Vegetation gradients, soil microbial pools and carbon sequestration in cactus-invaded semi-arid rangelands of western Free State

by

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EXECUTIVE ABSTRACT

Vegetation gradients, soil microbial pools and carbon sequestration in cactus-invaded semi-arid rangelands of western Free State

This study was done in the Xhariep district, western Free State region. The western Free State rangeland is classified as Nama Karoo biome, and is characterized by dwarf Karoo shrubs mixed with grasses. *Eriocephalus eriocoides*, *Eriocephalus spinescens*, *Pentzia* spp., *Pteronia* spp., *Euryops asparagoides*, *Lycium* spp. and *Asparagus* spp. are dominant shrubs. The grass stands are dominated by *Aristida* spp., *Eragrosti*s spp. and *Stipagrostis* spp. However, cacti (*Opuntia humifusa*) and companion invaders are overrunning the rangelands. The study therefore assessed the effects of invasive creeping prickly pear on the composition of forage grasses and shrubs in rangelands continuously grazed by sheep and cattle herds. *The objective of study 1* was to characterize the vegetation profiles in sheep- and cattle-grazed areas. The rangeland was stratified based on utilization and density of cacti. The newly invaded zone (NI) resembled the typical western Upper Karoo vegetation type, where disturbance indicator (DI) grasses constituted 86%, intermediate grasses (*Aristida adscensionis* and *Aristida congesta*) constituted 10%, and shrubs were 4% of the vegetation. The dominance of DI grasses suggests that grazing management, climate and competition for nutrient resources exerted by cactus (*O. humifusa*) invasions were affecting vegetation characteristics.

The objective of study 2 was to (a) determine the relationship between vegetation cover type on soil carbon, microbial populations and minerals in degraded rangelands, and (b) to characterize above-ground forage quality in the degraded rangelands. Four cover types were defined as cactus cover (CC), shrub cover (SC), grass cover (GC) and bare area (BA). The soil in bare area (BA) had the highest N content as nitrate (NO_3^-) and ammonium (NH_4^+) forms. Bacterial and fungal populations were the lowest in the BA. The bacterial count was 30%; and the fungal count 15% less than in areas covered by

vegetation. Mean crude protein of forages in late summer was low (about 7%), and new leaves of *O. humifusa* (cactus) had
5.1 % CP DM. Higher soil cover, OM and carbon sequestration were positive attributes of *Opuntia* invasion, whilst impoverishment of bacterial populations and loss of soil NO_3N and NH_4N assimilated by *Opuntia*-affected grazing land carbon pools were noted. Plantsoil-animal shifts driven by invasive species are critical in validation of global vegetation models that predict the response of fragile rangelands to climate change.

In study 3, interactions of rainfall and invasive species on rangeland grazing capacity were assessed. Semi-structured questionnaires were administered on 40 cattle and sheep farms within the Eastern Parkland vegetation type and the Transitional Zone. There was an increase in the grass component in both zones; however, the former had a higher proportion of DI. Shrub density increased by 16% over the past 30 years. Subclimax grass increased by 15.4%, and by 7.1% in the Eastern Parkland and Transitional Zone, respectively. There were no differences in change of palatable species in both zones. However, a small increment of 5.1% was noted with unpalatable shrubs in the Transitional Zone, and 1.7% in the Eastern Parkland. The Eastern Parkland's vegetation type was generally more stable and less sensitive to annual rainfall changes, compared to the Transitional Zone. It is uncertain whether vegetation patterns in the Koffiefontein rangeland (Eastern Parklands, Eragrostis-Karoo shrub and Transitional stage between Eastern Parkland and Eragrostis karoo shrub vegetation type) represent short-term cycles or permanent retrogression. There is a need for further analysis of the interactions of moisture, invasive and carrying capacity, which most likely will shape Karoo vegetation and utilization patterns in the next half century. It is also critical to assess the soil organic matter changes and carbon sequestration attributable to cacti invasion, and to ascertain if improvements in carbon accumulation would provide ecosystem services that compensate for losses in palatable forages in the next half century.

DECLARATION

I hereby declare that this thesis titled "Vegetation gradients, soil microbial pools and carbon sequestration in cactus-invaded semi-arid rangelands of western Free State" submitted for the DOCTOR TECHNOLOGIAE: AGRICULTURE to Central University of Technology, Free State is my original work, and that it has not been submitted by me in respect of a degree to any other institution, and the views expressed are my own. Literature and other reference materials used in this thesis have been acknowledged and included in the reference list.

L. Chipfupa   Date

DEDICATION

To my mother, Sarah.

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LIST OF ACRONYMS

AAS	Atomic Absorption Spectrophotometer
ADF	Acid Detergent Fiber
ADL	Acid Detergent Lignin
ANOVA	Analysis of Variance
BA	Bare area
C	Carbon
Ce	Cattle
Ca	Calcium
CAM	Crassulacean acid metabolism
CC	Cactus cover
CO_2	Carbon dioxide
CP	Crude Protein
^0C	Degree Celsius
DI	Disturbance indicators
DM	Dry matter
GC	Grass cover
GrC	Grazing Capacity
GDP	Gross Domestic Product
GRI	Grass Response Index ha
	hectares

HI	Heavily invaded zone
IG	Intermediate grasses
K	Potassium
LSD	Least Squares Differences
LSU	Large stock unit
m	metres
Mg	Magnesium
ml	milliliter
mm	millimeters
m^2	Square meters
N	Nitrogen
NDF	Neutral Detergent Fiber
NI	New invasion
OH	*Opuntia humifusa*
OM	Organic Matter
P	Phosphorus
PG	Palatable grasses
PLFA	Photo Lipids Fatty Acid
PS	Palatable shrubs
S	Sheep
SOC	Soil organic matter
SC	Shrub cover
SRI	Shrub Response Index

TI	Transitional zone
UPS	Unpalatable shrubs

INTRODUCTION

1.1 Background

The western Free State region is arid to semi-arid (Noy-Meir, 1973), and locally referred to as the Nama Karoo rangeland. The Nama Karoo supports a large diversity of flora that sustains wildlife and livestock. Small stock production dominated this region during the 20th century. However, there is now a major shift to large ruminants - mostly beef cattle - to meet market demands for red meat, and these changes seem to be aligned to shifts in vegetation possibly resulting from high grazing pressure (Acocks, 1955; Roux, 1980). Bare patches are more notable, and dwarf shrubs dominate in areas associated with large herds of ruminants. Overgrazing of the semi-arid areas alter vegetation composition and decreased primary productivity as noted by Kinyua, McGeoch, Georgiadis and Young (2010), and Fomara and Tilman (2008). Soil micro-organisms, which are principle drivers in carbon, oxygen, nitrogen and phosphorus uptake, are affected, which in turn affects the soil's fertility recovery rate. Ecosystem resilience is reduced and retrogression ensues. Invasive plants such as imbricate prickly pear (*Opuntia imbricata*), sweet prickly pear (*Opuntia ficus indica*), torch cactus (*Echinopsis spachiana*), and moon cactus (*Harrisia martinii*), which are hardy, overrun the landscape. These species reduce biodiversity and the grazing capacity of fragile ecosystems (Van Wilgen, Richardson, Le Maitre, Marais and Magadlela, 2001). Other invaders common in the western Free State include three thorns (*Rhigozum trichotorum*), *Prosopis* spp. and silver leaf. *Opuntia humifusa* is the most dominant invasive plant in the western Free State. Other common cacti species are *O. imbricata* and *H. martinii* that are classified under category 1 - prohibited and controlled (Henderson, 2001). Invaders such as *Prosopis spp.* and *R. trichotorum* fall under category 2: controlled utilization (Henderson, 2001). Cactus invasion poses severe challenges on rangeland nutrition support for herbivores.

The Cactacea are a dicotyledonous angiosperm family of about 2 260 total accepted taxa: 1 306 species, 301 accepted heterotypic subspecies, 582 provisionally accepted species and hybrids, and 71 provisionally accepted species and hybrids (Hunt, 1999). Cacti occur in dry, arid and degraded rangelands of America, the Mediterranean basin, the Middle East, South Africa, India and Australia (Brighton and Rose, 1919; Anderson, 2001). *Opuntia* is a genus of the *Opuntiodeae* family, with 181 species and 10 naturally occurring hybrids. *Opuntia humifusa* has a 0-10 cm plant height. It is dark green and of orbicular or blog joint shape. It has a 3-13 cm joint size, and one to five gray to brownish spines (Labra *et al*., 2003). *The flowers are* yellow, and stigma lobes have white flowers and 2.5 – 5 cm long fruits (Labra *et al*., 2003). *Opuntia humifusa* is a CAM plant (crassulacean acid metabolism), enabling it to adapt to harsh environments (DiTomaso, 2000). Leaves (cladodes) have a high ash content (201 g/kg dry matter), Ca (1967.8 mg/100g DM), Mg (1411.2 mg/100g DM), K (1269.6mg/100g DM), and P (1110 mg/100g DM), crude fibre (503.3 g/kg DM) and soluble fibre (233.2g/kg DM) (Jun, Cha, Yang, Choi and Kim, 2013). Its physiological attributes, apart from spines, nutrient composition and adaptability give cacti a favourable outlook as dryland forage. However, physical growth habits of cladodes present a challenge, as leaves creep and multiply rapidly, thereby accelerating displacement of palatable annual species. These alterations in the balance of grasses and other herbaceous species affect organic matter, carbon and nitrogen cycles (Novara, Pereira, Santoro, Kuzyakov and La Mantia, 2014). Novara *et al.* (2014) noted that the high adaptability and fast growth could increase C stock in semi-arid ecosystems.

Opuntia humifusa presents a rangeland conundrum - on the one hand it improves ecosystem nutrient cycles - sequesters C, and on the other it provides soil cover and high biomass. It is perennial and rich in nutrients, but not necessarily of high forage value, and on the extreme end it is invasive and displaces palatable herbaceous species. and injures animals. This study therefore focuses on the imprint of *O. humifusa* in the Nama Karoo rangeland of the western Free State, and its effects on soil bacteria, herbaceous palatables and shrubs in sheep and cattle grazing areas.

1.2 Problem statement

South Africa, Australia and Spain are world hotspots of invasive species, with 35, 26 and 24 species recorded, respectively (Novoa et al. 2014). The combined effects of explosive *O. humifusa* invasion, recurring drought in the western Free State, and overgrazing, may be influencing forage nutrient supply and livestock turnover. *O. humifusa* imposes a major threat to the conservation of native species and the integrity of the ecosystem. Novoa, Le Roux, Robertson, Wilson, and Richardson (2015), and Richardson and Van Wilgen (2004) noted that invasive alien plants reduce the capacity of rangelands to support livestock and wildlife, and reduce biodiversity. The creeping prickly pear suffocates palatable herbaceous species and injure grazers. Van der Westhuizen (2003) indicated that *Eragrostis* and *Aristida* species and partly Karoo shrubs dominate the rangeland, previously covered by red grass species such as *Themeda triandra*, *Digitaria* and *Panicum*. About 180 alien species have invaded more than 10 million ha of land in South Africa (Obiri, 2011; De Lange and Van Wilgen, 2010 and Van Wilgen *et al.*, 2001). This represents about 0.3% of South African GDP, which is estimated to escalate to 5% of GDP if invasive plants are not controlled (De Lange and Van Wilgen, 2010). In Madagascar, invasive *Opuntia* caused problems of low forage biomass yield and low cattle turnovers (Larsson, 2004). Interventions are therefore necessary. At ecosystem level, species changes affect carbon flows (Gower, 2003; Houghton, 2005). Bacteria, fungi, micro-arthropods and nematodes play a very important role in the cycling of carbon and nitrogen in desert system (Whitford, Stinnett and Anderson, 1988). The semi-arid region of Coquimbo, Chile, lost about 50% of the native plant species as a result of desertification (Mabbutt and Floret, 1980), and a similar trend may occur in semi-arid rangelands of South Africa that are invaded by cacti. *Opuntia* species reproduce rapidly both sexually and asexually (through seeds and cladodes).

Assessment of vegetation structural changes and microbiome in fragile ecosystems of the western Free State rangeland hosting cattle and sheep herds is crucial for managing nutrient flows in dry areas severely invaded by *O. humifusa*.

1.3 Research questions

The research question set is the following: What are the ecological inter-relations between creeping prickly pear (*Opuntia humifusa*) and indigenous herbaceous plants with regard to:

I. soil carbon, organic matter and micro-organisms;

II. forage quality and nutritional value; and III. carrying capacity of invaded rangelands?

1.4 Objectives of the study

The objectives of the study were to:

I. characterize indigenous grasses and shrubs species; composition and abundance in sheep and cattle rangelands invaded by *O. humifusa* invasion;

II. to assess rangeland carbon pools, microbial content and relative forage value in rangeland invaded and degraded by creeping prickly pear in the western Free State and; assess interrelations between livestock stocking rates, rainfall and grass and shrub abundance in rangeland invaded by *O. humifusa*.

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CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

The review covers global cactus-pear invasion, particularly in South Africa, and the effects thereof on rangeland productivity, ruminant production, soil ecology and carbon cycling. There are three invasion hotspots in the world: South Africa (35 invasive species recorded), Australia (26 species) and Spain (24 species) (Novoa et al. 2014). However, there are large areas of the world with climates suitable for cacti that are at risk of future invasion, in particular parts of China, eastern Asia and central Africa. Intervention strategies - mainly biological and chemical control methods - and grazing management programmes for rehabilitating cactus-invaded rangelands, in order to mitigate the rate of invasion and spread, are also reviewed. Commitment of the government of South Africa to eradicate or contain the invasion of *Opuntia* species through organizations such as the Working for Water Programme, and the Agricultural Research Council, were noted. An understanding of the trajectories in cactus pear invasions and the implications to gross domestic product (GDP) from livestock is critical in view of the fact that the cactus pear has decimated productivity of rangelands in other environments, and would impact livelihoods of rural communities in resource-poor areas of South Africa. Technological and biological innovation in livestock management would be critical in rangeland rehabilitation. Intense appraisal and climate smart mitigation strategies are essential to improve rangeland ecosystem resilience.

2.2 Cacti and other succulent plants

Thousands of plant species are introduced into new environments, both purposively and inadvertently, as food crops, fodder, timber and firewood, ornamentals, medicinal, spiritual, for soil erosion control (conservation), stabilization of sand dunes and as barriers and hedge plants (Henderson, 2007 and Moran, Hoffmann and Zimmermann, 2013). The extensive invasion by cacti in South Africa has been documented since the 20th century, when *Opuntia ficus indica* (L). Mill occupied vast tracts of Karoo (Henderson, 2015).

South Africa is the second most invaded of all countries, with 35 taxa recorded (Novoa, Le Roux, Robertson, Wilson and Richardson, 2014). *Opuntia humifusa* - commonly known as creeping prickly pear, which originated from North America (Henderson, 1999), has invaded arid grassland and savannah. Zimmermann (2010) reported at least 11 *Opuntiae* that are invasive in South Africa, including the prickly pears *Opuntia ficusindica*, *Opuntia stricta*, *Opuntia aurantiaca*, *Opuntia monacantha*, *Opuntia lindheimeri*, *Opuntia humifusa (creeping prickly pear)* and *Opuntia engelmannii (small round-leaved prickly pear)*; and the "cholla" prickly pears *Cylindropuntia (Opuntia) fulgida (chain fruit cholla)*, *Cylindropuntia imbricata (imbricate cactus)*, *Cylindropuntia Leptocaulus (pencil cactus)* and *Cylindropuntia tunicata (yellow-flowered cholla).*

Opuntia species belong to Cactacea family, originating from the plateau of Mexico. Prickly pear (*Opuntia ficus indica*) was introduced to the Cape over 300 years ago (Hosking et al. 1988). The cactus plant has been growing profusely in South Africa, and has adapted well to the arid zones. There are wild spiny varieties and thornless species that originated from Mexico, where it is under intensive cultivation. According to Schweig (2017), cacti plants and other succulent plants have swollen stems that contain water storage tissues, and the stems have thick water epidermis, usually covered with a thick waxy cuticle to help prevent water loss. The cacti typically have extensive root systems, spreading just below the soil surface. The root layout system assists the cacti plants to absorb even the relatively small amounts of water that moisten the soil surface during the light showers of rain. To help them store water in the tissues of plants, the stems of many cacti are fluted with ribs, so that the stem can expand and contract without damage to the surface tissue.

2.2.1 *Opuntia humifusa*

Opuntia humifusa is a clump-forming succulent shrub bearing few yellow flowers (Figure 2.1). The plant is propagated through seeds and cladodes (ramets). Golden-yellow flowers appear from October to December followed by red or purple fruits. The plant is a problem because it competes or replace existing indigenous species as shown in figures 2.1 and 2.2. Dense infestations reduce the grazing potential and hence the carrying capacity of the land, and restrict access by domestic and wild animals.

Figure 2.1 *Opuntia humifusa* with yellow flowers and red fruits and palatable shrub (*Walafrida geniculata*).

2.3 Physiological adaptations of cacti plants

Cactus derives first products of photosynthesis from the crassulacean acid metabolism (CAM) pathway, which occur under conditions of high temperature and low water availability (Schweig, 2017). CAM plants take CO_2 during night hours and convert it to organic acid, with the help of enzymes. During day the CAM plants have C_3 metabolism – converting CO_2 directly into sugars or storing it for dark metabolism (Schweig, 2017; Winter and Holtum, 2014).

In the western Free State, the cacti species commonly include *O. humifusa*, *O. imbricata*, *O. ficus indica* and *H. martinii*. According to Novara et al. (2014) the land use change from C_3 plants (dwarf shrubs) to cactus pear (CAM plants) lead to soil organic carbon (SOC) decrease by 65% over 28 years of cultivation. The root turnover rate of cactus decrease along the soil profile from 7.1% per year in 0-15cm to 3.7% in 60-75 cm soil depth. Novara, Perreira, Santoro, Kuzyakov and La Mantia (2014) concluded that SOC was higher and had a longer residence time in C_3 plants, compared to the cactus pear.

Nobel (1994) estimated (in 1994) that Opuntia covers between 687 000 ha and 2.3 million ha worldwide, including low-density populations in northern Mexico (Grobler, Dearlove and Scholtz, 2010). About 92% of these resources of spineless Opuntia species, are useful as stock feed. The spineless *O. ficus indica* is also used as fodder for cattle in the western Free State. During periods of drought, wild cactus is utilised by ruminants and other herbivores (Nefzaoui, Inglese and Belay, 2010). The young stems and leaves have a crude protein content of 2.5 to 9.5%, low fat (1-2%), high ash (14-21%) and high levels of non-nitrogen extracts (60-68%) in dry matter (Fuentes-Rodrigues, 1977; Pimienta Barrios and Munoz-Urias, 1999). Grobler et al. (2010) noted that the average daily intake varied between 11,3 kg and 13 kg on a wet basis for sheep. The relationship of cactus invasion to the rangeland and/or space occupied can be of nuisance or of benefit, creating a scientific dilemma. The land degradation and displacement of palatable indigenous grass and shrub species are direct impacts of cactus invasion. On the other hand, control of soil erosion is a notable benefit where creeping pear dominates.

2.4 Opuntia distribution

Opuntia humifusa is widely spread in South Africa, but is not classified as naturalized *Opuntia*. Henderson (1999) attributed an anomaly to misidentification of this plant as *Opuntia lindheimeri engelm*. The spread of cacti is mainly through natural propagation, with animals, mainly ruminants, playing a significant role in spreading of seed. Humans are equally responsible for inadvertently spreading *Opuntia* through propagation as ornamental plants around homes and hedging. Large areas of the Nama Karoo and the thicket biomes in the Eastern Cape are invaded by *Opuntia species* and saltbushes (*Atriplex* spp.) (Richardson, Macdonald, Hoffman and Henderson, 1997). Kraaji and Milton (2006) reported massive invasion of over two million hectares in the early 20th century, severely affecting agriculture productivity. In the Nama Karoo woody invaders - mesquite (*Prosopis spp.*) in particular - invaded large areas of alluvial plains and seasonal and ephemeral watercourse. The invasive cacti overran at least 20 000 km^2 since 1932. Van Wilgen, De Wit, Anderson, Le Maitre, Kotze, Ndala, Brown and Rapholo (2004) estimated that 10 million ha of South Africa are invaded by the 180 cacti species (see Table 2.1). The Nama Karoo (semi-desert shrubland, summer rainfall) is the fourth-most invaded biome, fynbos, thicket, and grassland being first, second and third respectively. Dense infestations diminish browse and grassland production (Zimmermann, 2010), causing high livestock mortalities. Spines on leaves act as a defence mechanism against herbivory, which makes the cacti also unpalatable (Henderson, 1999).

Kaplan (2013) noted that cactus species are economic and ecological threats to South Africa. Paterson and Hill (2013) also observed that cactus plants out-competes native vegetation, with devastating effects on native plant biodiversity. Species disappearance, change in species' composition and abundance, with high losses in highly palatable grass species, are evident in the areas overrun by cacti. Francis (2013) also reported a negative association involving diversity and abundance of woody species, the levels of nitrogen (N) and the increase in density levels of *Opuntia fulgida*. High livestock mortality was reported, with high and medium densities of *Opuntia fulgida* (Francis, 2013). Visual observation shows that the western Free State is overwhelmingly invaded by *Opuntia humifusa.* The adaptability and naturalization of *O. humifusa* in the semi-arid rangeland of the western Free State could be attributed to climate change. Without intervention, desertification and/or permanent ecological changes are inevitable (Kgosikoma, Mojeremane and Harvie, 2013), and this may result in depreciation of invaded farms. The invasion by the creeping prickly pear in the Karoo biome displaced grasses and herbaceous legumes in most parts of sub-Saharan Africa (Vetter, 2005). Overgrazing, coupled with low rainfall in semi-arid biomes, depress growth of annuals and increase the spread of creeping prickly pear. Schmidt and Stubbendieck (1993) attributed the rapid invasion by shrubs to livestock, hooves with higher displacement force, as the most effective dispersal factors. Cattle ingest and scarify seed and deposit it in nutrient-rich dung. Thus, seed deposits are usually far from the seed source (Brown and Archer, 1987).

Table 2.1 Areas invaded by alien plants in the nine provinces of South Africa, and the mean canopy cover (Le Maitre, 2000). Data on biomes is from Low and Rebelo (1996).

Province	Major biomes of the province (%)	Area (km^2)	Total area invaded		Mean Canopy
		Km2	Km2	%	Cover (%)
Eastern Cape	Grassland (40) Nama Karoo (25) Thicket (16)	167 398	6 720	4.01	22.51
Free State	Grassland (72) Nama Karoo (22) Savanna (6)	129 936	1 661	1.28	14.56
Gauteng	Grassland (78) Savanna (22)	16 519	223	1.35	58.56
KwaZuluNatal	Savanna (54) Grassland (36) Thicket (8)	94 596	9 220	9.75	27.21
Mpumalanga	Grassland (64) Savanna (36)	79 571	12 778	16.06	14.49
Northern Cape	Nama Karoo (54) Savanna (30) Succulent Karoo (14)	361 981	11 784	3.26	14.10
Northern Province	Savanna (97) Grassland (3)	122 143	17 028	13.94	15.45
North West	Savanna (71) Grassland (29)	116 010	4 052	3.49	13.88
Western Cape	Fynbos (47) Nama Karoo (24) Succulent Karoo (24)	129 314	37 274	28.82	16.80

Lemma, Haile, Fetene and Belay (2010) reported that cacti increase soil fertility, as pads, roots and fruits of cacti decompose and mineralize easily, releasing plant nutrients and improving the soil structure. Lemma *et al.* (2010) also observed that denser cacti areas are richer in organic matter content compared to cleared and cultivated areas. Although the turnover period of the carbon cycles in the cactus periods are lengthy, the restoration of soil fertility is worthwhile. What remains unclear is the period of rehabilitation for agriculture use, and the ecosystem products to be derived, such as dye production from cochineal infestations, which will be discussed later.

2.5 Arid and semi-arid biomes vegetation and livestock support

Southern Africa is mostly arid (<250 mm per annum) and semi-arid rangelands (250 – 600 mm per annum) (Palmer and Ainsilie, 2006). The arid rangelands consist of large sections of the desert, Nama Karoo and succulent Karoo biomes, and occupy 231 220 km^2 19% of South Africa (Le Maitre, 2000 and Low and Rebelo, 1996). A complex mix of grass and subshrub are the dominant vegetation types, which are subject to dynamic changes in species composition; and which species are dependent on seasonal rainfall events. Common shrubs or Karoo bushes include *Pentzia incana*, *Eriocephalus eriocoides* and *Hermanniana* spp., while grass such as *Aristida* spp., *Eragrostis* spp. and *Themeda triandra* may dominate the landscape after good summer rains (Fouche et al. 2014).

The arid-biome vegetation is best described by the arid grassland, arid savanna and Nama Karoo biome. Arid grassland has a wide range in floristic composition associated with the environmental variables, dynamics and management options. There is a strong dominance of hemicryptophytes of the Poaceae (Noy-Meir, 1973). Standing biomass is moisture dependent and decrease with rainfall gradient. Herbivory from domestic and wild herbivores has a decisive impact on standing biomass and species composition (Botha, 1981). Arid savanna has a strong rainfall summer seasonality which encourages woody shrub productions. The savanna biome is the region where large portions of national beef production occur under extensive conditions. The Nama Karoo biome characterizes the central and western region of South Africa and Southern Namibia (Cowling, 1986). The biome is dominated by a steppe-type vegetation, comprising a mixture of shrubs, dwarf shrubs, and annual and perennial grasses (Cowling, 1986). The biome is associated with moderate rainfall regions (250 - 450 mm per annum), and is ideal for sheep and goat production. The summer seasonality of the rainfall in the eastern parts of the biome means that there is often abundant grass production during the growing season, and grazers are able to optimize production during this time. In the winter the dwarf shrubs maintain their crude protein at around 8%, providing excellent forage. Woody encroachment, *Acacia mellifera* and *Rhigozum trichotorum* (Table 2.2) thicken up in regions with a long history of herbivory (Cowling, 1986).

Table 2.2 Dominant growth and life forms in the Karoo biome (modified from Cowling, 1986)

Growth form	**Life form**	**Leaf consistency[1]**	**Dominant genera**
Annuals	Therophytes	Orthophyll, succulent	*Aristida*, *Hermannia*,
Geophytes	Crytophytes	Orthophyll	
Grasses	Hemicrytophytes	Orthophyll	*Aristida*, *Digitaria*, *Enneapogon*, *Eragrostis*, *Stipagrostis*
Dwarf and low deciduous shrubs	Chamaephytes	Orthophyll, fleshy	*Eriocephalus*, *Felicia*, *Galenia*, *Lycium*, *Pentzia*, *Rosenia*, *Walafrida*
Dwarf and low evergreen shrubs	Chamaephytes, Phanerophytes	Fleshy, sclerophyll	*Chrysocoma*, *Eriocephalus*, *Pteronia*, *Felicia*, *Gnidia*
Dwarf and low succulent shrubs	Chamaephytes	Succulent	*Zygophyllum*, *Euphorbia*
Mid-high and tall deciduous shrubs	Phanerophytes	Orthophyll	Acacia, Lycium, Rhigozum, Rhus

[1]Consistency classes according to Cowling and Campbell (1983)

2.6 Effects of Opuntia and companion invaders on ruminant livestock production

No direct correlation has been noted between invasive species and animal production; however, conclusions are derived from relating low livestock turnover to severity of invasion. The effects of mesquite were found to be more severe at 80% invasive cover- reducing stocking density to zero (Kaiser, 1999). At low density, mesquite does not significantly alter animal production, as the plant produces pods that improve diet quality. However, higher density decimates grass growth (Kaiser, 1999). Rangelands invaded by creeping prickly pear and prickly pear cause high mortality in sheep, as is evidence from the case of Laikipia in Kenya (Akumu, 2016). The glochids on the cladodes injure the gut; lodging in the mouth, stomach and intestines. Glochids also result in blisters around the mouth - a condition known as pear mouth - with notable abscesses, which result in the animals being unable to eat. Akumu (2016) also reported that large spines prick and damage the eye. *Prosopis* spp., cactus and saltbush were established as a drought mitigating forage shortage strategy, and birds and livestock facilitated its invasion in South Africa (Richardson and Van Wilgen, 2004) through their droppings and displacement of materials used for propagation. Invasive alien plants such as *O. humifusa* and *O. ficus indica* became unwanted (Richardson and Van Wilgen, 2004). The invasive plants became firmly established in disturbed habitats, overgrazed paddocks, and they diminished the productivity and value of the land.

