain to the nearest pan.

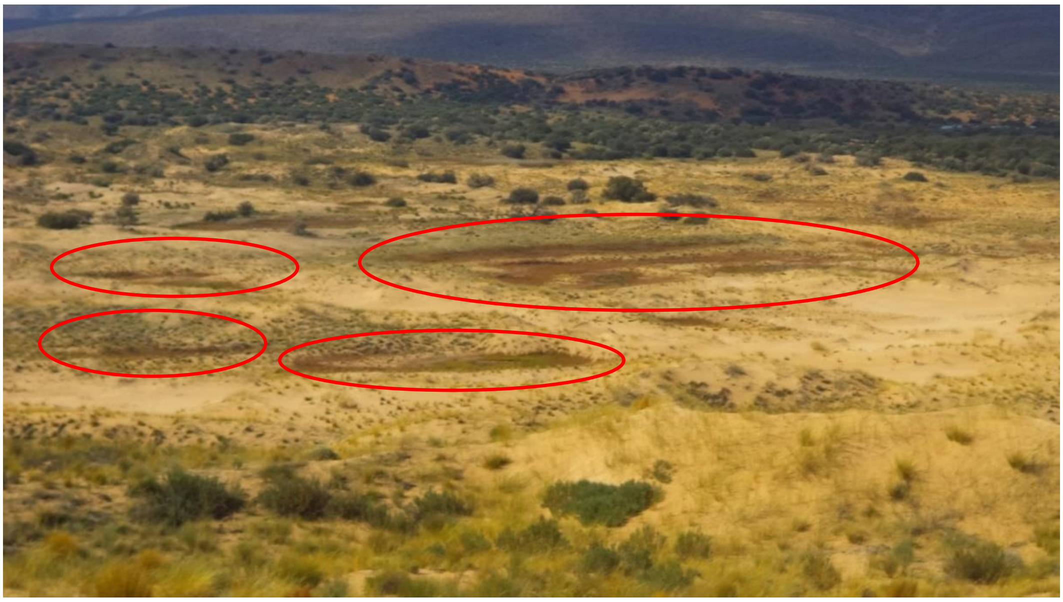

Figure 2.6: Dry pans (circled in red) located in the Northern parts of the Witsand Nature Reserve.

2.7 Flora and fauna

The WNR falls within the Savanna Biome (Mucina & Rutherford, 2006). The Savanna Biome is a major vegetation unit, characterized by the dominance of hemicryptophytes (mainly grasses) and phanerophytes (trees and shrubs) (Henderson, 1991). Savanna ecosystems are dynamic and covers approximately 65% of land surface in Africa (Rasanen *et al.,* 2017). The structure and composition of the savanna is determined by water, nutrient availability, fire and herbivory (Kamuhuza *et al.,* 1997). Savannas occur in many regions of the world, with varying climatic conditions (Martinez-Garcia *et al.,* 2012). Two classes of savannas namely humid and semi-arid savannas are characterized by the amount of rainfall they receive (Martinez-Garcia *et al.,* 2012). Most conservation areas in Africa are in both humid and semi-arid savanna ecosystems (Beale *et al.,* 2013). According to Henderson (1991) stock farming (cattle and sheep) is the main land use factor in the sparsely populated savanna of the semi-arid Kalahari, where the study area is located.

2.7.1 Broad vegetation types

Acocks (1988) classified the vegetation of the study area as a western form of the Kalahari Thornveld. According to Mucina & Rutherford, (2006) the Witsand Nature Reserve is situated in the Olifantshoek Plain Thornveld (SVk 13). This vegetation unit is characterised by wide and open layers of trees and shrubs dominated by *Vachellia erioloba* [*Acacia erioloba*] and *Vachellia haematoxylon* [*Acacia haematoxylon*]. The open shrubby thornveld consist of a dense shrub layer often lacking a tree layer in certain areas. The Olifantshoek Plains extends from the west of the Langeberg Mountain towards Olifantshoek and it covers some areas to the north of Niekerkshoop (Mucina & Rutherford, 2006). The vegetation in this unit is least threatened, however poorly conserved (Mucina & Rutherford, 2006). Grazing pressure have been mentioned by Acocks (1988) as a possible future threat to this vegetation unit, if proper veld management is not practiced. Important taxa includes tall trees such as *Vachellia erioloba*, small trees are *Vachellia karroo* and *Zizipus mucronata* (Mucina & Rutherford, 2006). Tall shrubs such as *Searsia tridactyla*, *Diospyros lycioids*, *Grewia flava* and *Tarchonanthus camphoratus* also form part of the important taxa (Mucina & Rutherford, 2006). Low shrubs includes *Vachellia hebeclada* [*Acacia hebeclada*]. Graminoids consisting of *Digitaria eriantha, Eragrostis lehmanniana, Stipagrostis amabilis, S. ciliata, S. obtusa* and *Aristida congesta* dominate the ground layer (Mucina & Rutherford, 2006). Within this vegetation unit, species of *Vachellia erioloba* and *Vachellia haematoxylon* are absent along the rivers and on the hills and mountain ranges (Acocks, 1988). Although very little of this vegetation unit is transformed (Mucina & Rutherford, 2006), its conservation remains important. The WNR is a potential area of plant endemism, with species such as *Brachiaria dura* and *Justicia thymifolia* being considered endemic to the area (Frisby, 2016; Anderson 1996).

2.7.2 Broad faunal description

Veldsman (2008) mentioned a total of 41 mammal species occurring at WNR which includes springbok (*Antidorcas marsupialsis*), gemsbok (*Oryx gazella*) and red hartebeest (*Alcelaphus buselaphus*), grey duiker (*Sylvicapra grimmia*), steenbok (*Raphicerus campestris*), aardvark (*Orycteropus afer*), porcupine (*Hystrix africaeaustralis*), springhare (*Pedetes capensis*) and numerous small mammal species. A total number of 170 bird species have been recorded in the WNR (Veldsman, 2008). The recorded herpetofaunal species (reptiles and amphibians) totals 39 reptile and five amphibian species (Veldsman, 2008). The reserve also host a large number of invertebrates. Both plants and animals coexist in the WNR and their co-existence simply indicates that the species share similar abilities to tolerate the environmental conditions (Huggett, 1995).

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CHAPTER 3: Literature review

3.1 Vegetation patterns of the Kalahari

The rich southern African flora has an estimated 21 137 indigenous species, across all biomes (Cowling & Hilton-Taylor, 1997). Species richness is not uniformly distributed across southern Africa, due to the effect of climate, geological formations and altitude (Bond *et al.,* 2003). The floristic diversity of the south-western parts of the Cape region is richer than other regions (Cowling & Hilton-Taylor, 1997). Although the Kalahari is known to be the largest phytogeographical region in southern Africa, it is poorly vegetated with only a few endemic species (Cowling & Hilton-Taylor, 1997). The Kalahari region lies in the arid parts of the savanna biome (Huntley, 1984; Mucina & Rutherford, 2006), which covers approximately 24.2% of South Africa's land surface (Huntley, 1984). Arid savannas are diverse in terms of physiognomy and include open space with scattered shrubs and trees (Huntley, 1984).

Growth forms of species may include weeds, grasses, dwarf shrubs, shrubs and trees. Plants of rocky outcrops occur on basalt, dolerite, quartzite, etc., mostly occurring as hills and mountains. Sedges and other aquatic plants are well established in aquatic systems such as rivers and wetlands. Parasitic plants include *Viscum rotundifolium* and *Tapinanthus oleifoleus* which are associated with woody species such as *Vachellia erioloba* and *V. haematoxylon*. In some areas trees form dense impenetrable thickets with herbaceous layers being unnoticeable. The most common trees are *Vachellia* [*Acacia*] and *Senegalia* [*Acacia*] species with *Eragrostis* species as the most common grass species (Huntley, 1984). The open grassy plains are dominated by *Stipagrostis* species. The nature of savanna vegetation supports a variety of game species (Huntley, 1984). Trees, shrubs and grasses create a suitable habitat for both grazing and browsing animals that are adapted to this environment.

Leistner and Werger (1973) studied the vegetation of the Southern Kalahari with great focus on habitat types and life forms. In their study Leistner & Werger (1973), noted that vegetation description in terms of the plant communities is lacking and recommended detailed future studies. Veldsman (2008) focused on vegetation degradation gradients and ecological index with great emphasis on grass species in the south-eastern Kalahari. In his study Veldsman (2008), covered other areas within the vicinity of Witsand. It is envisioned that the state of the environment might have changed over time. Although the study covered the aspect of plant communities, it did not pay attention to the factors influencing floral distribution and the management of biodiversity in conservation areas. Hearn *et al.* (2011) emphasized the importance of conducting vegetation studies as it aid in planning and managing conservation sites. When repeatedly conducted, these studies could display the vegetation patterns and changes occurring over time (Hearn *et al.,* 2011). The study conducted by Frisby (2016) focused on defining floral and faunal endemism within the Griqualand West Centre of Endemism. The great emphasis was on endemic and near-endemic plant taxa (Frisby, 2016). Frisby (2016) found *Brachiaria dura* var*. pilosa, Amphiglossa tecta* and *Justicia thymifolia* to be endemic to the study area.

3.2 Biotic factors influencing the Kalahari vegetation

Vegetation of any landscape is influenced by both biotic and abiotic factors. Abiotic factors influencing the Kalahari vegetation were discussed in the previous chapter. These include: geology, topography, climate and fire. The biotic factors may include overgrazing, bush encroachment and biological invasions. These factors influence ecosystems in different ways and the level at which they contribute towards vegetation patterns varies. In some ecosystems, landscape modification due to human activities have been reported to influence vegetation structures (Godron & Forman, 1983).

(a) Overgrazing

Acocks (1988) recognised grazing as an important factor contributing towards variation in vegetation. This could mean that different management practices in terms of grazing pressure has an influence on shaping the vegetation patterns. Moderate grazing refers to a phenomenon where grass cover remains fairly stable and not heavily impacted by herbivores (Farming Connect, 2013). Moderate grazing have no negative impact on the ecosystem but instead it supports production as opposed to excessive grazing (Lamotte, 1983). However, veld species may become moribund and possibly die if they are not grazed for a number of years (Tainton, 1999). The removal of top growth of ungrazed species by burning could help to overcome moribund and death (Tainton, 1999). Overgrazing is a threat to the vegetation and could result in extinction of species in ecosystems (Kondoh, 2003). If not managed properly, grazing intensity could pose a threat to the ecosystem. Hesse *et al.* (2017) mentioned both subsistence and commercial grazing as the common land use on most sand dunes of the semi-arid to arid environments. When left uncontrolled, the effect of overgrazing could be a serious threat to these environments. The Kalahari grasses were heavily grazed, since the introduction of cattle and small livestock (Dougill & Cox, 1995). Cattle was introduced in the mid-nineteenth century by the Tshwana people who occupied land at that time (Radatz, 2003). Acocks (1988) mentions extinction of certain grass species in the Witsand area due to heavy grazing pressure during the past. Dougill & Cox (1995) points out the effect of overgrazing in the Kalahari as the factor that have intensely modified ecological conditions for a while. Together with drought, the effect of overgrazing exposes the sand to wind transportation (Hesse *et al.,* 2017). This phenomenon reduces plant cover over the dune system (Hesse *et al.,* 2017).

(b) Bush encroachment

Bush encroachment have been described by Stafford *et al.* (2017) as the invasion and/or thickening of woody plants which results in ecosystem imbalance. These woody plants are indigenous and occur in their natural environment (Smit, 2004). The ecological imbalance due to bush encroachment involves the decrease in biodiversity and in carrying capacity (Stafford *et al.,* 2017). When in a natural ecological condition, savanna ecosystems are dominated by perennial grasses with scattered trees and shrubs (Lohmann *et al.,* 2014). The balance between trees and grasses bears both ecological and economic benefits (Harmse *et al.,* 2016). In savanna ecosystems, bush encroachment entails the proliferation of woody plants at the expense of grasses (Smit, 2004; Munyati *et al.,* 2013). During this process, woody plants outcompete the grasses, which results in woody vegetation dominating the system (Lohmann *et al.,* 2014). The major impact of bush encroachment is that it degrades ecosystems, especially rangelands (Lukomska *et al.,* 2014).

In South Africa, bush encroachment is estimated at about 10-20 million ha of land and this occurs mainly in the grassland and savanna ecosystems (Stafford *et al.,* 2017; Ward, 2005). Bush encroachment is one of the factors which have been seen taking place in the Kalahari ecosystems (Dougill & Cox, 1995) and it has altered savannas throughout the world (Ward, 2005). Plant species such as *Senegalia mellifera, Vachellia reficiens, Vachellia tortilis, Vachellia nilotica, Vachellia karroo, Dichrostachys* *cinerea, Terminalia sericea, Rhigozum trichotomum* and *Tarchonanthus camphoratus* are known to be the most dominant candidates for bush encroachment in semi-arid and arid regions (Stafford *et al.,* 2017).

Bush encroachment have been mentioned by Dougill & Cox (1995) and Sianga & Fynn (2017) as an ecological disturbance shaping the Kalahari ecosystems. Although bush encroachment is mostly associated with disturbed environments, Dougill & Cox (1995) expressed an opinion that it doesn't always indicate land degradation in the Kalahari ecosystems. In contrast, Lukomska *et al.* (2014) considered bush encroachment as a form of land degradation in arid and semi-arid regions. Factors such as high grazing intensity and fire suppression are reported as the main causes of bush encroachment (Kgosikoma & Mogotsi, 2013; Munyati *et al.,* 2013; Lohmann *et al.,* 2014). Overgrazing suppresses the grass species and support the dominance of woody species (Kgosikoma & Mogotsi, 2013). Frequent burning destroys juvelile trees and shrubs, preventing them from becomming mature (Kgosikoma & Mogotsi, 2013). In addition to overgrazing and fire suppression, environmental factors such as rainfall and soil properties are known to have an impact on bush encroachment (Kgosikoma & Mogotsi, 2013). According to Kgosikoma & Mogotsi (2013), an increase in rainfall results to an increase of woody cover and density in arid and semi-arid savannas. Sandy soils favours the woody cover and density, while soils with high clay content suppresses woody plants (Kgosikoma & Mogotsi, 2013). Lohmann *et al.* (2014) stated that the increase of carbon dioxide (CO_2) in the atmosphere also leads towards bush encroachment.

Bush encroachment is viewed by Dougill & Cox (1995) as symptomatic to a non-resilient system. Species diversity is very low in areas affected by bush encroachment (Ethekwini Municipality, *undated article*; Lohmann *et al.,* 2014). Non-resilience in Kalahari ecosystems are thought to be as a result of infertile soils containing negligible amounts of organic matter (Dougill & Cox, 1995). Frequent burning is mentioned as an effective management tool to control bush encroachment, especially in grassland ecosystems (Ethekwini Municipality, *undated article*; Lohmann *et al.,* 2014). Lohmann *et al.* (2014) and Sianga & Fynn (2017) specify *Senegalia mellifera* as an aggressive encroacher in semi-arid savannas, with significant post fire reduction. Mineral-rich soil supports the formation of dense stands of *Senegalia mellifera* in the Kalahari (Sianga

& Fynn, 2017). Although fire is a good management tool for bush encroachment, it poses a risk to infrastructure as well as livestock and game species. Another remedial action to bush encroachment is the removal of some or all woody vegetation (Smit, 2004). Smit (2004) warns that care must be taken when removing woody vegetation, as it is ecologically important in the ecosystem. Harmse *et al.* (2016) mentions other bush-control practices (other than fire) which include the use of chemicals and mechanical treatment. Caution is essential when applying any of these bush-control practices as they may possibly be financially expensive but give little effect to the veld condition (Filmalter, 2010).

(c) Biological invasions

Biological invasion refers to the introduction, establishment and spread of alien plants in places where they don't naturally occur (Stafford *et al.,* 2017). This phenomenon have affected more than 10 million ha of land in South Africa and Lesotho (Department of Environmental Affairs and Tourism, 2007; Holmes, 2000). Van den Berg *et al.* (2013) mention that "Alien plant invasions have a major impact on biodiversity, ecosystem services, agriculture, forestry, the economy and human welfare". Invasive alien plants have negative effects in the environment, as they degrade mostly riparian ecosystems (Van den Berg *et al,* 2013; Department of Environmental Affairs). Invasive alien plants are known to consume more water than the native plants (Van den Berg *et al.,* 2013; Department of Environmental Affairs, 2016). The impacts of biological invasions result in the government of South Africa spending billions of Rands, through monitoring programs such as Working for Water (Holmes, 2000). The Department of Environmental Affairs (DEA) mentioned the biological invasion as the critical factor affecting almost all biomes in South Africa (Department of Environmental Affairs, 2016). This statement was supported by Stafford *et al.* (2017) where he stated "Biological invasions threaten biodiversity and ecosystem functioning".

According to Stafford *et al.* (2017), alien species are introduced to support industries such as agriculture, forestry, horticulture and recreation. More than 750 tree species and 8 000 herbaceous species have been introduced in South Africa (Department of Environmental Affairs and Tourism, 2007). Biological invasion is influenced by a range of environmental factors such as soil texture, slope, geology, water availability and climate (Van den Berg *et al.,* 2013). These environmental factors determine the suitability of establishment and spreading of invasive alien plants. Disturbed ecosystems are prone to biological invasions as they become favourable for alien plant establishment (Stafford *et al.,* 2017). If not managed properly, these plants disperse to occupy areas where they do not naturally occur. South Africa has an estimation of about 9 000 introduced plant species of which about 198 are declared invasive aliens (Department of Environmental Affairs, 2016; Stafford *et al.,* 2017). The genus *Prosopis* (Fabaceae) is a declared invasive (Van den Berg *et al.,* 2013). In South Africa different species of *Prosopis* namely; *Prosopis velutina* (cartegory 2 invader) and *P. glandulosa* (cartegory 2 invader) continue to invade most areas of South Africa (Van den Berg *et al.,* 2013). Plant species such as *Prosopis velutina* and *Opuntia ficus-indica* were recorded by Henderson (1991) as the most common invasive alien species in the Kalahari region of the Northern Cape, South Africa. Van den Berg *et al.* (2013) stated that *Prosopis* is an aggressive invader in arid areas, which have shown an increase over the past 30 years, in the Northern Cape region. Other invasive alien plants mostly occur in the moist regions of South Africa (Stafford *et al.,* 2017).