Land degradation, including overgrazing, is regarded as one of the main environmental problems in Southern Africa (Darkoh, 2009), with the gravest impact on biodiversity loss (Biggs, Simons, Bakkenes, Scholes, Eickhout, Van Vuuren and Alkemede, 2008; Scholes and Biggs, 2005). In the arid Karoo, representing a significant proportion of the western part of South Africa and Southern Namibia, degradation processes have been evident since the colonial occupation, and the associated decrease of nomadic grazing and increase in livestock numbers in permanent settlements (Dean, Hoffman, Meadows and Milton, 1995). Soil erosion is also a major concern (Lesoli, Gxasheka, Solomon and Moyo, 2013). Invasive species suppress growth of mostly herbaceous plants (Ward, 2005). Furthermore, due to competition for light, water, and nutrients between native and invading species, the grazing capacity of rangelands declines (Ward, 2005). Therefore, invasions are considered one of the largest threats to the ecosystems of the earth (Kaiser, 1999; Van Wilgen, De Wit, Anderson, Le Maitre, Kotze, Ndala, Brown and Rapholo, 2004), and the services that they provide to humanity (Kaiser, 1999). These species are characterised by rapid spread, and they displace native vegetation (Figures 2.1 and 2.2) and disrupt important ecosystem processes, which, in turn, leads to serious environmental impacts (Kaiser, 1999 and Bright, 1998). The rapid spread of O. humifusa is enhanced by the way the plant propagates, both asexual and sexual. The seeds are spread by birds; the propagule pressure is caused by grazing cattle detaching raments which are propagation materials.

Figure 2.2 *Opuntia humifusa* displacing *Themeda triandra* and *Heteropogon contortus* on Koffiefontein grazing land.

2.7 History and current efforts of control of invasive *Opuntia*

Public awareness campaigns (via media such as magazines, radio, television, extension services) on the nature of *Opuntia*, its mechanisms of spread and negative environmental effects are wide spread, resulting in most rural households shunning this weed (SAPIA, 2012). SAPIA (2012) published material advising the community to remove and destroy any cacti species, and to avoid planting them in gardens. People have different perceptions, and responses are variable. Families whose livelihood depends on farming are more likely to respond to the request to remove invasive plants. The lack of enforcement for populations to take voluntary action in managing the invasive plants retards the efforts to manage *Opuntia*. Other control mechanisms, such as chemical and biological mechanisms, are applicable. Zimmermann (2010) reported that early detection of new alien plant invaders is the first control point, and that it is cost effective. Prior to 1985, Picloram in paraffin or diesel was widely applied against many *Opuntiae* (Moran and Annecke, 1979; Zimmermann, 1979). *Monosodium methanearsonate* (MSMA) was registered for cactus control in 1947. From 1913, parallel biological control was applied with the use of cochineal insect (*Dactylopius ceylonicus*). Cochineal was introduced to control *Opuntiae monacantha* on the southern and eastern coasts of South Africa. The cactus moth (*Cactoblastis cactorum*) and cochineal (*Dactylopius opuntiae*) originated in

Australia, where the insects were used to control *O. stricta* and *O. ficus indica (Henderson, 2007)*. The biological control of *O. lindhemeri*, *O. humifusa* and *O. engelmannii* and *C. tunicate* was unsatisfactory, and further technological research is obligatory (Henderson, 1999). *Opuntia humifusa* was controlled biologically using cochineal in Australia (Hosking, Macfadyen and Murray, 1988; Volchansky, Hoffmann and Zimmermann, 1999). In South Africa the new weeds include *O. humifusa*, *O. stricta*, *O. engelmannii* and two chollas, *Cylindropuntia fulgida* and *Cylindropuntia tunicata*. Although the moths *D. opuntiae* and *D. tomentosus* occur naturally on *Opuntia* in their native areas, the insect populations introduced to South Africa as biological controls for *O. ficus-indica* and *C. imbricate* were ineffective. The utilization of pests to control weeds has unintended consequences, as moths also attack other crops such as the cultivated spineless cacti fodder banks. Palatable and spineless Mexican varieties that are being propagated in semi-arid environments as fodder and for fruit production are susceptible to moth damage, creating an antagonistic scenario.

There is minimal effort to control cacti spread. Chemical and biological control methods are either not affordable or ineffective. Paterson and Hill (2013) pointed out that mechanical and chemical control is ineffective, expensive and unsustainable, as herbicides are not translocated within the plant tissue. Control using cochineal has unintended consequences, as butterflies also devastate cultivated pastures of cacti. An estimated 1 500 ha in South Africa are now being cultivated for fruit, and a further 3000 ha exclusively for fodder - although the success of established orchards depends on the ability and diligence of individual farmers to combat pests (ICARDA, 2013).

2.8 Environmental importance of Opuntia and other invaders: Carbon and organic matter pools and soil minerals

The rangelands (grazing lands) function as a multifunctional system within the ecosystem. The above-ground biomass sequesters carbon from the atmosphere, and sinks it into the soil. Cactus-invaded grazing areas force large ruminants to change their grazing behaviours and veld utilization strategies, targeting areas around the prickly pear. The above-ground biomass is over-utilized, causing bare patches, resulting in loss of carbon (Li, Hao, Zhao, Han and Wills, 2008; Maraseni, Mathers, Harris, Cockfield, Apan and Maroulis, 2008; Ritchie, 2012). Management of grazing lands, control of stocking densities, stocking rates, grazing pressures and overgrazing are crucial in checks and balances of atmospheric carbon via carbon storage in above-ground biomass and generation of soil organic matter (Derner and Schuman, 2007). Improved management of grasslands and savannas increases significant sequestration, and sinks were noted (Booker, Huntsinger, Bartolome, Sayre and Stewart, 2013). Derner and Schuman (2007) reported that carbon sequestration also provides the associated ecosystem co-benefits such as increased soil water-holding capacity, better soil structure, improved soil quality and nutrient cycling, and reduced soil erosion. Land use, such as grazing approaches, has an effect on carbon sequestration. Derner and Schuman (2007) observed that grazing-induced changes in plant community composition were related to changes in carbon sequestration and stocking rates. Invaders such as *Prosopis* spp. had a positive effect on arid- and semi-arid ecosystems, as they increased soil organic matter and soil N (Herrera-Arreola *et al.*, 2007).

South African soils have low organic matter levels. Research showed that about 58% of South African soils contain less than 0.5% of organic carbon and only 4% contain more than 2% organic carbon. Soil quality has been typically equated with soil organic matter (SOC) or its associated indicator elements, C and N. The low humus content and wide spread aridity in South African soils, result in an extremely delicate nature and lack of resilience in comparison to soils in temperate areas (Du Toit, 1938). The removal of vegetation by livestock results in a net depletion of soil organic reserves in the landscape (Allsopp, 1999). The lower biomass production and greater soil temperature in poor and moderate veld resulted in 16 – 25% soil organic losses over 15 years. Degradation of rangelands due to overgrazing results in low biomass production and this significantly results in soil organic matter losses. Soil support diverse microbial community that play important roles in ecosystem level processes such as decomposition of organic matter and nutrient cycling (Wright and Reddy, 2001). The richness, abundance and activity of microbial community is vulnerable to influence by soil physical and chemical properties such as pH, moisture, organic matter content and nutrient availability (Moussa et al., 2007). Alterations in the physical and chemical nature of the soil may lead to shifts in microbial community, composition and changes in microbial function (Bella et al., 2013). Interms of biomass, fungi dominate in the soils followed by bacteria and actinomycetes (Moussa et al., 2013). Rangeland plant community distribution and species composition are known to be related to specific soil properties such as soil climate, texture, depth, structure, fertility and pH, salinity and toxic influences.

2.9 Conclusion

Inadequate research on management of weedy cacti and policies on the control of cacti are indicators of laxity in rehabilitation of degraded areas. The degraded Makapanstad, in north-west province of South Africa, rangelands and debushing efforts for rehabilitation stand as evidence of apathy and poor prioritization with regard to the management of rangelands. Range surveillance and monitoring programmes require a cooperative approach by community stakeholders. The biological and chemical control approaches may not be readily accessible and affordable to ordinary farmers. Furthermore, the biocontrol methods are slow acting, and require a substantial amount of time to effect significant changes on invaded lands. Finally, a change in land use toward carmine production should be considered in environments that are severely degraded, and carbon credits should be given to farmers with invaded areas.

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CHAPTER 3

ASSOCIATION OF INVASIVE CREEPING PRICKLY PEAR WITH FORAGE GRASSES AND SHRUBS IN A SEMI-ARID RANGELAND OF SOUTH AFRICA

Abstract

Displacement of palatable forages affects nutrient supply to herbivores, reducing livestock turnover in marginal areas. Anthropogenic factors such as overgrazing and cropping and climate change are major drivers of vegetation change. The objective of the study was to characterize forage species composition and abundance in rangeland invaded by *Opuntia humifusa*. The study area shows that, creeping cactus invaded about 18.2% and 60.1% of the cattle and sheep heavily invaded grazing areas, respectively. The affected rangeland had distinct zones of new invasion (NI) < 3 colonies, heavily invaded zone (HI >30 colonies), and transitional zone (5 - 20 colonies TI). The intercept method was used to determine the *Opuntia humifusa* density. Cattle grazing area; NI (7.7%), TI (12.2%) and HI (60.1%) and in the sheep grazing area; NI (0.8%), TI (5.5%) and HI (18.2%). Species composition and distribution were determined using the line transect and point survey methods. Twenty-nine plant species were recorded, 11 families were unpalatable species; and 15 woody species were identified. Unpalatable shrubs (*Penzia calcarea* and *Zygophyllum incrustatum*), disturbance indicator grasses (*Aristida congesta, Chloris virgata* and *Cynodon*), and intermediate species (*Eragrostis chloromelas and Heteropogon contortus*) were dominant. Disturbance indicator grasses constituted 86%, intermediate grasses 10%, and dwarf shrubs 4%. Only three palatable grasses were noted - *Themeda triandra*, *Stipagrostis uniplumis* and *Schmiditia pappophoroides*. There were no palatable grasses in Cattle HI. Sheep HI zone had 15 palatable plants/m^2 relative to NI (223 plants/m^2) and TI (123 plants/m^2). Percentage rangeland condition and grazing capacities for NI, TI and HI zones were determined using Dankwerts grazing model procedure. The % rangeland condition and grazing capacity (GC) in both cattle and sheep grazing areas were lowest in HI zones, with a GC of 11-13 ha/lsu compared to 6.8 ha/lsu in NI and TI zones in both cattle and sheep areas. Vegetation composition was typical of the western Upper Nama Karoo, except for the high *Opuntia* density. Invasion by *Opuntia*

affected rangeland species composition, which may influence nutrition and offtake of ruminant livestock and game from the South Western rangeland of South Africa.

3.1 Introduction

The Karoo vegetation of the western Free State province supported large herds of ruminant livestock during the last century. However, the increase in bare areas associated with herbaceous vegetation loss and scant cover by dwarf shrubs is evidence of a decline in biomass production. Rainfall in the Karoo is low and seasonal (Desmet and Cowling, 1999) which reduces the diversity of plant species. Grasses, such as *Aristida spp.*, *Eragrostis spp.* and *Heteropogon contortus*, as well as indigenous shrubs such as *Pentzia*, *Eriocephalus* spp., *Felicia muricata*, *Thysium hystrix*, *Pteronia* spp. and *Walafrida* spp., dominate the landscape. Opportunistic weeds, such as creeping wild cactus, are also colonising the rangelands, *and Opuntia humifusa* is the most common creeping invader in the Karoo. Eleven invasive species including the prickly pears (*Opuntia ficus-indica*), *O. stricta, O. aurantiaca, O. monacantha, O. lindheimeri, O. humifusa, O. engelmannii* and *Cylindropuntia, O. fulgida, Cylindropuntia imbricata, Cylindropuntia leptocaulus* and *Cylindropuntia tunicate* occur in South Africa (Zimmermann, 2010). *Opuntia ficus indica* (L). Mill has invaded vast tracts of Karoo (Henderson, 2015). Novoa, Le Roux, Robertson, Wilson and Richardson (2014) stated that South Africa has the highest levels of alien species invasion, including *O. humifusa*. At the time of their research (2010), about 10 million hectares was invaded by 180 alien species. The species aggressively colonize rangelands due to its morphological characteristics (Reynolds & Arias, 2001; Masters and Sheley, 2001), affecting water balances (Novoa *et al.*, 2015). Ruminants avoid the creeping cactus because of its spines that cause gut injuries (Van Wilgen, Richardson, Le Maitre, Marais and Magadlela, 2001).

Opuntia humifusa is a single species without variety. It multiplies vegetatively and also by means of seed; grows in clumps, up to 10 cm in height (Abella and Jaeger, 2004); and reaches maturity at 6 to 10 years (COSEWIC, 2010). The shallow-spreading root systems, water-repelling and sun-reflecting epidermis increase water utilization efficiency (Szarek and Ting, 1974; Potter, Pettersen and Ueckert, 1984). The spread of *Opuntia* *humifusa* in the Nama Karoo biome with its western Upper Karoo vegetation type will reduce ecosystem services, as plant species' diversity will decline and subsequently affect animal and wildlife production. Climate change, alien species and overgrazing therefore pose serious challenges to ruminant livestock production from the semi-arid rangelands.

This study assessed the composition and abundance of native forage grasses and shrubs, and the relationship with *O. humifusa* in degraded semi-arid rangelands utilized for sheep and beef cattle production.

3.2 Materials and methods

3.2.1 Study site

The study was done on a commercial farm in the western Free State region, within a transition zone of the Nama Karoo biome to the west (the Koffiefontein region), the eastern savanna grassland and northern grasslands (latitude and longitude: 29^{0}16ʾ59''S; 24^{0}59'1''E). The area is lime rich, with effective soil depth of 450 mm (O'Connor and Roux, 1995). The region receives summer rainfall and flash floods of 100 mm to 450 mm, with maximum temperatures of 40^{0} C and minimum temperatures of – 5^{0} C. Over the past 16 years, the region experienced frequent droughts. The carrying capacity of the Koppieskraal farm within Koffiefontein rangeland was 15 ha/LSU (large stock unit), which is higher than the level recommended for the Nama Karoo (17 ha/LSU) (Du Toit, 2010).

3.2.2 Cattle grazing camp*: Species composition and abundance*

The total cattle grazing zone was 6,500 ha at Koppieskraal farm (latitude and longitude: 29^{0}16ʾ59''S; 24^{0}59'1''E) and under rotational grazing for at least three years at a stocking rate of 15 ha/LSU. About 446 ha of the cattle zone invaded by *O. humifusa* was selected. The southwestern zone had older and larger colonies, the eastern part newer colonies; and the central portion - defined as the transition zone - had mixtures of small colonies to the east, and large colonies that were sparsely distributed. The area was stratified based on *O. humifusa* occurrence as new invasions (NI), transition (TI) and heavy invasion (HI) zones. Transects and point survey methods were used for assessment of species abundance and species composition (Du Toit, 2010) within each stratum. Four plots of 25 m x 25 m were randomly selected in one grazing camp and marked per zone (NI, TI and HI). In each plot, four (25 m long) transects were marked, totaling 12 transects per zone. Species abundance was determined by marking quadrats (1 m^2) every five meters along each transect (Du Toit, Van den Berg and O' Connor, 2015). A total of 80 quadrats/zones were surveyed for species abundance. For species' composition, assessment was done every 1 m, using the point survey method (Du Toit *et al.*, 2015) along a transect. One hundred points were surveyed/plotted, and a total of 1 200 points in the cattle area.

3.2.2.1 Determination of O. humifusa density

An intercept method was used to determine proportion cover in experimental plots. A transect of fixed length of 25 m was laid out in a 25m x 25m plot. The length of creeping prickly pear in contact with the line was measured and totaled. Total cover and total length. % cover = Total cover/Total length x 100

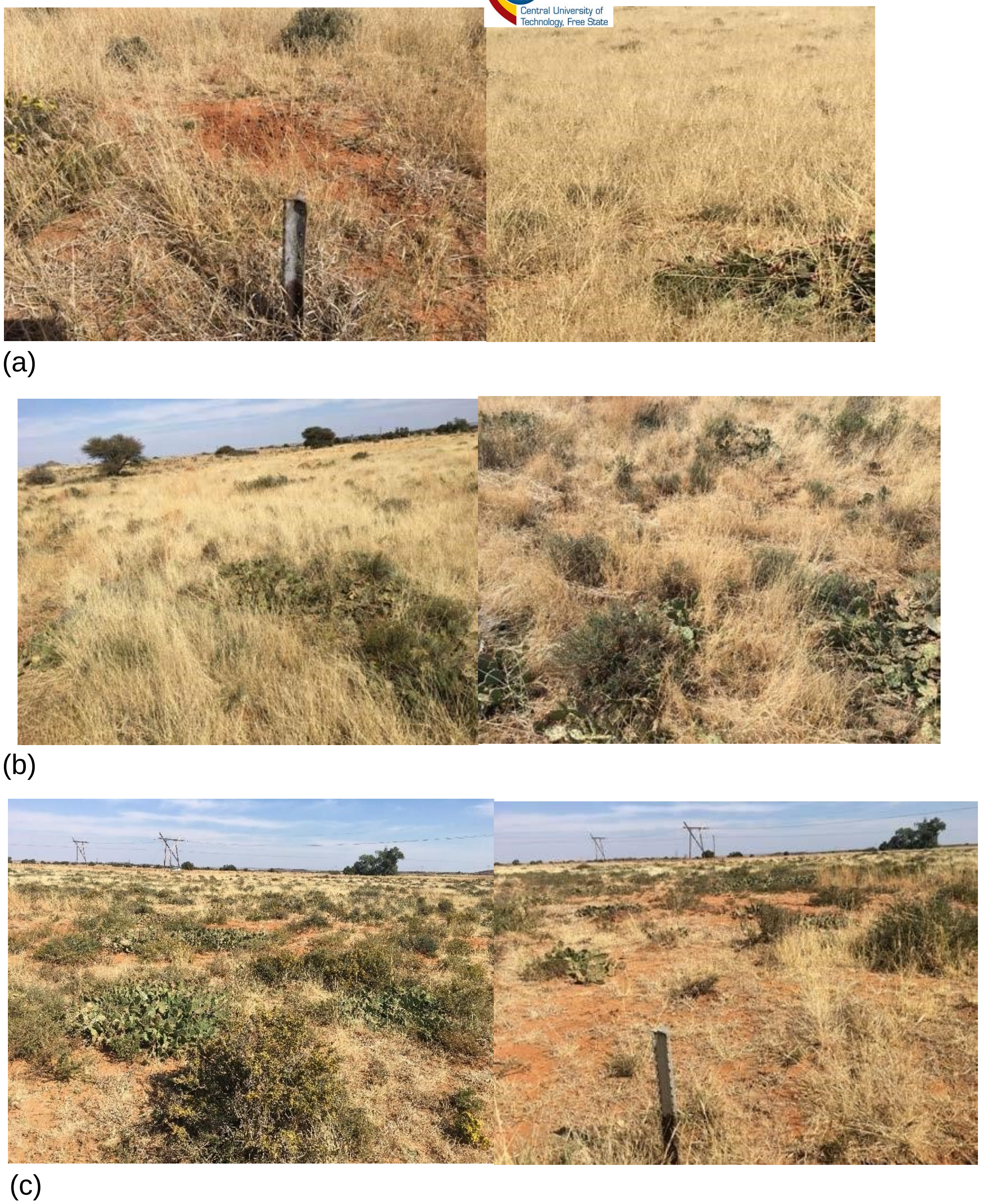

Figure 3.1 The photos of (a) newly invaded (NI), (b) transitional zone (TI) and (c) heavily invaded (HI) plots as defined in this chapter.

3.2.2.2 Cattle grazing area

Table 3.1 % cover determination of *O. humifusa* density in cattle grazed area

Cactus plant	**Length/mm**		
	NI	**TI**	**HI**
1	0	5110	12300
2	0	3320	12720
3	6070	2840	12200
4	1650	900	22915
Mean cover per plot ± SD	1930 ± 2867.5	3042.5 ± 1730.4	15033.8 ± 5258.9
Total length	25000	25000	25000
% cover	**7.7**	**12.2**	**60.1**

3.2.3 Sheep grazing land

The total sheep grazing area was 1 400 ha at Koppieskraal farm (latitude 29^{0}17'9''S and longitude 24^{0}58'17''E), which had been under rotational grazing for at least three years. Koppieskraal is 8140 ha in size. A zone of about 192 ha invaded by *O. humifusa* was selected. Spatial distribution of *Opuntia humifusa* was similar to the cattle area, with a southwest-easterly direction. The recommended carrying capacity of the rangeland is 13 ha/LSU (Department of Agriculture, Free State province (2013).

The line transects and point survey methods were used for determination of species abundance and species composition (Du Toit, 2010). The 192 ha grazing area was also stratified into three zones, based on *O. humifusa* occurrence: new invasions (NI), transition (TI) and heavy invasion (HI). Three plots measuring 25 m x 25 m were randomly selected in each zone in one grazing camp. The grazing camp was selected because of its distinct levels of *O. humifusa* invasion and spread. In each plot, four (25 m long) transects were marked, totaling 12 transects/zone. Species abundance was determined by marking quadrats (1 m^2) every five meters along each transect, as described by Du Toit *et al.* (2015).

A total of 60 quadrats/zone were surveyed. Plant species composition assessment was done using the point survey method of Du Toit (2002). Assessments were done every 1 m along the transect lines. One hundred points were surveyed per plot, and a total of 900 points in the sheep area. All plant surveys were conducted at the end of the growing season, in the month of March, as recommended by Du Toit (2002). Grasses and shrubs were identified in the field as described by Fouche, Van der Westhuizen and Avenant (2014), and Le Roux, Kote and Nel (1994).

Table 3.2 % cover determination of *O. humifusa* density in sheep grazed area

Cactus plant	**Length/mm**		
	NI	TI	HI
1	0	0	640
2	150	3190	8210
3	50	1050	4770
Mean cover per plot ± SD	67 ± 76.4	1413 ± 1625.8	4540 ± 3790.3
Total length/mm	25000	25000	25000
% cover	**0.8**	**5.7**	**18.2**

3.2.4 Control plots

Two camps were selected as control area. The camps were adjacent to the cattle and sheep grazing areas. There were not activities in this camps for the past 5 years and were selected for comparison sacks. One camp was not invaded and the other camp invaded with *O. humifusa*. Three plots measuring 25 m x 25 m were randomly selected in each area. In each plot, four (25 m long) transects were marked, totaling 12 transects. Species abundance was determined by marking quadrats (1 m^2) every 5m along each transect, as described by Du Toit *et al.* (2015). A total of 60 quadrats/zone were surveyed. Plant species composition assessment was done using the point survey method of Du Toit (2002). Assessments were done every 1 m along the transect lines. One hundred points were surveyed per plot, and a total of 900 points in the sheep area. All plant surveys were conducted at the end of the growing season, in the month of March, as recommended by Du Toit (2002).

3.2.3.1 Determination of % rangeland condition and grazing capacity

The determination of % rangeland condition and grazing capacity in the western Free State was estimated using a grazing capacity model by Dankwerts (1982);

Frequency = No of plants/ total count x 100

EIV Factor = frequency x grass species index

The indices values used to calculate EIV were adapted from van der Westhuizen et al. (2001) & Du Toit, (2000).

3.2.3.1.1 Veld condition score (vcs)(X1)

EIV/1000*100

3.2.3.1.2 Carrying capacity of site

Carrying capacity of the selected site was calculated using the Danckwerts model, using the following formula.

GC = {(-0.03) + (0.00289) (X1)} + {(X2- 419.7) (0.000633) GC

= Grazing capacity in large animal unit per hectare.

X1 = Veld condition index as a percentage of a benchmark site's veld condition score.

X2 = Mean annual rainfall in mm.

3.2.4 Categories of grasses and shrubs species

Identified plants were classified by functional group as: palatable grasses, (PG) intermediate grasses (IG), disturbance indicator grasses (DI), palatable shrubs (PS) and unpalatable shrubs (UPS), as described by Le Roux *et al.* (1994). The plant species were identified by the parts of the grass plant and type of inflorescence.

3.3 Data analysis

Species composition (percentage frequency) and abundance (percentage cover) were analyzed using descriptive statistics in Minitab (2015). Differences in species composition and abundance were determined using analysis of variance (ANOVA) procedures for a complete randomized block design. Fisher's Least Squares Differences (LSD) procedure was used for mean separation, and a significant difference was declared at $p < 0.05$. Partial correlation analysis was done to test the relationship of *O. humifusa* occurrence and forage species frequency and percentage cover.

3.4 Results and Discussion

Tables 3.3, 3.4, 3.5, 3.7, 3.8, 3.9 and 3.10 contain the most common shrub and grass species in the western Free State rangeland grazed by sheep and cattle herds. Only three palatable grasses (*Themeda triandra*, *Stipagrostis uniplumis* and *Schmidtia pappophoroides*) had higher occurrence. *T. triandra* and *Stipagrostis uniplumis* were present in the sheep area, whilst *T. triandra* and *Schmidtia pappophoroides* occurred in the cattle camp. *Stipagrostis uniplumis* is considered a feed bank during droughts, and contributes up to 80% of forage intake (Fouche *et al.*, 2014), and this resonates with the findings from this research. Unpalatable shrubs *(P. calcarea*, *Euryops asparagoides* and *Zygophyllum incrustatum)*, disturbance indicator grasses (*Aristida*, *Chloris virgata* and *Cyanodon)* and intermediate species (*Eragrostis* and *Heteropogon)* dominated. Palatable shrubs such as *Walafrida geniculata* and *Felicia muricata* were also common, characteristic of arid areas where dwarf shrubs (chaemaphytes) and grasses (hemicryptophytes) dominate rangelands. Shrubs such as *Drosanthemum*, *Eriocephalus*, *Galenia*, *Pentzia*, Pteronia, and *Ruschia* were also abundant. Perennial grasses including *Aristida*, *Digitaria*, *Enneapogon*, and *Stipagrostis* spp. were common, and are indicators of rangeland degradation. Tables 3.6 and 3.11 show the % rangeland condition and carrying capacities as influenced by the frequency of different grass and shrub species in different invaded zones.

3.4.1 Species composition and abundance in cattle grazing areas

Figures 3.1 and 3.2, and Table 3.7 show the variations in grass and shrub composition and abundance in the cattle area. The NI resembled the typical western Upper Karoo vegetation type, where DI grasses constituted 86%, intermediate grasses 10%, and shrubs 4% of the landscape. Disturbance indicator grasses - mainly *A. adscensionis* and *A. congesta* - (Table 3.3) occurred mainly in NI with a frequency of 51%. The dominance of disturbance indicator grasses in NI suggests that poor grazing management, climate factors and increased competition for resources resulting from new cactus invasions were affecting vegetation characteristics. *Aristida congesta* (white stick grass) is very low in nutritive value, and only grazed when immature. Unpalatable shrubs were abundant in cattle HI ($p < 0.001$), with *P. calcarea* dominating with an area cover of 60%. The presence of *P. calcarea* is also an indicator of land disturbance and degradation (Le Roux *et al.*, 1994). Fouche *et al.* (2014) reported that dominance of poor quality annual grasses is a sign of deterioration in veld condition. Intermediate grasses (mainly *Eragrostis* species) were mostly abundant in TI, with 59% cover plants/plot, compared to 9% and 24% covering NI and HI, respectively. *Eragrostis* spp. are of moderate palatability and mainly sub-climax grasses, which could be an indicator that the TI in the cattle area was still in a fair condition.

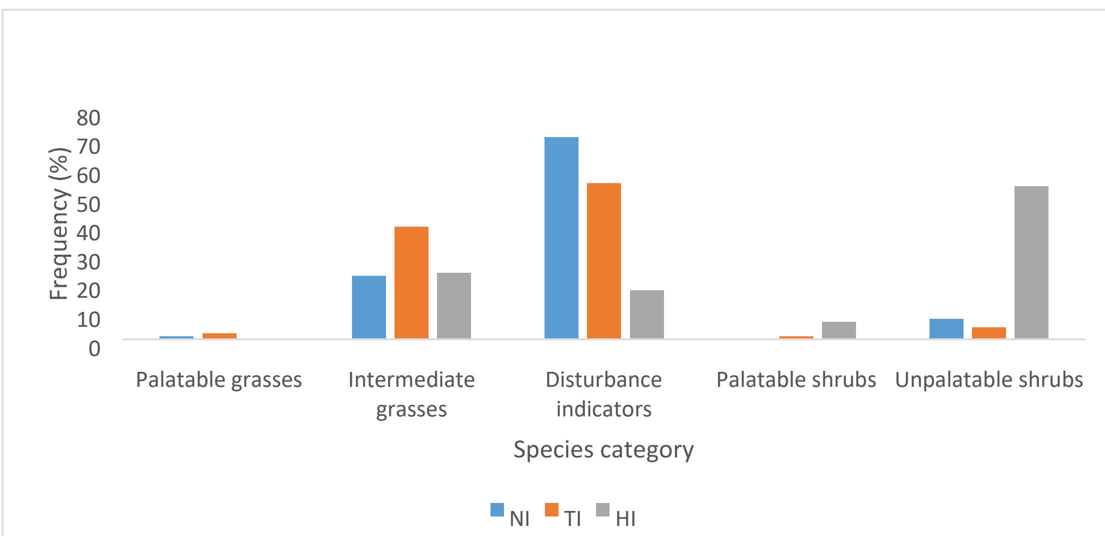

Figure 3.2 Grass and shrub species composition in *O. humifusa* invaded semi-arid rangeland grazed by cattle.

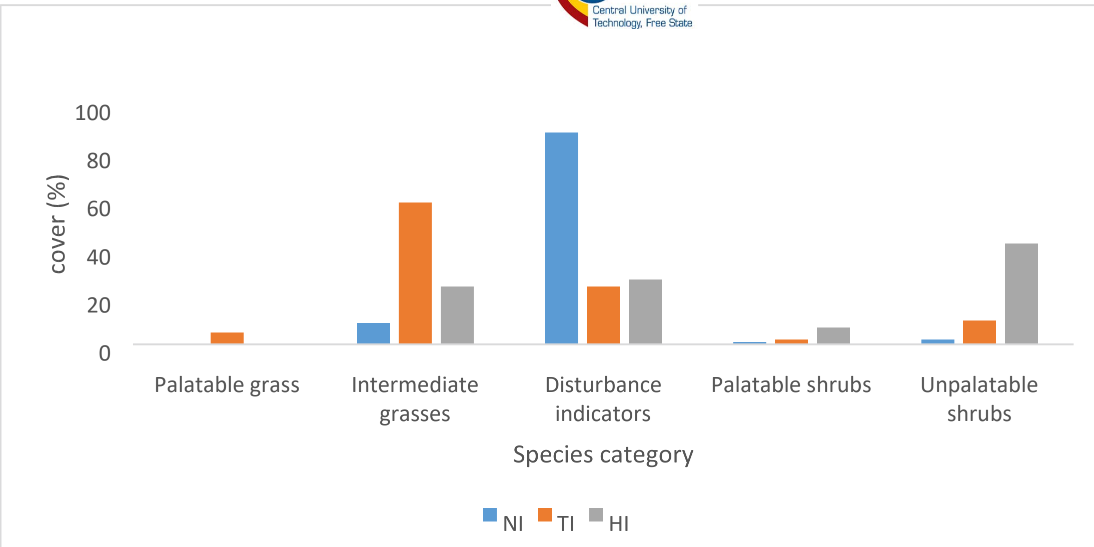

Figure 3.3 Grass and shrubs abundance in *O. humifusa* invaded semi-arid rangeland grazed by cattle.

Table 3.3 Species list in the *O. humifusa* newly invaded (NI) cattle grazing area for 2015 season

Species (NI zone)	Species count	Frequency (%)	Index*	EIV** factor
Aristida adscensionis	183	51.7	8	413.6
Aristida congesta	3	0.8	9	7.2
Aristida stipitata	1	0.3	7	2.1
Chloris virgata	51	14.4	4	57.6
Chrysocoma ciliata	1	0.3	3	0.9
Cynodon hirsutus	2	0.6	3	1.8
Eragrostis chloromelas	24	6.8	4	27.2
Eragrostis obtusa	32	9	7	63
Eragrostis trichophora	18	5	5	25.5
Heteropogon contortus	1	0.3	6	1.8
Pentzia calcarea	28	7.9	3	23.7
Pentzia globosa	2	0.6	4	2.4
Pteronia tricephala	1	0.3	1	1.2
Themeda triandra	5	1.4	10	14
Thesium hystrix	1	0.3	1	0.3
Walafrida saxitilies	1	0.3	1	0.3
	354	**100**		**642.6**

*Adapted from van der Westhuizen et al. (2001) & Du Toit, (2000). **EIV – Ecological Index Value

Table 3.4 Species list in the *O. humifusa* Transitional zone (TI) cattle grazing area for 2015 season

Species (TI zone)	**species count**	**frequency (%)**	**index**	**EIV** factor**
Aristida adscensionis	27	8.5	8	68
Aristida congesta	12	3.8	9	34.2
Aristida stipitata	3	1	7	7
Cynodon dactylon	14	4.4	4	17.6
Eragrostis chloromelas	37	11.7	4	46.8
Eragrostis lehmanniana	12	3.8	10	38
Eragrostis obtusa	20	6.3	7	44.1
Eragrostis superba	10	3.2	4	12.8
Eragrostis trichophora	76	24.1	6	144.6
Felicia muricata	2	0.6	8	4.8
Gnidia tricephala	2	0.6	6	3.6
Schmiditia pappophoroides	6	1.9	10	19
Themeda triandra	6	1.9	10	19
Thesium hystrix	6	1.9	1	1.9
Walafrida geniculata	5	1.6	8	12.8
Heteropogon contortus	64	20.3	6	121.8
Pentzia calcarea	2	0.6	3	1.8
Pentzia globosa	5	1.6	4	6.4
Pteronia tricephala	7	2.2	1	2.2
	316	**100**		**606.4**

**EIV – Ecologica Value Index

Table 3.5 Species list in the O. humifusa Heavily invaded (HI) cattle grazing area for 2015 season

Species (HI zone)	Species count	Frequency (%)	Ecological Index value	EIV** factor
Aristida adscensionis	27	8.6	8	68.8
Aristida congesta	6	2	9	18
Aristida stipitata	5	1.6	7	11.2
Asparagus spp.	3	1	1	1
Chloris virgata	2	0.6	4	2.4
Chrysocoma ciliata	5	1.6	3	4.8
Cynodon dactylon	14	4	4	16
Cynodon hirsutus	1	0.3	3	0.9
Eragrostis chloromelas	4	1.3	4	5.2
Eragrostis lehmanniana	1	0.3	10	3
Eragrostis obtusa	14	4	7	28
Eragrostis superba	13	4.1	4	16.4
Eragrostis trichophora	22	7.1	4	28.4
Euryops asparagoides	25	8.1	1	8.1
Felicia muricata	5	1.6	8	12.8
Heteropogon contortus	18	5.7	6	34.2
Lycium spp	8	2.5	6	15
Pentzia calcarea	29	9.2	3	27.6
Pentzia globosa	69	22	4	88
Pteronia tricephala	1	0.3	1	0.3
Thesium hystrix	13	4.1	1	4.1
Walafrida geniculata	15	5	8	40
Zygophyllum incrustatum	15	5	1	5
	315	**100**		**439.2**

**EIV – Ecological Value Index

Table 3.6 Rangeland condition (%) and grazing capacity (ha/LSU) of O. humifusa invaded rangeland zones grazed by cattle

Cattle area						
Year	2015		2016		2017	
	VCS	GC	VCS	GC	VCS %	GC
NI	64.3	6.8	64.2	6.8	57.9	7.7
TI	60.6	7	59.3	7.5	61.6	7.1
HI	43.9	11	38.8	13.5	43.5	11.2

VCS – veld condition score; GC – grazing capacity

Table 3.7 Plant species composition (species/m^2) and abundance (plants/m^2) in cattle grazing area

	Palatable grasses	Intermediate indicators	Disturbance shrubs	Palatable grasses	Unpalatable shrubs
			Species composition Mean ± std		
NI	5^{b}±1.9	18^{b}±10.7	60^{a}±7.4	0$_{c}$	9^{b}±6.0
TI	12^{a}±3.5	53^{a}±5.9	13^{b}±2.6	7^{b}±2.8	11^{b}±3.8
HI	0$_{c}$	24^{b}±16.4	18^{b}±12.7	10^{a}±4.7	45^{a}±17.8
			Species count		
NI	8^{b}±3.4	121^{b}±54.4	963^{a}±729.5	17^{b}±4.7	31^{c}±5.3
TI	90^{a}±31.1	269^{a}±84.7	111^{b} ±61.1	14^{b}±6.6	45^{b}±13.4
HI	0^{c}	88^{c}±51.3	112^{b}±99.6	27^{a}±7.1	158^{a}±35.1

3.4.1.1 Trend analysis – cattle area

NI: There was a 1,3% increase in the palatable species' abundance in the NI zone (cattle), from 2016 to 2017. Yearly trends in the NI zone were still dominated by disturbance indicator species, with a significant decrease from 2016 (93,3%) to 2017 (77,8%). There was no change in unpalatable shrubs in the three-year period.

HI: In three successive years there were no records of palatable grass species in heavily invaded zones (HI_cattle). There was a decrease in both palatable and unpalatable shrubs. This could have been due to change in foraging behavior of cattle shifting more to browsing due to the drought. The unpalatable shrubs were depleted from 41,3% to 10% in 2017 and the palatable shrubs from 6.8% to 1%. The disturbance indicator species sharply increased in the HI zone. Grass species dominated HI zone, mainly *Aristida adscenionis*, *Aristida congesta* and *Chloris virgata*.

TI: In the transitional (TI) zone, intermediate grasses were significantly depleted from >50% in 2015 to < 35% in 2017. Contrary to the intermediate trend, the disturbance indicators significantly increased with 100% from 2015 to 2017. The unpalatable shrubs decreased from 10% to 4,6% in 2017 (Figure 3.8), this could be due to increase in grazing pressure and drought induced mortality on shrubs.

The % rangeland condition and the grazing capacity in the cattle grazed area significantly declined in HI zones from 2015 to 2017 (Table 3.6). In the NI and TI zones similar % rangeland condition and grazing capacity values were determined from 2015 to 2017 (Table 3.6). Overall, the HI zones (yearly), had the lowest grazing capacity of 11 – 13 ha/lsu compared to 6.8 ha/lsu in NI and TI zones. This could have been due to % frequency increase of disturbance indicators such as *Aristida spp*, and unpalatable shrubs such as *Pentzia calcarea*. This also highlights the depletion of *T. triandra* in HI zones.

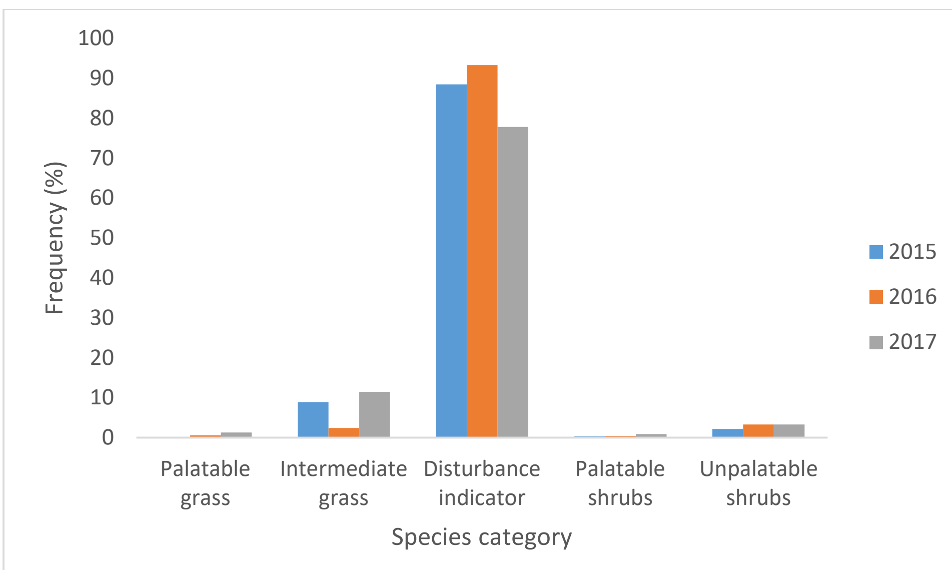

Figure 3.4 Yearly distribution of grass and shrub species classes in NI zone (Cattle area).

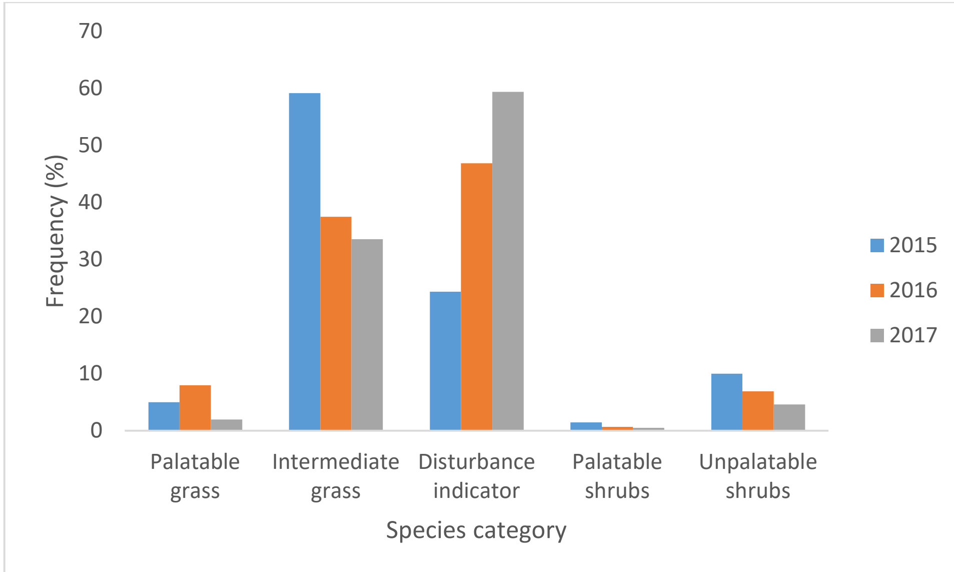

Figure 3.5 Yearly distribution of grass and shrub species classes in TI zone (Cattle area).

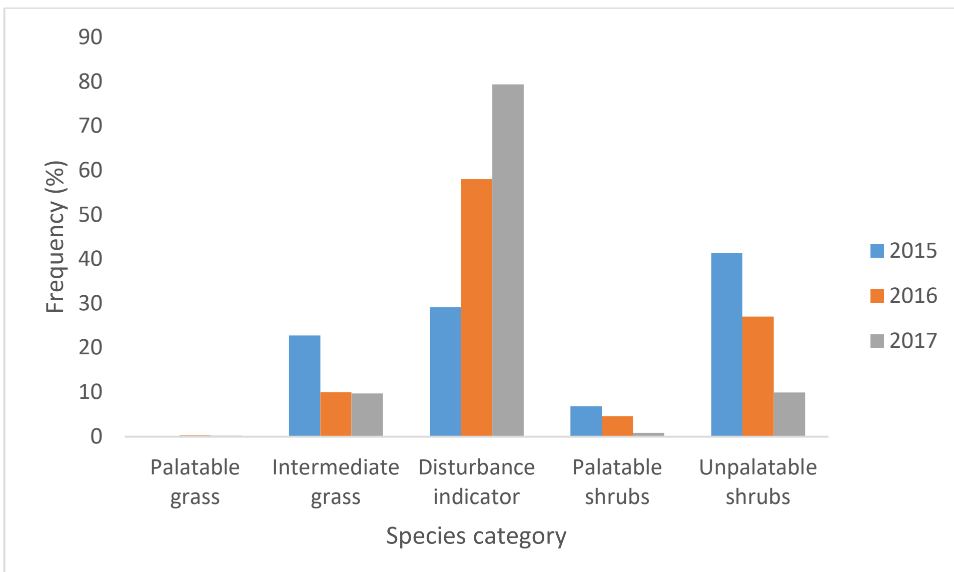

Figure 3.6 Yearly distribution of grass and shrub species classes in HI zone (Cattle area).

3.4.2 Species composition and abundance in sheep grazing areas

Figures 3.6 and 3.7, and Table 3.8, 3.9 and 3.10, show species distribution and species abundance relative to *O. humifusa* occurrence. Palatable grasses had the least density in

HI, relative to NI and TI (Figure 3.7). Unpalatable shrubs had the highest percentage cover in HI, and disturbance indicator grasses were dominant in all zones (Figures 3.6 and 3. 7). Palatable shrubs had the least occurrence (Figure 3.6), which could be related to sheep foraging habits. Fouche *et al.* (2014) reported that rangelands dominated by *Themeda triandra* have balanced ecosystem functions, as observed in the sheep NI. However, the highest occurrence of intermediate grasses was noted in NI, followed by TI (Figure 3.6). The low occurrence of palatable grasses and shrubs in TI and HI is characteristic of poorly managed grazing areas.

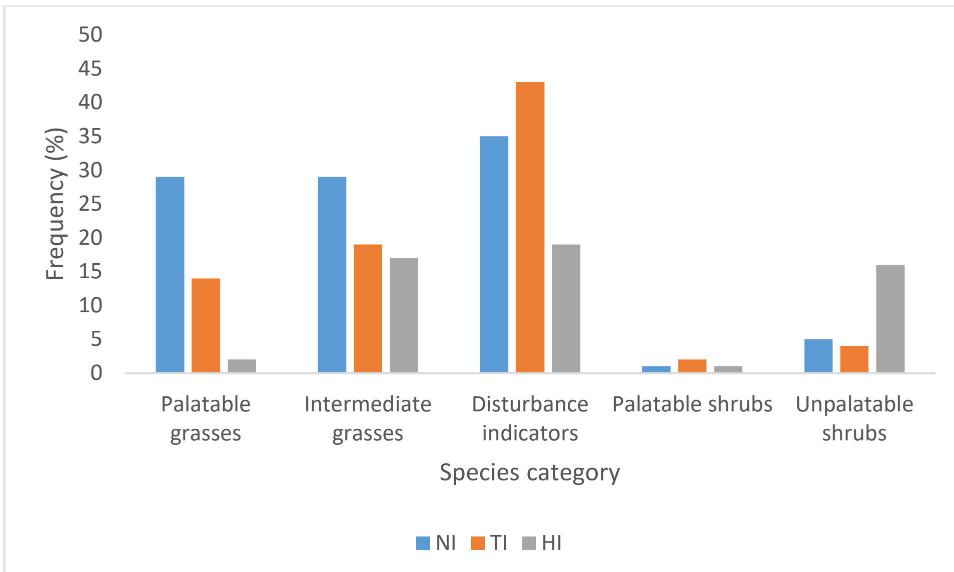

Figure 3.7 Grass and shrubs species composition in *O. humifusa* invaded semi-arid rangeland grazed by sheep.

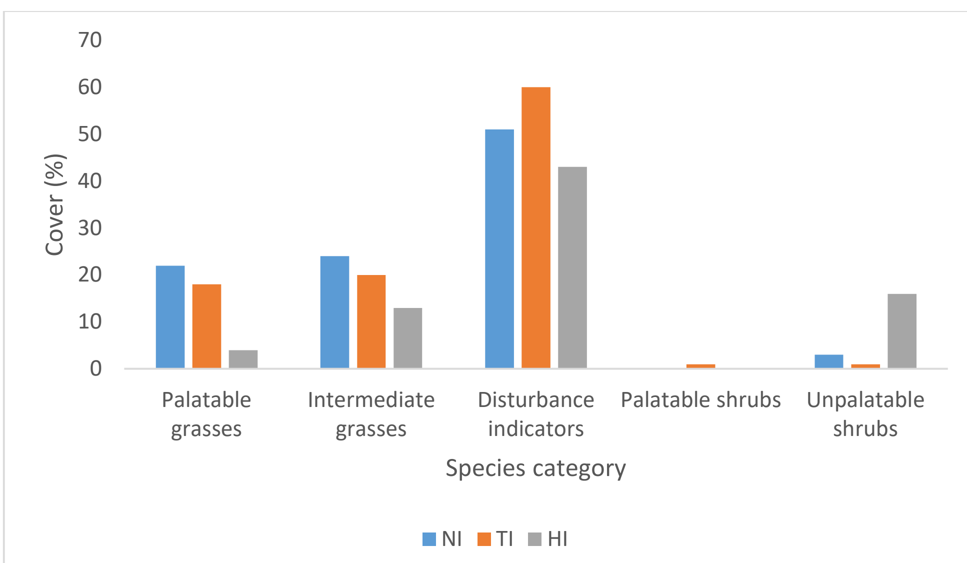

Figure 3.8 Grass and shrubs species abundance in *O. humifusa* invaded semi-arid rangeland grazed by sheep

Table 3.8 Species list in the *O. humifusa* newly invaded (NI) sheep grazing area for 2015 season

Species (Sheep NI zone)	Species count	Frequency (%)	Index	EIV factor
T. triandra	78	28	10	280
S. uniplumis	3	1.1	7	7.7
E. chloromelas	80	28.2	4	112.8
E. obtusa	1	0.4	7	2.8
E. superba	1	0.4	1	0.4
H. contortus	1	0.4	6	2.4
A. adscensionis	29	10	8	80
A. congesta	70	25	9	225
C. virgata	2	0.7	4	2.8
F. muricata	1	0.4	8	3.2
W. geniculata	1	0.4	8	3.2
P. calcarea	9	3	3	9
P. globosa	5	2	4	8
	281	**100**		**737.3**

Table 3.9 Species list in the *O. humifusa* transitional zone in sheep grazing area for 2015 season

Species (Sheep Species count TI zone)		Frequency	Index	EIV factor
T. triandra	43	16.6	10	166
E. chloromelas	59	23	8	184
E. obtusa	3	1	7	7
H. contortus	1	0.4	6	2.4
A. adscensionis	27	10.7	8	85.6
A. congesta	105	40.9	9	368.1
C. virgata	5	1.9	4	7.6
F. muricata	4	1.6	8	12.8
P. calcarea	7	2.7	3	8.1
P. globosa	2	0.8	4	3.2
Z. incrustum	1	0.4	0	0
	257	**100**		**844.8**

Table 3.10 Species list in the *O. humifusa* heavily invaded (HI) sheep grazing area for 2015 season

Species (Sheep HI zone)	Species count	Frequency (%)	Index	EIV factor
T. triandra	8	3.5	10	30
E. chloromelas	16	7	8	56
E. obtusa	5	2	7	14
H. contortus	21	9.2	6	54
A. adscensionis	70	30.7	8	23
A. congesta	30	13.3	9	108
C. virgata	1	0.4	4	1.6
F. muricata	3	1.3	8	8
P. calcarea	34	14.9	3	42
P. globosa	38	16.8	4	64
Z. incrustum	2	0.9	0	
	228	**100**		**400.6**

Table 3.11 Rangeland condition (%) and grazing capacity (ha/LSU) of *O. humifusa* invaded rangeland zones grazed by sheep

Sheep area						
Year	2015		2016		2017	
	VCS	GC	VCS	GC	VCS %	GC
NI	73.7	6.4	73.4	5.8	68.9	6.2
TI	84.5	5.3	83.3	4.9	71.2	5.9
HI	40.1	13.5	59.9	7.4	65.1	6.7

Disturbance indicators outnumbered other species. The NI zone had the highest abundance, followed by TI, and then HI (Figure 3.7). The survey results from NI are similar to those from control plots (Figures 3.8 and 3.9) A similar pattern was observed with PG and IG. Shrubs were less abundant relative to grasses. The abundance of disturbance indicators in the newly invaded areas (NI) could be attributed to disturbances due to overgrazing and droughts.

Table 3.12 Plant species composition (species/m^2) and abundance (plants/m^2) in sheep grazing area

O. humifusa density	Palatable grasses	Intermediate grasses	Disturbance indicator grasses	Palatable shrubs	Unpalatable shrubs
		Species composition (mean ± std)			
NI	$27^{a} \pm 19.3$	$28^{a} \pm 10.5$	$34^{b} \pm 15.0$	$1^{a} \pm 0.6$	$5^{b} \pm 2.7$
TI	$14^{b} \pm 17.6$	$24^{a} \pm 5.9$	$45^{a} \pm 7.0$	$2^{a} \pm 1.0$	$4^{b} \pm 1.0$
HI	$3^{c} \pm 3.8$	$14^{b} \pm 13.6$	$33^{b} \pm 10.0$	$1^{a} \pm 1.0$	$29^{a} \pm 1.0$
		Species abundances (mean ± std)			
NI	$223^{a} \pm 62.9$	$174^{a} \pm 29.8$	$389^{a} \pm 234.5$	$4^{a} \pm 4.7$	$20^{b} \pm 7.9$
TI	$123^{b} \pm 67.9$	$110^{b} \pm 47.6$	$329^{b} \pm 43.0$	$4^{a} \pm 2.1$	$12^{c} \pm 8.3$
HI	$15^{c} \pm 26.6$	$68^{c} \pm 28.1$	$180^{c} \pm 39.3$	$3^{a} \pm 2.7$	$59^{a} \pm 7.1$

std – standard deviation; means with different superscripts within the column are significantly different (LSD, $p < 0.05$).