The Department of Environmental Affairs has developed a policy framework, recommended to eradicate and control biological invasions in all affected areas including protected areas (Department of Environmental Affairs, 2016). The National Environmental Management Act: Biodiversity Act, 2004 (Act 10 of 2004) (NEMBA) and the Conservation of Agricultural Resources Act, 1983 (Act 43 of 1983) (CARA) provide the legal framework for control and eradication of the invasive alien plants in South Africa (Department of Environmental Affairs, 2016). In 1995, the Government of South Africa initiated the Working for Water programme (Holmes, 2000). This programme was aimed to clear out and eradicate invasive alien plants, thus restoring indigenous vegetation countrywide (Holmes, 2000). Van den Berg *et al.* (2013) recommended best management practices such as strategic follow-up surveillance and control programmes as well as early detection of new infestations. Control measures to eradicate invasive alien plants involves initial clearance, follow-up clearance and maintenance clearance (Holmes, 2000).

3.3 Management practices in protected areas

Conservation areas (protected areas) are described as sites isolated from development due to their recognized natural, ecological and/or cultural resources

(Bezuidenhout, 2009). National parks, nature reserves and game farms are examples of conservation areas. The idea to establish nature reserves in South Africa began during the 21st century (Keddy, 2007). The primary aim of conservation areas is to protect biodiversity and the land on which they occur (Dudley, 2010). Sianga & Fynn (2017) includes soil and moisture as important environmental gradients that should form part of conservation in protected areas. Dudley (2010) mentioned wildlife, more especially endangered plant and animal species as key components to consider in protected areas.

Generally, management of natural ecosystems on conservation areas should strive to achieve and maintain a more or less equilibrium state of interactions between biotic and abiotic components (Gertenbach, 2010). In conservation areas, management of biodiversity is of great importance. Keddy (2007) specified monitoring of biological resources as key aspect when managing conservation areas. This involves selection of indicators and determining thresholds, through which strategic objectives could be drawn (Keddy, 2007). In the event where these objectives are not met, the review and amendment of management plans is recommended (Keddy, 2007).

When drawing up management plans, information about classification, description and distribution of plant communities is crucial (Bezuidenhout, 2009). Since vegetation forms the basis for establishment of any ecosystem, ecological factors influencing the vegetation patterns must be monitored. These ecological factors include overgrazing, bush encroachment, biological invasions (discussed above) and fire. Of all these factors, management of overgrazing is the main concern as it influences vegetation directly (Bezuidenhout, 2009). The influence on vegetation determines the introduction for game species in the future, since it affects the carrying capacity of the veld. Climate change is a global threat to the ecosystems of the world and it poses a challenge in managing conservation areas (Dudley, 2010). Vegetation in various biomes may respond differently to the effect of climate change. Therefore, conservation managers should take cognisance of the effect of climate change when planning and drawing up management plans for conservation areas. These management plans may vary according to the biome in which the conservation area is located (Dudley, 2010). It is recommended that the response strategy to climate change should be developed to form part of the management plan (Dudley, 2010).

Community involvement is recognised by Castley *et al.* (2009) as crucial in order to inform and achieve the best management practice in conservation areas. This include educational programs such as environmental education. Implementing the Integrated Environmental Management Systems (IEMS) is viewed as the best management practice in conservation areas (Castley *et al.,* 2009). The South African National Parks is already in the process of implementing IEMS with the aim to improve the management actions in their parks (Castley *et al.,* 2009).

3.3.1 Management plans

Management plans in protected areas serve as a reference to the management and development at that particular time including possible future changes. The primary objective of the management plan is to protect, conserve and manage biodiversity within the protected area concerned (South African National Parks, 2017). This ensures conservation and protection of natural resources within protected areas. The development of these management plans is in accordance with the National Environmental Management: Protected Areas Act, 2003 (Act 57 of 2003), (NEM: PAA) (South African National Parks, 2017). Management plans for protected areas are approved by the relevant authorities. They can be reviewed and amended when necessary. Their period of validity is usually ten years (South African National Parks, 2017).

Protected areas are spatially zoned in such a manner that conservation, tourism and visitor experience initiatives are well coordinated and do not conflict each other (Kalahari Gemsbok National Park, 2016; Mokala National Park, 2017). Castley *et al.* (2009) mentioned Conservation Development Frameworks (CDF) as a necessity in addition to strategic management plans. These CDF’s incorporating sensitivity mappings and zonation schemes form part of the management plan for conservation areas (Castley *et al.,* 2009). In protected areas, conservation of biodiversity is the core mandate and management plans are developed with more focus on biodiversity management. Most parks and nature reserves are used as tourism destinations and offer tourism services such as 4x4 trails, hiking trails, game drives and picnic sites with braai areas. Tourists visiting such areas may interfere with natural ecosystems and pose threats to these ecosystems (Dudley, 2010). Some of these natural ecosystems and habitats are susceptible to human interference and conservation managers should identify these areas in conservation areas (Dudley, 2010, Kalahari Gemsbok National Park [Kgalagadi Transfrontier National Park], 2016; Mokala National Park, 2017). .

Once identified, management plans should be drawn to create buffers that protect these ecosystems from human destruction (Dudley, 2010). Dudley (2010) also recommended the isolation or restriction of the sensitive habitats and ecosystems from tourists. Biodiversity management programmes are aimed to prevent decline or loss of species (flora and fauna) of conservation concern by identifying, monitoring and managing such species. Another important aspect is determining changes in the habitats and plant communities, which have direct consequences for the faunal species (Bezuidenhout, 2009; Dudley, 2010; Kalahari Gemsbok National Park, 2016; Mokala National Park, 2017). In instances where degradation of ecosystems occur, (Department of Environmental Affairs and Tourism, 2007) immediate restoration is recommended in order to try and solve the situation. Sustainable utilisation of water resources is essential to support both plant and animal life. Fire is considered as a natural ecological tool which maintains balance in plant diversity (Kalahari Gemsbok National Park, 2016; Mokala National Park, 2017). However, human intervention is recommended as fire could lead to adverse ecological effects, if not properly managed. When implementing management plans in conservation areas, it must be noted that ecosystems are naturally dynamic and management plans must be structured in a manner that supports their dynamic nature.

3.3.2 Management practices in semi-arid savanna

Arid and semi-arid environments are generally described by conditions of hot and dry climate, as they receive very low rainfall. Both plants and animal species occurring in these regions are well adapted to these environmental conditions. Management decisions are mainly driven by the conservation needs, which is primarily preservation of natural resources (Dudley, 2010; Tokura *et al.,* 2018). Overgrazing is a serious threat in arid and semi-arid ecosystems as it takes time for vegetation to re-establish once it has been disturbed by overgrazing. In Rooipoort Nature Reserve (RNR), the hunting of both large and small mammals was introduced to manage and overcome extensive grazing (Bezuidenhout, 2009). This reduces the population of game species and as a result relieves pressure of grazing intensity. Sound ecological knowledge is used as the basis for management and conservation policy frameworks in RNR

(Bezuidenhout, 2009). This involves the understanding of plant communities and their associated habitats (Bezuidenhout, 2009; Kalahari Gemsbok National Park, 2016). The information about species composition and plant communities could, therefore, anable conservationists to develop effective management plans (Bezuidenhout, 2009).

Special attention should be drawn to endemic species and Dudley (2010) recommended a buffer to be created for the purpose of restricting disturbance to such communities. These management plans do not represent separate communities occurring in the reserve but they are inclusive. According to Gertenbach (2010) smaller conservation areas (spatial size) are easier to manage as opposed to bigger ones. However, extremely large parks such as Kruger National Park (KNP) requires less management interventions (Gertenbach, 2010). This is because most ecosystems are able to naturally restore its processes and become as close as possible to the more natural stable equilibrium (Gertenbach, 2010). Bezuidenhout (2009) recommended grouping of plant communities as an effective method when drawing up management plans for conservation areas. The hierarchical grouping of these plant communities together with abiotic components, such as topography, geology and soil makes up a defined management unit (Bezuidenhout, 2009). These management units must be regularly surveyed in order to determine their average veld condition, including the density of woody species and alien invasion (King, 1989; Department of Environmental Affairs and Tourism, 2007).

Various management practices are being implemented in conservation areas situated in different biomes. These include artificial removal of invasive alien plants and restoration of native vegetation (Dudley, 2010). Invasive alien species have been reported to be a widespread phenomenon in conservation areas (Department of Environmental Affairs and Tourism, 2007; Dudley, 2010). In some instances, fire is used as a management tool to control bush encroachment as it reduces the woody vegetation in ecosystems (Tainton, 1999; Lohmann *et al.,* 2014). The effectiveness of these management practices may differ across biomes. Most conservation areas in South Africa are in the Savanna biome, both semi-arid and humid. In order to determine the effect of the management practices, there must be ongoing monitoring on sensitive ecosystems (Gertenbach, 2010). These monitoring programmes must be conducted regularly and changes in the ecosystem must be detected at an early stage (Gertenbach, 2010). Detection of changes at an early stage could enable conservation managers to apply remedial actions at low costs (Department of Environmental Affairs and Tourism, 2007).

South African National Parks (SANParks) recommended the development of proper environmental management tools which could assist to control development activities within conservation areas (Namaqua National Park, 2013). These management tools should be consistent with the legislative and policy framework governing the protected area (Namaqua National Park, 2013). The spatial planning is considered important as it presents the zoning (Namaqua National Park, 2013). The zoning plan provides spectrum for all land usage in protected areas (Namaqua National Park, 2013; Kalahari Gemsbok National Park, 2016; Mokala National Park, 2017).

(a) Fire

Fire influences the distribution, structure and functioning of terrestrial ecosystems (Bond & Keane, 2013; Burger & Bond, 2015). Most conservation areas in South Africa are prone to fire (Van Wilgen *et al.,* 2011). Savanna, Grassland and Fynbos are the biomes adapted to fire and are regularly affected by fire in South Africa (Edwards, 1984). Plant species associated with these biomes have over time developed strategies to survive these fires (Edwards, 1984). Fire is not a frequent phenomenon in arid savannas due to herbivore grazing and browsing, leaving almost no vegetation to burn (Huntley, 1984; Bond, 1997). Extensive fires only occurred in the Kalahari sandveld between 1974 and 1977 (Huntley, 1984). This occurred after the rainy season, where rainfall was above average, and it caused severe damage to woody vegetation (Huntley, 1984). Fourie (2010) also stated that natural fires occur more often after above average rainy seasons. The increase in rainfall might have increased the grass layer and consequently the fuel load. Post-fire, succession may occur and possibly form dense thickets as a result of disturbance (Huntley, 1984). Surface fires mostly occur in the semi-arid savannas (Trollope, 2010). Generally, the above-ground biomass in any ecosystem determines the natural fuel and behaviour of various communities in the event of fire (Edwards, 1984). In savanna and grassland biomes, fire is supported by grassy fuel (Edwards, 1984; Bond, 1997; Fourie, 2010). Dead plants have low moisture content and their flammability is high, as opposed to green plants (Bond, 1997). The conditions of hot and dry winds strongly support veld fires (Bond, 1997). Generally, lightning is the source of ignition in most veld fire instances occurring in semi-arid Savannas (Edwards, 1984; Mucina & Rutherford, 2006; Fourie, 2010).

However, events of human induced fire have been widely recognized in certain conservation areas of South Africa (Hall, 1984; Fourie, 2010). In such instances, fire is used as a management tool with the primary objective to achieve the well-established and balanced ecosystems (Van Wilgen *et al.,* 2011). Conservation managers introduce fire into ecosystems primarily to influence vegetation structure and species composition (Van Wilgen *et al.,* 2011). In so doing, conservation managers should apply their understanding of species and ecosystem response to fire. Conservation managers have adopted prescribed burning as an adaptive management option (Van Wilgen *et al.,* 2011). Scott (1984) recommended that such burning should continue in plant communities occurring on basalt, but excluding vegetation in sandveld areas. Trollope (1984) mentioned occurrence of crown fires is savanna as rare, only supported by extreme dry, windy and hot weather conditions. The response of plants to fire may vary from species to species but the overall effect may shape the ecosystem. Fire was found to retard seedling development of the Sweet Thorn (*Vachellia karroo*) species in the Eastern Cape sweetveld (Scott, 1984). Germination or seedling establishment is not necessarily restricted by fire. In savanna vegetation, fire regulates the density of woody vegetation by keeping it low (Kruger, 1984; Fourie, 2010).

Another important aspect of fire is preservation of physiognomy of the vegetation (Scott, 1984). Although fire is destructive in nature, plants can survive in environments prone to fire. This could be achieved through plant resistance to fire or post fire recovery (Frost, 1984). Resistance to fire largely depends on plant tissues' ability to protect it from heat (Frost, 1984). Thick bark in trees is a good example of how plants adapt to protect aerial parts from heat damage. The level of damage by heat also depends on the relationship between plant height and flame height. Recovery of plants from fire involves resprouting from dormant buds of the branches, stems, roots and/or root collar (Frost, 1984). Species which were entirely destroyed by fire could either regenerate from seed or could become extinct (Frost, 1984).

Fire management programmes are recommended to be incorporated into the management plans for conservation areas (Kalahari Gemsbok National Park, 2016; Mokala National Park, 2017). This programme should allow fire to naturally control and maintain ecosystems within protected areas (Kalahari Gemsbok National Park, 2016; Mokala National Park, 2017). The South African National Parks recommends fire management polices with the aim to manage fires in conservation areas (Van Wilgen *et al.,* 2011). Fire management policies may vary across biomes, since vegetation in different biomes respond differently to fire. The National Veld and Forest Fire Act, 1998 (Act 101 of 1998) (NVFFA) makes provision for conservation managers to establish firebreaks at least along the boundaries of conservation areas (Filmalter, 2010). Summer months (August to April) are reported to have natural fires in the region due to lightning storms, which ignites fires, occurring during this period (Kalahari Gemsbok National Park, 2016). Although this does not happen each year, the estimated return interval is approximately 11 years (Kalahari Gemsbok National Park, 2016). Intentional burning aimed to control woody plants usually occur during the winter season (Fourie, 2010; Trollope, 2010). High intensity fires are recommended to counter the woody plant density (Van Wilgen *et al.,* 2011). This practice is somehow being criticised as it could result in the loss of available grazing for approximately six weeks (Fourie, 2010). Prescribed burning should be considered when grazing intensity is low and certain sections could be burnt, which allowing sufficient grazing in other sections.

(b) Habitat and vegetation programme

A programme aimed to monitor potential changes in the vegetation and habitat are considered as crucial in both arid and semi-arid conservation areas (Filmalter, 2010; Kalahari Gemsbok National Park, 2016). According to Filmalter (2010), these changes are due to climatic effects and/or management practices. Changes in vegetation structure and composition directly influence faunal species, as it provide food and habitat. In order to successfully monitor vegetation, Filmalter (2010) recommended a wide distribution of monitoring plots in all communities within the conservation area. Monitoring of these plots should be done at the end of the growing season on a three-year cycle (Filmalter, 2010). This gives a better understanding of changes occurring in the vegetation and habitat over a short period of time and it informs managers of necessary immediate actions. Monitoring of vegetation and habitat should be driven by the results from vegetation research (Mokala National Park, 2017). At Kalahari Gemsbok National Park, veld condition is assessed on a two-year interval, followed by implementation of recommended monitoring programmes (Kalahari Gemsbok National Park, 2016). Biodiversity monitoring in protected areas is also a legislative requirement in terms of the national legislation (National Environmental Management: Protected Areas Act, 57 of 2003).

(c) Herbivore management programme

Herbivores can be described as animals feeding primarily on plants. In terrestrial environments, focus is on vertebrates which graze grass or browse leaves or twigs (Kruger National Park, 2018). Herbivores have direct effects on vegetation as it facilitates seed dispersal and compensatory growth (Kruger National Park, 2018). Herbivore management is essential in protected areas as it provides spatial understanding of the distribution of herbivores (Kalahari Gemsbok National Park, 2016). The management of herbivores should be included in the management plan and the policy framework for the entire conservation area. The management of herbivores should cover the aspect of biodiversity values, adaptive management and methods to control herbivores (Kalahari Gemsbok National Park, 2016). The effect of herbivores on vegetation should be adequately monitored (Kruger National Park, 2018). When managed properly, herbivore programmes could enhance the maintenance of carrying capacity in protected areas (Kruger National Park, 2018). Herbivory, water provision and climatic conditions are mentioned as essential ecosystem drivers in conservation areas (Kalahari Gemsbok National Park, 2016). Large migratory and nomadic herbivores are well adapted to the semi-arid conditions of the Kalahari region (Kalahari Gemsbok National Park, 2016). The increase in population of springbok (*Antidorcas marsupialis*) could be favoured by the food availability, where reproduction increases, which results in an increase in the number of springbok (Gertenbach, 2010). This population increase could put more pressure on grazing capacity, which then might result in culling of the animals (Gertenbach, 2010). In the event of environmental changes, migratory species face serious challenges in their need to search for suitable habitats (Dudley, 2010). The movement patterns of herbivores is generally restricted by the boundary fences of protected areas. The migration of these animals is mainly driven by the need for water and food (Stapelberg *et al.,* 2008). During the conditions of severe drought when food and water becomes scarce, supplementary feeding and water is recommended for game (Gertenbach, 2010). Their main challenge usually occur when there is a change or disturbance to their migratory route such as roads or any management practice which may interfere with the migratory route (Dudley, 2010). To overcome this challenge, management should make it compulsory that all developments taking place within the conservation areas must undergo an Environmental Impact Assessment (EIA) (Kalahari Gemsbok National Park, 2016; Mokala National Park, 2017). The EIA is a legislative requirement for all developmental activities taking place in conservation areas, in terms of the National Environmental Management Act, 1998 (Act 107 of 1998).