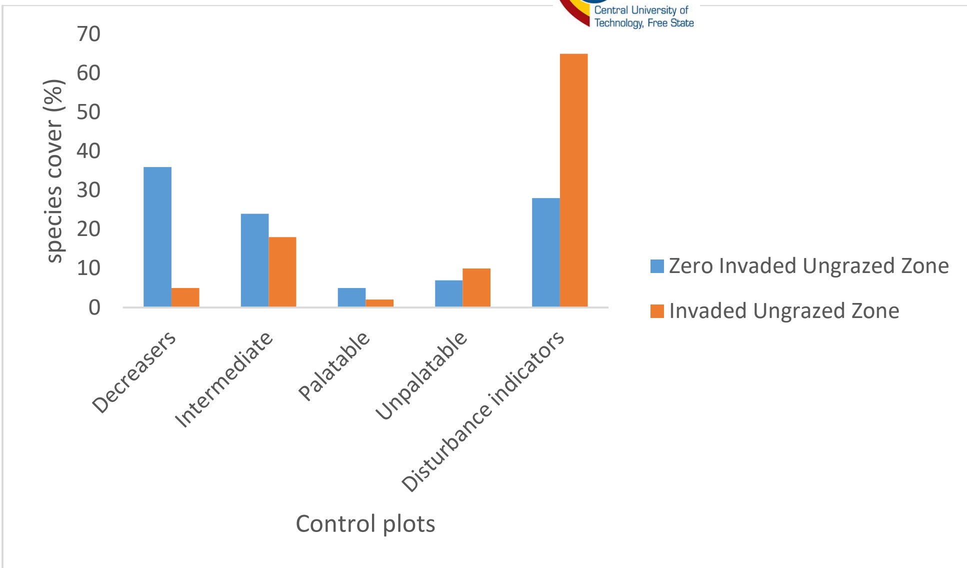

Figure 3.9 Species abundance in ungrazed zone (control plots)

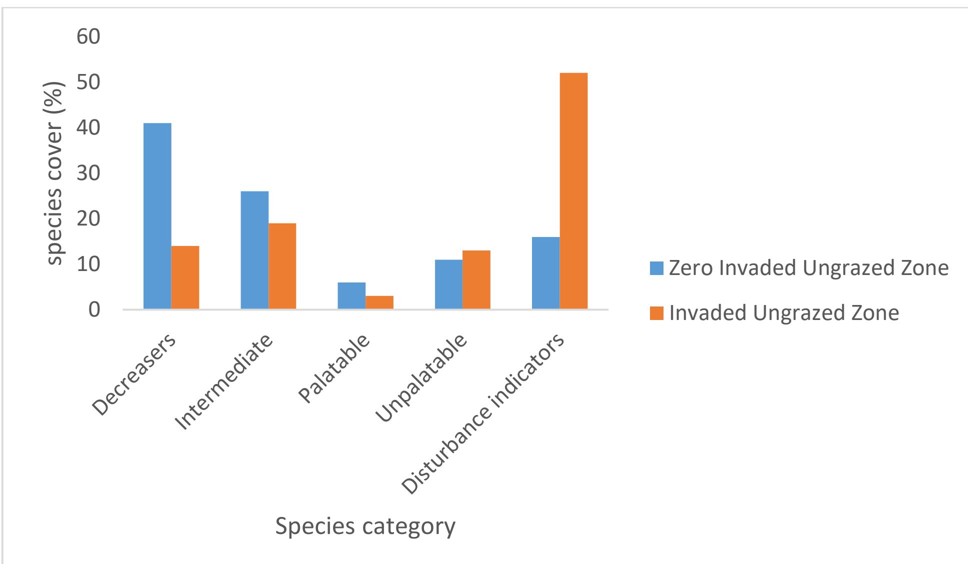

Figure 3.10 Species composition in ungrazed zone (control plots).

There was an inverse correlation between palatable grasses and *O. humifusa* density (sheep; r = - 0.75; P<0.05, Table 3.4; cattle: r = - 0.47; P >0.05, Table 3.13). Inverse correlations were also observed between *O. humifusa*, shrubs and disturbance indicators and palatable grass species, whilst correlations with intermediate grass species were positive. A strong positive correlation was noted between *O. humifusa* and palatable shrubs (r = 0.97; P < 0.001). *W. geniculat*a and *F. muricata* were the most abundant species. This could be as result of palatable shrubs being underutilized due to association with the creeper, the glochids on the creeper being the deterrence effect. The relationship of *O. humifusa* with unpalatable shrubs was also positive (sheep and cattle camp: r = 0.97). These species are unlikely to compete for resources due to their morphological difference, and *O. humifusa* also seem to prefer bare patches and not shaded areas.

Table 3.13 The correlation matrices between *O. humifusa* density and grass species

Block		***Opuntia humifusa***	**Palatable grasses**	**Intermediate grasses**
Sheep	Palatable grasses	-0.745*		
	Intermediate grasses	-0.727*	0.663	
	Disturbance indicators	-0.133	-0.367	-0.431
	Shrubs	0.973**	-0.724*	-0.659
Cattle	Palatable grasses	-0.468		
	Intermediate grasses	-0.651*	0.621*	
	Disturbance indicators	-0.452	-0.102	-0.274
	Shrubs	0.974**	-0.445	-0.635*

* $p < 0.05$; ** $p < 0.01$

3.4.2.1 Sheep trend analysis

NI: There was a depletion of palatable grasses in the NI zone, from 2015 to 2017. There was also a significant decline of intermediate grass species, while disturbance indicators significantly increased from 51% to 83% in three years. There were no records of palatable shrubs in the NI_sheep zone, with a yearly average abundance of 2% of unpalatable shrubs. *Walafrida geniculata* and *Felicia muricata* are most common palatable shrubs found in the area and due to records of overgrazing and droughts this may resulted in complete depletion. Most unpalatable shrubs are spiny with thorns that protects them from overutilization hence records of their presence. Disturbance indicators remains the most abundant species, they are positively correlated to increase in rain and can only be utilized when still young. Grass species such as *Aristida adscensionis* and *Aristida congesta* are sticky and thorny when old and this limits grazing and utilization.

TI: The palatable grasses declined from 18% (2015) to 4% (2017), with similar trends recorded for intermediate grasses. The decline in grass species could have been due to displacement by geographical spread of *Opuntia humifusa*, evidence of increase in yearly diameter of O. humifusa. The disturbance indicator increased from 60% in 2015 to 90% in 2016, with a 10% decline in 2017. No significant changes in shrub density occurred from 2015 to 2017.

HI: In the HI sheep area, palatable grass and shrubs species did not improve on a yearly basis. However, the unpalatable shrubs were depleted by 50% from 2015 to 2017. The disturbance indicator species remained high, averaging 80% in three years (Figure 3.12).

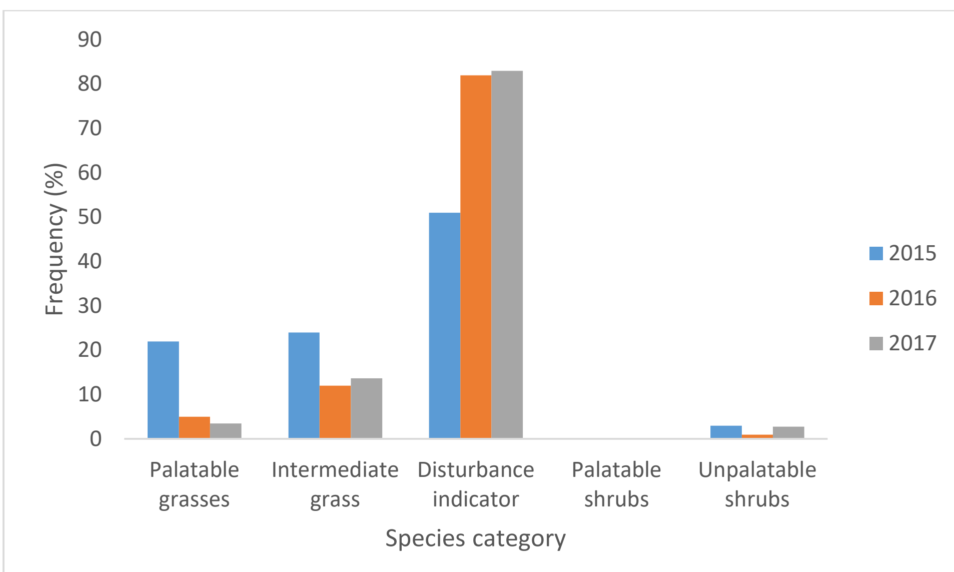

Figure 3.11 Yearly distribution of grass and shrub species classes in NI zone (sheep area).

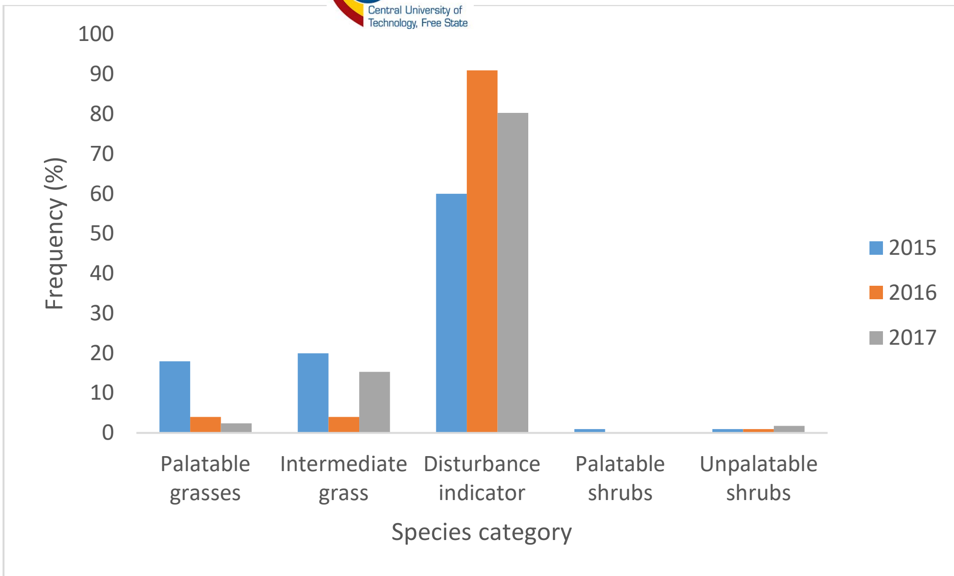

Figure 3.12 Yearly distribution of grass and shrub species classes in TI zone (sheep area).

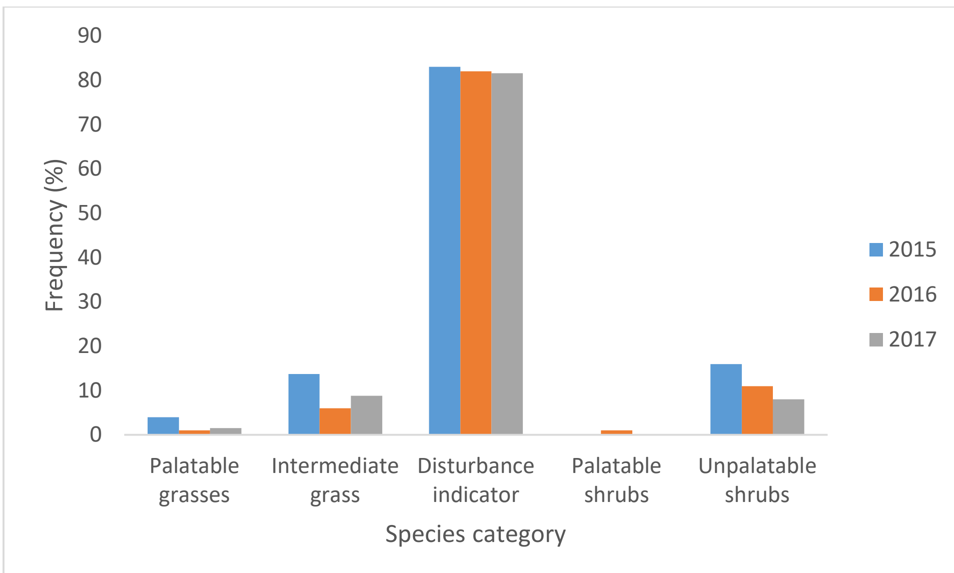

Figure 3.13 Yearly distribution of grass and shrub species in HI zone (sheep area).

Table 3.11 shows a decline in % rangeland condition and grazing capacity in NI and TI from 2015 to 2017. In the heavily invaded zones (HI) the % rangeland condition increased from 40.1% in 2015 to 65.1% in 2017. This could have been due to increased frequencies of *A. congesta* and *A. adscensionis* (Tables 3.8, 3.9 and 3.10) as the area received better rains during 2016/2017 rain season. Percentage of RC was better in TI through the seasons of research. Percentage of RC and GC tends to be depleted in the HI zones. In 2015 HI had the lowest GC of 13.5 ha/lsu compared to 3–6 ha/lsu in NI and TI zones. The decline in percentage of RC and GC in HI zones could be attributed to lost in *T. triandra* from 28% in NI and 16.6% TI to 3.5% in HI zones, concurrently unpalatable shrubs *P. globosa* and *P. calcarea* increased. *Pentzia globosa* increased from 3% in NI zones to 16.8% in HI zones, *P. calcarea* increased from 2% in NI zones to 14.9% in HI zones in 2015.

3.4.3 Species abundance in zones heavily invaded (HI) by *Opuntia humifusa*

Species composition in the HI zone (sheep area) reflected a better ecosystem function in terms of proportions of shrubs and grasses, whilst the presence of disturbance indicators points to retrogression. Vegetation characteristics were influenced by grazing behaviours: the cattle area had less herbaceous species and had an abundance of shrubs. According to Van Soest (1994) and FriT, De Garine-Wichatitsky and Letessier (1996), cattle are mostly grazers, and they will only browse to meet nutrient requirements, while sheep are intermediate feeders. The low composition of grasses and high occurrence of *O. humifusa* in the cattle area indicate that both invasive species and overgrazing have affected the carrying capacity of the rangeland. Novoa, Le Roux, Wilson and Richardson (2014), and Price, Heidschmidt, Dowhower and Frasure (1985) argued that cactus invasion devastated the productivity of rangelands, influencing grazing behaviour. Ueckert (1997) reported that *Opuntia* colonies reduce forage availability by 25%, which negatively impacts on nutrient intake and the performance of extensively managed ruminant livestock. However, the ability of cacti to conserve soil moisture is important, as it influences ecological moisture balance (Clapp, 1969). Ouendraogon-Kone and Kabore (2007) indicated that grazing behaviour is crucial when developing strategies for nutrient harvesting on fragile ecosystems such as the Karoo. Although Gitanjali and Marcos (2017) noted that shrubs were not a major driver of perennial grass change, inverse relationships were noted in this study. Restoration of the grass climax to support productivity of small ruminants is therefore crucial.

Lovegrove (1993) indicated that poor farming practices and invasive alien species, including cactaceae, are major causes of range degradation and biodiversity loss. The results in this study are similar to those of Todd (2006), Folke, Carpenter, Walker, Scheffer, Elmqvist and Gudnerson (2004) and Fuhlendorf, Briske and Simens (2001), who noted that palatable plant species of the Karoo were not resilient, which tended to shift rangelands to less desirable status. Todd (2006), Owen-Smith and Danckwerts (1997), Milchunas and Lauenroth (1993), and Milchunas, Sala and Lauenroth (1988) asserted that ecosystems of southern Africa are long-term habitats of indigenous herbivores. The ecosystems are therefore adapted to intensive grazing by ruminant livestock, and the vegetation is resilient to alien species' invasion and intensive utilisation. However, there is no certainty whether vegetation patterns noted in the western Free State region of Koffiefontein represent shortterm cycles of degradation and restoration of the original climax vegetation, or permanent shifts in the vegetation structure that would be followed by shifts in grazing strategies.

3.5 Conclusion

The Koffiefontein rangeland of the western Free State is degraded, as is indicated by the low proportion of palatable grasses, and a high density of creeping cactus in the cattle camp. Unpalatable shrubs and disturbance indicators dominate, and the creeping cactus pear has colonized bare areas. It is uncertain whether vegetation patterns in the Koffiefontein rangeland represent short-term cycles, or permanent retrogression. The later state is most likely. There is a need for long-term veld resting to rehabilitate the rangelands, and to determine their carrying capacity. Farmers with invaded rangeland should avoid overstocking and overutilization to avoid accelerated rate of spread and invasion of creeping prickly pear. There is also a need for surveillance to determine the rate of colonization of new areas by the invader species, and for rapid response in formulation of rehabilitation strategies and approaches to manage existing invasions effectively. It is also important to assess the positive contribution of invasive cactus plants in climate change adaptation and mitigation. Future research to determine the rate and direction of colonization by *O. humifusa* and other companion invader species and levels of carbon sequestration is envisaged. The effects of species displacement on rangeland nutrient supply and animal grazing behaviour should also be determined.

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CHAPTER 4

VARIATIONS IN SOIL CARBON POOLS, AND MICROBIAL POPULATIONS AND FORAGE VALUE UNDER DIFFERENT VEGETATION COVER TYPES IN A DEGRADED RANGELAND

Abstract

Degradation of natural rangelands affect ecosystem services in fragile environments. The creeping prickly pear (*Opuntia humifusa*) is invading the Nama Karoo Biome of western South Africa, and it is affecting herbaceous plant structures. Species mortality and loss of ephemerals, geophytes, C3 and C4 grasses, and chamaephytes, due to invasive creepers, have effects on soil fertility and net productivity of the rangeland. The aim of the study was to assess soil minerals, carbon pools, soil microbial populations, and relative forage value in a rangeland invaded by creeping prickly pear. A rangeland of 544 ha in the semi-arid region of western part of Free State province, with lime rich soils, was stratified based on herbaceous vegetation cover. Data was collected on the following study sites i) cactus cover (CC), ii) shrub cover (SC), iii) grass cover (GC), and bare area (BA). Six soil samples (0 – 30 cm deep) were randomly collected per plot for soil mineral analysis. Soils were analysed for organic matter, C, N, P, K, Ca, Mg and selected micro-minerals. For microbial analysis, the depth was 10 cm, and the soil was cleaned for vegetative materials. About 50% of rangeland was covered by large old colonies of *O. humifusa*. Herbage samples were collected for all species within each quadrat. Samples of palatable, intermediate grasses and palatable shrubs were pooled for every five consecutive quadrats, and sub-sampled for chemical analysis. Sampling was done for wet season. Leaf nitrogen, acid detergent fiber (ADF), neutral detergent fiber (NDF) and acid detergent lignin (ADL) in the forage samples were determined. Mean crude protein (CP) of grasses was, on average, 8% in summer, and *Themeda triandra* had 10% CP level. The shrubs averaged 9.6% CP levels and Salsola spp had 14% CP level in summer. Soil content of Mg, Ca and K under different vegetation cover types differed ($P<0.001$) creeping cactus having 439: 2479:339 mg/kg, for dwarf shrubs 424:2479:343 mg/kg and for grass 296:1787:171 mg/kg, respectively. Soil C ranged from 0.2% to 0.5%, and varied with vegetation cover. The soil organic matter was 0.3 – 0.7%, and this could have influenced the microbial population in the soil. Bare area had the lowest values of both

bacterial and fungal count. The SC and OC cover types were 30.6 and 28.4%, respectively, higher in bacterial count, compared to the bare area. Although *Opuntia* spp. seems to be the major challenge on rangelands, beneficial attributes include higher carbon sequestration, soil cover, and minerals that are critical in reducing the carbon footprint. This is the positive ecological contribution of *O. humifusa*, as soil carbon restoration periods are likely to be shortened.

4.1 Introduction

Rangeland degradation is widespread in South Africa, and affects plant species diversity and nutrient yield, allowing opportunistic species to invade and dominate. *Opuntia* spp. (prickly pear) is an aggressive invader in semi-arid regions of the western Free State, owing to its high metabolic efficiency for space, water and nutrient utilisation. As crassulacean acid metabolism (CAM) species dominate, nutrient deficiencies are exacerbated. Invasive species, mostly the creeping prickly pear (*O. humifusa*), adapted to harsh climate, is incrementally dominating, causing mortality of ephemerals, geophytes, C_3 and C_4 grasses, and chamaephytes, thereby changing vegetation structures. Unpalatable dwarf shrubs and large colonies of *Opuntia* are progressively dominating the landscape. A shift in species' composition alters carbon sequestration and nutrient supply. Although the South African National Biodiversity Institute (SANBI) monitors ecological and vegetation shifts of the South African biomes, components such as fluctuations in forage quality and carbon sequestration on rangelands colonized by succulents, are limited. Effects of invasive succulents on carbon stocks and soil organic matter accumulation should be recognised in view of low soil organic matter content, and the vulnerability of semi-arid areas to climate change reflected in fluctuating rainfall data. Increasing dominance by prickly pear, soil fertility and range productivity are affected. *Opuntia humifusa* is a single species without variety, and grows in clumps up to 10 cm in height (Abella and Jaeger, 2004). It propagates through vegetative means and seed, reaching maturity at six to eight years (Abella and Jaeger, 2004). The shallow root system and epidermis that repels water and reflects sunlight, increase water utilisation efficiency (Tegegne, 2001; Potter, Pettersen and Ueckert, 1984). In temperate climates, flowering occurs from May to July; however, in the warm Karoo climate flowering is year-round (Wunderlin, 1998). *Opuntia humifusa* may colonise the terrain through animal excretion and detached cladodes.

Exotic plant species impact below-ground processes by influencing resource availability through enhanced microbial activity, as a consequence of litter input. Soil microbial community is a major component of the below-ground ecosystem that influence exotic plant invasion by 1) making nutrients available through litter decomposition, and 2) exerting negative or positive plant-soil feedback (Ross et al.,1999). Low-resource environments are defined as those where productivity is severely limited by light, water or soil nutrient availability, e.g. semi-arid regions. The theory of limiting similarity (MacArthur and Lerins, 1967) predicts that invasive species will have different traits from native species and fill vacant niches (i.e. resource acquisition in the case of low-resource environments). Ultimately, the specific strategy or traits of successful invaders will depend on the type of frequency of resource limitation, disturbance limitation, disturbance regimes, propagule pressure, and a number of other factors.

In poorly managed rangelands, and during periods of drought when the rangeland reaches its nutritional bottleneck, *O. humifusa* becomes an alternative feed source. Crude protein of cactus is as high as 100 g/kg of DM (Tegegne, 2004). However, the plant has glochids on the stems that cause severe blisters inside the mouths of livestock, and on lacerate gut organs. Rangeland plant community distribution and species composition are known to be related to specific soil properties such as soil climate, texture, depth, structure, fertility and pH, salinity and toxic influences. These properties relate to spatial variability of vegetation responses, ranging from broad geographical distributions, to landscape influences, to specific site characteristics.

The availability of soil phosphorus is strongly influenced by environmental and plant physiological factors such as temperature, moisture, plant growth and root activity, and by organic matter accumulation from litter fall and rhizodeposition (Perrott, Sarathchandra and Waller, 1990; McGrath, Comerford and Duryea, 2000). Vegetation cover influences soil properties, biological and chemical processes (Ross, Tate, Scott and Felthman, 1999; Zeng, Hu, Chang and Fan, 2009). Changes in vegetation cover may alter soil P transformation by modifying the amount of plant P demand, litter quality and quantity, and the soil's physical, chemical and biological properties (Ross *et al.*, 1999; Chen, Condron and Sherlock, 2003; Chen, Condron and Xu, 2008). Alien plant invasion is one of the major forms of land cover change in the western Free State.

The soil organic pool influences soil nutrient quantity and quality. This is important for primary productivity of above-ground biomass in terrestrial ecosystems (Franzluebbers, Haney and Hons, 1999; Gregorich, Liang, Drury, Mackenzie and MacGill, 2000; Haney, Franzluebbers, Hons, Hossner and Zuberer, 2001). Therefore, quantifying microbial biomass is an important tool for understanding and predicting the long-term effects on shift in land use and vegetation cover profiling, and associated soil conditions (Sharma, Rai, Sharma and Sharma, 2004). It is postulated that soil carbon replenishment takes at least 100 years, and climate and microbial population influencing the environment regulate these processes (Sharma et al., 2004). It has been noted that there is a very low probability of recovery without intervention (Sigwela, 2004). In turn, the scale of degradation and the costs of restoration indicate that considerable financial investment will be required to restore the viability of the soil. The current level of atmospheric carbon dioxide exceeds levels not reached for the past four-hundred-and-twenty-thousand years. The level of carbon dioxide is highly correlated to land use change, and is worse in degraded lands.

4.2 Research objectives

The objective of the study was:

I. to assess rangeland carbon pools, microbial content and relative forage value in rangeland invaded and degraded by creeping prickly pear at Koppieskraal farm in the western Free State province.

4.3 Materials and methods

4.3.1 Study site

A rangeland at Koppieskraal farm (Figures 4.2 and 4.3) in Koffiefontein region, of 544 ha under continuous grazing by beef herds over 30 years was selected (29°16’59’’S; 24°59’1’’E). The annual rainfall of the area is 350 mm. The soil has an average clay percentage which ranges from 4 – 15%. The surface area was covered by creeping prickly pear (*O. humifusa*), shrubs and grass. The current grazing capacity GC is 17 ha/LSU, as indicated in Figure 4.1 (Free State Department of Agriculture, 2013). In 1980 the GC was 15 ha/LSU (Van der Westhuizen, 2012). *Opuntia humifusa* colonies dominate the landscape, with large colonies of 3-5 m in diameter in the southwestern rangeland (120 ha), and its density progressively declines to the north east.

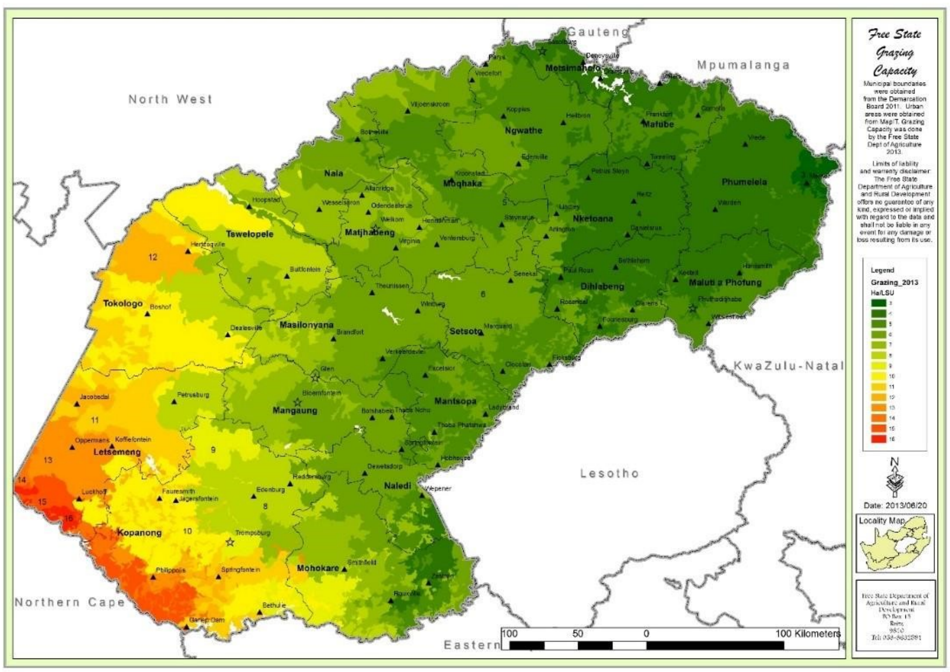

Figure 4.1 Grazing of Free State province rangelands in 2013. Source: Department of Agriculture, Free State Province.

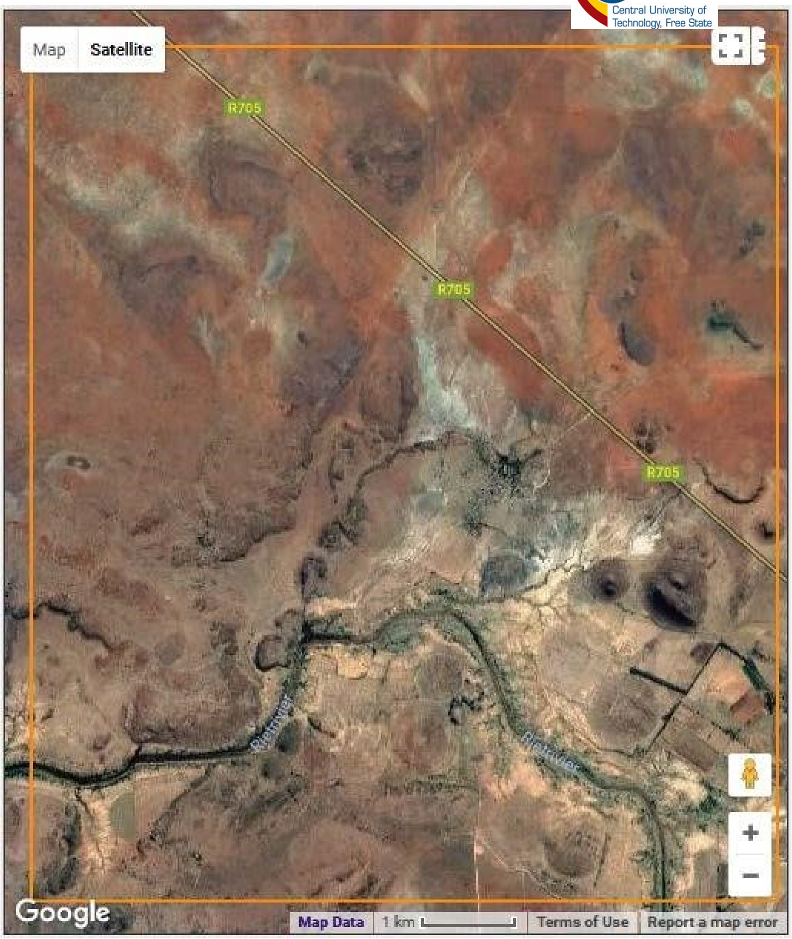

Figure 4.2 Google map of Koppieskraal farm (study site).

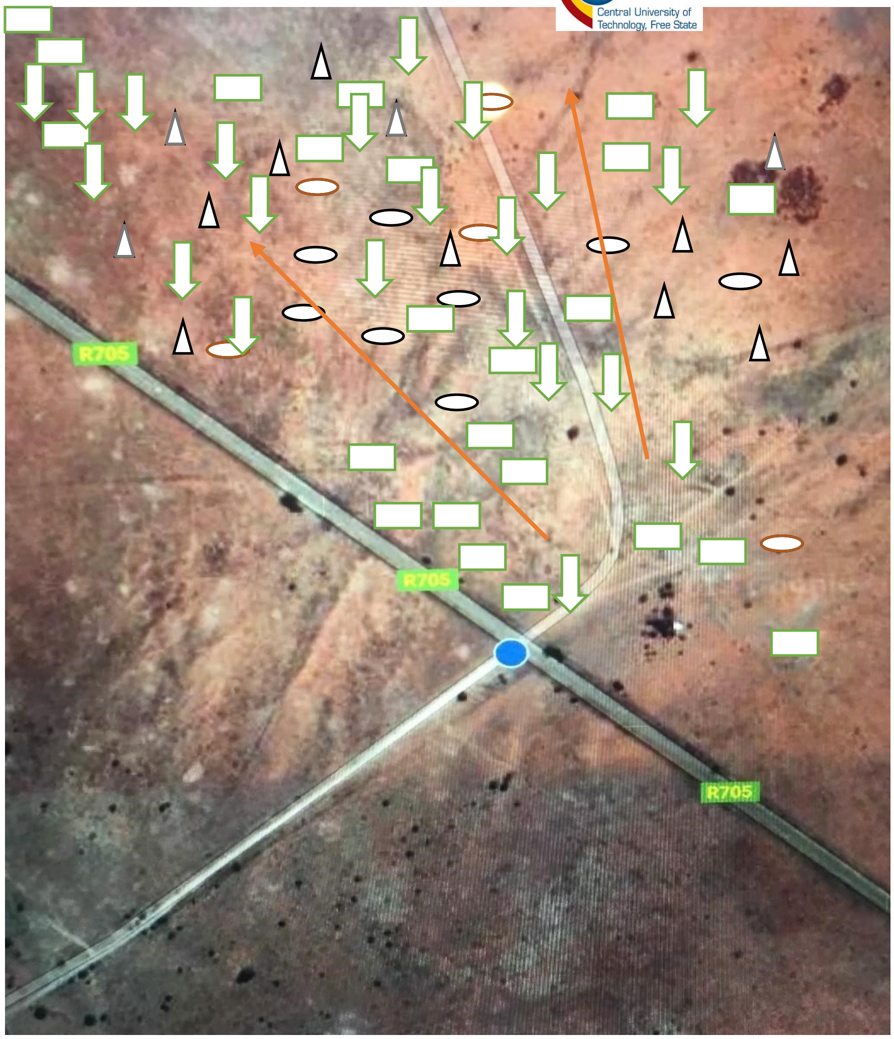

Figure 4.3 A sketch diagram showing the direction of prickly pear invasion at Koppieskraal farm in Koffifontein region, western Free State province. Rectangles = cactus; circles = bare area; triangles = shrub cover and arrow = grass cover.

4.3.2 Experimental design/layout

A 544 ha cattle grazing area was stratified, based on vegetation cover types. Four types of covers were noted and demarcated as bare area (BA), grass cover (GC), shrub area (SC) and cactus cover (CC). Figure 4.4 shows the state of the invaded zones where different plots were demarcated.

Table 4.1 Experimental plots

Vegetation cover type	Description
Bare area (BA)	Less than 10% cover, interspaced by small *Opuntia* colonies (3-5 cm diameter)
Shrub area (SC)	*Common shrubs - Euryops asaparagoides, Pentzia calcarea*, *Walafrida geniculata*, *Felicia muricata* and *Eriocephalus spinescens*) Undercover – cactus colonies (3-15 cm diameter)
Grass cover (GC)	Most abundant grasses - *Themeda triandra*, *Eragrostis chloromelas*, *Schmiditia pappophoroides and Chloris virgata* *O. humifusa* colonies (7 m – 20 m apart), and shrubs
Cactus cover (CC)	Heavily invaded zones (HZ) - mostly *O. humifusa* (60% cover), secondary cactus colonies - diameter of 200 - 250 cm

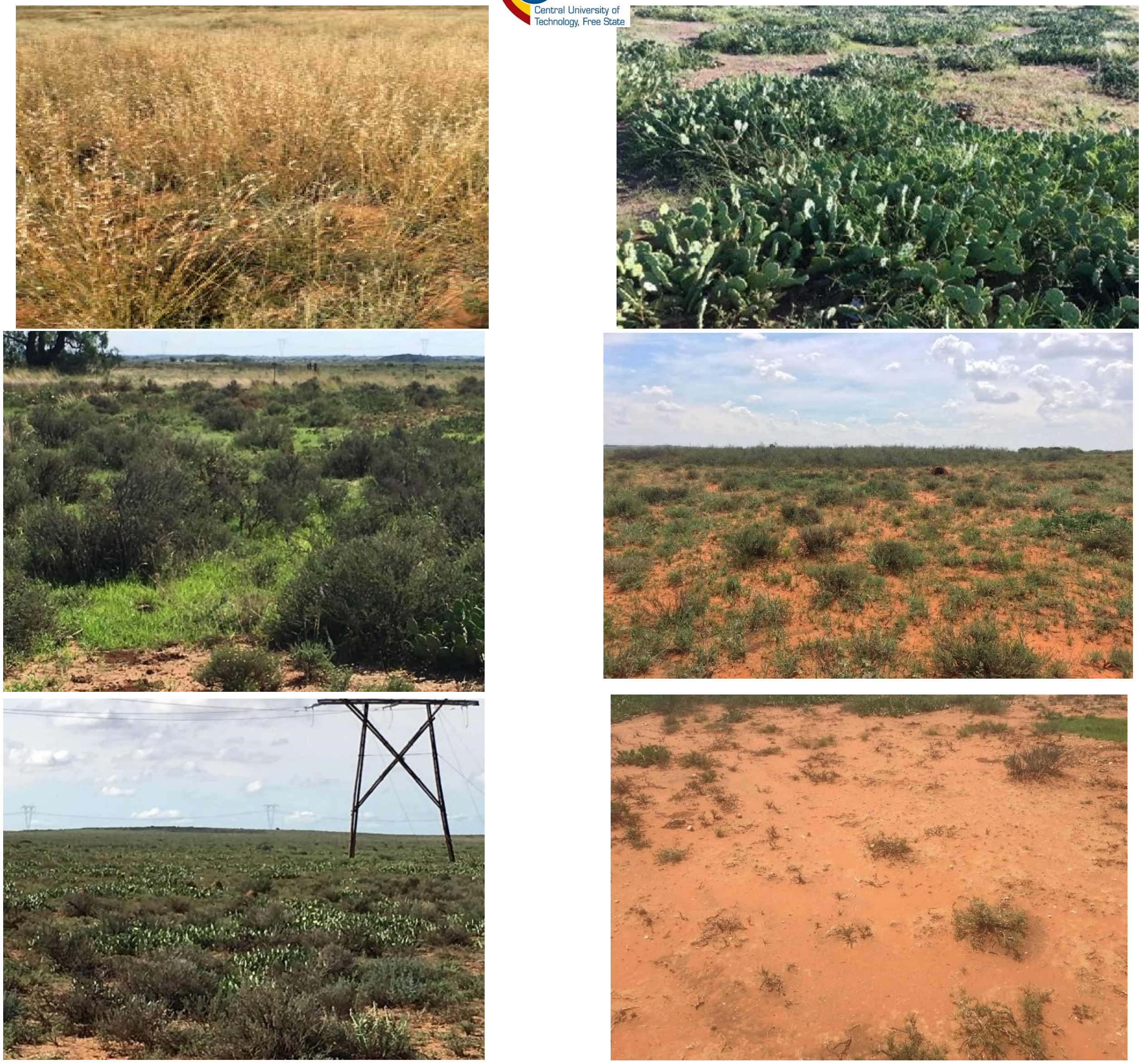

Figure 4.4 A view of the state of grazing area showing different vegetation covers invaded by creeping prickly pear (*O. humifusa*); Grass cover, *O. humifusa* cover, shrub cover and bare area. Author's photos (February, 2015).

The photographs above show the rangeland is under disturbance by the invasion of creeping prickly pear (*O. humifusa*) coupled by overgrazing, resulting in a profiling of it to shrub dominated covers, bare areas, and creeping prickly pear and shrub dominated areas.

4.3.3 Soil microbial profiling and mineral analysis

4.3.3.1 Soil sampling procedure

Soil sampling was done during the rainy season when microbial viability was high (Lester, Satomi and Ponce, 2007). A soil auger was used, and sampling depth was 30 cm. Three soil samples were randomly collected per sub-plot (GC, SC and CC and BA). Debris were removed from the soil surface before sampling, and the soil was sieved for roots and other organic materials before packaging it in polyethylene bags. The samples were stored at –18^0 C pending analysis.

4.3.3.2 Soil mineral analysis

The samples were analyzed for phosphorus, calcium, magnesium, potassium and sodium using a Solaar M Series Atomic Absorption Spectrophotometer (AAS) with the flame system (Garcia, Torres and Baez, 2008). Soil minerals, K and Na, were analyzed using an air/acetylene flame, while Ca and Mg were analysed using a nitrous oxide/acetylene flame. Zinc, copper, iron and manganese (Zn, Cu, Fe and Mn respectively) were determined by treating a 10 g of air-dried soil with 20 ml of Diethylenetriamine-pentaacetic acid extracting solution. After shaking it for two hours using an inliner shaker with a 2.5 cm throw, the sample was filtered, and the extract analysed by an inductively coupled plasma atomic emission spectrophotometer (Shahandeh, Hons, Provin, Pitt and Waskom, 2017). Total nitrogen (N) concentration was determined using the Kjeldahl method with a K-350 Buchi Distillation Unit. The soil pH was determined using the potentiometer method.

4.3.3.3 Soil microbial analysis

Three random soil samples were collected from four random spots within the GC, SC, CC and BA. Soil sampling was done at the depth of 5 cm after removing debri. Samples were stored in polyethylene bags, which were cold-sterilised in a uv-radiation box, and analysed within 24 hours. The soils were sieved (4 mm mesh size), stored at 4^{0}C, and analysed within 14 days. Microbial analysis was done at the Agricultural Research Council Animal Production Laboratories in Pretoria, South Africa. The extraction of bacteria from the soils followed the method described by Baath (1992). A soil core of 10 g was homogenized in 100ml of distilled water, using an Omnimixer (1 min, 80% full speed), and the soil suspension was centrifuged at 5^{0}C (10 min, 75g). A 2 ml sample was taken for bacterial counting from the 200 ml bacterial suspension, after which the remaining suspension was centrifuged for 20 minutes. The new suspension measuring 100 ml was taken for microscopical counts, while the rest was used for lipid extraction. The values from bacterial counts and PLFA analysis were calculated per gram organic matter (measured as loss on ignition at 600^0C for 4 hours). Total bacterial and yeast count using the horizontal method for the enumeration of micro-organisms, and the pour plate technique (ISO Standard 4833-1) were then performed (Frostegard and Baath, 1996).

4.3.3.4 Vegetation analysis

Herbage samples were collected for all species within the GC, SC and CC plots, using a 1 m x 1 m quadrat. Five quadrats were systematically selected per plot. Samples of palatable, intermediate grasses and palatable shrubs, as described by Fouche *et al* (2014) were pooled for every five consecutive quadrats, and sub-sampled for chemical analysis. The upper sections of the grasses were cut for chemical analysis. Leaves and twigs were sampled and analysed, and new cladodes were sampled for chemical analysis. Sampling was done over two wet seasons. Samples were weighed and oven dried at 105^0C for 48 h for DM determination (AOAC, 1990, method number 2.1.2). The dried samples were ground to pass through a 1 mm sieve, and samples were kept in airtight containers pending chemical analysis.

4.3.3.5 Soil carbon pool and organic matter determination

The organic matter was determined by the mass loss in the interval from 110 to 420^0C in the thermogravimetric curve using Thermogravimetric method (TGA) (Miyazawa et al., 2000).

The rangeland carbon pools were determined using the following conversion factor:

Organic matter (%) = Total organic carbon (%) x 1.72

The conversion factor assumes organic matter contains 58% organic carbon

4.3.3.5 Chemical analysis and relative feed value of herbage

Dry matter was determined using residual weight following drying. The method involves oven drying of feeds at 135^0C for two hours (Association of Official Analytical Chemists, 1990, method number 930.15). The nitrogen content was determined using the combustion method (AOAC,1990, method 990.03), and crude protein was determined by multiplying the N with the factor 6.25. Acid detergent fiber (ADF), neutral detergent fiber

(NDF) and acid detergent lignin (ADL) were determined using the method of Van Soest et al. (1991). Relative feed value (RFV) was calculated according to Stalling (2005):

RFV = (dry matter digestibility (DMD) x dry matter intake (DMI))/1.2.

The following equations were used:

1. Dry matter digestibility (DMD) % = 88.9 – (ADF% x 0.779).
2. Dry matter intake (DMI) % = 120/%NDF.
3. Relative Feed Value (RFV) = (%DMD x %DMI)/1.2.

4.4 Data analysis

The data were analysed using analysis of variance (ANOVA) procedures in SAS (2013 version 8), and mean differences were tested using Fisher's Least Significant Difference (Fisher's LSD) at $p < 0.05$ probability level. Vegetation cover type, species type and site difference acted as categorical predictor variables. Correlation analysis was performed using SPSS version 17. Correlation coefficients of soil minerals and bacterial count, fungal count, carbon and organic matter pools under *O. humifusa*, grass, shrub cover and bare ground in the Nama Karoo biome were done using the Pearsons partial correlation matrix method. Correlation coefficients of nutritional composition and relative feeding values of grasses and shrubs in the Nama Karoo biome were also done using the Pearsons method. Statistical significance was reported at $p<0.05$.

4.4.1 Model

Complete randomized designed;

$$Y_{ij} = \mu + \alpha_j + \varepsilon_{ij}$$

where,

Y_{ij} : is the score of the ith observation in the jth treatment level (soil mineral and microbial population levels)

μ : is the general mean; and

α_{ij} : is the effect of A treatment level j (vegetation cover type). ε_i

: error component

4.5 Results

4.5.1 Influence of vegetation cover type on soil minerals

The soil on bare areas (BA) had the highest nitrate (NO_3^-) and ammonium (NH_4^+) content (Tables 4.2). The level of NO_3^- in BA was 73% higher than CC, 78.6% greater than SC and 87.9% more than GC soils. The content of NH_4^+ in BA soils was similarly higher than areas under cover. Organic matter differed ($P<0.05$), with the highest amounts recorded for cactus and shrub areas (Figure 4.5). BA plots had the least C, compared to covered plots (Table 4.4), this reflects the importance litter accumulation and microbial influence. Phosphorus levels were lowest in grass-covered plots. The grass covered plots were 87% less in P content, compared to BA soils. The P levels in BA soils were 45% more compared to shrubcovered plots, and cactus covered plots were 36.8% less in P content, compared to BA soils. The K values of BA and GC were similar, and lower compared to CC and SC soils, which were 16.2% more compared to BA soils. The soil Mg differed, ($p < 0.05$), across all plots. However, BA had the highest Mg value, and was 14%, 13% and 42% more compared to CC, SC and GC plots respectively. The CC was 3% and 22.6% more compared to SC and GC plots. The Ca differed, ($p < 0.05$), across all plots, with BA soils having a more than 50% Ca content, compared to SC, CC and GC plots.

Grass and SC plots had similar Fe content. Cactus-covered plots had the highest of Fe, and BA theleast. Copper and Zn in SC differed from BA, CC and GC contents.

Table 4.2. Top soil mineral (mg/kg) composition under cactus, shrub and grass cover and bare area

Minerals	Bare area	Cactus	Shrub	Grass cover
NH4-N	$8.3^{a} \pm 3.9$	$1.97^{b} \pm 0.36$	$1.35^{b} \pm 0.24$	$5.25^{b} \pm 0.15$
NO_3-N	$14.0^{a} \pm 6.67$	$3.8^{b} \pm 1.86$	$3^{c} \pm 0.37$	$1.69^{c} \pm 2.26$
P	$87^{a} \pm 4.97$	$55^{a} \pm 25.66$	$48^{b} \pm 21.33$	11 ± 4.04
K	$284^{a} \pm 100$	$339^{b} \pm 89.02$	$343^{c} \pm 80.25$	$171^{d} \pm 41.04$
Na	$43^{a} \pm 14.22$	$22^{b} \pm 1.53$	$31^{c} \pm 7.37$	$23^{b} \pm 10.59$
Mg	$511^{a} \pm 145.58$	$439^{b} \pm 148.33$	$424^{c} \pm 76.45$	$296^{d} \pm 200.65$
Ca	$4343^{a} \pm 1355.12$	$2479^{b} \pm 771.20$	$2479^{b} \pm 1397.90$	$1787^{c} \pm 680.40$
Fe	$40.7^{a} \pm 10.29$	$54.5^{b} \pm 15.58$	$49.0^{c} \pm 12.47$	$47.30^{c} \pm 19.88$
Mn	$75.9^{a} \pm 72.80$	$73.1^{a} \pm 20.21$	$101.9^{b} \pm 57.29$	$60.9^{c} \pm 29.22$
Cu	$2.7^{a} \pm 1.93$	$2.2^{a} \pm 0.39$	$3.4^{b} \pm 1.22$	$2.3^{a} \pm 0.92$
Zn	$2.4^{a} \pm 0.64$	$2.2^{a} \pm 0.49$	$2.9^{b} \pm 0.73$	$2.0^{a} \pm 1.96$
S	$10.6^{a} \pm 7.09$	$8.2^{b} \pm 1.00$	$10.3^{a} \pm 4.10$	$5.1^{c} \pm 2.06$
B	$0.9^{a} \pm 0.71$	$0.5^{b} \pm 0.29$	$1.0^{a} \pm 0.48$	$0.4^{b} \pm 0.09$
Al	$437.5^{a} \pm 245.72$	$469.2^{b} \pm 93.18$	$529.3^{c} \pm 182$	$427.1^{d} \pm 166$
pH(KCl)	6.51^{a}	5.52^{b}	6.33^{a}	5.68^{b}

Ls means with different superscripts across rows differ at $p<0.05$.

Table 4.3 below shows that soils under *F. muricata* and *O. humifusa* had more P (48 and 55 mg/kg, respectively), compared to other plants. Soils under *T. triandra* and *S. pappophoroides* had the least P. Highest values of K were recorded in soils under *F. muricata* and *W. geniculata*, and 339 mg/kg recorded in soils under *O. humifusa*. The lowest K was reported under *S. pappophoroides* (133 mg/kg). Soils under *T. triandra*, *E. chloromelas*, *W. geniculata*, *F. muricata* and *O. humifusa* did not differ (p>0.05) in Na content. The lowest Mg value was recorded in soils under *S. pappophoroides* (165 mg/kg). Mg levels did not differ (p>0.05) with soil under *O. humifusa.*

Table 4.3. Top soil mineral (mg/kg) composition under grass species, shrub species and *O. humifusa*.

Soil minerals	*T. triandra*	*S. pappophoroides*	*E. chloromelas*	*W. geniculata*	*F. muricata*	*Salsola* spp	*O. humifusa*
		Grass (NI)			Shrub (TZ)		Cactus (HZ)
NH_4N	1.3 ± 0.41	1.6 ± 017	1.3 ± 0.16	1.4 ± 0.22	1.3 ± 0.31	1.7 ± 0.62	1.4 ± 0.36
NO_3N	1.1^{g} ± 0.56	5.3^{a} ± 2.45	1.7^{f} ± 0.63	2.7^{d} ± 1.61	3.1^{c} ± 0.37	2.3^{e} ± 1.4	3.8^{b} ± 1.86
P	4^{e} ± 1.32	4^{e} ± 1.86	11^{d} ± 3.46	31^{c} ± 8.2	48^{b} ± 22.1	6^{e} ± 2.34	55^{a} ± 25.66
K	215^{d} ± 86.23	133^{e} ± 46.8	171^{d} ± 34.34	343^{a} ± 80.21	343^{a} ± 80.21	204^{c} ± 60.34	339^{b} ± 89.02
Na	31^{a} ± 12.3	10 ± 3.45^{e}	23 ± 12.45^{c}	28^{b} ± 18.72	31^{a} ± 2.24	17^{d} ± 6.45	22^{c} ± 1.56
Ca	1451^{e} ± 600.56	477^{g} ± 214.5	1787^{d} ± 346.02	2788^{b} ± 886.77	3706^{a} ± 345	960^{f} ± 124.65	2479^{c} ± 777.25
Mg	559^{a} ± 200.13	165^{f} ± 68.34	296^{c} ± 72.34	412^{b} ± 154.81	424^{e} ± 80.34	286^{d} ± 45.34	174^{e} ± 148.33
Fe	68.5^{a} ± 24.67	28.4 ± 12.34^{f}	44.5^{d} ± 29.04	54^{c} ± 22.43	58.2^{b} ± 22.45	34.8^{f} ± 8.13	42^{e} ± 15.58
Mn	69.3^{d} ± 33.31	28.4^{f} ± 16.12	84.9^{c} ± 34.65	123.1^{b} ± 61	145.6^{a} ± 78.45	32.08^{e} ± 8.13	86.4^{c} ± 20.21
Cu	3.1^{b} ± 1.5	1.3^{e} ± 0.45	2.5^{c} ± 1.2	4^{a} ± 1.72	4.3^{a} ± 1.23	2^{d} ± 0.43	2.6^{c} ± 0.39
Zn	1.8^{e} ± 0.65	2^{d} ± 1.20	2.2^{c} ± 0.65	2.8^{b} ± 0.92	3.7^{a} ± 0.34	2.3^{c} ± 1.23	2.7^{b} ± 0.49
S	6.1^{e} ± 2.34	2.7^{f} ± 0.80	6.6^{d} ± 2.67	14.2^{a} ± 3.45	10.8^{b} ± 1.34	8^{e} ± 2.34	8.7^{c} ± 1
B	0.4^{a} ± 0.2	0.3^{a} ± 0.12	0.5^{a} ± 0.3	1.1^{c} ± 0.45	1.5^{b} ± 0.87	0.5^{e} ± 0.32	0.9^{d} ± 0.29
Al	602.7^{b} ± 345.5	272.6^{b} ± 123.1	406^{e} ± 200	582.8^{c} ± 245.2	679.1^{a} ± 1.45	325.5^{a} ± 45.67	424.2^{d} ± 93.18
Soil pH (KCl)	5.2	5.2	6.34	6.48	6.67	5.83	4.15

Different superscripts across are significantly different, $p<0.05$.

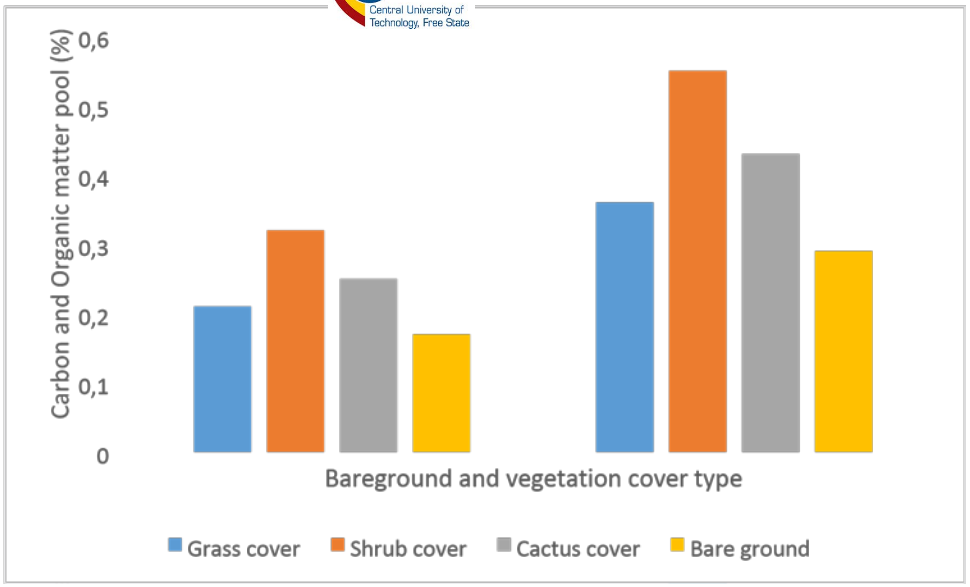

Figure 4.5 Carbon and organic matter pools (%) on different vegetation cover types and bare area.

Table 4.4. Carbon and organic matter pools (%) in common palatable grass species and shrub species in western Free State rangelands

	T. triandra	*S. pappophoroides*	*E. chloromelas*	*W. geniculata*	*F. muricata*	*E. eriocoides*	*O. humifusa*	Bare area
Carbon pool (%)	$0.21^{d} \pm 0.02$	$0.22^{d} \pm 0.06$	$0.19^{d} \pm 0.06$	$0.37^{b} \pm 0.1$	$0.43^{a} \pm 0.2$	$0.16^{f} \pm 0.08$	$0.31^{c} \pm 0.1$	$0.18^{c} \pm 0.04$
Organic matter pool (%)	$0.36^{d} \pm 0.12$	$0.38^{d} \pm 0.05$	$0.33^{e} \pm 0.04$	$0.64^{b} \pm 0.2$	$0.74^{a} \pm 0.08$	$0.28^{f} \pm 0.08$	$0.53^{e} \pm 0.03$	$0.32^{e} \pm 0.06$

Different superscripts across are significantly different, $p<0.05$.

4.5.2 Soil microbial analysis and vegetation cover type

Figures 4.6 and 4.7 show microbial mass on bare area and different plant species cover. Bare area (BA) had the lowest values of both bacterial and fungal count. The shrub and grass cover types were 30.6 and 28.4% higher in bacterial count than bare ground. SC and GC were also 15% more in fungal count, compared to BA. The CC cover type did not differ in bacterial count compared to BA; however, the CC was 67% more in bacterial count compared to BA. CC differed ($p < 0.05$) with BA, in fungal count with 19.4% more. The GC was 42% more, and SC was 45% more in bacterial count compared to CC. CC and GC did not differ ($p>0.05$) in fungal count. GC was 14% more in fungal count than CC. SC was 85% more than BA. The BA had the lowest bacterial count. The bacterial count under shrubs (*E. chloromelas*, *Walafrida geniculata*, *F. muricata*, *Salsola* spp.) and *O. humifusa* did not differ ($p>0.05$). Under *O. humifusa* the bacterial count was 89% higher than in BA. Soil under *O.*

humifusa differed in fungal count from BA with *Salsola* spp., *F. muricata*, *W. geniculata*, *E. chloromelas*, *S. pappophoroides* and *T. triandra*. The soils covered by *O. humifusa* were 91.8% more in fungal count, compared to BA.