Management practices for herbivores include monitoring and recording their movement, with great emphasis to large species being monitored on a monthly basis (Gertenbach, 2010; Kalahari Gemsbok National Park, 2016; Mokala National Park; 2017). This could be supported by conducting ground counts for all large herbivores on a quarterly basis (Kalahari Gemsbok National Park, 2016; Mokala National Park, 2017). The outcomes of all these management programmes must be documented and implemented into a policy. The Kalahari Gemsbok National Park (2016) recommended ongoing research to determine the impacts that permanent water have on the ecosystems, focusing on decline in nomadic ungulate species. In the study conducted by Stapelberg *et al.* (2008), it was found that springbok (*Antidorcas marsupialis*) have preference to eat leaves of the indigenous invader *Rhigozum trichotomum* throughout the year. The management of the veld in such instances should consider the springbok population and their migratory routes (Stapelberg *et al.,* 2008). When necessary, the recommendations from these studies must be properly implemented.

(d) Freshwater ecosystem programmes

Freshwater is essential to support and sustain biodiversity in conservation areas. The primary objective of this programme is to efficiently utilise water resources within protected areas (Kalahari Gemsbok National Park, 2016). The management of water resources involves determination of users, the quantities they use as well as the specific areas where water is used (Kalahari Gemsbok National Park, 2016). It is recommended to measure the water-use from the source on an annual basis (Mokala National Park, 2017). This could assist in determining the amount of water-used and when necessary to develop strategies to minimise such usage. The National Water Act, 1998 (Act 36 of 1998) is a national legislative framework which governs water use and management through the permitting system administered by the Department of Water and Sanitation (DWS). In semi-arid regions, surface water is very minimal and ground water is the reliable source of water. Artificial water supply is considered as an option for water provision (Fourie, 2010). Artificial water could be in a form of drilling boreholes and could provide water for both humans and animals. To ensure sustainable utilisation of ground water resources, a monitoring programme must be developed and properly implemented (Kalahari Gemsbok National Park, 2016). This monitoring programme should involve measuring groundwater levels on a quarterly basis (Kalahari Gemsbok National Park, 2016). In semi-arid regions, it is recommended to link the management plan for freshwater with the herbivore management (Mokala National Park, 2017). This is due to the basic information associated with artificial surface water provision to sustain large herbivores (Mokala National Park, 2017). Herbivore migration occur mostly because of their search for freshwater (Fourie, 2010).

(e) Degradation and rehabilitation

Ecosystems are prone to degradation due to both natural and anthropogenic effects. However, impacts associated with these disturbances can be identified, assessed, minimised or prevented where possible (Kalahari Gemsbok National Park, 2016). Such impacts include soil erosion, invasive alien plants and effects of 4x4 trails (Kalahari Gemsbok National Park, 2016). Sensitive ecosystems such as riparian communities are usually considered as priority areas for rehabilitation (Kalahari Gemsbok National Park, 2016). Activities such as construction of roads and tourism facilities have the potential to cause ecosystem degradation (Kalahari Gemsbok National Park, 2016). Ecosystem degradation needs to be rehabilitated adequately, in order to restore the ecosystem closer to its natural condition (Kalahari Gemsbok National Park, 2016). It is recommended for conservation managers to adopt and implement environmental programmes such as rehabilitation which could restore degraded ecosystems. In certain protected areas such as Kalahari Gemsbok National Park, occurring in semi-arid regions, excavations such as dams are man-made with a purpose to hold storm water (Kalahari Gemsbok National Park, 2016). A general recommendation is that all artificial excavations (when present) in protected areas must be rehabilitated (Kalahari Gemsbok National Park, 2016). Furthermore, it is recommended that riparian habitats and other sensitive habitats which are prone to degradation be identified and mapped every two years (Kalahari Gemsbok National Park, 2016).

Bare soil due to overgrazing leaves land prone to erosion by wind and surface runoff (Fourie, 2010). Rehabilitation of soil erosion should begin at the source of erosion with construction of structures that may reduce water velocity during peak flow (Fourie, 2010). An ongoing monitoring programme for erosion control also needs to be developed and adequately implemented (Kalahari Gemsbok National Park, 2016).

It is recommended that invasive alien plants should be detected at their early stage of establishment (Department of Environmental Affairs and Tourism, 2007; Kalahari Gemsbok National Park, 2016). Early detection of invasive alien plants must be followed by appropriate clearing methods (Department of Environmental Affairs and Tourism, 2007). Follow-up strategies to determine the effectiveness of the clearing methods is necessary. The use of off-road and 4x4 vehicles should only be permitted and restricted in the least ecological sensitive areas. This could minimize the effect and contribution of these vehicles to ecosystem degradation.

The Working for Wetlands programme aim to rehabilitate degraded wetlands and are mostly funded by the Department of Environmental Affairs (Department of Environmental Affairs, 2016). It has been found effective in rehabilitating most degraded wetland ecosystems in the country (Department of Environmental Affairs, 2016). In the event of wetland degradation, this programme could be adopted and implemented by the conservation managers.

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CHAPTER 4: Materials and methods

4.1 The importance of vegetation ecology

Individual plants are the building blocks of plant communities (Kent & Coker, 1992). Vegetation refers to the general plant cover on earth, without giving any reference to growth form. It is made up of individual plants which when grouped together form a population (Daubenmire, 1968, Kent & Coker, 1992; Van Aardt, 2010). Vegetation ecology refers to the study of plant communities in relation to the environment in which they occur (Van der Maarel, 2005). Different groups of species populations collectively form a community (Daubenmire, 1968; Kent & Coker, 1992; Van Aardt, 2010). Groups of plant species showing abundance, distinguished that particular community from the other (Daubenmire, 1968). Plant communities occur under uniform environmental conditions with similar floristic composition (Daubenmire, 1968; Van der Maarel, 2005; Van Aardt, 2010). The vegetation structure and floristic composition of plant communities differ from the surrounding vegetation due to the heterogeneity of the environment (Daubenmire, 1968, Kent & Coker, 1992; Van der Maarel, 2005; Van Aardt, 2010). Vegetation is seen as the most physical representation of the environment (Brown *et al.,* 2013). According to Kent & Coker (1992) vegetation forms the basis and it is the most important representative of the ecosystem. It serves as the primary source of food, mostly for herbivores (Kent & Coker, 1992). Plants are the primary producers, through which photosynthesis occur. Vegetation is also important for the provision of suitable habitat for other living organisms (plants and animals) (Kent & Coker, 1992).

4.2 History of vegetation classification in South Africa

Phytosociology is a branch of plant sciences that focus on the classification of vegetation into plant communities, sub-communities and variants. Plant communities are classified and described in relation to environmental factors influencing their geographical distribution (Brown *et al.,* 2013). Historically, the floristic description was done in an informal manner, due to the lack of formal classification techniques (Evans, 2001). The informal vegetation classification and description in southern Africa began in the late 1400's (Brown *et al.,* 2013). In early times, informal vegetation classification processes had no reference to the physical environment, such as climate, environmental factors and wildlife (White, 1983). It only focussed on providing a species list of a particular region, lacking emphasis on the descriptive nature of plant communities (Brown *et al.,* 2013). The classification was mainly based on plants themselves and their physiognomy (White, 1983). Vegetation classification, when considering physiognomy covers all the aspect of vegetation structure (White, 1983). As time went by, scientists gained interest and began to explore the vegetation in South Africa and in various parts around the World (Brown *et al.,* 2013). In the 1960's computers were introduced in the field of vegetation science, which made it even easier to analyse and interpret vegetation data (Podani, 2006). Through technological advancements, these computer programs have been developed and equipped with modern technology, making them even more efficient to be used in vegetation studies (Podani, 2006).

The formal vegetation classification and description began in the early 20th century on various continents of the world (Brown *et al.,* 2013). White (1983) described environmental factors influencing vegetation distribution in Africa, which includes climate, topography and geology. Vegetation science as a field of study has therefore developed as a result of ecological assessments which classify, and interpret different ecosystems (Brown *et al.,* 2013). Acocks (1953, 1988) focused mainly on describing veld types in various biomes. The vegetation of South Africa has been classified and described by Mucina and Rutherford (2006), with latest updates done by Dayaram *et al*. (2017). The vegetation classification and description by Mucina and Rutherford (2006) is on a broader regional scale, which creates the need for vegetation description at a local scale. In their formal classification Mucina and Rutherford (2006), revealed a wide variety of ecosystems in South Africa which includes nine biomes.

Vegetation classification, and mapping as described by Mucina and Rutherford (2006) and Brown *et al.* (2013) is one of the most crucial tools used to simplify complex ecosystems. The vegetation maps are essential in conservation areas as they describe the ecological state and sensitivity of the environment. Knowing the state of the environment, one can compile adequate and proper environmental management practices, which is essential in conservation (Hearn *et al.,* 2011). The occurrence and distribution of vegetation is mainly driven by natural processes, such as climate, topography and dispersal mechanisms. Once established, plant communities could then be shaped by anthropogenic effects, herbivores and abiotic factors (such as climate and topography). This phenomena shapes almost all ecosystems of the world. Campetella *et al.* (2011) stated that "processes shaping the patterns of vegetation dynamics have traditionally been approached by quantifying the changes in plant species composition over time". The physical environment is mainly described by the state of its vegetation and any change in the environment could be seen though vegetation (Brown *et al.,* 2013). Therefore, vegetation science can be used as a tool for assessing the ecological functioning and enhance effective environmental management.

At present, formal vegetation classification and description is done with the use of modern computer programs such as JUICE (Tichý *et al.,* 2010). Modified TWINSPAN (Two-Way Indicator Species Analysis) contained within JUICE is used to analyse floristic data (Hill & Šmilauer, 2005). Thus far, the vegetation scientists in South Africa have adopted a flexible approach to vegetation studies, which involves the application of numerous statistical classification methods (Brown *et al.,* 2013). In formal classification the description of plant communities are refined by applying the Zurich-Montpellier method, which allows the movement of species within clusters after analysis (Brown *et al.,* 2013). According to Brown *et al.* (2013) the introduction of TWINSPAN was a major development in vegetation science where classification techniques produce a phytosociological table. The phytosociological table is therefore necessary in all phytosociological studies as it provides hierarchical classification, species composition of each plant community, constancy, species fidelity, species cover and abundance (Brown *et al.,* 2013). Both formal and informal vegetation classification have played a crucial role in classifying and interpreting South African vegetation (Brown *et al.,* 2013).

4.3 The Braun-Blanquet method

The Braun-Blanquet method (also called Zurich-Montpellier method) was developed in Europe during the early 1900s by Josias Braun-Blanquet, (Werger, 1974; Whittaker, 1978a). The purpose was to classify and interpret plant communities (Whittaker, 1978a). According to Whittaker (1978a), the Braun-Blanquet approach recognises:

- Plant communities as vegetation units, build up by individual plant species.

- Certain plant species as being more dependant and forming relationship with other species.

Since its origin, the Braun-Blanquet approach have been widely recognised as the most efficient and reliable method for vegetation survey and classification across the World (Werger, 1974; Kent & Coker, 1992). However, language barriers were amongst reasons which resulted in late recognition of this method in certain countries of Africa (Werger, 1974). In South Africa, the science of plant ecology has been in practice since the beginning of the 21st century (Werger, 1974). The phytosociological survey of the Upper Orange River was the first vegetation survey in which the Braun-Blanquet method was applied in 1969 (Werger, 1974). This vegetation survey was then followed by other smaller surveys in which this method was successfully applied, which resulted in the acceptance of this method in South Africa (Werger, 1974).

The Braun-Blanquet method involves the selection of homogeneous plots of a certain size, representing the vegetation of the area to be surveyed (Werger, 1974; Brown *et al.*, 2013). The selection of sites for sample plots is done subjectively (Werger, 1974; Brown *et al.,* 2013). These plots must be randomly placed in homogeneous vegetation units of the surveyed area (Van Aardt, 2010; Brown *et al.,* 2013). Heterogeneous plots must be avoided as far as possible, as it could result in errors in classification (Werger, 1974; Whittaker, 1978a). According to Werger (1974) all the varieties of the area of study must be well known prior to commencement of the survey. The knowledge of these varieties could enhance the location of sample plots such that all vegetation units could be represented.

The Braun-Blanquet method is recommended by Brown *et al.* (2013) for phytosociological studies in South Africa. It has been adopted in most countries and much of the vegetation of the World is continuously surveyed through this method (Brown *et al.,* 2013). Numerous ecological studies have been done in various biomes using this method in South Africa (Brown *et al.,* 1997; Siebert *et al.,* 2002; Daemane *et al.,* 2012; Brand *et al.,* 2013; Lötter *et al.,* 2014). This method is known to be efficient, reliable and versatile (Leistner & Werger, 1973; Van Aardt, 2010). The Braun-Blanquet method requires less time in the field (Wikum & Shanholzer, 1978).

The Braun-Blanquet method is however criticised for some reasons. Firstly, for its subjectivity (Werger, 1974; Kent & Coker, 1992). Secondly, the representative relevés are considered to be biased (Kent & Cocker, 1992). Thirdly, it could exclude non-homogenous and transitional vegetation (Kent & Cocker, 1992). Werger (1974) criticised the scale that it is not proportional and combining abundance and cover in one scale is not viewed positively. The arrangement of the table could differ from each researcher even though there are agreed principles (Kent & Coker, 1992). The terminology used in the method is not always familiar to some users (Kent & Coker, 1992). The method is not well described in literature, which makes it difficult for young researchers to understand all concepts (Kent & Coker, 1992).

4.4 Vegetation data collection at Witsand Nature Reserve (WNR)

The WNR hosts a wide diversity of both flora and faunal species (Van den Berg *et al.,* 2007; Witsand Nature Reserve, 2015). As a protected area, the conservation of fauna and flora species is of great importance. These unique ecosystems of Witsand are not only important for conservation purposes, but also for tourism. Therefore, studies on flora and fauna are crucial for the management of the reserve. When conducted frequently, floral studies (in particular) could greatly contribute in drawing up the best management practices for the reserve. Vegetation studies (floristic description) have not extensively been conducted in this reserve. This supported the decision for a detailed description of vegetation in the WNR.

The Braun-Blanquet phytosociological technique has been widely recognised by scientists due to its efficiency in the history of vegetation science (Podani, 2006; Brown *et al.,* 2013). This method was also used to survey the vegetation of WNR. The field observation involves the selection of the sample plot size, in which species names and environmental data is recorded (Podani, 2006). Brown *et al.* (2013) recommended randomly distribution of sample plots within homogenous vegetation units across the study area. A total of 120 sample plots were randomly placed within homogeneous vegetation in the WNR. The purpose was to include as many plant species as possible in the WNR during sampling. The size of sample plots may vary according to the growth form of the vegetation (Xianping *et al.*, 2006; Brown *et al.,* 2013). Brown *et al.* (2013) recommended a minimum of 100 m^2 for the savanna vegetation, which were also applied to survey the vegetation at Witsand. A similar plot size was applied by

Veldsman (2008), in his study of vegetation degradation gradients and ecological degradation index of key grass species in the south-eastern Kalahari. This was based on the actual size of Witsand and the homogeneity of the vegetation in the reserve. The exact location of each sample plot was taken using a Global Positioning System (GPS). Other similar studies used aerial photographs, linked with GIS (Geographical Information System) to interpret vegetation distribution within a specific geographic area (Accad & Neil, 2006). Although this method could be quicker than field surveys, it could result in misinterpretation of data if resolution of the image is low or if the image is impacted by cloud cover (Accad & Neil, 2006). Another disadvantage associated with aerial photographs are that if the vegetation in the field has changed, then using old images could not result in the true reflection of the current vegetation (Accad & Neil, 2006).

The data collection was done during autumn (April – June) 2016, due to the late summer rainfall which occurred in the area. During this period, vegetation had responded to the rainfall received which resulted in vegetation being at its maximum level of growth, allowing for each species to be easily identified. This positively influenced the identification of plant species. All species occurring in each sample plot were recorded in a field data sheet. The information recorded includes the species name and their cover abundance according to the Braun-Blanquet cover abundance scale (Table 4.1). The unknown plant species were collected and identified in the Geo Potts Herbarium at the University of the Free State. The environmental data was also recorded in each sample plot. The environmental data recorded were visually observed and included topography, slope, exposure, drainage and geology.

Table 4.1: The Braun-Blanquet cover-abundance scale defining the cover of each species present within each sample plots (Van Der Maarel, 2005; Peet & Roberts, 2013).

Cover Values	Description
r	Rare occurrence (one or few individuals)
+	Cover less than 1 %
1	Cover less than 5 %
2	Cover between 5-25%
3	Cover between 25-50%
4	Cover between 50-75%
5	Cover between 75-100%

4.5 Data analysis

Vegetation science mainly focus on collection, analysis and interpretation of vegetation data with the principal objective of describing ecosystems in terms of their plant communities (Kent, 2012). Classification and description of plant communities, however, is a further important aspect as it makes vegetation data even more usable (Kent, 2012). The floristic data was captured into a macros enabled Excel sheet called VegCap (unpublished database tool designed by N. Collins). VegCap is specifically designed to capture phytosociological data which is intended to be analysed in JUICE (Tichý, 2002). JUICE has been described by Tichý (2002) as a multifunctional editor of phytosociological tables with advanced classification and parametrization functions. TWINSPAN (Hill, 1979) contained within the JUICE program, is widely used in phytosociology to classify vegetation data into communities (Kent, 2012). The modified TWINSPAN (Two Way Indicator Species Analysis) contained within JUICE, use the divisive method where a large data set is divided into clusters of plant communities. Modified TWINSPAN differs from the original version in that it doesn't enforce a dichotomy of classification, instead it divides only the most heterogeneous clusters of previous hierarchical levels (Roleček *et al.,* 2009). The modified TWINSPAN was applied to the data set and clusters of plant communities were produced. These clusters of plant communities were further refined by applying Braun-Blanquet procedures using the rules stipulated in Brown *et al.* (2013).

The running of TWINSPAN resulted in the identification of plant communities, presented in the phytosociological table (Table 5.1). The process involves identification of the major vegetation communities occurring in the study area (Siebert *et al.,* 2002). Their distinct characteristics is described according to their geographical distribution across the study area.