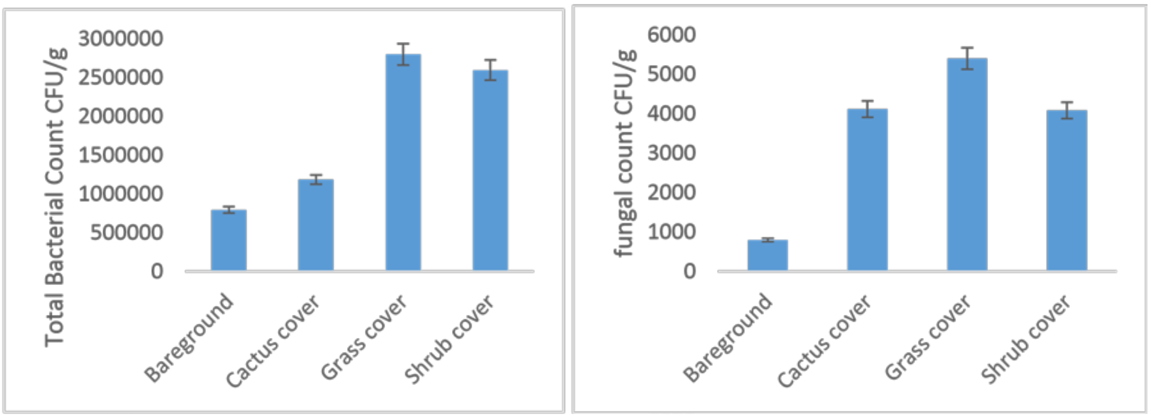

Figure 4.6 Total (a) bacterial and (b) fungal counts.

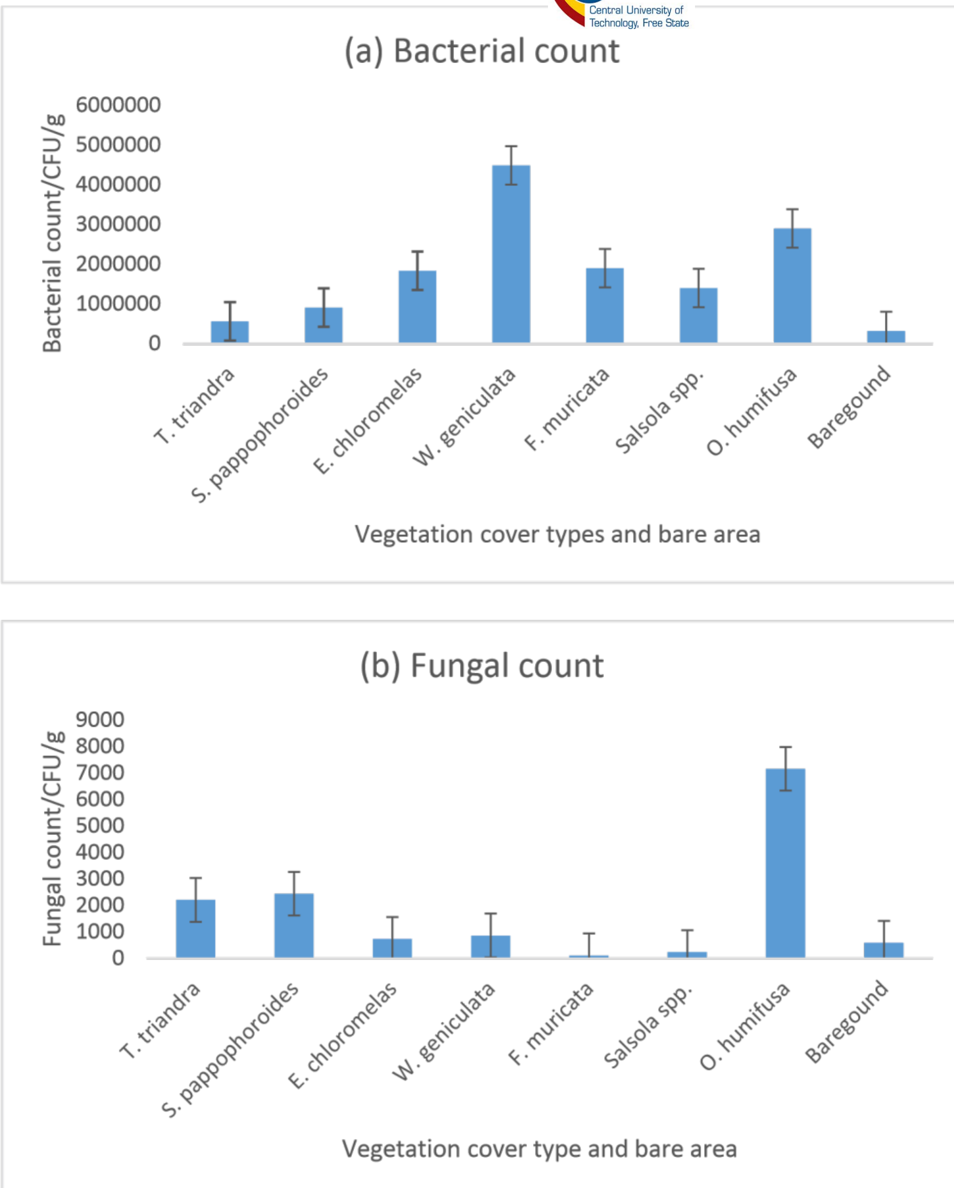

Figure 4.7 Soil (a) bacterial and (b) fungal count in soils under *O. humifusa* and common grass and shrub species and bare area.

4.6 Grass and shrub nutritive values

Table 4.5. Nutrient composition (%) of palatable grasses and palatable shrubs at Koppieskraal farm in Koffiefontein during summer season

	GC				SC		CC
	T. triandra	*S. pappophoroides*	*E. chloromelas*	*W. geniculata*	*F. muricata*	*Salsola spp.*	*O. humifusa*
				Mean stdev			
CP	10.1^{b} ± 2.1	7.7^{c} ± 3.6	6.5^{d} ± 1.4	6.1^{d} ± 1	7.6^{c} ± 1.6	14.4^{a} ± 6.7	5.2^{e} ± 1
Fat	9.1^{d} ± 1.4	6.8^{e} ± 1.7	7.3^{e} ± 0.8	19.5^{b} ± 8.4	16^{c} ± 6.9	22^{a} ± 8.4	2.2^{f} ± 0.6
Ash	11.2^{c} ± 2.5	8.37^{e} ± 2.2	10.6^{d} ± 2.6	8.2^{e} ± 1.2	6.2^{f} ± 1	16^{b} ± 9.2	17.5^{a} ± 12
P	0.3^{c} ± 0.06	0.7^{a} ± 0.2	0.8 ^{a}± 0.5	1.6^{c} ± 0.15	0.8^{a} ± 0.4	3.5^{b} ± 0.8	-
Ca	3^{d} ± 0.6	3^{d} ± 0.6	3.9^{c} ± 1.0	8.5^{b} ± 1.0	8.1^{b} ± 1.0	12.6^{a} ± 2.1	-
				Structural and non-structural carbohydrates			
NDF	42.5^{e}± 11.2	45.4 ± 14.8	56^{b} ± 30.8	64.9^{a} ± 21.1	50.6^{c} ± 10.3	25.1^{f} ± 11.2	14.5^{g} ± 3.4
ADF	31.1^{d} ± 8.4	37.1^{c} ± 5.1	38^{b} ± 2.1	50^{a} ± 20.1	39^{b} ± 21.5	19^{e} ± 4.3	13^{f} ± 1.8
ADL	5.6^{e} ± 0.8	8.6^{c} ± 0.8	6.8^{d} ± 1.2	21.9^{a} ± 5.8	13.2^{b} ± 3.4	6.8^{d} ± 1.2	2.1^{f} ± 0.6
Cellulose	25.4^{c} ± 3.6	28.4^{b} ± 2.6	31.2^{a} ± 21.2	28.2^{b} ± 13.2	25.8^{c} ± 12	12.2^{d} ± 6.9	10.8^{e} ± 0.8
Hemicellulose	11.4^{c} ± 1.4	8.4^{d} ± 0.6	19^{a} ± 8.4	14.9^{b} ± 7.3	11.6^{c} ± 6	6.2^{e} ± 1.2	1.6^{f} ± 0.5
Non fiber CHO	27.1^{c} ± 5.8	31.8^{b} ± 18.9	18.6^{e} ± 12.3	1.3^{f} ± 0.3	19.6^{e} ± 10.2	22.4^{d} ± 14.6	60.7^{a} ± 21.3
Lignin	2.4^{d} ± 0.5	3.9^{c} ± 1.3	3.9^{c} ± 1	14.2^{a} ± 0.8	6.7^{b} ± 0.8	1.7^{e} ± 1.1	0.3^{f} ± 0.08
Available CHO:B2	34.3^{c} ± 2.8	34.3^{c} ± 12.8	47.7^{a} ± 4.8	40.5^{b} ± 16.4	34.9^{c} ± 16.9	15.9^{e} ± 3.6	9.9^{f} ± 1.9
Indigestible Fibre CHO: C	13.6^{e} ± 1.8	20.6^{d} ± 10.3	16.3^{c} ± 2.2	52.4^{a} ± 18.4	31.7^{b} ± 1.4	16.3^{c} ± 12.2	5.2^{f} ± 1.8
Unavailable CHO	5.7^{d} ± 0.9	9.4^{c} ± 1	9.3^{c} ± 1.2	34^{a} ± 12.9	16^{b} ± 4.7	4.1^{e} ± 1.2	0.8^{f} ± 0.5
				Forage value			
DMD	64.7^{c} ± 22.6	60.1^{c} ± 20.4	59.3^{d} ± 28.3	50^{e} ± 14.3	58.5^{d} ± 18.2	74.1^{b} ± 21.2	78.8^{a} ± 23.4
DMI	2.8^{c} ± 0.5	2.6^{c} ± 0.4	2.1^{e} ± 0.1	1.9^{e} ± 0.2	2.4^{d} ± 0.5	4.8^{b} ± 0.8	8.2^{a} ± 1.3
RFV	152.5^{d} ± 38.6	132.3^{e} ± 10.8	104.1^{g} ± 30.9	77^{h} ± 25.7	115.6^{f} ± 34	294.4^{b}±110.1	539.9^{a} ± 87.3

Different superscripts across are significantly different, $p<0.05$.

Table 4.6. Correlation coefficients of nutritional composition and relative feeding values (RFV) of grasses and shrubs in the Nama Karoo biome.

Parameter	RFV (Grass)	RFV (Shrub)
CP	0.9	0.9
Fat	-0.7	-0.8
Ash	-0.6	-0.9
NDF	-0.5	-1.0
ADF	-0.1	-1.0
ADL	-0.7	-0.9

Table 4.6 shows mid-summer chemical composition of common palatable grasses and shrubs in the Koffiefontein rangelands. Palatable grasses and shrubs had more nutrients in the summer season. The common palatable grasses included *T. triandra*, *S. pappophoroides* and *E. chloromelas*, and sampled palatable shrubs were *W. geniculata*, *F. muricata* and *Salsola spp* (gannabos). The summer season crude protein (CP) content of grasses averaged 6%. *Salsola* spp. had the highest CP content (14.6%), and new leaves of *O. humifusa* were 5.1 % CP, whilst NDF was low. Neutral detergent fibre was 67.8 to 83.1% DM in grasses, and less than 65% in shrubs (Table 4.6 above).

Relative feed value (RFV) differed across grass and shrub species. New leaves of *O. humifusa* had the highest RFV. The RFV was strongly and positively (0.9) correlated to the CP percentage of forages (Table 4.7).

4.7 Discussion

4.7.1 Soil minerals, microbial biomass, carbon pools and vegetation cover types

Creeping prickly invasion of rangelands displaces indigenous herbaceous species, and affects nutrient flow patterns. The abundance of bacteria and fungi should be an indicator of typical environments that are rich in species and functional diversity.

Generally, South African soils are depleted of organic matter (Du Preez, Van Huyssteen and Mnkeni, 2011). The soils under different vegetation cover types in this study ranged from 0.2 to 0.4% in carbon pools. This confirms the observations of Du Preez et al. (2011) on soil minerals in South African soils. Their report noted that a greater percentage of South African soils had less than 0.5% organic carbon, and that only 4% contains more than 2% organic carbon. Degradation of rangeland as a result of overgrazing has resulted in significant loses of OM as a result of lower biomass production. However, the displacement of indigenous herbaceous materials by creeping prickly pear could result in soil protection from loss of OM. This is supported by the results obtained in this study; with soils under *O. humifusa* averaging 0.53% OM compared to 0.36 – 0.38% in soils under grass species. However, OM under certain shrub species such as W. geniculata was averaging 0.7 – 0.8% OM.

The improvement in soil pH from acid to neutral has an effect on the carbon. Pettersson (2004) noted that raising pH in soils increases the amount of carbon, as decomposition under conditions is slow; and that organic matter becomes more susceptible to microbial attack at higher pH levels. Micro-organisms utilize carbons for growth; hence this element is a limiting factor in soil organic matter decomposition. The bacterial and fungal biomasses were noted to vary with vegetation cover types, which is expected, as different plants exude and control soil metabolic functions differently. Shrub covered areas had the highest counts of bacterial and fungal populations. This was supported with higher carbon and organic matter content. Cactus-covered areas fared better in carbon and microbial biomass, compared to grass-covered areas. This was also down to different pH levels and organic matter content. Therefore, environments that are covered by shrubs are likely to provide more above-ground biomass, and with faster decomposition cycles.

Lack of litter in BA directly affected OM, C and soil microbial biomass. The high NH_4^+ and NO_3, Ca, P and Mg on BA were related to zero mobilisation by soil microbes and plants.

Generally, Mg under all cover types was less than levels for optimal plant growth of 1.5 – 3.5 g/ kg (Guo, Nazim, Liang and Yang, 2016). This is possibly an indicator of the overutilisation of herbage. Variations in soil P fractions among vegetation types can be attributed to changes in biomass production and nutrient cycling processes associated with vegetation conversion (Hubova, Tejnecky, Ceskova, Boruvka, Nemecek and Drabek, 2017). Hubova *et al.* (2017) also noted that herbaceous vegetation cover has an influence of Al behaviour in the soils, whilst poor herbaceous localities lead to lower mobilisation of Al.

The veld in this study falls within the Koffiefontein rangeland described by Acocks (1953) as western Upper Karoo veld type. This is a rangeland in gradual transition, consisting of savannah and grassland biomes. Humphreys (1972) observed that protein deficiency was common in tropical grasses due to poor soil fertility. Ali, Qamar, Ali, Arshad and Javed (2001) reported a range of 1.7 to 5% CP in cultivated tropical grasses (*Cenchrus ciliaris,* *Panicum antidotale, Pennisetum purpureum* and *E. superba*), whilst Norton (1982) reported low P and Ca concentrations. The high NDF content of grasses leads to high rumen fill. Animals' grazing forage high in NDF also face the challenge of gut fill, as small ruminants have a limit of 3% of body weight. Grass quality was very poor, which necessitates extended supplementation programmes. Such regimes are unsustainable within extensive systems, with inherently low off-takes.

4.8 Conclusion

Although higher soil cover, OM and carbon sequestration are positive attributes of *Opuntia* invasion, impoverishment of bacterial populations and loss of soil NO_3N and NH_4N assimilated by *Opuntia* affect grazing land carbon pools. Plant-soil-animal shifts driven by invasive species are critical in validation of global vegetation models that predict the response of fragile rangelands to climate change. There are large differences in OM content within and between soil forms, depending on climatic conditions, vegetation cover type, topographical position and soil texture. Increasing OM levels in degraded rangeland soils by preventing overgrazing could attribute to restoration of degraded rangelands. Rangeland restoration is critical for sustainable extensive stock farming in South Africa. The current scenario of invasive species on rangelands therefore calls for a determination of whether rangeland function has to change, and whether the changes will be aligned to achieving a new ecological balance or food security through sustainable extensive livestock production.

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CHAPTER 5

EFFECTS OF ALIEN SPECIES INVASION ON RANGELAND GRAZING CAPACITY

Abstract

The vegetation in the western Free State has supported large herds of herbivore for centuries; however, transition toward a semi-desert is noticeable, especially in the 20th century. Alien species seem to dominate; and ruminant livestock less prefer these. The objective of the study was to determine long-term interrelationships of alien species and grazing capacity in semi-arid areas. A semi-structured questionnaire was administered to 40 farmers with sheep and cattle on extensive production systems, within the Eastern Parkland or Transitional vegetation zone. Rainfall data collected over 30 years was correlated with vegetation types. The grass indicator species for excellent veld condition increased by 7.7% in Eastern Parkland vegetation type, and with 4.8% in the Transitional zone. Subclimax grass increased by 15.4% and 7.1% in the Eastern Parkland and Transitional zone; respectively. Over the 30-year period there were more disturbance indicators (DI) in Eastern Parkland (15%) compared to the Transitional zone (10%). In both the areas the grass response index (GRI) increased with increase in annual rainfall. When rainfall was below 400 mm, a negative GRI was noted. At median carrying capacity, 17 ha/LSU (cattle) and 3.5 ha/SSU (sheep), shrub density increased in the Transitional zone, and a steep increase in shrub density was observed in the Eastern Parkland vegetation type. Annual rainfall and carrying capacity are key drivers of vegetation patterns in the western Free State region; hence, it is critical to incorporate these components as first limiting factors in rangeland modelling. When rainfall was below 200 mm, GRI was negative at all levels of cattle-stocking rates in Eastern Parkland vegetation areas. The Eastern Parkland areas were inclined to lose more grass species at median and high cattle stocking rates (13 and 10 ha/LSU respectively). At annual rainfall above 300 mm, the vegetation change index was positively correlated. In Eastern Parklands areas, cattle stocking rates influenced grass species' abundance. At annual rainfall < 200 mm, there was a strong negative vegetation change index (- 4,5), whilst median and low cattle stocking rates had a positive index. At annual rainfall >300 mm, there was a strong negative linear correlation between all levels of cattle stocking rates and average annual

rainfall received in the semi-arid area. Grass species composition seem to be threatened when cattle stocking rates are (12 ha/LSU). The cattle stocking rates at annual rainfall <200 mm had a positive response index in the Transition zone. At lower stocking rates (21 ha/LSU) there was a strong positive index (2), at high stocking rates the vegetation index was zero. Above 300 mm annual rainfall, the response index was negative at all levels of cattle stocking rates, with high stocking rates having a highest negative gradient. The results show that the Eastern Parklands vegetation type was more resilient to climate fluctuations, and alien species pressure, compared to the Transition zone.

5.1 Introduction

The western Free State region is semi-arid and extensively utilized for grazing herbivores and livestock. The region was diverse in botanical compositions (Acocks, 1973), due to landscape (soil types) and rainfall (Mucina and Rutherford, 2004). Rainfall intensity and its distribution are key determinants of herbage production (Snyman, 2003). However, grazing management, production systems and invasive species change the vegetation profiles of the western Free State. Van der Westhuizen (2015) noted that correct stocking rate is the most important factor in grazing management. Over the years, sheep grazing was predominant, but livestock (sheep) losses to predation and other anthropogenic factors are shaping production systems more toward cattle farming. The shift in livestock production systems has an effect on the extent and nature of the utilization of the rangeland (Van Soest, 1994). The overriding ecological problem in the Karoo biome is the deterioration of veld resources as a result of inappropriate veld and stock management practices. Van der Westhuizen (1998) reported that the average rangeland condition is 60% in the southern Free State, Koffiefontein and Jacobsdal regions, reflecting a veld in deterioration, with a loss of palatable and subclimax grass species. According to Sampson (1985), veld utilisation patterns in the Nama Karoo biome were damaged by over-utilisation, which accelerated deterioration with the growth of commercial livestock farming. The current scourge of invasives (*Acacia mellifera* ssp. detinens, *Rhogozum trichotorum*) and the elimination of desirable ones (*Cenchrus ciliaris* and other Poacea, *Felicia ovata*, *Portulacaria afra*) is evidence of shifts in vegetation and utilisation capacity. Invasive alien plants reduce the veld's carrying capacity, and are associated with an increase in livestock mortalities. For example, sheep ingesting the cladodes had mouth blisters and internal hemorrhaging (Hanselka and Paschal, 1991).

5.2 Objectives

The objective of the study was to assess interrelations between livestock stocking rates, rainfall and grass and shrub abundance in rangeland invaded by *O. humifusa*.

5.3 Materials and methods

5.3.1 Study area

The research on vegetation types was done around the farms in the western Free State region. The rangeland condition of the surveyed farms was described as moderate, good and excellent by Van der Westhuizen (2012). The area is dominated by *Schmidtia pappophoroides*, *Eragrostis lehmanniana* and *Cynodon* species (Van der Westhuizen, 2012), and other common grass and shrub species include *Aristida* species, *Eragrostis* species and *Stipagrostis* species; and common Karoo shrubs such as *Eriocephalus* spp., *Pentzia* and *Lycium* spp. The region falls under the Nama Karoo biome, and the vegetation taxa is classified under Eastern Parkland vegetation (see Figure 5.1 below). The region receives an annual rainfall of between 100 mm and 500 mm, with Figure 5.2 showing the yearly rainfall means. Minimum temperatures of - 5^0C were recorded in the months of May, June and July, whilst maximum temperatures of 35^0C to 40^0C were recorded in the months of December and January.

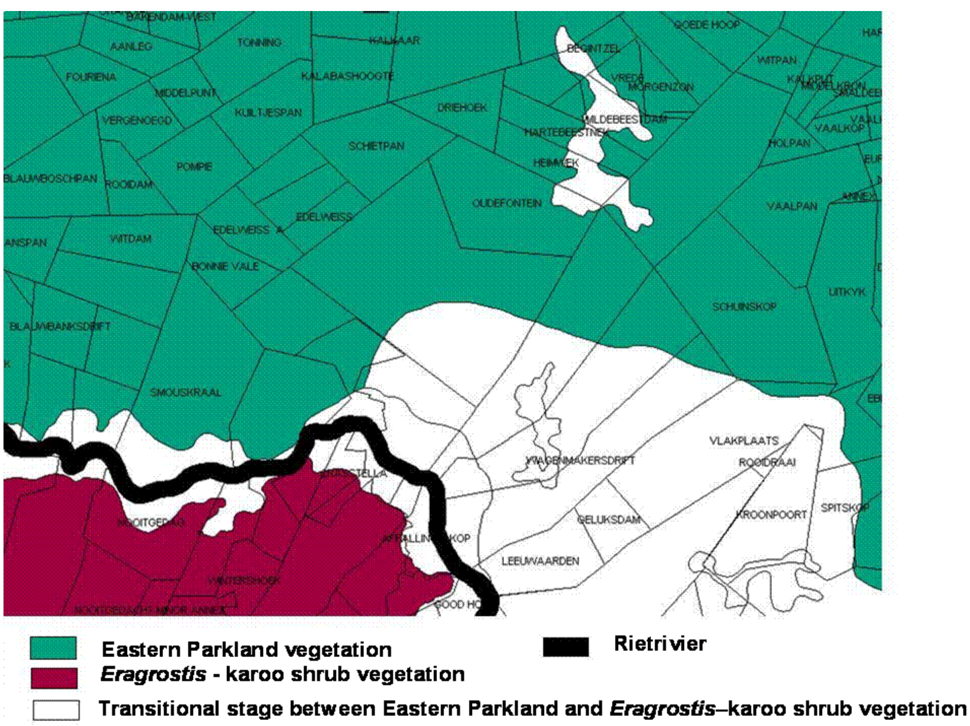


Figure 5.1 Relatively homogenous plant communities of the study area (Van der Westhuizen, 2003).

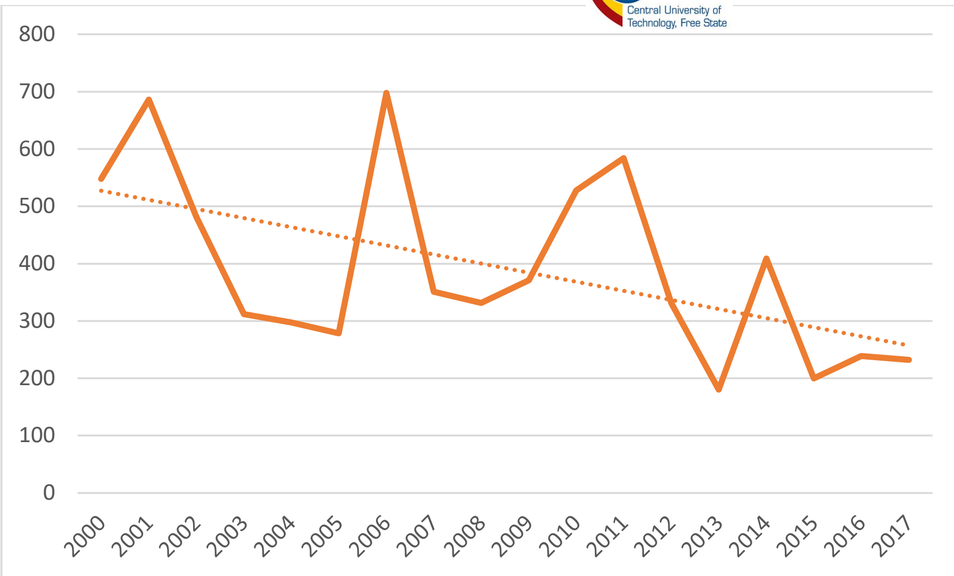


Figure 5.2 Annual rainfall (mm) pattern from 2000 to 2017 in the Koffiefontein area.

5.3.2 Data collection

A structured questionnaire was used for data collection purposes (Appendix 1). The questionnaire was administered on large farms which were 2 000 ha or more in size. Cattle and sheep production was common on surveyed farms, and all surveyed farms practiced rotational grazing. The questions addressed the following aspects: 1) rangeland management issues; 2) changes in common grass and shrub species composition and abundances; 3) trajectories of cattle and sheep numbers over the years; and 4) invader species and control aspects. A total of 18 farms were surveyed in the region, with a total grazing area of 40 000 ha. Other important factors such as the age of the farmer, the period of farming on the same land, and the farming system practiced were important in assessing continuation of decision making on rangeland changes. Farmers had training in grazing camps management system, identification of grasses and shrubs common in the region, had books/manual of grass and shrubs identification materials in the form of books. Therefore, their assessment of the veld was considered valid.

5.3.3 Data analysis

Data coding was done on the qualitative data on grass and shrub species occurrence as identified by farmers. Bar graphs on relative frequency on species availability, changes in species composition and abundance and trends in carrying capacity were constructed using Microsoft Excel.

To assess the vegetation drivers in the western Free State, a discrete choice model (multinomial logistic model) was used to determine the factors affecting vegetation dynamics. The grass and shrubs species' changes were qualitatively coded as 1-species increase, 2-species decrease and 0-no change in species abundance from year 1995 to present. Factors considered as vegetation drivers in this region were sheep-carrying capacity, cattle-carrying capacity and annual rainfall.

5.3.4 Multinomial logistic model

The dependent variables a) grass species change, and b) shrub species abundance change, had polytomous outcomes, hence the use of multinomial logistic regression.

Following Greene (2012), the probability of each outcome was defined as:

^{k}

$$\sum \alpha + \beta_{kj} x_{kij}$$

$$\overline{\qquad\qquad\qquad}$$

$$P_{ij} = {}_{j}e\ {}_{j}\sum_{kj=1} \alpha + \beta_{kj} x_{kij}\ e$$

$\sum_{j=1}$ i = cases

j = categories; 1 (increase), 2 (decrease) and 3 (no change) k = independent variables

k = sheep-stocking rates last five years (ShSR5); cattle-stocking rate last five years (CSR5); cattle-carrying capacity last 30 years (CSR30); and annual rainfall last five years (Rain_5yrs).

Other independent variables such as humidity, temperature, rainfall over 30 years, ShSR30 and farm size were removed from the model due to high multicollinearity. The remaining variables used had a 1,79 VIF value, which indicates insignificant multicollinearity. The above model was run in Stata statistical programme (version 8), to determine the important factors affecting changes in grass and shrub species' abundance in the western Free State region from 2000 to 2017.

The coefficients generated from multinomial analysis were used to generate grass and shrub response indices. The x-axis has annual rainfall intervals as follows (see Figure 5.2):

I. 180 mm - lowest received in the region over a 30-year period)

II. 350 mm – median

III. 450 mm – average

IV. 550 mm - high value

V. 698 mm - highest received in the region

5.4 Results

Table 5.1 below shows the common plant species as identified by individually surveyed farmers.

Table 5.1. Common grasses, shrubs and invasive species surveyed in Koffiefontein area (western Free State) grazing area for years 2000 and 2010.

Grass species name	Botanical name	Species count/2000	%Frequency/2000	Species count/2010	%Frequency/2010
Red grass	*Themeda triandra*	23	6.5	25	5.6
Kalahari sand quick	*Schmiditia pappophoroides*	15	4.3	19	4.3
Tick grass	*Eragrostis echinochloidea*	12	3.4	13	2.9
Curly leaf	*Eragrostis chloromelas*	16	4.5	17	3.8
Lehmann's love grass	*Eragrostis lehmanniana*	20	5.7	20	4.5
Dew grass	*Eragrostis obtusa*	9	2.6	10	2.3
Saw-toothed grass	*Eragrostis superba*	9	2.6	14	3.2
Annual bristle grass	*Aristida adscensionis*	26	7.4	37	8.4
White stick grass	*Aristida congesta*	26	7.4	37	8.4
Bitterbos	*Chrysocoma ciliata*	26	7.4	25	5.6
Meerkatkaroo	*Pentzia calcarea*	14	4	12	2.7
Vaalkaroo	*Pentzia gllobosa*	13	3.7	13	2.9
Januariebos	*Gnidia polycephala*	14	4	16	3.6
Doringkapok	Eriocephalus spinescenes	20	5.7	18	4.1
Kapokbos	*Eriocephalus eriocoides*	18	5.1	22	5
Witkriedoring	*Zygophyllum Incrustanum*	8	2.3	9	2
Waterfinder	*Walafrida geniculata*	12	3.4	13	2.9
Bloublommetjie	*Felicia muricata*	13	3.7	16	3.6
Acacia	*Acacia spp*	13	3.7	19	4.3
karee	*Searsia lancea*	8	2.3	14	3.2
Buffalo shrub	*Ziziphus mucronata*	10	2.8	13	2.9
Prosopis	*Prosopis spp*	5	1.3	10	2.3
Three thorns	*Rhyzogum tritochorum*	10	2.8	19	4,3
Prickly pear	*Opuntia ficus indica*	7	2	13	2.9
Creeping prickly pear	*Opuntia humifusa*	5	1.4	10	2.3
		352	**100**	**443**	**100**

The relative frequencies of grass species are presented in Table 5.1above. Red grass (*Themeda triandra*), *Aristida congesta* and *Aristida adscensionis* had the highest frequency ranging from 6 – 8%. Six other grass species had frequencies below 6%. Five shrub species had relative frequencies ranging from 1 to 4%. *Chrysocoma ciliata* had the highest occurrence, with a relative frequency of 7%.

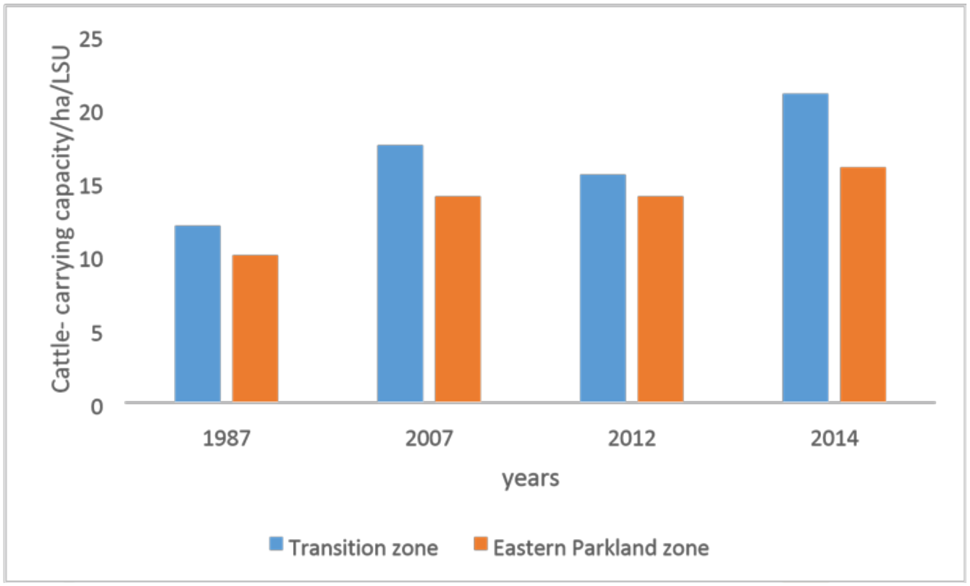


Figure 5.3 Cattle-carrying capacity from 1987 to 2014 in the western Free State.

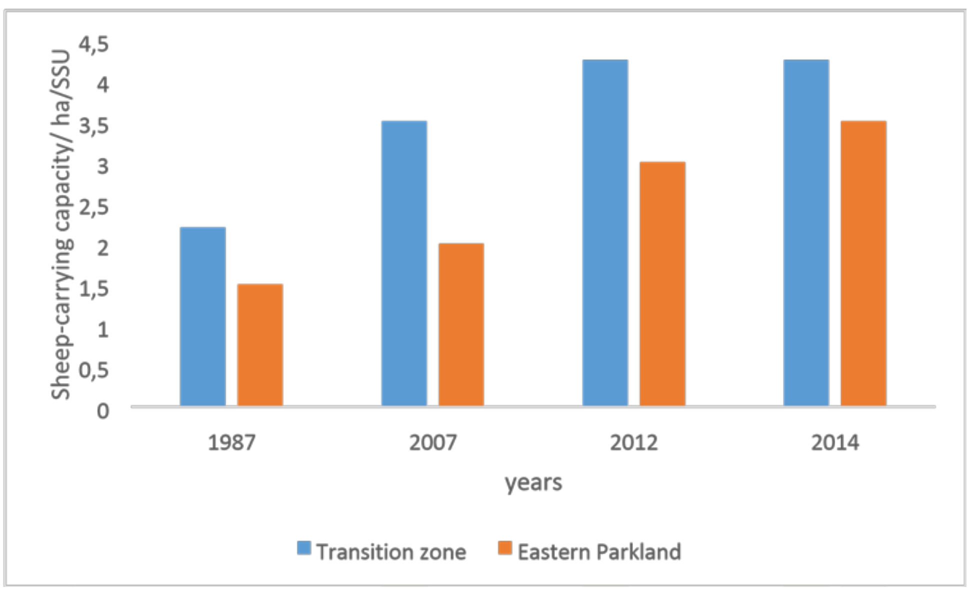


Figure 5.4 Sheep-carrying capacity from 1987 to 2014 in the western Free State Transition and Eastern Parkland vegetation areas.

The diameter of cactus colonies increased by at least 31 cm between 2015 and 2017 (Figure 5.5).

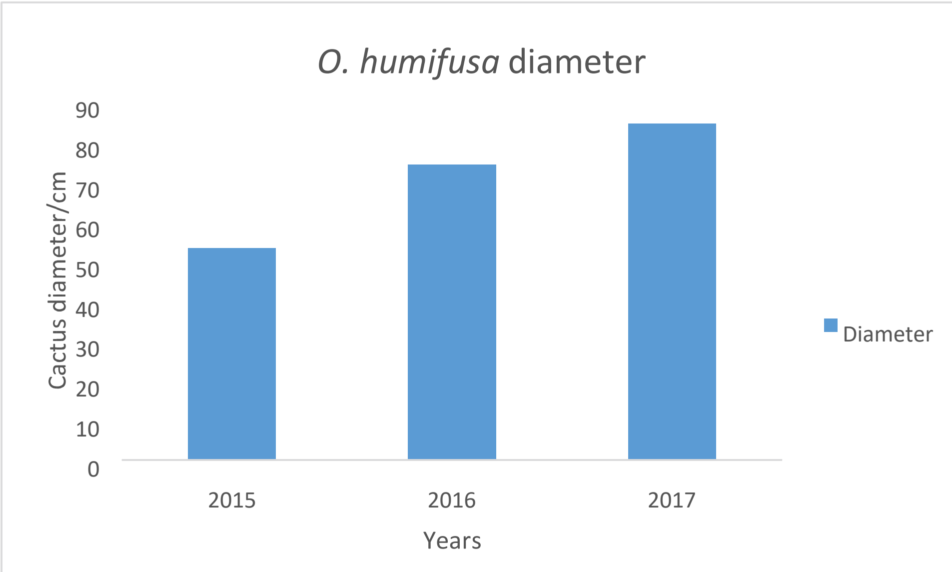


Figure 5.5 Mean seasonal diameter of *O. humifusa* at Koppieskraal farm, Xhariep district, western Free State.

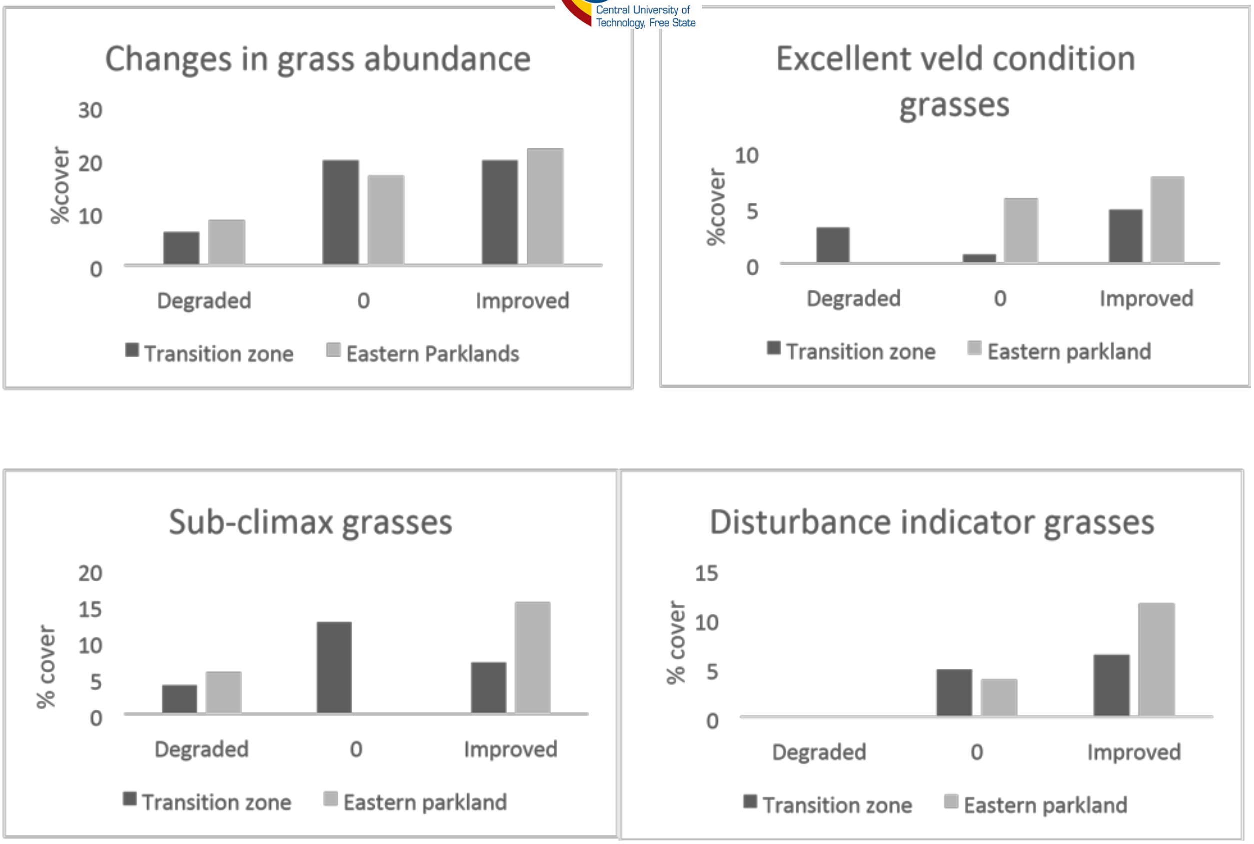


Figure 5.6. Percentage grass cover changes: (a) overall grass change; (b) excellent veld condition grasses; (c) sub-climax; (d) disturbance indicator grasses in Transition and Eastern Parklands rangeland of the western Free State

Figures 5.8 and 5.9 show vegetation dynamics, grass and shrub species changes. *Chrysocoma ciliata* (Bitterbos) was the most abundant shrub, which indicates that the area is overgrazed. There was an 22% increase in grass species in Eastern Parkland, compared to 19.8% in the Transition zones. Shrub density increased by 16%.

The changes in grass species are shown in Figure 5.8. Most grazing camps had a 3% increase EC more than the Transition zone, 50% higher in sub-climax and disturbance indicators. There was however, a 3.2% decline in EC indicators in the Transition zones.

There was an overall 16% increase in shrub density (Figure 5.9). From year 2000 to 2017 there was a 3.8 - 4.8% increase in *Felicia muricata* and *Walafrida geniculata* in both zones. The Transition zones, however, had a higher increase in unpalatable shrubs (5.6%) compared to the non-invaded areas (1.9%).

Cattle-carrying capacity declined from 1[illegible] ha/LSU in 1987 to 16 ha/LSU in 2014 in Eastern Parklands areas, and similarly in the Transition zones (12 ha/LSU to 21 ha/LSU, Figure 5.6). Similar trends were observed for sheep carrying capacity (Figure 5.4). The cattle and sheep carrying capacity trends reflected the decline in annual rainfall in the region (Figure 5.2).

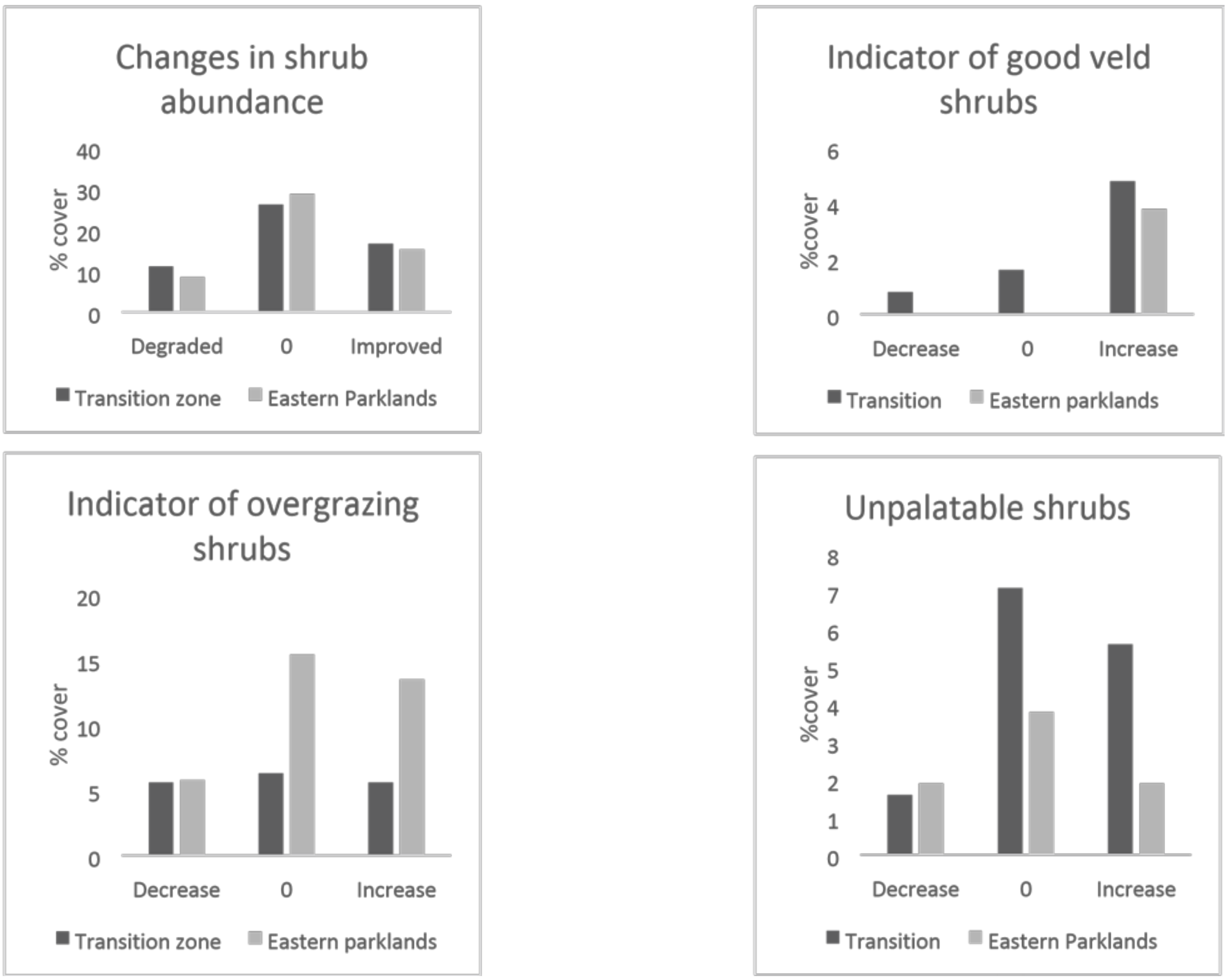


Figure 5.7 *Shrub* cover changes: (a) overall shrub abundance change; (b) indicator of overgrazing shrubs; (c) indicator of good veld shrubs; (d) unpalatable shrubs in Transition and Eastern Parklands rangeland of the western Free State

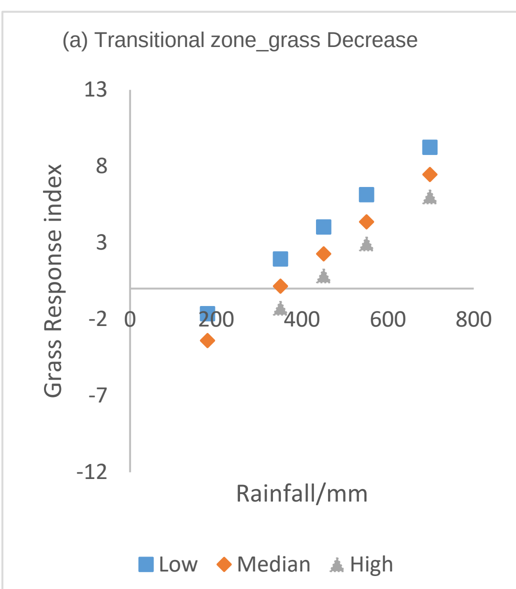
5.4.1 Factors influencing grass species abundance

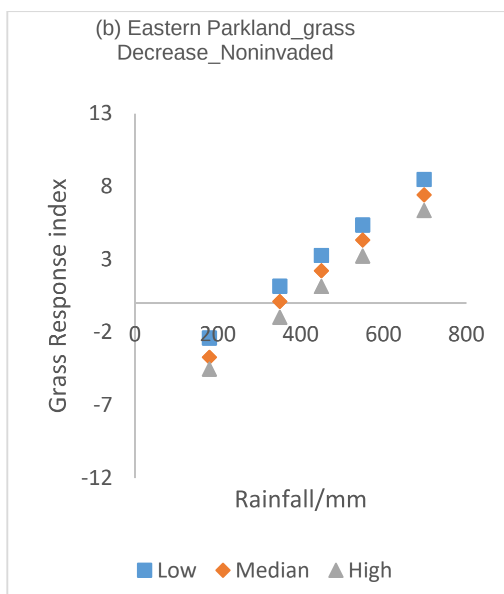
Rainfall_5yrs and CSR30 were significant predictors that vegetation change and stocking rates in the last five years did not affect grazing capacity.

Table 5.2. Multinomial model showing vegetation drivers (grass and shrub changes) in the western Free State region

Model	Veld status	RAIN_5YR	CSR5	CSR30	SHSR5	Constant
			Coefficients ± S.E			
Grass change	Zero	- 0,02** ± 0.01	0,10 ± 0.07	0,23** ± 0.07	0,79 ± 0.70	0,67 ± 1.29
	Degraded	0,02** ± 0.01	0,36** ± 0.13	-0,49* ± 0.19	-1,3 ± 0.79	-6,93** ± 2.02
Shrub change	Degraded	0.04* ± 0.02	- 0.06 ± 0.26	- 0.16 ± 0.18	1.6 ± 0.92	- 16.36** ± 5.79
	Improved	0.01* ± 0.01	0.2** ± 0.07	- 0.12 ± 0.08	1.27* ± 0.65	- 7.33** ± 1.59

$^{**}p < 0.001$, $^{*}p < 0.05$





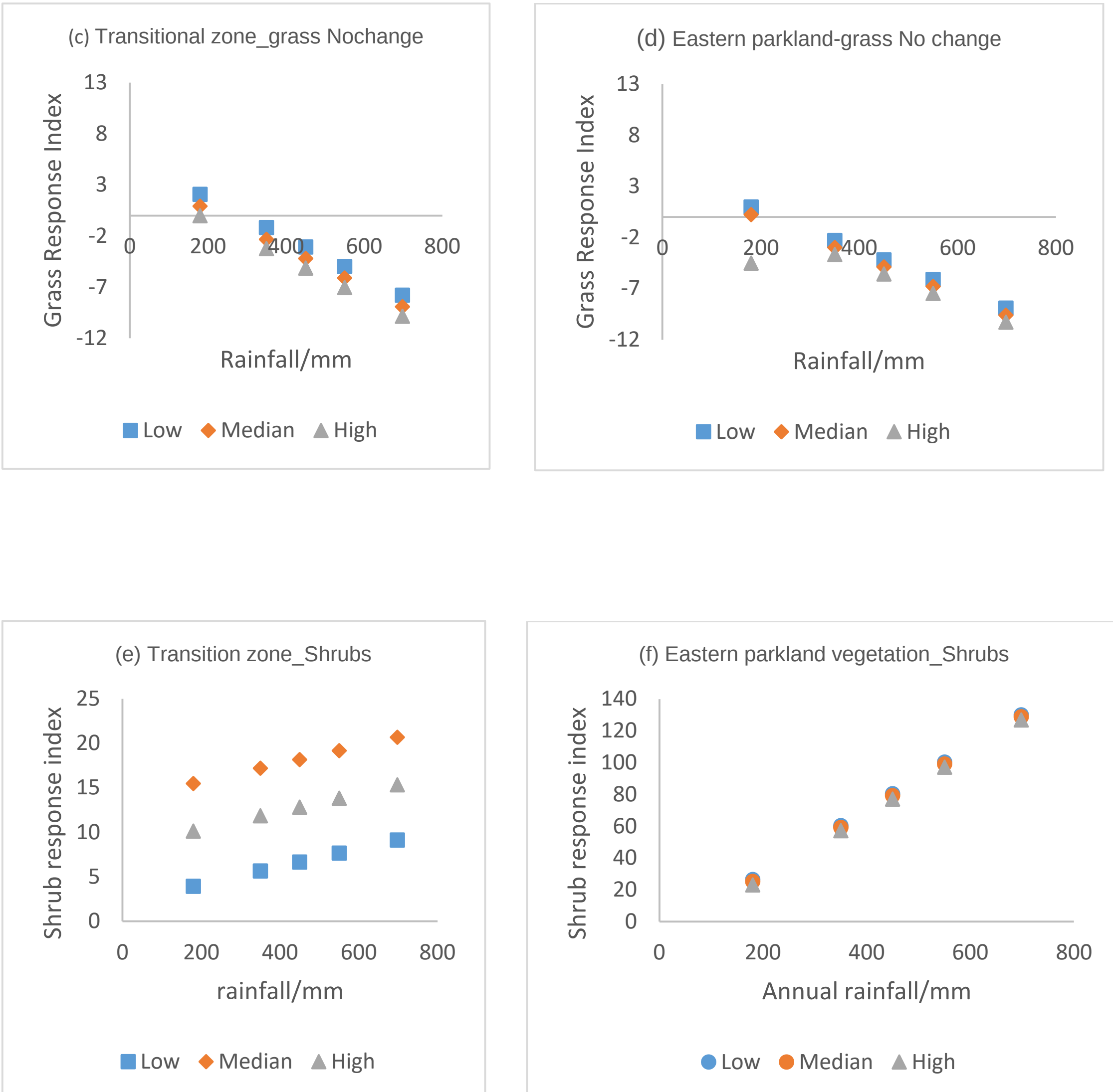


Figure 5.8 Grass and shrub response indices in the Eastern Parkland and Transition vegetation types

When rainfall was below 200 mm, GRI was negative at all levels of cattle-stocking rates in Eastern Parkland vegetation areas. The Eastern Parkland areas were inclined to lose more grass species at median and high cattle stocking rates (13 and 10 ha/LSU respectively). At annual rainfall above 300 mm, the vegetation change index was positive.

In Eastern Parklands areas, cattle stocking rates influenced grass species' abundance. At annual rainfall < 200 mm, there was a strong negative vegetation change index (- 4, 5), whilst median and low cattle stocking rates had a positive index. At annual rainfall >300 mm, there was a strong negative linear correlation between all levels of cattle stocking rates and average annual rainfall received in the semi-arid area. Grass species' composition seem to be threatened when stocking rates are (12 ha/LSU). The cattle stocking rates at annual rainfall <200 mm had a positive response index in the Transition zone. At lower stocking rates (21 ha/LSU) there was a strong positive index (2), at high stocking rates the vegetation index was zero. Above 300 mm annual rainfall, the response index was negative at all levels of cattle stocking rates, with high stocking rates having a highest negative gradient.

5.4.2 Shrub species abundance

The 5 years and 30 years sheep and cattle stocking rates had no effect on abundance of shrubs. The median interaction level of 16 ha/LSU and 3.5 ha/SSU, had the highest shrub response index at all levels of annual rainfall.

5.5 Discussion

Vegetation of the Karoo biome seem to be shifting toward arid types (Acocks, 1975) as a result of overgrazing and climate deterioration. As the sweet grassveld disappears the karroid shrubland become dominant. According UNEP report (Arnold, 1992) indicated that 61% of the region of earth's surface are utilized for ranching, hence impact of grazing mainly comes from large herbivores in grasslands. Grasslands are in decline, a trend expected to continue, for a number of reasons that include invasive species as some of the factors causing woody plant encroachment (FAO, 2003).

This study confirmed the receding trend; shrubs increased over a 30-year period in the semiarid region of the western Free State. The results confirm report by Asner et al. (2004) who noted increases in woody species dominance in arid and semi-arid ecosystems. De Klerk (1974) indicated a rapid spread of Karoo over the last 100 years in to sweet grassveld in the southern Free State. Long taproots of shrub are enablers for higher resilience to drought, and over browsing. High seed dispersal and ability to utilize carbon dioxide (Archer, 1994, Morgan et al, 2007) also impact resilience in shrubs. Provenza et al. (2003) suggested short duration grazing systems with, high-density stocking to forced non-selective grazing.