Phytosociological table

The phytosocilogical table presents the arrangement of species and relevés (Werger 1974). The guidelines recommended by Brown *et al.* (2013) were used to compile the phytosociological table. The diagnostic species of plant communities, sub-communities and variants were distinguished. Diagnostic species could be described as a combination of species restricted to a certain community and species of medium to low constistancy which occur together in a series of relevés (Kent & Cocker, 1992). Next to the diagnostic species is the value indicating the strength of its fidelity to the cluster (Collins, 2011). Constant species are species that could be seen in numerous relevés (Kent & Cocker, 1992). The dominant species are those species that are abundant, occurring with high cover abundance within clusters (Kent & Cocker, 1992). Species groups were arranged alphabetically, indicating the diagnostic groups. The description of plant communities, sub-communities and variants was done in accordance with the recommendations made by Brown *et al.* (2013).

In order to describe the different communities, sub-communities and variants the diagnostic, constant and dominant species were determined using the ‘Analysis of Columns of Synoptic Tables’ (a function in JUICE program). The recommendations made by Brown et al. (2013) were used to describe clusters. The lower thresholds for diagnostic, constant and dominant species was set to be 75, 60 and 50 respectively. The upper thresholds were set at 80, 80 and 60. All species exceeding the lower threshold were listed and species exceeding the upper threshold were printed in bold, for example:

Diagnostic species: ***Cyperus esculentus 83.3***
Constant species: *Cyperus esculentus 80*
Dominant species: *Cyperus esculentus 20, Cyperus margaritaceus 20, Imperata cylindrical 20, Phragmites australis 60, Schoenoplectus littoralis 20*
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.

Ordination

Ordination of the data set is crucial to determine the link between plant communities and environmental factors such as soil colour and nature of substrate (rocky outcrops, sandy plains, sandy dunes or wetlands). These environmental factors were considered during the ordination. Gradient analysis reflected changes of plant communities along environmental gradients (Whittaker, 1978b). CANOCO is a software programme used for multivariate analysis (Lepš & Šmilauer, 2003). CANOCO draw (Lepš & Šmilauer, 2003) was used in order to produce ordination diagrams (Kent & Cocker, 1992). Ordination diagrams are produced reflecting patterns of variation in floristic composition and demonstrate the relationship between species and their environment (Kent & Coker, 1992; Lepš & Šmilauer, 2003). When species are clustered together, their distribution could be linked to the homogeneous environmental gradient (Whittacker, 1978). The ordination diagram consist of axes which describes the variability of community composition and similarity structure of vegetation (Lepš & Šmilauer, 2003).

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CHAPTER 5: Results and discussion

5.1 Classification of plant communities

Based on the results of the TWINSPAN classification, the vegetation of WNR were classified as belonging to eight communities that can be grouped into four major communities, those occurring on sandy dunes, sandy plains, rocky outcrops and wetlands. The phytosociological classification is presented in Table 5.1. The vegetation of the WNR is divided into four plant communities, four sub-communities and four variants.

Plant communities identified are as follows:

1. *Cyperus esculentus – Phragmites australis* Community
2. *Brachiara dura – Stipagrostis amabilis* Community
    - 2.1 *Brachiara dura – Stipagrostis amabilis – Diospyros lycioides* Sub – Community
    - 2.2 *Brachiara dura – Stipagrostis amabilis – Eragrostis pallens* Sub – Community
        - 2.2.1 *Lopholaena cneorifolia* Variant
        - 2.2.2 *Eragrostis trichophora Variant*
3. *Searsia tridactyla – Digitaria eriantha* – Community
4. *Vachellia haematoxylon– Enneapogon cenchroides* Community
    - 4.1 *Vachellia haematoxylon – Enneapogon cenchroides – Vachellia erioloba* Sub – Community
    - 4.2 *Vachellia haematoxylon– Enneapogon cenchroides – Heliotropium ciliatum* Sub- Community
        - 4.2.1 *Schmidtia pappophoroides* Variant
        - 4.2.2 *Trachyandra laxa* Variant

5.2 Description of the communities

1. *Cyperus esculentus – Phragmites australis* Community

Habitat

<u>Geology</u>: Kalahari Group and Olifantshoek Supergroup

<u>Soils:</u> White aeolian sand

Soil depth: < 0.5 m

Habitat: Depressions in dune valleys

Hydrology: Water saturated sandy soil

Exposure: Full sun

Disturbance: None to very low

Species

Average number of species per relevé: 13

Number of relevés in the community: 5

Number of diagnostic species: 1

Diagnostic species: ***Cyperus esculentus 83.3***

Constant species: *Cyperus esculentus 80*

Dominant species: *Cyperus esculentus 20, Cyperus margaritaceus 20, Imperata cylindrica 20, Phragmites australlis 60, Schoenoplectus littoralis 20*

Figure 5.1: *Cyperus esculentus – Phragmites australis* Community.

Discussion:

Habitat description:

This community (Figure 5.1) occurs in pans with standing water. These pans are called shallow groundwater-fed depressions which occur in the dune valleys (Leistner & Werger, 1973).

Vegetation description:

This community is a wetland community and is characterised by hydrophytes. The community is well established with little or no disturbance observed. This community is composed of four sedges (*Cyperus esculentus, Cyperus margaritaceus, Juncus rigidus* and *Schoenoplectus littoralis*) (Species Group A), two hydrophilous grasses (*Imperata cylindrica* and *Andropogon eucomus*) (Species Group A) and the common reed (*Phragmites australis*) (Species Group A). According to Leistner & Werger (1973) and Veldsman (2008) who found similar communities, these communities can be regarded as aquatic and are restricted to the wetland environments. According to Veldsman (2008), vegetation occurring in these pans is not comparable to the vegetation of other pans in the Kalahari. This uniqueness could be due to the white sand and shallow water table.

2. *Brachiara dura – Stipagrostis amabilis* Community

Habitat

Geology: Kalahari Group and Olifantshoek Supergroup

Soils: White aeolian sand

Soil depth: > 1.5 m

Habitat: Dune slopes and crests

Hydrology: Well drained sandy soil

Exposure: Full sun

Disturbance: Disturbance caused by wind erosion

Species

Average number of species per relevé: 31

Number of relevés in the community: 45

Number of diagnostic species: 1

Diagnostic species: ***Brachiara dura 76.1***

Constant species: *Brachiara dura 67, Crotolaria orientalis 64*

Dominant species: *Anthephora pubescens 2, Brachiara dura 4, Cyperus esculentus 2, Diospyros lycioides 2, Eragrostis pallens 4, Stipagrostis amabilis 9, Ziziphus mucronata 2*

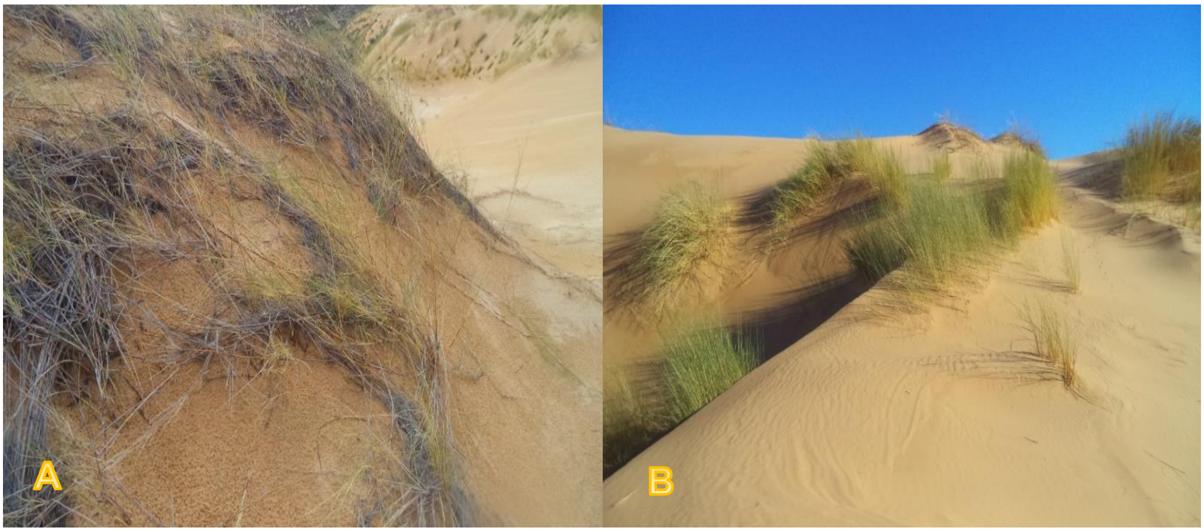

Figure 5.2: *Brachiara dura – Stipagrostis amabilis* Community: (A) showing an area where sand has been eroded, (B) showing an area where sand has been deposited.

Discussion:

Habitat description:

The white dunes of the Witsand Nature Reserve is a unique dune ecosystem and influenced the decision for proclamation of the nature reserve (Witsand Nature Reserve, 2015). This plant community is restricted to the white sand dunes of the study area (Figure 5.2). The sand deposits are deep and is frequently being shifted by strong winds. Plant species growing in this habitat are well adapted to handle exposure of their root systems when rain water and wind erodes the loose sand away or when plants become buried by shifting sand.

Vegetation description:

Brachiara dura, *Stipagrostis amabilis, Selago speciose, Crotolaria orientalis* (Species Group B) and *Tricholaena monachne* (Species group E) defines this community. The vegetation cover is sparse in certain parts of the dune system and denser in other parts. Vegetation in this community compares to the description of "*Stipagrostis amabilis* – *Brachiaria dura* var. *pilosa* Dune Vegetation" made by Veldsman (2008), in terms of species composition. Veldsman (2008) found the same grasses on the dunes namely *Stipagristis amabilis* and *Brachiara dura* (Species group B). These dune grasses, *Stipagristis amabilis* and *Brachiara dura* (Species group B) are dominant in the dunes and distinguish this community from other communities at Witsand. *Stipagrostis amabilis* is described by Leistner & Werger (1973) as a tall, perennial grass that stabilizes the loose sand with its roots in other parts of the Kalahari region. Although *Stipagrostis amabilis* is known for stabilizing sand, wind erosion still creates unstable conditions on the open areas in the dune ecosystem at Witsand (Figure 5.2 A). This result in sand movement from one part of the dune system to another (Lancaster, 1988). This phenomenon was described by Thomas & Leason (2005) as shaping the dune system. These conditions exposes roots of some plant species occurring in this community (Figure 5.2 A). Sand deposition creates a dissimilar phenomenon where roots are beneath the sand (Figure 5.2 B). At Witsand, *Brachiara dura* is known to be endemic in the reserve (Frisby, 2016), while *Stipagrostis amabilis* is endemic to the Kalahari region (Leistner & Werger, 1973). In the study conducted by Leistner & Werger (1973) *Stipagrostis amabilis* was found forming an association with *Eragrostis trichophora* and *Crotolaria spartioides* with *Brachiaria dura* being absent.

The *Brachiara dura* – *Stipagrostis amabilis* Community is subdivided into two sub-communities namely:

2.1 *Brachiara dura* – *Stipagrostis amabilis* – *Diospyros lycioides* Sub – Community

2.2 *Brachiara dura* – *Stipagrostis amabilis* – *Eragrostis pallens* Sub – Community

2.1. *Brachiara dura* – *Stipagrostis amabilis* – *Diospyros lycioides* Sub – community

Habitat

<u>Geology:</u> Kalahari Group

<u>Soils:</u> White aeolian sand

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

<u>Habitat:</u> Dune slopes and crests

<u>Hydrology:</u> Well drained

<u>Exposure:</u> Full sun

<u>Aspect:</u> Southern and eastern slopes of sand dunes

<u>Disturbance:</u> None

Species

<u>Average number of species per relevé</u>: 17

<u>Number of relevés in the community</u>: 7

<u>Number of diagnostic species</u>: 3

<u>Diagnostic species</u>: ***Diospyros lycioides 100, Lycium hirsutum 86, Stipagrostis amabilis 100***

<u>Constant species</u>: ***Brachiara dura 86, Diospyros lycioides 100, Lycium hirsutum 86, Stipagrostis amabilis 100***

<u>Dominant species</u>: *Diospyros lycioides 14, Stipagrostis amabilis 43, Ziziphus mucronata 14*

Figure 5.3: *Brachiara dura – Stipagrostis amabilis – Diospyros lycioides* Sub – Community.

Discussion:

<u>Habitat description:</u>

This sub-community occurs towards the southern edge of the 'roaring' white sand dunes at Witsand. It occurs mainly on the steep southern and eastern slopes of the white sand dunes. In the southern hemisphere, south-facing slopes receive less solar radiation as opposed to north-facing slopes (Holland & Steyn, 1975). As a result, south-facing slopes are cooler than north-facing slopes. Subsequently the soil moisture content is higher (Daubenmire, 1974). This microclimate therefore supports shrubs species growing on this dune face.

Vegetation description

The diagnostic species of this sub-community are the shrubs *Diospyros lycioides, Lycium hirsutum,* (Species Group I) *and the grass Stipagrostis amabilis* (Species Group B). The perennial dwarf shrub *Justicia protracta* and trees *Vachellia haematoxylon* and *Ziziphus mucronata* as well as the hemi-parasite *Viscum rotundifolium* from Species group I, occur in this sub-comminity. The shrub *Pteronia teretiifolia* (Species group F) and grass *Melinis repens* (Species group H) also occur in this sub-community. The absence of the species of species group C further differentiate this sub-community.

Vegetation in this sub-community is not impacted by the herbivores, due to the steep slopes and loose sand. Woody species of *Vachellia haematoxylon, Ziziphus mucronata* and *Diospyros lycioides* (Species Group I) are dominant. In his vegetation survey, Veldsman (2008) identified this as a community rather than a sub-community. Similar to this study, Veldsman (2008) described this sub-community as being related to *Brachiaria dura – Stipagrostis amabilis* community.

2.2. *Brachiara dura – Stipagrostis amabilis – Eragrostis pallens* Sub – Community

Habitat

Geology: Kalahari Group

Soils: White aeolian sand

Soil depth: > 1.5 m

Habitat: Dune slopes and crests

Hydrology: Well drained

Exposure: Full sun

Disturbance: None

Species

Average number of species per relevé: 25

Number of relevés in the community: 30

Number of diagnostic species: 2

Diagnostic species: ***Eragrostis pallens 67****, Aristida stipitata 63*

Constant species: *Brachiara dura 63, Crotolaria orientalis 73, Eragrostis pallens 67*

Dominant species: *Anthephora pubescens 3, Brachiara dura 7, Cyperus esculentus 3, Eragrostis pallens 7*

Figure 5.4: *Brachiara dura – Stipagrostis amabilis – Eragrostis pallens* Sub – Community.

Discussion:

Habitat description:

This grassy sub-community occurs on the undulating white sandy plains in the northern parts of Witsand. The absence of high dunes is diagnostic of this habitat.

Vegetation description:

The diagnostic species of this sub-community are the grasses *Eragrostis pallens, Aristida stipitata* (Species group C), *Stipagrostis uniplumis*, *Eragrostis trichophora* and *Aristida congesta* (Species group O) as well as the dwarf shrubs *Pteronia sordida* and *Elephantorrhiza elephantina* (Species group C). The absence of the species of species group H further differentiate this sub-community. It is also interesting to note that there are no tree or shrub species present in this sub-community.

Eragrostis pallens is a widespread and dominant member of this sub-community with cover-abundance values of 50% and higher in most of the sample plots. Most of the grasses in this sub-community are not very palatable and grazing animals are rarely seen in this sub-community at Witsand. There are no signs of disturbance observed in this community.

The *Brachiara dura – Stipagrostis amabilis – Eragrostis pallens* Sub-community is subdivided into two variants namely:

2.2.1 *Lopholaeana cneorifolia* Variant

2.2.2 *Pteronia teretifolia Variant*

2.2.1 *Lopholaena cneorifolia* – Variant

Habitat

Geology: Kalahari Group and Olifantshoek Supergroup

Soils: White aeolian sand

Soil depth: < 1 m

Habitat: Dune slopes and crests

Hydrology: Well drained

Exposure: Full sun

Disturbance: None

Species

Average number of species per relevé: 25

Number of relevés in the community: 15

Number of diagnostic species: 1

Diagnostic species: ***Lopholaena cneorifolia 86.1***

Constant species: *Brachiara dura 80, Crotolaria orientalis 80,* ***Lopholaena cneorifolia 87,*** *Pteronia teretifolia 67*

Dominant species: 0

Figure 5.5: *Lopholaena cneorifolia* Variant.

Discussion:

Habitat description:

This variant occurs on the south-facing slopes of low quartzite ridges. The soil consists of a shallow white sandy deposit. Outcrops of quartzite rocks are visible in places.

Vegetation description:

Species of this sub-community are the dwarf shrubs *Lopholaena cneorifolia, Helichrysum callicomum* (Species group D), *Pteronia teretifolia* (Species group F) as well as the grasses *Cymbopogon pospischillii* (Species group D) and *Melinis repens* (Species group H).

This variant with its diagnostic species occurs scattered around the nature reserve. This shrubby variant is a suitable habitat for small mammals but other larger faunal species may not necessarily be excluded. Only the footprints of small mammals were observed in this variant. There are no signs of disturbance in this variant.

2.2.2. *Eragrostis trichophora* – Variant

Habitat

Geology: Kalahari Group and Olifantshoek Supergroup

Soils: White aeolian sand

Soil depth: > 1.5 m

Habitat: Dune slopes and crests

Hydrology: Well drained

Exposure: Full sun

Disturbance: None

Species

Average number of species per relevé: 31

Number of relevés in the community: 15

Number of diagnostic species: 1

Diagnostic species: ***Eragrostis trichophora 80***

Constant species: *Crotolaria orientalis 67, Eragrostis pallens 80*

Dominant species: *Eragrostis pallens 13*

Figure 5.6: *Eragrostis thrichophora* Variant.

Discussion:

Habitat description:

This variant occurs on deep well-drained white sand on dune slopes and crests. This habitat is restricted to the white sand dunes of the Witsand Nature Reserve.