The increase in pioneer species, reduces grazing capacity of the Karoo rangelands. Voster and Meyer (1983) estimated 30 and 50% decline in grazing capacity in overutilized rangelands. There is gradual increase in invasive species such as Opuntia and *Prosopis* spp. (Table 5.1). Studies by Jacoby et al. (1982) demonstrated that *Proposis* removal increased herbaceous forage production. In a study of *P. glandulosa* removal, McDaniel et al. (1982) found out that the increase in production of more desirable perennial grasses occurred most significantly in areas formerly under *Prosopis* canopy and then expanded into the inter-spaced over the years. Veld management approaches that incorporates deferment of grazing in the first growing season allows grasses the opportunity to increase vigour and set seed prior to the initiation of grazing in the dormant season (McDaniel et al. 1982).

Rainfall and cattle stocking rates affected grass species composition, cattle stocking rates in the period 2013 – 2017 affected shrub density in the grazing areas in the western Free State region. This is in line with the assertion by Roux and Vorster (1983b), who indicated that the Karoo was affected by over-exploitation by sheep production and climate variability that caused instability of the vegetation. Globally, there is a shift in vegetation profiles, as climate changes and production systems intensify as noted by (Schofield and Butcher, 1986; Le Houreou, 1989; Westoby, Walker and Noy-Meir, 1989). These changes include a decrease in the density of palatable plants (Noy-Meir, 1982; Westoby *et al.*, 1989; O'Connor, 1991) and an increase in the defended (Weaver and Clements, 1929; Moore, 1989; Taylor and Ralphs, 1992) and ephemeral plants (Hoffman and Cowling, 1990; Bosch and Booysen, 1992). Carrying capacity of natural rangelands for domestic livestock (Friedel, Foran and Stafford Smith, 1990; Taylor and Ralphs, 1992) is affected (Milton and Hoffman, 1994). It is also important to note that with little precipitation the grasslands tend to degrade into deserts. To the other hand, there is a general trend of increasing cover of trees and bushes as the precipitation increases (Oesterheld et al., 1999). The conclusion is climates determines overall attributes of grassland ecosystem.

The changes in cattle, sheep and goat populations could have resulted in an increase in shrub density in the western Free State region; cattle herds increased whilst sheep and goat populations declined. Extensive small stock farming in Nama Karoo biome affected the vegetation; small stock has distinct grazing habits and selective preferences (Botha, 1981). Van Soest (1994) noted the differences in veld utilization by cattle and sheep; when grazing is not limiting cattle harvest 60% whilst sheep harvest 40%. This radical change in grazing regime inevitably evoked major changes in the vegetation especially in respect of species composition and phytomas. In general, herbivores consume 15% to 60% of annual aboveground biomass, and 5% to 15% of below ground NPP (Detling, 1988) of which 10% are grazed by small herbivores and the rest by large herbivores (Gibson, 2009). These species weaken the competitiveness of grasses in relation to trees and shrubs, and hence promote woody vegetation encroachments when their biomass exceeds a certain threshold (Van Langevelde, Van de Vijver, Kumar, Van de Koppel, De Ridder and Van Andel, 2003; Ward, 2010; Sankaran, Ratnam and Hanan, 2008). Grazing affects plant parts (leaves, flowers, stems, roots), resulting in reduced photosynthesis surfaces, seed production, as well as water, carbohydrates and nutrient supplies. This compromises the capacity of the plant to capture solar energy, which leads to competitiveness and productivity.

The results show that the Eastern Parklands vegetation type was more stable, compared to the vegetation type in the Transition zone. This could be attributed to consistence in grazing management aspects, mainly optimal stocking rates and interaction of stocking rates and rainfall variability, adaptation of the vegetation type, resilience and growth. The Transition zone was less stable, vulnerable, and sensitive to rainfall and stocking rates changes, and a shift toward *Eragrostis*-Karoo type of vegetation is highly likely. The findings of this study are similar to trends observed by (O'Connor, 1995 and O'Connor and Roux, 1995), who noted that rainfall tends to have the major influence on compositional change, with stocking rate playing an additional less conspicuous role in the short term, but increasingly larger effect in the longterm. Productive and palatable species such as *Tetrachne dregei* (Roux, 1968) and *Plithus karoocus* (Theron, 1964) require relatively high soil moisture conditions for growth and establishment. The hardier, less palatable and encroaching species such as *Chrysocoma tenuifolia*, *Eriocephalus spinescenes*, *Lycium*, *Pteronia*, have lower transpiration rates than the more palatable species such as *P. parvifolium* (du Preez, 1964). The replacement of the more reproductive and palatable species by hardy unpalatable shrubs can be regarded as a major facet in vegetation change in the biome.

5.6 Conclusion

Vegetation changes are dynamic and not predictable due to multiplicity of variables. The invasion by succulent plants such as *O. humifusa* promotes shrub dominance. Rapid changes in cactus diameter entail that in the longterm the rangeland would be over-run into "cactus carpets", and completely devoid of herbaceous, with no economic value for game and livestock production. Interventions are critical, as the Karoo is warming up and the prickly pear is expanding north easterly. The decline in ruminant livestock numbers, attributed to drought, and changes in production enterprises, this could have resulted in the shift in rangeland utilization pattern. Foraging behavior seems to be grazing inclined than browsing resulting in more shrub-dominated areas.

Vegetation change is often accompanied by gross changes in the distribution and density of species. Perennial grasses that were depleted include *Digitaria* species, *Panicum* species and *Themeda triandra*. Numerous undesirable species increasingly dominate the western Free State region including Acacia spp, *Rhizogum trichotomum*, *Lycium* spp, *Pentzia globosa*, *Pentzia calcarea, Pteronia* species and *Chrysocoma ciliata*. Invasive alien species that are spreading within the Karoo biome include *Opuntia humifusa* and*Opuntia ficus indica*.

The increase in geographical spread of creeping prickly pear (*Opuntia humifusa*), *Prosopis* and *Rhizogum trichotomum*, *Rhus* spp. coupled by drought induced mortality on annual grass and shrub species, is worrisome and threaten to reduce grazing capacities and ruminant livestock production. The zones in which the most rapid change appears to be taking place are in the transitional zone between Karoo and various grassveld types. The monitoring of the vegetation change, good grazing management and monitoring of animal numbers over the short and long term in these transitional zones can be regarded as high priority. Monitoring will require the use of rotational grazing and enclosures, plant surveys, soil surveys, climatic data and aerial photography.

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CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Recap of study objectives

The combined effects of explosive *O. humifusa* invasion, recurring drought in the western Free State, and overgrazing affects forage nutrient supply and livestock turnover. *Opuntia humifusa* imposes a major threat to the conservation of native species and the integrity of the ecosystem. The objectives were to characterize indigenous grasses and shrubs species composition and abundance in sheep and cattle rangelands invaded by *O. humifusa*; to determine variations in soil carbon, organic matter and microbial mass under grass, shrub and *Opuntia humifusa*-cover in a semi-arid rangeland; and to assess the interrelations between livestock stocking rates, rainfall and grass and shrub abundance in rangeland invaded by *O. humifusa.*

Grass and shrub species identification were done through plant survey techniques, using the point transect and quadrat method. The *O. humifusa* density in different invasion classes was determined using The Intercept Method. To determine the nutritive value, the most dominant shrub and grass species were sampled for laboratory chemical analysis. Chemical analysis was for CP, NDF, ADL, P, Ca and fat. To establish the relationship between different profiled vegetation cover types in *O. humifusa*-invaded rangeland, soil cores were randomly sampled for soil mineral and microbial analysis. Soil macro and micro minerals, bacterial and fungal population were analysed. A structured questionnaire was used to collect data from farmers around the Koffiefontein area, in an attempt to establish the vegetation changes over a 30-year period from farmers' perspectives.

6.2 Conclusion

The Koffiefontein rangeland is characterized by a low proportion of palatable grasses and shrubs, and high density of *O. humifusa*. The *O. humifusa* densities were 7.7, 12.2 and 60.1% cover in NI, TI and HI respectively. Over the years there has been an increase in unpalatable shrubs and disturbance indicator grass species, rendering the rangeland less productive. Cactus-covered area had high OM and C pools, compared to bare area and grass covered plots. The creeping prickly pear (*O. humifusa*) reduces the farming carrying capacity and displaces indigenous herbaceous materials. The grazing capacity in sheep area decreased to 13.5 ha/lsu in *O. humifusa* heavily invaded zones compared to 6.4 ha/lsu and 5.3 ha/lsu in NI and TI respectively. However, it does have some positive attributes. The benefits from *O. humifusa* includes reduction in soil erosion, preservation of carbon in the soil, and sequestering carbon. The interaction between annual rainfall and grazing capacity was important in determining the vegetation drivers in the study area.

Invasive alien species such as *O. humifusa* and poor grazing management affect production of the Koffiefontein rangelands. Abiotic factors such as rainfall, coupled with high grazing pressure, also affects vegetation. Bare areas in grazing lands are depleted of carbon and organic matter pools. Restoration efforts through re-seeding may be derailed due to a lack of sufficient soil minerals in bare patches. There was in sufficient evidence to establish if soil minerals were a result of *Opuntia humifusa* invasion. However, higher organic matter and carbon pools were found under *O. humifusa*-covered plots, which is a positive attribute

6.3 Recommendations

There is a need for control of the creeping prickly pear and other companion invaders to avoid further veld deterioration.

The western Free State rangeland seems to be in retrogression, although the variables of change were not fully quantified. The interface between carrying capacity and rainfall and invasive species needs further analysis to determine how these would shape Karoo vegetation in the next half century. Cactus colonies continue to increase in number and size, and threaten biodiversity more diversely in species that support herbivores that directly feed the human population. The threat noted in this study was related to loss in microbial flora under cacti colonies. The conundrum of reduced microbial flora but higher carbon pools and carbon sequestration requires further investigation to affirm the role of *Opuntia*-invasion in semi-arid rangelands.

6.4 Future research

The current research study could open up further research opportunities as follows:

1. long-term studies on the impact of climate change on naturalisation and geographical spread of *O. humifusa*;
2. long-term assessment of soil ecology in *O. humifusa*-invaded regions, and the effect thereof on the rehabilitation efforts on degraded lands.
3. further surveys on indigenous knowledge of farmers on impact of climate on vegetation changes, and application of different stocking rates/grazing capacity in sustainable management of grazing/browsing resources.

Appendix 1

A survey of change in vegetation structure of the western Free State rangeland Lukas Chipfupa[1#], Florence V Nherera-Chokuda[2] & Pieter J Fourie[1]

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I, Lukas Chipfupa, a doctorate student with Central University of Technology, undertaking a research project to do an assessment of vegetation changes in the western Free State rangelands, South Africa. To this end, I kindly request that you complete the following questionnaire regarding the vegetation on your farm. It should take no longer than 30 minutes of your time. Your honest responses are of utmost important to me, it will remain anonymous. Should you have any queries or comments regarding this survey, you are welcome to contact me telephonically at 0848277449 or email me at lucas1620@yahoo.co.uk

NB: Please read the following instructions carefully in order to complete this questionnaire correctly;

a) To protect the farm's confidentiality, the producer need not to mention the name of his/her farm or the organization where she or he manages the farm.
b) The farmers or the farm mangers should provide accurate information as far as possible.
c) Mark with **"X"** where you have to choose and give reasons where applicable.

Objectives of the study;

1. to determine vegetation changes over 30 years
2. to determine changes in ruminant livestock on the rangelands
3. to determine major drivers of vegetation change in the western Free State region

Name of farm_________________

Location GPS coordinates: ________________

1. Farm size; i) arable ________________ ii) rangeland size________________
2. Farm classification
   a. Subsistence________________
   b. Smallholder________________
   c. Commercial________________
3. Means of farm ownership
   a. Private ________________
   b. PLAS________________
   c. LRAD________________
   d. Succession________________
4. How many years have you been farming on this land? ________________
5. Farming system
   a. Extensive________________b. intensive system________________
6. Describe the stocking rates of your farm 5 years ago and 30 years ago?

Parameter		Grazing management system			
		Continuous	Rotational		
Cattle stocking rate 5 years ago					
Cattle stocking rate 30 years ago					
Sheep stocking rate 30 years ago					
Sheep stocking rate 5 years ago					
Goats stocking rate 30 years ago					
Goats stocking rate 5 years ago					

7. Crop production: __________________type of crops________________
8. Mixed farming________________
9. Forage production: ___________type of crops__________________
10. What were the changes of your livestock numbers for the past 10 to 30 years? Fill in the table below.

Parameter	Yes/ no	LSU/ha Carrying capacity	Stoc[illegible]g	[illegible]plementary feeding Yes/no	Turnover/year	Comments
Cattle last 10 years						
Cattle last 30 years						
Sheep last 10 years						
Sheep years last 30						
Goats last 10 years						
Goats last 30 years						
Others						

11. Which palatable and unpalatable grass species that were present 10 years and 30 years ago?
    a. Palatable grass species dominant 30 years
    b. Palatable grass species dominant 10 years ago
    c. Unpalatable grass species dominant 30 years ago
    d. Unpalatable grass species dominant in the last 10 years

fill in the table 3 below with a number from 0 to 5

0–not present	1 – very low	2 – low	3 – high	4 – very high	5 – no change

Species	Before 2000	After 2010	Comment
Red grass/Rooigrass			
Kalahari sand quick/Kalahari sandkeek			
Tick grass/Bosluisgras			
Curly leaf/Krulblaar			
Lehmann's love grass/Knietjiesgras			

Dew grass/Douvatgras			
Saw-toothed grass/Weeluisgras			
Annual bristle grass/Eenjarige steekgrass			
White stick grass/witsteekgrass			

12. Which shrubs and browsable tree species were present 10 and 30 years ago?

0–not present	1 – very low	2 – low	3 – high	4 – very high	5 – no change

Species	Before 2000	After 2010	Comment
Bitterbos			
Pentzia calcarea/meerkatkaroo			
Pentzia globose/vaalkaroo			
Gnidia polycephala/januariebos			
Eriocephalus spinescens/Doringkapok			
Eriocephalus eriocoides/kapokbos			
Walafrida geniculate/waterfinder/persaar			
Felicia muricata/bloumblommetjie			
Zygophyllum spp/witkriedoring			
Other shrubs			
Acacia spp			
Searsia lancea/karee			
Rhus spp/suurkaree			
Ziziphus mucronata/Buffalo thorn/Waga-bitjie			

13. Which invasive species have you noticed on your farm 10 years and 30 years ago? Please complete the table below.

Species	1st occurrence	Order of dominance 1;2;3	Areas where species dominate	Selection by animals	Which season	Size of area invaded (acres/ha)	Method of control
Prickly pear							
Silver leaf night shade/Satansbos							
Three thorns							
Prosopis spp							

14. Effects of invasive species on vegetation structure and livestock performance

	Yes	no	If yes, describe changes noted
Effect on palatable species			
Soil cover			
Animal losses			

15. What strategies have you employed on your farm in dealing with the invasive plants? Select below.

Strategy	**Tick the appropriate box**
Selling of the property	
Change of production system comment	
No action taken	
Spraying/ chemical control	

Appendix 2

Table 3.1a O. *humifusa* Newly invaded (NI) sheep grazing area-2016

Species (Sheep NI zone)	Species count	Frequency (%)	Index	EIV factor
T. triandra	78	27.7	10	277
S. uniplumis	3	1.1	7	7.7
E. chloromelas	80	28	4	112
E. obtusa	1	0.4	7	2.8
E. superba	1	0.4	1	0.4
H. contortus	1	0.4	6	2.4
A. adscensionis	29	10.3	8	82.4
A. congesta	70	24.8	9	223.2
C. virgata	2	0.7	4	2.8
F. muricata	1	0.4	8	3.2
W. geniculata	1	0.4	8	3.2
P. calcarea	9	3.2	3	9.6
P. globosa	5	1.8	4	7.2
P. tricephala	1	0.4	1	0.4
	282	**100**		**734,3**

Appendix 3

Table 3.1b *O. humifusa* Transitional zone (TI) sheep grazing area2016

Species (Sheep TI zone)	**Species count**	**Frequency (%)**	**Index**	**EIV factor**
T. triandra	43	16.5	10	165
E. chloromelas	59	22.6	4	90.4
E. obtusa	3	1.2	7	98.8
H. contortus	1	0.4	6	2.4
A. adscensionis	27	10.4	8	83.2
A. congesta	103	39.6	9	356.4
C. virgata	5	1.9	4	7.6
C. ciliata	2	0.8	3	2.4
F. muricata	4	1.5	8	12
W. saxitilis	1	0.4	1	0.4
P. calcarea	7	2.7	3	8.1
P. globosa	2	0.8	4	3.2
P. parvifolium	1	0.4	8	3.2
P. tricephala	1	0.4	1	0.4
Z. incrustatum	1	0.4	1	0.4
	260	100		**833.9%**

Appendix 4

Table 3.1c *O. humifusa* Heavily inv p grazing area2016

Species (Sheep HI zone)	ecies ount	uency (%)	ndex	V factor
T. triandra	8	3.3	10	33
E. chloromelas	16	6.6	4	26.4
E. obtusa	5	2.1	7	14.7
H. contortus	21	8.7	6	52.2
A. adscensionis	70	29	8	232
A. congesta	30	12.4	9	111.6
C. virgata	1	0.4	4	1.6
C. ciliata	12	5	2	10
F. muricata	3	1.2	8	9.6
P. calcarea	34	14.2	3	42.6
P. globosa	38	15.9	4	63.6
P. tricephala	1	0.4	1	0.4
Z. incrustatum	2	0.8	1	0.8
	241	**100**		**598.5**

Appendix 5

Table 3.1a *O. humifusa* newly invaded (NI) sheep grazing area-2017

Species (Sheep NI zone)	ies count	uency (%)	ndex	V factor
T. triandra	58	20	10	200

E. chloromelas	17		4	23.6
A. meriodenalis	4	1.4	4	5.6
D. erinthea	1	0.3	10	3
H. contortus	15	5.2	6	31.2
A. adscensionis	94	32.4	8	259.2
A. congesta	30	10.3	9	92.7
E. cenchroides	42	14.5	4	58
E. desvauxii	3	1	0	0
C. virgata	8	2.8	4	11.2
P. calcarea	2	0.7	3	2.1
Fingerhuthia africana	2	0.7	10	7
P. tricephala	6	2.1	1	2.1
E. spinescenes	8	2.7	1	2.7
	290	100		689,3

Appendix 6

Table 3.1b *O. humifusa* Transitional zone (TI) sheep grazing area 2016

Species (Sheep TI zone)	**Species count**	**Frequency (%)**	**Index**	**EIV factor**
T. triandra	21	7.7	10	77
E. lehmanniana	10	3.7	10	37

E. chloromelas	18		4	26.4
E. obtusa	1	0.4	7	2.8
E. cenchroides	22	8.1	4	32.4
E. desvauxii	1	0.4	0	0
H. contortus	9	3.3	6	19.8
A. adscensionis	65	23.8	8	190.4
A. stipitata	1	0.4	7	2.8
A. congesta	85	31	9	279
C. virgata	19	7	4	28
C. ciliata	1	0.4	2	0.8
R. humilis	1	0.4	8	3.2
P. tricephala	3	1	1	1
E. spinescenes	7	2.6	1	2.6
E. asparagoides	3	1	1	1
P. calcarea	4	1.5	3	4.5
P. globosa	2	0.7	4	2.8
	273	**100**		**711.5**

Appendix 7

Table 3.1c *O. humifusa* Heavily invaded (HI) sheep grazing area-2017

Species (Sheep HI zone)	Species count	frequency (%)	index	EIV factor
T. triandra	17	6.5	10	65
E. lehmanniana	1	0.4	10	4
E. chloromelas	6	2.3	4	9.2

E. obtusa	2		7	5.6
E. cenchroides	5	1.9	4	7.6
E. desvauxii	6	2.3	0	0
Fingerhuthia africana	1	0.4	7	2.8
Panicum spp	2	0.8	10	8
H. contortus	22	8.4	6	50.4
A. adscensionis	109	41.4	8	331.2
A. congesta	23	8.7	9	78.3
C. virgata	20	7.6	4	30.4
F. muricata	1	0.4	8	3.2
C. ciliata	2	0.8	2	1.6
P. calcarea	18	6.8	3	20.4
P. globosa	10	3.8	4	15.2
R. humilis	2	0.8	8	6.4
P. tricephala	3	1.1	1	1.1
W. geniculata	2	0.8	8	6.4
E. spinescenes	8	3	1	3
Z. incrustatum	3	1	1	1
	263	**100**		**650.8**

Appendix 8

Table 3.1a newly invaded (NI) cattle grazing area-2016

Species (NI zone) cattle	Species count	Frequency (%)	index	EIV factor
Aristida adscensionis	183	51.7	8	413.6
Aristida congesta	3	0.8	9	7.2
Aristida stipitata	1	0.3	7	2.1

Chloris virgata	51	14.4	4	57.6
Chrysocoma ciliata	3	0.8	3	2.4
Eragrostis chloromelas	24	6.8	4	27.2
Eragrostis obtusa	32	9	7	63
Eragrostis trichophora 18		5.1	5	25.5
		0.3	6	1.8
Heteropogon contortus	1			
Pentzia calcarea	28	7.9	3	23.7
Pentzia globosa	2	0.6	4	2.4
Pteronia tricephala	1	0.3	4	1.2
Themeda triandra	5	1.4	10	14
Thesium hystrix	1	0.3	1	0.3
Walafrida saxitilies	1	0.3	1	0.3
	354	**100**		**642.3**

Appendix 9

Table 3.1b *O. humifusa* Transitional zone (TI) sheep grazing area-2016

Species (TI zone)	**Species count**	**Frequency (%)**	**ndex**	**EIV factor**
Aristida adscensionis	27	9.3	8	74.4
Aristida congesta	12	4.2	9	37.8
Aristida stipitata	3	1	7	7
Cynodon dactylon	9	3.1	4	12.4
Eragrostis chloromelas	37	12.8	4	51.2

Eragrostis lehmanniana	12	4.2	10	42
Eragrostis obtusa	22	7.6	7	53.2
Eragrostis trichophora 76		26.3	5	131.5
	52	18	6	108
Heteropogon contortus				
Pentzia calcarea	2	0.7	3	2.1
Pentzia globosa	5	1.7	4	6.8
Pteronia tricephala	5	1.7	4	6.8
Themeda triandra	6	2.1	10	21
Schimidtia pappophoroides	6	1.7	10	17
Felicia muricata	2	0.7	8	5.6
Thesium hystrix	6	2.1	1	2.1
Gnidia tricephala	2	0.7	1	0.7
Walafrida geniculata	5	1.7	8	13.6
	289	**100**		**593.2**

Appendix 10

Table 3.1c *O. humifusa* Heavily invaded (HI) cattle grazing area-2016

Species (HI zone)	Species count	Frequency (%)	index	EIV factor
Aristida adscensionis	26	8.6	8	68.8
Aristida congesta	6	2	9	18
Aristida stipitata	5	1.7	7	11.9
Chloris virgata	2	0.7	4	2.8
Cynodon dactylon	8	2.6	4	10.4
Chrysocoma ciliata	5	1.7	3	5.1
Cynodon hirsutus	1	0.3	3	0.9

Eragrostis chloromelas	4	1.4	4	5.6
Eragrostis lehmanniana	1	0.3	10	3
Eragrostis obtusa	11	3.6	7	25.2
Eragrostis superba	13	4.3	1	4.3
Eragrostis trichophora	22	7.3	5	36.5
Euryops asparagoides	25	8.3	1	8.3
Felicia muricata	2	0.7	8	5.6
Heteropogon contortus	18	5.7	6	34.2
Lycium spp	8	2.7	6	16.2
Pentzia calcarea	29	9.6	3	28.8
Pentzia globosa	69	22.9	4	91.6
Pteronia tricephala	1	0.3	4	1.2
Thesium hystrix	13	4.3	1	4.3
Zygophyllum incrustatum	15	5	1	5
	302	**100**		**387.7**

Appendix 11

Table 3.1a *O. humifusa* newly invaded (NI) sheep grazing area-2017

Species (NI zone)	Species count	Frequency (%)	index	EIV factor
Aristida adscensionis	5	1.3	8	10.4
Aristida congesta	114	28.9	9	260.1
Fingerhuthia africana	2	0.5	4	2
Chloris virgata	142	36	4	144
Chrysocoma ciliata	6	1.5	3	4.5
Enneapogon cenchroides	1	0.3	4	1.2
Enneapogon desvauxi	9	2.3	0	0

	39	9.9	4	39.6
Eragrostis chloromelas				
Eragrostis obtusa	21	5.3	7	37.1
Eriocephalus eriocodes	1	0.3	0	0
Eriocephalus spinescenes	1	0.3	1	0.3
Felicia muricata	5	1.3	8	10.4
Heteropogon contortus	1	0.3	6	1.8
Lycium spp	4	1	6	6
Pentzia calcarea	15	3.7	3	11.1
Rosenia humilis	1	0.3	8	2.4
Themeda triandra	12	3	10	30
Walafrida geniculata	8	2	8	16
Zygophyllum incrastatum	7	1.8	1	1.8
	394	**100**		**578.7**

Appendix 12

Table 3.1b *O. humifusa* Transitional zone (TI) sheep grazing area-2017

Species (TI zone)	Species count	Frequency (%)	index	EIV factor
Aristida adscensionis	39	9.8	8	78.4
Aristida congesta	115	28.7	9	258.3
Asparagus spp	2	0.5	1	0.5
Fingerhuthia african	3	0.8	4	3.2
Chloris virgata	33	8.3	4	33.2
Chrysocoma ciliata	5	1.3	3	3.9
Enneapogon desvauxii	3	0.8	0	0

Eragrostis chloromelas	67	16.8	4	67.2
Eragrostis lehmanniana	4	1	10	10
Eragrostis obtusa	32	8	7	56
Eragrostis superba	9	2.3	1	2.3
Eriocephalus spinescenes	7	1.8	1	1.8
Gnidia polycephala	2	0.5	1	0.5
Heteropogon contortus	44	11.1	6	66.6
Lycium spp	1	0.2	6	1.2
Panicum spp	1	0.2	10	2
Pentzia calcarea	1	0.2	3	0.6
Pteronia tricephala	4	1	4	4
Themeda triandra	7	1.8	10	18
Thesium hystrix	4	1	1	1
Walafrida saxitilies	3	0.8	1	0.8
Walafrida geniculata	5	0.8	8	6.4
	398	**100**		**615.9**

Appendix 13

Table 3.1c Species list in the *O. humifusa* Heavily invaded (HI) sheep grazing area- 2017

Species (HI zone)	Species count	frequency (%)	index	EIV factor
Aristida adscensionis	20	5.2	8	41.6
Aristida congesta	46	12	9	108
Asparagus spp	4	1	1	1
Fingerhuthia africana	22	5.8	4	23.2
Chloris virgata	92	24.2	4	96.8
Chrysocoma ciliata	1	0.3	3	0.9
Enneapogon desvauxii	4	1.1	0	0
Eragrostis chloromelas	23	6	4	24
Eragrostis lehmanniana	7	1.8	10	18
Eragrostis obtusa	11	2.9	7	20.3

Eragrostis superba	8		1	2.1
Euryops asparagoides	16	4.2	1	4.2
Heteropogon contortus	21	5.5	6	33
Salsola spp	11	2.9	1	2.9
Panicum spp	4	1	10	10
Lycium spp	11	2.9	6	17.4
Pentzia calcarea	18	4.7	3	14.1
Thesium hystrix	11	2.9	1	2.9
Thimble grass	1	0.3	7	2.1
Walafrida geniculata	41	10.8	1	10.8
Zygophyllum incrastatum	8	2.1	1	2.1
	380	**100**		**434.5**