Vegetation description:

This variant's diagnostic species group is Species group O with grass *Eragrostis trichophora* and the presence of the grass *Anthephora pubescens* (Species group M) as diagnostic species. This variant also has species from various other species groups (*Pteronia teretifolia* (Species group F) and *Eragrostis curvula* (Species group O)) which are present here but absent from the *Lopholaena cneorifolia* Variant. Species of this variant include trees and shrubs such as *Vachellia haematoxylon, Diospyros lycioides* (Species group I), dwarf shrubs such as *Selago speciosa* (Species group B), and *Hermannia eenii* (Species group O) as well as grasses such as *Tricholaena monachne* (Species group E). The diagnostic forbs are the geophyte *Trachyandra laxa* (Species group M) and *Senecio harveianus* (Species group P).

It is a typical grassy variant with few individuals of *Diospyros lycioides,* and *Vachellia haematoxylon* scattered through this variant. The shrub *Hermannia eenii* (Species Group O) does not dominate vegetation and grow scattered amongst the tufts of *Eragrostis curvula* and *E. trichophora* (Figure 5.6). The fact that so many species from other communities are diagnostic for this variant shows that this variant can be regarded as a transition between community 2 and community 4. This variant is well established with no visible signs of disturbance and it could be a habitat suitable for a variety of faunal species.

3. *Searsia tridactyla – Digitaria eriantha* Community

Habitat

Geology: Kalahari Group and Olifantshoek Supergroup

Soils: Red aeolian sand

Soil depth: < 1m

Habitat: Slopes and crests of rocky outcrops

Hydrology: Well drained

Aspect: Northern and southern slopes of rocky outcrops

Exposure: Full sun

Disturbance: None

Species

<u>Average number of species per relevé</u>: 45

<u>Number of relevés in the community</u>: 7

<u>Number of diagnostic species</u>: 5

<u>Diagnostic species:</u> *Digitaria eriantha 62*, *Cenchrus ciliaris 62*, *Justicia thymifolia 62*, *Aristida diffusa 75* and *Searsia tridactyla 62*

<u>Constant species</u>: *Cenchrus ciliaris 62, Cleome rubella 62, Digitaria eriantha 62, Eragrostis curvula 75,* ***Hermannia amoena 88,*** *Justicia thymifolia 62, Lycium pumilum 62, Melinis repens 75, Searsia tridactyla 62, Senegalia mellifera 75*

<u>Dominant species</u>: 0

Figure 5.7: *Searsia tridactyla – Digitaria eriantha* Community.

Discussion:

<u>Habitat description:</u>

This community occur on rocky outcrops, where quartzite occur as stones, rocks and boulders (Figure 5.7). It is located in the south-western and eastern parts of the reserve. Plants with different growth forms grow between these rocks.

Vegetation description:

The diagnostic species of this community are *Digitaria eriantha*, *Cenchrus ciliaris*, *Justicia thymifolia*, *Aristida diffusa* and *Searsia tridactyla,* (Species group G). *Digitaria eriantha* and *Cenchrus ciliaris* (Species Group G) are grass species dominanting this community. The shrub *Croton gratissimus* and climber *Rhynchosia totta* (Species Group G) are rocky outcrop species giving this community its distinctive character. This community is similar to the one found by Veldsman (2008) at Witsand, with *Croton gratissimus* (Species Group G) and *Cymbopogon pospischilli* (Species Group D) being the dominant species. *Cleome rubella* (Species Group G) was recorded only in the rocky outcrops at Witsand. There are no visible signs of disturbance in this community.

4. *Vachellia haematoxylon* – Enneapogon *cenchroides* Community

Habitat

Geology: Kalahari Group and Olifantshoek Supergroup

Soils: Red aeolian sand

Soil depth: > 1.5 m

Habitat: Flat red sand-covered plains

Hydrology: Well drained

Exposure: Full sun

Disturbance: Overgrazing (towards the south)

Species

Average number of species per relevé: 56

Number of relevés in the community: 45

Number of diagnostic species: 0

Diagnostic species: No diagnostic species

Constant species: *Asparagus suaveolens 69, Enneapogon cenchroides 64, Lycium pumilum 62, Stipagrostis uniplumis 62, Tribulus terrestris 74, Vachellia haematoxylon 64*

Dominant species: *Diospyros lycioides 2, Enneapogon cenchroides 5, Heliotropium ciliatum 2, Rhigozum trichotonum 3, Senegalia mellifera 7, Stipagrostis amabilis 2, Stipagrostis uniplumis 2, Vachellia haematoxylon 3*

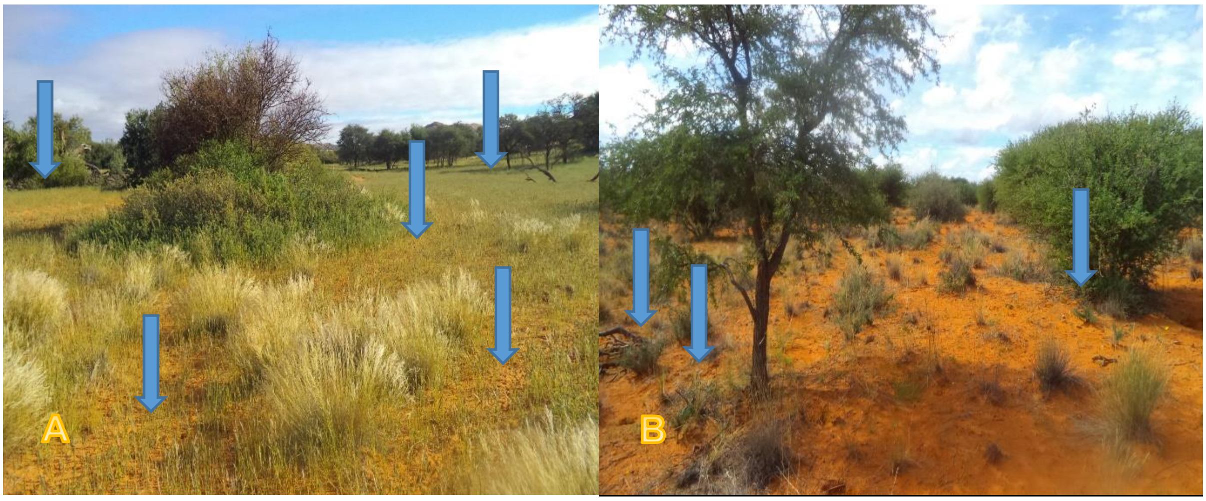

Figure 5.8: *Vachellia haematoxylon* – Enneapogon *cenchroides* Community (A showing grass *Stipagrostis uniplumis* in areas with well-established vegetation and B showing *Asparagus suaveolens* in poorly vegetated areas).

Discussion:

<u>Habitat description:</u>

This community (Figure 5.8) occurs on the red sandy plains in the eastern parts and extend towards the south of the reserve. Sandy soils generally have poor nutrient content (Leistner & Werger, 1973; Hagos & Smit, 2005). According to Leistner and Werger (1973), the mineral content is low in red sand than in white sand.

<u>Vegetation description:</u>

The dominant species are *Enneapogon cenchroides* and *Asparagus suaveolens* (Species Group J). Other species includes *Vachellia haematoxylon* (Species Group I), *Vachellia hebeclada* (Species Group K). *Tribulus terrestris* and *Prosopis velutina* (Species group N) also occur in this community and they are sparsely distributed. The silky bushman's grass (*Stipagrostis uniplumis*; Species Group O) is present in this community, but have affiliation in other communities. *Prosopis velutina* is an invasive alien species. Dense populations of *Prosopis velutina* occur along the plains towards the western parts of Witsand. When left uncontrolled, *P. velutina* may pose a threat to the indigenous plants as it is a strong competitor (Shackleton *et al*., 2015). This species may outcompete the indigenous vegetation for water, nutrients and space (Shackleton *et al*., 2015).

The bare soil (Figure 5.8 B) indicates the effect of overgrazing that occurred on the red sandy plains towards the south of the reserve. This phenomenon could possibly cause water erosion if left uncontrolled for a prolonged period. The negative impact of water erosion includes land degradation and loss of top soil (Botanical Society 2010; Mganga *et al*., 2018). Nutrient rich top soil is washed away, leaving behind soil with poor nutrients which is less favourable for vegetation establishment. As a result, both flora and fauna suffers due to loss of fertile soil needed for plant growth (Mganga *et al*., 2018). Animals depend on plants as their source of food. The effect of overgrazing becomes less towards the north and vegetation cover is improved (Figure 5.8 A).

The *Vachellia haematoxylon* – *Enneapogon cenchroides* Community can be subdivided into the following two sub-communities, namely:

- 4.1 *Vachellia haematoxylon* – *Enneapogon cenchroides* – *Vachellia erioloba* Sub- Community
- 4.2 *Vachellia haematoxylon* – *Enneapogon cenchroides* – *Heliotropium ciliatum* Sub- Community

4.1. *Vachellia haematoxylon* – *Enneapogon cenchroides* – *Vachellia erioloba* Sub-community

Habitat

<u>Geology</u>: Kalahari Group and Olifantshoek Supergroup

<u>Soils</u>: Red aeolian sand

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

<u>Hydrology:</u> Well drained

<u>Exposure:</u> Full sun

<u>Disturbance</u>: None

Species

<u>Average number of species per relevé</u>: 56

<u>Number of relevés in the community</u>: 45

<u>Number of diagnostic species</u>: 0

<u>Diagnostic species</u>: No diagnostic species

Constant species: *Asparagus suaveolens 69, Enneapogon cenchroides 69, Senegalia mellifera 80, Tribulus terrestris 78*

Dominant species: *Diospyros lycioides 2, Enneapogon cenchroides 4, Rhigozum trichotonum 4, Senegalia mellifera 9, Stipagrostis amabilis 2, Stipagrostis uniplumis 2, Vachellia haematoxylon 2*

Figure 5.9: *Vachellia haematoxylon – Enneapogon cenchroides – Vachellia erioloba* Sub – Community.

Discussion:

Habitat description:

This sub-community (Figure 5.9) occurs on the red sandy plains, towards the east at Witsand. There are no rocky outcrops visible in this habitat.

Vegetation description:

The dense vegetation forms a closed woodland. In his study, Veldsman (2008) described this sub-community as a community. Species of *Vachellia hebeclada* and a parasite *Tapinanthus oleifolius* (Species Group K) distinguish this sub-community from sub-community 4.2. Other species occurring in this sub-community includes *Lycium pumilum, Hermannia amoena, Tribulus terrestris, Grewia flava* and *Pollichia campestris* (Species Group N). Although these species occur in this sub-community, they are also present in other communities. Veblen (2012) indicates that habitats with similar vegetation are preferred by most herbivores, especially larger herbivores.

4.2. *Vachellia haematoxylon* – Enneapogon *cenchroides* – *Heliotropium ciliatum* Sub – community

Habitat

Geology: Kalahari Group and Olifantshoek Supergroup

Soils: Red aeolian sand

Soil depth: > 1.5 m

Hydrology: Well drained

Exposure: Full sun

Disturbance: None

Species

Average number of species per relevé: 56

Number of relevés in the community: 45

Number of diagnostic species: 1

Diagnostic species: ***Heliotropium ciliatum 86.7***

Constant species: *Asparagus suaveolens 65, Eragrostis curvula 71,* ***Heliotropium ciliatum 82, Hermannia eenii 94,*** *Lycium hirsutum 71, Lycium pumilum 71, Stipagrostis uniplumis 65, Tribulus terrestris 65,* ***Vachellia haematoxylon 88***

Dominant species: *Enneapogon cenchroides 6, Heliotropium ciliatum 6, Vachellia haematoxylon 6*

Figure 5.10: *Vachellia haematoxylon – Enneapogon cenchroides – Heliotropium ciliatum* Sub–community.

Discussion:

Habitat description:

This sub-community (Figure 5.10) occurs on the red sandy plains towards the dune system at the south-east of WNR. It can be seen as the transition between the vegetation on the red sand dunes and white sand dunes. The colour of the sand is a mixture of red and white sand and therefore, has an orange appearance.

Vegetation description:

It is distinguished by the presence of *Heliotropium ciliatum* and *Bulbostylis burchellii* (Species Group L). Leistner & Werger (1973) found *Heliotropium ciliatum* associated with *Sericorema remotiflora* and *Chascanum pumilum* in the southern Kalahari. In their study, Leistner & Werger (1973) found this association occurring on sand with a similar colour (mixture of white and red sand). *Centropodia glauca* (Species Group L), commonly known as "gha grass" (Leistner & Werger, 1973) is the grass species occurring in this sub-community and it is sparsely distributed. The *Centropodia glauca* is described by Leistner & Werger (1973) as a hard, tufted grass occurring in red sands of the Kalahari. This grass, *Centropodia glauca,* has been found heavily grazed in most parts of this sub-community at Witsand. This could be an indication that certain game species prefer to graze *Centropodia glauca* more than other grasses.

Centropodia glauca is a highly palatable grass (Van Oudtshoorn, 1999), heavily grazed particularly by gemsbok (Rutherford & Powrie, 2009). Van Oudtshoorn (1999) stated that the common occurrence of this grass indicates that the veld is in good condition.

The *Vachellia haematoxylon – Enneapogon cenchroides – Heliotropium ciliatum* Sub–community can be subdivided into the following two variants, namely:

- 4.2.1 *Schmidtia pappophoroides* Variant
- 4.2.2 *Trachyandra laxa* Variant

4.2.1. *Schmidtia pappophoroides* Variant

Habitat

Geology: Kalahari Group and Olifantshoek Supergroup
Soils: Red aeolian sand
Soil depth: > 1.5 m
Hydrology: Well drained
Exposure: Full sun
Disturbance: None

Species

Average number of species per relevé: 56
Number of relevés in the community: 45
Number of diagnostic species: 0
Diagnostic species: No diagnostic species
Constant species: *Aristida congesta 62,* ***Asparagus suaveolens 88, Enneapogon cenchroides 100,*** *Eragrostis curvula 62, Grewia flava 62,* ***Heliotropium ciliatum 100,*** *Hermannia amoena 62,* ***Hermannia eenii 100,*** *Lycium hirsutum 75, Lycium pumilum 75,* ***Tribulus terrestris 100, Vachellia haematoxylon 88***
Dominant species: *Enneapogon cenchroides 12, Heliotropium ciliatum 12*

Figure 5.11: *Schmidtia pappophoroides* Variant.

Discussion:

Habitat description:

This variant (Figure 5.11) occurs on the red sandy plains in the eastern parts of the reserve.

Vegetation description:

It is distinguished from other variants by the presence of *Schmidtia pappophoroides, Tribulus terrestris, Grewia flava and Prosopis velutina* (Species Group N). *Tribulus terrestris* grows in the patches where grasses and shrubs are absent. The shrub *Grewia flava* and the grass *Schmidtia pappophoroides* dominate this variant. The grass *Stipagrostis uniplumis* (Species group O), present in this variant, also occur in other vegetation units at Witsand. This variant is absent from the other studies conducted in this area (Veldsman, 2008).

4.2.2. *Trachyandra laxa* Variant

Habitat

Geology: Kalahari Group and Olifantshoek Supergroup

Soils: Red aeolian sand

Soil depth: > 1.5 m

Hydrology: Well drained

Exposure: Full sun

Disturbance: None

Species

Average number of species per relevé: 56

Number of relevés in the community: 45

Number of diagnostic species: 0

Diagnostic species: No diagnostic species

Constant species: *Aristida stipitata 67, Eragrostis curvula 78, Heliotropium ciliatum 67,* ***Hermannia eenii 89,*** *Lycium hirsutum 67, Lycium pumilum 67, Stipagrostis uniplumis 78,* ***Vachellia haematoxylon 89***

Dominant species: *Trachyandra laxa 11, Aristida meridionalis 11*

Discussion:

Habitat description:

This variant is mostly dominated by grasses and occur on white sandy plains in the north-western parts of the reserve. It is absent from the other studies conducted in this area (Veldsman, 2008).

Vegetation description:

The dominant species are *Trachyandra laxa* and *Aristida meridionalis* (Species Group M), which gives this variant its grassy characteristic. This variant occur as an open grassland with *Pteronia teretifolia* (shrub) (Species Group F) sparsely distributed. It is least disturbed, however, overgrazing could be a potential threat to this variant.

5.3 Ordination

The ordination of the vegetation dataset described here conforms to the classification presented in Table 5.1. From Figures 5.12 and 5.13, four distinct groups of plant species can be recognised in Figure 5.12. These diagnostic species of each of the plant communities show distinct discontinuities and these groups are associated with four distinctive environmental factors, namely: rocky outcrops, surface water/water-logged soil, sand dunes and sandy plains. The sandy environments are further specified as sandy dunes, sandy plains, red sand and white sand. In Figure 5.13 the wetland associated species were omitted from the calculation and it shows distinct discontinuities among the diagnostic species. These terrestrial communities are associated with three distinctive environmental factors, namely: rocky outcrops, sand dunes and sandy plains.

Rocky outcrops occur as hills and ridges, characterised by shallow sand (< 1 m) over rocks. The vegetation associated with rocky outcrops is mostly small trees, shrubs, and grasses. Species such as *Croton gratissimus, Searsia tridactyla, Tarchonanthus camphoratus, Cadaba aphylla, Melhania rehmannii, Indigofera heterotricha, Justicia thymifolia* and *Rhynchosia totta* are well adapted to survive the environmental conditions of this habitat.

Wetlands with standing water occur in the central and northern parts of the reserve. These wetlands are situated between the white sand dunes. Water is present in these wetlands throughout the year because of the shallow water table. The vegetation present in wetlands is adapted to aquatic environments. These species include the common reed (*Phragmites australis*) and the hygrophilous grasses such as *Andropogon eucomus,* and *Imperata cylindrica* as well as the sedge *Cyperus esculentus*.

Plant communities in the Witsand Nature Reserve which occur on a sandy substrate occur either on the high dunes with white sand, undulating plains with white sand or on the plains with red sand. These sandy habitats cover almost the entire Witsand Nature Reserve (Figure 5.14). The high white sand dunes occur in the south-western parts of the reserve and extend towards the north. This environment is distinguished by the unique dune ecosystem dominated by grasses *Brachiara dura* and *Stipagrostis amabilis* (Figure 5.12). The lower undulating plains with white sand occur mostly in the central and northern parts of the reserve. Communities in these environments are distinguished by the presence of woody species such as *Vachellia haematoxylon* and *Vachellia erioloba*. The flat plains covered by red sand occur in the eastern parts of the reserve and are characterized by the dense stands of *Senegalia mellifera* and *Rhigozum trichotonum*. The distribution of the plant communities is presented in the vegetation map (Figure 5.14).

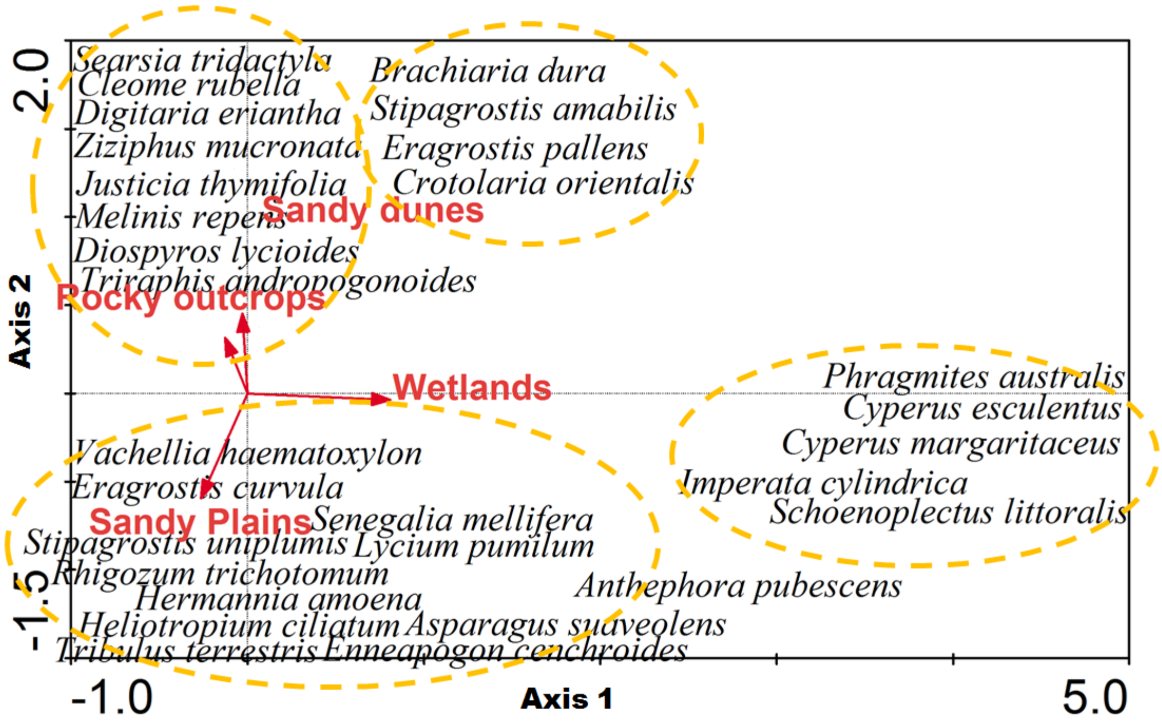

Figure 5.12: Ordination diagram (Axes 1 and 2) showing the relationship between the various diagnostic species of the plant communities and various environmental factors at Witsand Nature Reserve.

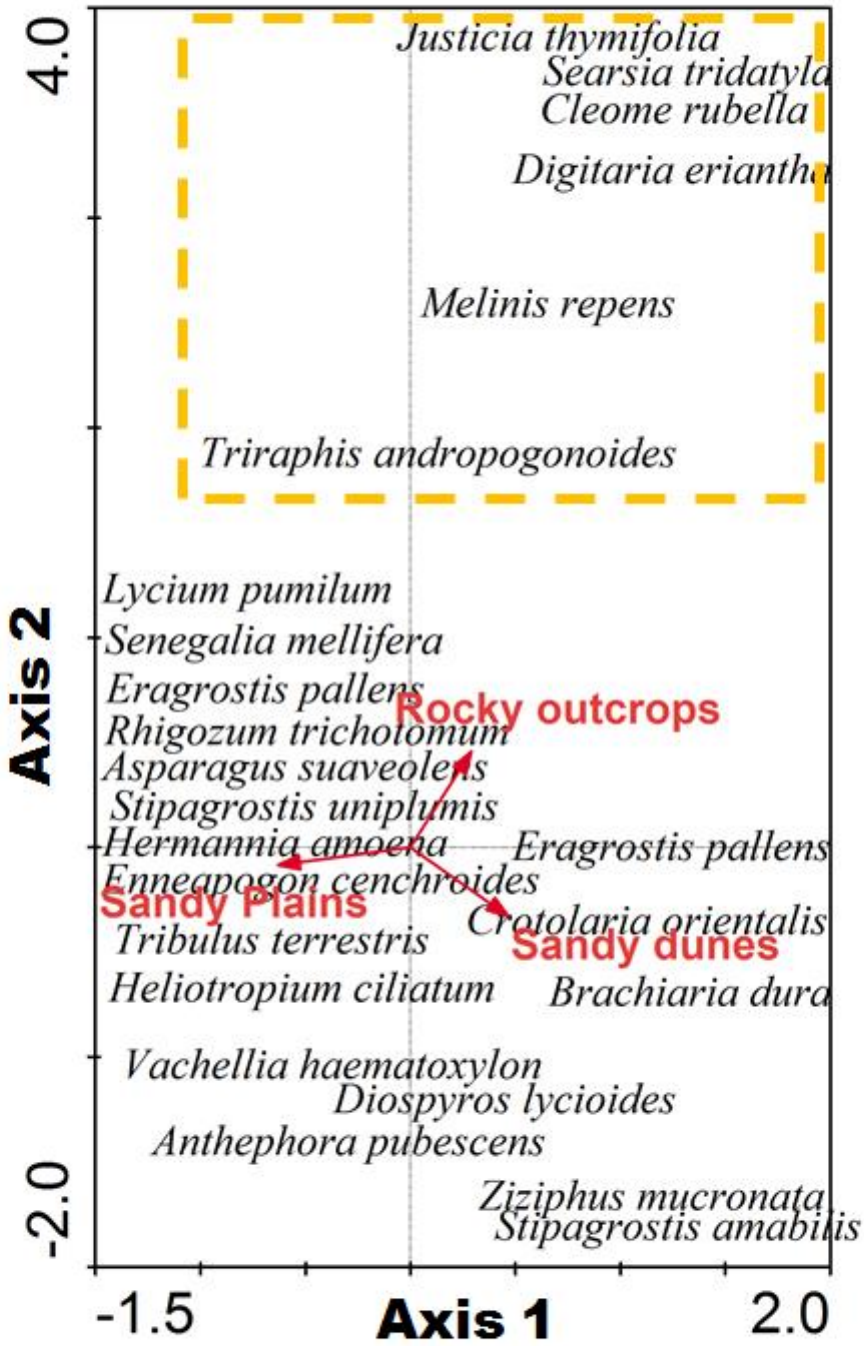

Figure 5.13: Ordination diagram (Axes 1 and 2) showing the relationship between the various diagnostic species of the terrestrial plant communities (wetland species being omitted from calculation) and various environmental factors at Witsand Nature Reserve.

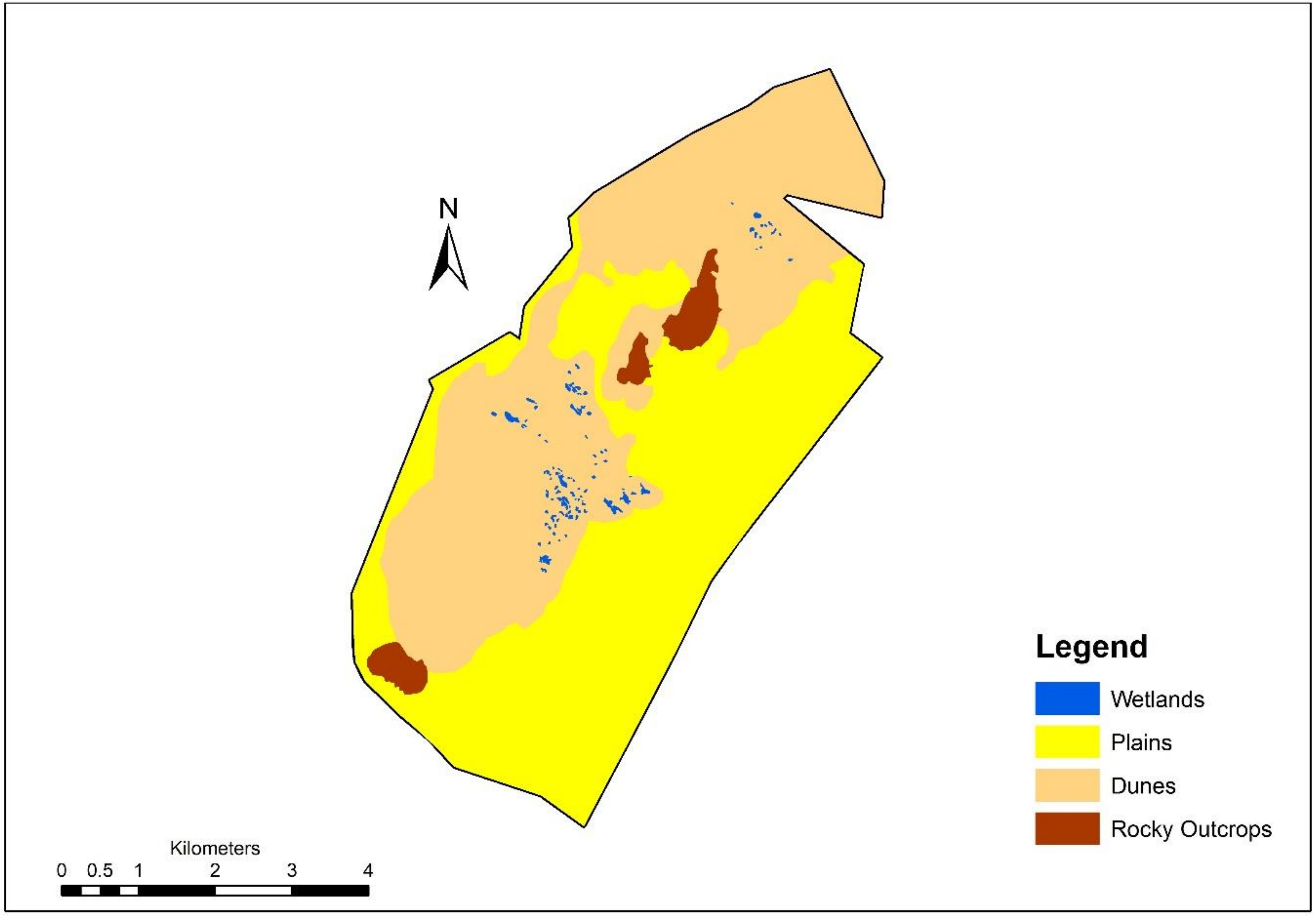

Figure 5.14 Map of Witsand showing various habitats.

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CHAPTER 6: Conclusion and recommendations

Vegetation at Witsand Nature Reserve has not been described in detail before. The need for a detailed classification and description has been long overdue. From the results (Chapter 5) distinct plant communities were identified. The study revealed four plant communities, four sub-communities and four variants (Table 5.1). This is in contrast to a study conducted by Veldsman (2008) in the south-eastern Kalahari of South Africa, in which included Witsand Nature Reserve. In his study, Veldsman (2008) identified seven plant communities with no sub-communities and no variants. This indicates the great variation in the outcomes of this study and the study conducted by Veldsman (2008). There are several reasons why a discrepancy exist. It could be the difference in scale of surveys, difference in assessment methods and style as well as variation in environmental factors such as climate and grazing. For example, Veldsman (2008) identified *Vachellia erioloba* – *Vachellia karroo* Low Grassy Woodland as a community, while in this study, this was described as a sub-community.

Floristic distribution is not uniform at Witsand Nature Reserve. This is due to shifting sand dunes, topography and geology of the area. From the results (Chapter 5), floristic composition varies across different substrates namely sandy dunes, sandy plains, rocky outcrops (quartzite ridges) and wetlands. Therefore, these plant communities are subjected to different threats. These threats include overgrazing, bush encroachment and alien plant invasion. Plant cover is minimal in certain parts of the reserve (especially towards the south-east), where trees and grasses are dominant. This study could therefore serve as a possible recommendation for management practices relevant to the WNR. These recommendations to a large extent may contribute towards conservation and future management of the natural resources within the reserve.

The Witsand Nature Reseve is located within the arid part of the savanna biome of South Africa and comprises a variety of plant communities and plant species. The savanna communities have a unique dissimilarity when it comes to plant communities found on various substrates, slopes and plateaus. The differences in plant communities of WNR have been observed and described in terms of species composition and species abundance. A similar phenomenon has been found applicable to sub-communities and variants at Witsand Nature Reseve. Species composition and abundance have defined various habitat conditions at Witsand Nature Reserve. This habitat diversity is caused by different geological substrates, soil types, slope aspect, percentage of rock cover and species composition as well as variations in soil moisture. Management practices are recommended in order to improve habitat conditions in certain areas of the Witsand Nature Reserve.

6.1 Recommended practices

(a) Managing overgrazing

The effect of overgrazing, characterised by the presence of bare soil was found in certain areas of the reserve (towards the south-east). These areas are poorly vegetated. Associated with overgrazing, is soil erosion. Soil erosion is a potential threat to plant communities occurring at the south-east of the reserve, due to poor vegetation cover. Soil degradation may occur in the event of extreme erosion, likely to be the result of heavy rainfall (Kalahari Gemsbok National Park, 2016). Soil degradation entails loss of top soil due to water or wind erosion (Kalahari Gemsbok National Park, 2016; Hesse *et al.,* 2017). A similar phenomenon was reported in the Kalahari Gemsbok National Park (Kalahari Gemsbok National Park, 2016). The effect of soil erosion does not only pose a threat to plants but also to the animals. Mechanisms to control overgrazing and soil erosion must be developed and properly implemented. The veld must be left to rest during the growing season, to allow vegetation to establish again. This could be achieved by restricting herbivores to access these areas. Importantly, game introduction should be avoided in the event of overgrazing.

(b) Managing bush encroachment

Communities occurring on the red sandy plains are characterized by the presence of *Senegalia mellifera* and *Rhigozum trichotonum*. These species occur as shrubs and are known as encroaching species in semi-arid regions (Ward & Esler, 2011). These species were found densely populated on the red sandy plains and this is an indication of bush encroachment at Witsand. Although these species occur in association with other species, they are dominant because of their ability to compete with grass species for water, nutrients and space (Stafford *et al.,* 2017). Continuous spreading of these encroaching species may reduce grazing potential in the reserve and as a result, reduce carrying capacity. Proper measures to control bush encroachment are recommended at WNR. These include frequent burning of the areas affected by bush encroachment (Trollope, 1984; Tainton, 1999; Trollope, 2010). Such burning is recommended during the dry season to allow intense fires to kill woody species (Tainton, 1999). Fire is recommended only to the areas affected by bush encroachment because it works as a management tool to control bush encroachment (Tainton, 1999). When using fire as a management tool, the reserve managers must ensure that it does not cause damage to other areas which are not intended to burn. Control measure must include extinguishing fire if other areas or property are in danger of being destroyed.

(c) Management of invasive alien plants

The study conducted by Veldsman (2008) revealed dense populations of *Prosopis velutina*, which was forming a community at Witsand. Recently this study identifies the presence of individuals of *Prosopis velutina* sparsely distributed at Witsand. *Prosopis velutina* is an invasive alien plant, threatening ecosystems in the Kalahari (Zachariades *et al.,* 2011; Van den Berg *et al.,* 2013). This species (*P. velutina*) outcompetes other species for space, water and nutrients (Van den Berg *et al.,* 2013). Measures to control the spreading of the *Prosopis* species are recommended and must be properly implemented. These includes eradication of this species by mechanical methods. The “cut-stump” method is the most appropriate and it is practiced by the “Working for Water Programme” of the Department of Environmental Affairs (Department of Environmental Affairs, 2018). Through this method, the stem of an individual plant is cut at the base and sprayed with herbicide to prevent further growth of the stem. This method have been mentioned by the Department of Environmental Affairs (Department of Environmental Affairs, 2018) as effective in eradication of invasive alien plants (Van den Berg *et al.,* 2013). The effectiveness of this method is subject to the “follow-ups” to ensure that the cleared areas do not grow invasive alien plants again. Follow-ups are recommended after each growing season (Department of Environmental Affairs and Tourism, 2007).

(d) Herbivore management

Herbivores have a direct impact on vegetation as they graze and brows on plants. In order to effectively manage vegetation at Witsand, the carrying capacity of the reserve must be determined and known. This could assist in keeping the herbivore populations within the carrying capacity of the reserve and avoid excessive grazing and browsing. In order to achieve this, game counts must be done annually (Mokala National Park, 2017). These game counts could assist in determining the increase of herbivore populations within the reserve. In the event of significant increase of herbivore populations, measures to reduce game species must be implemented. This may include culling or donating of game species to the private nature reserves (Kalahari Gemsbok National Park, 2016). The option for taking game species to auction may also be considered. The introduction of new game species is not recommended at this stage due to the grazing pressure (discussed above). However, in the event where game introduction could not be avoided, habitat analysis must be done. Habitat analysis could assist in determining the likelihood for game survival, once introduced into the reserve. The management of the reserve must ensure that game species do not exceed the carrying capacity of the reserve.

(e) Infrastructure development

The possible expansion of the infrastructure or development of new infrastructure within the reserve may interfere with the physical environment including plants. Such interference may include removal of indigenous vegetation. All activities taking place within the reserve must occur in harmony with nature. It is recommended that activities related to infrastructure development in the reserve must undergo screening by means of Environmental Impact Assessment (EIA). For example activities related to development of tourism infrastructure and roads are subject to EIA’s. EIA is a process that identify, assess and mitigate the environmental impacts associated with a development activity (Environmental Impact Assessment Regulations, 2014). The EIA is a legislative process in terms of Environmental Management Act, 1998 (Act 107 of 1998). EIA studies may contribute significantly in reducing harm to the environment while promoting conservation of natural resources, including flora and fauna.

(f) Management of water resources

The study revealed the presence to invasive *Prosopis velutina* towards eastern parrts of Witsand Nature Reserve. *Prosopis velutina* was also recorded in the south-western parts of Witsand Nature Reserve. Invasive alien plants are known for negative impacts on water resources (Department of Environmental Affairs and Tourism, 2007). Invasive alien plants consume more water than indigenous plants (Van den Berg *et al.,* 2013). Witsand is known to be rich in groundwater resources and it historically served as the reliable source of water to the local farmers (Anderson, 1996). Measures to prevent depletion of water resources due to invasive alien plants includes eradication of such species. This will ensure the long-term availability and sustainability of water resources at Witsand. Surface water in the Kalahari region is very minimal and in addition, the area receive very low rainfall (Anderson, 1996; Terblanche & Taylor, 2000). There is no permanent river within WNR. Two pans are located in the central parts of the reserve, which holds water throughout the year. These pans sustain its water from the shallow groundwater table and may recharge during heavy rains. These pans serve as a reliable source of drinking water to the herbivores. Water is essential to sustain life of all living organisms. Therefore, it is crucial to develop and document the management plan for water resources at Witsand Nature Reserve. Water resources should be managed in such a manner that it will be available on a sustainable basis.

(g) The overview of natural resources at Witsand Nature Reserve

The veld condition at WNR is fairly good, except for certain areas affected by bush encroachment, alien plant invasion and overgrazing. Human intervention is necessary in order to develop strategies that could improve these conditions. More scientific research from different disciplines (including Entomology, Geohydrology, Veld Management and Zoology) still needs to be done, since there is little documented information about Witsand.

The reserve host a variety of fauna, ranging from mammals, reptiles, insects as well as avifauna. All these animals are adapted to the environmental conditions of Witsand and they coexist in nature. The management of the reserve is recommended to identify all the possible threats to these biological resources and prevent them where possible. Although the water resources present, is able to meet the current demands, it is important for management to continue managing this crucial resource and prevent depletion in future.

6.2 Final remarks

In this study, the vegetation of the Witsand Nature Reserve (WNR) is classified and described, using the Braun-Blanquet procedures. The classification distinguishes communities, sub-communities and variants. The study further recommended the possible management practices relevant to WNR. These recommendations to a large extent may contribute towards conservation and future management of the natural resources within the reserve. Ecosystems identified in WNR are distinguished by the their environmental attributes such as pans, white sand dunes, white sand plains, red sand plains and rocky outcrops. In conservation areas, vegetation is important as it forms the basis of life and creates a suitable habitat for all living organisms which coexist in nature. The vegetation survey and monitoring is also crucial in nature reserves such as Witsand. Such surveys together with applicable legislations, aid in developing policies for managing conservation areas (South African National Parks, 2017).

Flora and ecosystems at WNR is well adapted to semi-arid environments (Frisby, 2016). The strategies to manage ecosystems must be developed and implemented. Such strategies should allow the natural functioning of ecosystems with little human interventions. Certain areas at WNR are affected by bush encroachment, alien plant invasion and overgrazing. Human intervention is necessary in order to develop strategies that could improve these conditions.

In order to effectively manage conservation areas; polices and management plans must be developed and implemented. These management plans serve as a guideline that defines management actions to be implemented by the conservation managers. According to SANParks, these management plans should be developed to serve for a 10 year-period. Thereafter, a management plan should be reviewed and be amended. Such review and amendment must be informed by the newly discovered information, such as changes in ecosystems. The review of management plans must also take into account the legislative framework governing the biodiversity and protected areas.

These are National Environmental Management: Biodiversity Act, 2004 (Act No. 10 of 2004) and the National Environmental Management: Protected Areas Act, 2003 (Act No. 57 of 2003) respectively.

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Appendix A: Species List of Witsand Nature Reserve

PTERIDOPHYTA

PTERIDACEAE

Pellaea Link

P. calomelanos (Sw.) Link

EUDICOTS

ACANTHACEAE

Barleria L.

B. rigida Nees

B. saxatilis Oberm

Blepharis Juss.

B. mitrata C.B. Clarke

Justicia L.

J. cuneata Vahl

J. protracta (Nees) T.Anderson

J. thymifolia (Nees) C.B.Clarke

AMARANTHACEAE

Kyphocarpa (Fenzl) Lopr.

K. angustifolia (Moq.) Lopr.

Pupalia Juss.

P. lappacea (L.) A.Juss.

Sericorema (Hook.f.) Lopr.

S. remotiflora (Hook.f.) Lopr.

ANACARDIACEAE

Searsia F.A.Barkley

S. burchellii (Sond. ex Engl.) Moffett

S. tridactyla (Burch.) Moffett

APOCYNACEAE

Riocreuxia Decne.

R. torulosa Decne.

ASTERACEAE

Amphiglossa DC

A. tecta (Brusse) Koekemoer

Berkheya Ehrh

B. bergiana Söderb

Chrysocoma L.

C. ciliata L.

Cineraria L.

C. burkei Burtt Davy & Hutch

Conyza Less

C. canadensis (L.) Cronquist

Dicoma Cass

D. macrocephala DC.

Eriocephalus L.

E. spinescens Burch.

Felicia Cass

F. fascicularis DC.

F. filifolia (Vent.) Burtt Davy

F. muricata (Thunb.) Nees

Geigeria Griess.

G. ornativa O.Hoffm

Helichrysum Mill.

H. callicomum Harv.

Hertia Less.

H. pallens (DC.) Kuntze

Kleinia Mill.

K. longiflora DC.

Lopholaena DC.

L. cneorifolia (DC.) S.Moore

Nidorella Cass.

N. resedifolia DC.

Pentzia Thunb.

P. cooperi Harv.

P. incana (Thunb.) Kuntze

Psiadia Jacq.

P. punctulata (DC.) Oliv. & Hiern ex Vakte

Pteronia L.

P. glauca Thunb.

P. sordida N.E.Br.

P. teretifolia (Thunb.) Fourc.

Senecio L.

S. burchellii DC.

S. harveianus MacOwan

Tarchonanthus L.

T. camphoratus L.

**Verbesina* L.

V. encelioides (Cav.) Benth. & Hook

BIGNONIACEAE

Rhigozum Burch.

R. trichotomum Burch.

BORAGINACEAE

Heliotropium L.

H. ciliatum Kaplan

H. lineare (A.DC.) Gürke

BRASSICACEAE

Sisymbrium L.

S. capense Thunb.

CAPPARACEAE

Boscia Lam

B. albitrunca (Burch.) Gilg & Gilg-Ben.

Cadaba Forssk.

C. aphylla (Thunb.) Wild

Cleome L.

C. foliosa Hook.f.

C. rubella Burch.

CARYOPHYLLACEAE

Pollichia Aiton

P. campestris Aiton

CELASTRACEAE

Maytenus Molina

M. ilicina (Burch) Loes.

Putterlickia Endl.

P. pyracantha (L.) Szyszyl.

CHENOPODIACEAE

Chenopodium L.

*C. *albam L.*

*C. *cristatum* F.Muell.

*C. *murale* L.

CONVOLVULACEAE

Ipomoea L.

I. bathycolpos Hallier f.

Merremia Dennst.

M. verecunda Rendle

CUCURBITACEAE

Momordica L.

M. balsamina L.

CYPERACEAE

Bulbostylis Kunth

B. burchellii (Ficalho & Hiern) C.B.Clarke

Cyperus L.

C. esculentus L.

C. margaritaceus Vahl

EBENACEAE

Diospyros L.

D. lycioides Desf.

Euclea Murray

E. crispa (Thunb.) Gürke

EUPHORBIACEAE

Croton L.

C. gratissimus Burch.

Euphorbia L.

E. mauritanica L.

E. spartaria N.E.Br.

FABACEAE

Crotalaria L.

C. orientalis Burtt Davy ex. I. Verd

C. sphaerocarpa Perr. ex DC.

Elephantorrhiza Benth.

E. elephantina (Burch.) Skeels

Indigofera L.

I. filiformis L.f.

I. heterotricha DC.

**Prosopis* L.

**P. velutina* Wooton

Melolobium Eckl. & Zeyh.

M. microphyllum (L.f.) Eckl. & Zeyh.

Requienia DC.

R. sphaerosperma DC.

Rhynchosia Lour.

R. nervosa Benth. ex Harv.

R. totta (Thunb.) DC.

Senegalia Raf.

S. mellifera (Vahl) Seigler & Ebinger

Senna Mill.

S. italica Mill.

Tephrosia Pers.

T. longipes Meisn.

T. polystachya E.Mey.

Vachellia Mill. [Acacia]

V. erioloba (E.Mey) J.P.H. Hurter

V. haematoxylon (Willd.) Seigler & Ebinger

V. hebeclada (DC.) Kyal. & Boatwr

V. karoo (Hayne) Banfi & Gallaso

JUNCACEAE

Juncus L.

J. exsertus Buchenau

J. rigidus Desf.

LAMIACEAE

Leucas Burm. ex R. Br.

L. martinicensis (Jacq.) R. Br.

Stachys L.

S. hyssopoides Burch. ex Benth.

LORANTHACEAE

Tapinanthus (Blume) Rchb.

T. oleifolius (J.C. Wendl.) Danser

MALVACEAE

Grewia L.

G. flava DC.

G. olukondae Schinz

Hermannia L.

H. amoena Dinter ex Friedr. – Holzh.

H. comosa Burch. ex DC.

H. eenii Baker f.

H. flammea Jacq.

H. pfeilii K. Schum.

H. stricta (E. Mey. ex Turcz) Harv.

Melhania Forssk.

M. rehmannii Szyszyl.

Pavonia Cav.

P. burchellii (DC.) R.A.Dyer

Sida L.

S. cordifolia L.

MESEMBRYANTHEMACEAE

Ruschia Schwantes

R. multiflora (Haw.) Schwantes

MOLLUGINACEAE

Limeum L.

L. africanum L.

L. fenestratum (Fenzl) Heimerl

L. viscosum (J.Gay) Fenzl

OXALIDACEAE

Oxalis L.

O. depressa Eckl. & Zeyh.

PHYLLANTHACEAE

Phyllanthus L.

P. parvulus Sond.

POLYGONACEAE

Persicaria (L.) Mill.

*P. *lapathifolia* (L.) Gary

PORTULACACEAE

Talinum Adans.

T. caffrum (Thunb.) Eckl. & Zeyh.

RHAMNACEAE

Ziziphus Mill.

Z. mucronata Willd.

RUBIACEAE

Kohautia Cham. & Schltdl.

K. amatymbica Eckl. & Zeyl.

K. cynanchica DC.

SCROPHULARIACEAE

Selago L.

S. geniculata L.f.

S. speciosa Rolfe

Sutera Roth

S. levis Hiern

SOLANACEAE

**Datura* L.

D. stramonium L.

Lycium L.

L. cinereum Thunb.

L. hirsutum Dunal

L. pumilum Dammer

Solanum L.

S. linnaeanum Hepper & Jaeger

S. panduriforme E.Mey.

*S. *pseudocapsicum* L.

THYMELAEACEAE

Gnidia L

G. polycephala (C.A.Mey.) Gilg

VERBENACEAE

Chascanum E. Mey.

C. hederaceum (Sond.) Moldenke

C. pinnatifidum (L.f) E. Mey

VISCACEAE

Viscum L.

V. capense L.f.

V. rotundifolium L.f.

ZYGOPHYLLACEAE

Tribulus L.

T. terrestris L.

<u>MONOCOTS</u>

ASPARAGACEAE

Asparagus L.

*A. suaveolen*s Burch.

ASPHODELACEAE

Trachyandra Kunth

T. laxa (N.E.Br.) Oberm.

COLCHICACEAE

Ornithoglossum Salisb.

O. viride (L.f.) Aiton

POACEAE

Andropogon L.

A. eucomus Nees

Anthephora Schreb

A. pubescens Nees

Aristida L.

A. congesta Roem & Schult subsp. *congesta*

A. diffusa Trin

A. meridionalis Henrard

A. stipitata Hack subsp. *stipitata*

Brachiaria (Trin.) Griseb.

B. dura Stapf

B. eruciformis (Sm.) Griseb.

Cenchrus L.

C. ciliaris L.

Centropodia Rchb.

C. glauca (Nees) Cope

Cymbopogon Spreng.

C. pospischilii (K.Schum.) C.E. Hubb

Cynodon Rich.

C. dactylon (L.) Pers.

Digitaria Haller

D. eriantha Steud.

Enneapogon Desv. ex P. Beauv.

E. cenchroides (Roem. & Schult.) C.E.Hubb

E. scaber Lehm.

Eragrostis Wolf

E. biflora Hack. ex Schinz

E. curvula (Schrad.) Nees

E. lehmanniana Nees

E. pallens Hack.

E. trichophora Coss. & Durieu

Imperata Cirillo

I. cylindrica (L.) Raeusch.

Melinis P.Beauv

M. repens (Willd.) Zizka

Miscanthus Andersson

M. capensis (Nees) Andersson

Paspalum L.

P. distichum L.

Phragmites Adans.

P. australis (Cav.) Steud.

Pogonarthria Stapf

P. squarosa (Roem. & Schult.) Pilg.

Schmidtia Steud. ex J.A.Schmidt

S. pappophoroides Steud.

Setaria P.Beauv.

S. verticillata (L.) P.Beauv.

Stipagrostis Nees

S. amabilis (Schweick.) De Winter

S. uniplumis (Licht.) De Winter

Tricholaena Schrad. in Schult.

T. monachne (Trin.) Stapf & C.E.Hubb.

Triraphis R.Br.

T. andropogonoides (Steud.) E.Phillips

TABLE 5.1: Phytosociological Table of the Witsand Nature Reserve, Northern Cape Province, South Africa.

Community		1	2				3	4		
Sub-community				2.1	2.2			4.1	4.2	
Variant					2.2.1	2.2.2			4.2.1	4.2.2
Relevé number		0 0 0 0 0	0 1 1 0 0 0 0 0	0 0 0 0 0 0 1	0 0 0 0 0 0 1 0 1 1 1 1 0 1 0	0 0 1 1 0 0 0 0 0 0 0 1 1 0 0	0 0 0 0 0 0 0	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 1 0 1 1 1 1	0 0 0 0 0 0 0 0	0 0 0 1 0 0 0 1 0
		3 3 7 8 7	6 0 0 6 8 6 6 4	7 9 9 9 9 9 1	4 8 8 8 4 4 1 8 0 1 1 0 4 0 4	7 8 0 0 8 5 7 5 7 5 5 1 0 3 3	4 6 6 8 2 8 2	2 0 1 2 2 2 0 0 3 7 1 2 2 0 6 0 1 0 1 0 1 0 0 4 2 1 1 3 4 2 3 4 9 5 2 6 5 9 7 1 6 1 1 0 1	3 9 1 9 1 1 9 3	7 5 6 1 5 7 5 0 5
		5 6 9 0 7	8 2 1 7 4 0 6 6	8 7 5 4 2 3 5	8 2 1 6 9 5 2 5 6 1 0 9 3 5 4	6 7 8 4 3 1 1 3 2 4 2 4 7 4 3	7 2 5 8 1 9 0	2 9 0 3 9 4 1 3 0 3 4 8 7 4 3 5 1 8 9 2 8 7 6 2 6 2 3 8 0 5 9 1 1 8 0 1 9 0 5 8 4 7 9 0 6	1 6 6 8 7 5 9 2	0 0 9 3 5 4 7 3 6
Number of relevès		5	8	7	15	15	7	45		
Number of species		13	15	17	25	31	45	56		
	Growth form									
SPECIES GROUP A										
Cyperus esculentus	Sedge	1 4 2 2 .	. . . .	. . . .	. . . .	2 4	. . . .	. . . .	. . . .	. . . .
Phragmites australis	Reed	5 . . 5 4	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .
Andropogon eucomus	Grass	. 2 3 3 .	. . . .	. . . .	. . . .	. . 1	. . . .	. . . .	. . . .	. . . .
Imperata cylindrica	Sedge	. . 5 3 3	. . . .	. . . .	. . . .	1	. . . .	. . . .	. . . .	. . . .
Cyperus margaritaceus	Sedge	. 4 . 2 .	. . . .	. . . .	. . . . r	. . . .	. . . .	. . . .	. . . .	. . . .
Schoenoplectus littoralis	Sedge	. 4 . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .
Juncus rigidus	Sedge	 3	. . . .	. . . .	. . . .	. . 3	. . . .	. . . . 3	. . . .	. . . .
SPECIES GROUP B										
Brachiara dura	Grass	. . . . .	3 1 . 3 2 3 . .	. 1 3 + 2 2 +	. 3 3 2 3 3 2 3 . r . 1 1 1 1	1 2 . 4 5 . 2 2 . . . . . 1 .	. . . .	. . . . 1	. . . .	. . . .
Stipagrostis amabilis	Grass	. . 1 . 1	2 2 3 3 3 1 4 .	4 4 2 2 1 1 4	. + ... 1 . . 2 .	1 . + . + 1 1 1 . . + . 1 + .	. . . .	. . . . 1 . . . . 2 . . . . 2 3 4 2 2 1	. . . .	. . . . 1 + 2 + .
Crotolaria orientalis	Shrub	. . . . .	r . . . 1 1 . .	. . 2 2 2 . 3	. 3 2 3 2 1 3 1 2 r 2 2 2 . .	. 2 2 3 . 2 3 1 . . 1 r 3 . 3	. . . .	. . r 2	. . . .	. . . . 3 2 . . .
Selago speciose	Dwarf shrub	. . + + .	. . . . . 2 . .	1 . 2	. . + ... + ...	1 . . 2 + ... r . + 1	. . . .	. . . .	. . . .	. . . . + ...
SPECIES GROUP C										
Eragrostis pallens	Grass	. . . . .	 2	. . . . 2 . .	. . . 2 2 . 1 . 2 r 1 . . 2 1	3 3 3 . 1 3 3 3 3 3 4 4 + 3 .	. . . .	. . . .	. . . .	2 2 . 2 . . . 2 .
Aristida stipitata	Grass	. . . . .	. . . .	+	. . . . . + . . 1 + . 2 1 2 1	. 3 . . 2 . . . + 2 + 3 . 1 2	. . . .	. . . . 1	. 2 . + . . 2 .	+ . . . 2 1 1 3 1
Pteronia sordida	Dwarf shrub	. . . . +	r	. . . .	. . . . . . 2 . 2 . . . . 2 .	+ 2 1 2 . + r 2	. . . .	. . . .	. . . .	. . . .
Elephanthorrhiza elephantina	Suffrutex	. . . . .	. . . .	. . . .	. . . . 1 3 1 . 1	. . . . . . 2 . 1 2 . 1 . . .	. . . .	. . . .	. 1	. . . 1 1 2 . 3 .
SPECIES GROUP D										
Lopholaena cneorifolia	Shrub	. . . . .	. . . .	. . . .	. 1 2 2 1 + 1 2 2 2 2 2 . 2 2	. . . .	. . . .	. . . .	. . . .	. r . . . .
Cymbopogon pospischillii	Grass	. . . . .	 2	. . . .	2 . . 3 . 1 + . 2 3 3 . . 1 2	. . . .	. . . .	. . . .	. . . .	. . . .
Helichrysum calicomum	Forb	. . . . .	 3	. . . .	2 . . 2 . . 2 . 3 3 2 . . 2 .	. 1	. . . . . 1 .	. . . .	. . . .	. 2 . . . .
Triraphis andropogonoides	Grass	. . . . .	. . . .	. . . .	. . . . 4 . . .	. . . .	. . . .	. . . .	. . . .	. 3 . . . .
SPECIES GROUP E										
Tricholaena monachne	Grass	. . . . .	 1	. . . .	. . . . 1	. . . . 2 1 1 . . 1 .	. . . .	. . . . + ...	1 1	+ 1 . . . 2 . 1 2
SPECIES GROUP F										
Pteronia teretifolia	Dwarf shrub	. . . . .	. . . .	. . . .	2 . + + 1 + 3 . . . 2 . 2 2 1	. . . . 2 . . 2 . . .	r 1 . 2 . 2 .	. 2 2	. . . .	. . . .
SPECIES GROUP G										
Digitaria eriantha	Grass	. . . . .	. . . .	. . . .	. . . .	. . . .	2 2 . 2 2 . 1	. . . .	. . . .	. . . .
Cenchrus ciliaris	Grass	. . . . .	. . . .	. . . .	. . . .	. . . .	. 2 . 2 1 2 .	1	. . . .	. . . .
Searsia tridactyla	Shrub	. . . . .	 2	. . . .	r 1	. . . . + ...	r 1 . 1 1 1 .	. . 1 . . . 1	. . . .	. + ...
Justicia thymifolia	Dwarf shrub	. . . . .	. . . .	. . . .	. . . .	. . . .	. 2 1 2 + . +	. . . .	. . . .	. . . .
Cleome rubella	Forb	. . . . .	. . . .	. . . .	. . . .	. . . .	1 1 + 1 + . .	. . . .	. . . .	. . . .
Tarchonanthus camphoratus	Shrub	. . . . .	. . . .	. . . .	2	. . . .	2 1 . 1 . . .	. . . .	. . . .	. . . .
Aristida diffusa	Grass	. . . . .	. . . .	. . . .	. . . .	. . . .	. 2 . . 2 . 2	. . 2 . . . . + ...	. . . .	. . . .
Indigofera heterotricha	Dwarf shrub	. . . . .	. . . .	. . . .	. . . .	. . . .	. r . . + 2 .	. . . .	. . . .	. . . .
Chascanum pinnatifidum	Forb	. . . . .	. . . . r	. . . .	. . . .	. . . .	. + . . 1 1 .	. . . .	. . . .	. . . .
Croton gratissimus	Shrub	. . . . .	. . . .	. . . .	. . . . r	. . . .	. + 2 . 1 . .	. . . .	. . . .	. . . .
Rhynchosia totta	Climber	. . . . .	. . . . +	. . . .	1 . . . . + . .	. . . .	1 + . . 1 . .	. . r	. . . .	. . . .
Cadaba aphylla	Shrub	. . . . .	. . . .	. . . .	. . . .	. . . .	. . + + r . .	. . . . . . 1 . . . . r	. . . .	. . . .
Melhania rehmannii	Dwarf shrub	. . . . .	. . . .	. . . .	. . . .	. . . .	. + r + . . .	. . . .	. . . .	. . . .
SPECIES GROUP H										
Senegalia mellifera	Tree	. . . . .	. . . .	. . . .	. . . .	. . . .	. + 1 1 + . 1	2 2 2 2 1 r 1 4 . 1 + 1 2 4 3 5 2 3 5 2 + 2 2 r 2 r . r 1 1 + 1 . . . + . 3 . 2 + . 2 . +	. . . . . . 2 .	. . . .
Boscia albitrunca	Tree	. . . . .	. . . .	. . . .	. . . .	. . . .	. 1 + r r . .	. + . + . . 1 1 . . . . r 1 . r + + . . r 1 1 . r . . 1 r . . . . . 2 + r . . . . 1 . . .	. . . .	. . . .
Rhigozum trichotomum	Shrub	. . . . .	. . . .	. . . .	. . . .	. . . .	. . . . . 2 .	1 1 . 2 . . . 1 . . . 3 4 2 . + . 2 . . . 1 2 . . . . 1 2 4	. . . .	. . . .
Melinis repens	Grass	. . . . .	. . . . +	. . . .	1 . . . . 1 2 2 + . .	. . . .	+ + 1 1 . r 1	. + ... 1 . . . . 1 . . . . . . + ...	. . . .	. 1 . . . .
Kyphocarpa angustifolia	Forb	. . . . .	. . . .	. . . .	. . . .	. . . .	. . . . 1 2 .	2 + ... 1 . . . . + ...	. . . .	. . . .
SPECIES GROUP I										
Diospyros lycioides	Shrub	 1	. . . .	+ 2 3 5 r + 1	. . . . . . 1	. . . . 2 . . + . 1 .	. . . .	. . . . 1 . . . . 2 4 . . . 1 . 1 1 r 2 + 2 1 2 . 1 . . 1	. . . + ...	2 . . . . + . 2 1
Lycium hirsutum	Shrub	. . . . .	. . . .	+ . + + + + 2	. . . .	r . . . . r .	. . . .	. . . . . + . . 1 . . 1 . + . . . r . r . . . . 1 1 2 + + 1 1 . 1 2 1 1 2	+ 2 + 2 . . 2 1	+ . + + . 1 . r r
Vachellia haematoxylon	Tree	. . . . r	. . . .	+ 3 3 . . . 3	. . . .	. . r . . . . 2 + . +	. . . .	. . . . . 2 . . + . 4 . . r + + ... + r + + . + . . . + . + 2 + 3 2 1 3 1 . 2 2 2 . 1	1 3 2 3 . 2 3 1	2 + 4 2 . + 1 3 +
Viscum rotundifolium	parasite	. . . . .	. . . .	. + ... 1	. . . .	. . . .	. . . .	. . . . + ... 2 + . . + 1 + . . 1 1 . 1	. . . .	1 . . 1 . . . . .
Ziziphus mucronata	Tree	. . . . .	. . . .	. 2 . . 2 4 r	. . . .	. . . .	. . . .	. . . . . . 1 . . r + . . 1 . + + r . . + r . + + ... 1 + ... r	. . . . r . . .	. . + . . + . . .
Justicia protracta	Dwarf shrub	. . . . .	. . . .	. 1 1 2 1 . .	. . . .	. . . .	. . . .	. + + ... r + ... r . . . . 1 + . r + ...	. . + . + . . .	+ . . . .
SPECIES GROUP J										
Asparagus suaveolens	Dwarf shrub	. . . . .	. . . .	. . . .	. . . .	. . . .	. . . . . . +	. + + 1 1 1 1 + 1 + + . + + + 1 2 1 + r + + 1 r 1 + + + . + 2 . . + . + ... r . .	+ 2 1 2 + . + +	+ + + ... +
Enneapogon cenchroides	Grass	. . . . .	. . . .	r	. . . .	. . . .	. . . . . 2 .	1 . . 2 + 2 . 2 2 . 2 1 . . 1 1 . 1 + 2 2 + 2 1 1 1 3 2 . 2 2 . . . 1 + . . 3 3 3 3 . 4 4	4 + 2 1 2 2 3 3	r . . . .
Eriocephalus spinescens	Dwarf shrub	. . . . .	. . . .	. . . .	. . . .	. . . . 3 . . .	+	+ + . . . 1 . r 1 3 2 . . . . . 2 . r + . 1 . . . + + + 2 . . 2 . . . . + .	. . + . + . . .	1 . + 2 . . . + 1
Justicia cuneata	Dwarf shrub	. . . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . . 3 2 . + 1 . . . . 2 . . . . 1 2 . 2	. . . .	. . . .
Amphiglossa tecta	Dwarf shrub	. . . . .	. . . .	. . . .	. . . .	. . . .	. . . . . + +	. . . . 2 . . . . r . . . . r	. 1 . . . . . +	2 . . 1 . 1 1 . +
Chenopodium cristatum	weed	. . . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . + ... 1 . . . . r . . . . . . + ... + ...	. . + ...	. . . .
Lycium cinereum	Dwarf shrub	. . . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . . . . 1 . . . . r r . + r	. . . .	. . . .
Eragrostis biflora	Grass	. . . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . 1 . . 1 . . . . + ... + 1 1 . 1 . 1 . . . . . 1 1	. . . .	1 . . . .
Senna italica	Forb	. . . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . . + ... + ... 1 . r . + ... r	. . . + . . + .	. . . .
Setaria verticillata	Grass	. . . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . . + 1 . 2 . . . . 1 . + 1 . . .	. . . 2 1 . . .	. . . . . 1 . . .
Momordica balsamina	geophyte	. . . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . . 1 . . . . + ... r	. . . . r	. . r . . . . . r
Gnidia polycephala	Dwarf shrub	. . . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . . + . . . 1 . . . . r . . . . 3 r . . + .	2 . . 2 . . + .	. . . .
SPECIES GROUP K										
Vachellia erioloba	Tree	. . . . .	. . . .	. . . .	. . . .	. . r . . . . r r +	. . . .	. . . . + r . 2 + . . + . + . . . + + . + . 1 + . 2 1 + + r . r	. . r . 3 . . .	. r . . . .
Tapinanthus oleifolius	parasite	. . . . .	. . . .	. . . + r . .	. . . . + ...	. . . .	. . . . . . r	r + . . 1 . . . . . . + . + . + + + . 1 . . + . + ... + . + + 1 . . . . + . +	. + ...	. r . . . .
Limeum viscosum	geophyte	. . . . .	. . . .	. . . .	. . . .	. . . . + ... +	. . . .	. r r . + + . . + . . . + . . . + + ... + ... r . . . . . . r	1	. . + ...
Vachellia hebeclada	Tree/shrub	. . . . .	. . . .	. . . .	. . . .	r	. . . .	. . . . 2 . . . . + . . . 1 . . . . + ...	. . . .	. . . .
Felicia filifolia	Dwarf shrub	. . . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . 1 . . . . + . . . 1 . . . . r 1	. . . .	. . . .
Solanum linnaeanum	Forb	. . . . .	. . . .	. . . .	. . . .	. . . .	. . . . + . .	. + + . . + ... + ... + ...	. . . . +	. . . .
Riocreuxia torulosa	Climber	. . . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . r . . . . r . . r . . . . + . . 1 . . .	. . . .	. . . . . . r . .
Senecio burchellii	Forb	. . . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . r r + ... r . . + ... r . .	. . . .	. . . .
Pupalia lappacea	Forb	. . . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. r . . . . . . + . . r . . . . + + ...	. . . .	. . . .
SPECIES GROUP L										
Heliotropium ciliatum	Forb	. . . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . . + ... 1	3 2 3 2 2 4 2 3	+ 1 . 2 1 + 2 . .
Centropodia glauca	Grass	. . . . .	. . . .	r	. . . .	. . . . 2 . 1 .	. . . .	. . . . + ... r 3 . . r . .	. 2 . + . . + .	r . . 2 . + . . .
Bulbostylis burchellii	Sedge	. . . . .	. . . .	. . . .	. . . .	. . . . + . . . 2	. . . .	. . . . 1 2 . . . . 2	. . . . . 1 . 2	+ 1 + 1 1 . . . .
SPECIES GROUP M										
Trachyandra laxa	Forb	. . . . .	. . . .	. . . .	. . . . r	. . r . . . . 1 . + 1 1	. . . .	. . . .	. . . .	1 r . . 1 . . . 2
Aristida meridionalis	Grass	. . . . .	. . . .	. . . .	. . . . + .	. . . . + ... +	. . . .	. . . .	. . . .	. 1 2 3
Anthephora pubescens	Grass	. . . . .	. . . .	. . . .	. . . .	. . . . 1 . . 4 1	. . . .	. . . .	. . . .	. . . . . . 3 . 2
Pteronia glauca	Shrub	 1	. . . .	. . . .	. . . .	1 . . . . 1 1 . 2 + +	. . . .	. . . .	. . . .	1 . . . + ...
SPECIES GROUP N										
Lycium pumilum	Dwarf shrub	. . . . .	. . . .	. . . .	. . . .	. . . .	+ . . + + 1 .	1 r r + ... + + + + + + 1 . . 1 . . + . . + 1 + + 1 + + + 1 . . . . + . . . + + 1 + .	r + 1 + + + . .	+ + 1 + . + . r .
Hermannia amoena	Forb	. . . . .	. . . .	. . . .	. . . .	. . . .	. r r + + + +	1 + + 1 . . . r + 1 + . . + r 1 . + r . . 1 . 1 1 + + + + 1 1 . 1 . . . . . r + r . . 2 .	. r 1 . + . + +	. . . . . . r . +
Tribulus terrestris	Forb	. . . . .	. . . .	. . . .	. . . .	. . . .	. . . + . + .	+ . r 2 1 1 . 2 1 r + 1 . + 1 1 . r r 2 1 + + + 1 + . + . 2 1 + . . 1 + . r + . 3 1 2 1 +	1 1 1 1 + r 1 1	r . . . + + . . .
Grewia flava	Shrub	. . . . .	. . . .	. . . 1 + . .	. . . .	. . . . r	r . + 1 . . .	. . . r + 1 . . . r 1 . . . . r . r . 3 1 . 1 . . 1 . r + + . + . + . + ... r 1 2 .	r 2 . 2 + . 2 .	+ r r . . . . . .
Prosopis velutina	Tree	. . . . .	. . . .	. . . .	. . . .	. . . .	. 3	. . . . r . . . . + ... r . . . . 2 . . 3 . 3 2 3 3 1 3	. r r . . . + +	. . . .
Pollichia campestris	Forb	. . . . .	. . . .	. . . .	. . . . 2	. . . .	. . r	. . . 1 1 . 1 . + . . 1 1 . + r r + r r . + 1 . 1 . . 1 1 1 1 1 . . . . + ...	. r . . . . . +	r . + ...
Grewia olukondae	Shrub	. . . . .	. . . .	. . . .	. . . .	. . . .	r	. . . . + ... r . . . . + r . . . . . . r	. . r + . . 1 .	. . r . . . . . .
Schmidtia pappophoroides	Grass	. . . . .	. . . .	. . . .	. . . .	. . . .	. . + . . + .	. r . . . . + ... + . . 2 . . 1	. . 1 + . 1 . 1	. . . . r .
Leucas martinicensis	Forb	. . . . .	. . . .	. . . .	. . . .	. . . . + 1	. . . .	. . . . . + ... + ... r . . . 2 . . . . . r	. . + . + . . .	+ 1 1 . . . . . .
Limeum linifoleum	Forb	. . . . .	. . . . +	. . . .	. . . .	. . . .	. . . . . + r	. . . . r r . . + ... + ...	. . . .	r . . . .
Phyllanthus parvulus	Forb	. . . . .	. . . .	. . . .	. . . .	. . . .	. . . . + . .	. . . . + + ...	. . . . r . r .	. . + ...
SPECIES GROUP O										
Stipagrostis uniplumis	Grass	. . . . .	 1	. . . .	. . . . r . . 1 . . .	. 2 . . . . . . 1 + + 2 . . .	1 . + 1 . 1 .	. 2 . 1 2 4 . 2 1 + 1 1 1 1 + + . 2 . 1 2 3 + 2 1 1 . 2 1 1 . 1 . . . . 1 . . . r .	. . 2 . 2 1 1 .	3 2 3 . 2 . 2 3 +
Hermannia eenii	Dwarf shrub	. . . . .	. . . .	. . . .	. . . . + . .	1 . 1 . . . . . . 2 . 1 2 1 +	. . . .	. . . . r + 1 . . . . + ... r . 1 + ... + ... 2 . 1 . 1 + 1 + + 1 2	1 2 1 1 1 2 + +	1 1 + 1 2 . 2 2 2
Eragrostis curvula	Grass	+	 2	. . . .	. . . .	. + . . . 1 . . 2 1 2 . . . 1	1 2 1 . 2 . 1	1 + . . 1 1 . . . 1 . 1 . . + . + . . . + . . 1 1 . . . . 1 . + . . . 1 . . . 1 . . . + .	1 2 . 2 . . 1 1	. 1 2 2 1 . 2 1 2
Eragrostis trichophora	Grass	. . . . .	. . . .	. . . .	. . . . + 1 2 2 + + +	. . 2 . . . . . 2 . . 2 . 2 1	. . . .	. . . . + ... 1 . 1 2	. . . .	1 . . . . 2 . 2 .
Aristida congesta	Grass	. . . . .	. . . .	. . . .	1 . . . . r	. 1 r 2	. . . .	. . . . 1 r . . . . + 1 1 . . . . + ... 2 + . . 1 1 + ... r	. 1 + + . . 1 2	. . 1 . 2 . . r .
SPECIES GROUP P										
Senecio harveianus	Forb	. . r + .	. . . .	. . + . . 1 .	. . . .	+ . . . + ... 1 1	. . . .	. . . . + . + ...	. + ...	. . + + . r . 2 .
Euphorbia spartaria	Succulent	. . . . .	. . . .	. 1 . . r . .	. . . .	. . . .	. . + r . . .	r . . . . r . . . . 1 . . . 1	. . . .	. . . .