REHABILITATION AS A METHOD OF UNDERSTANDING VEGETATION CHANGE IN PAULSHOEK, NAMAQUALAND

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A thesis submitted in partial fulfilment of the requirements for the degree of Magister Scientiae, in the Department of Biodiversity and Conservation Biology, University of the Western Cape

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Co -Supervisor: Dr Richard Knight

March 2005

This thesis is dedicated to my father, who introduced me to the beauty of Namaqualand and its people.

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Liora–lee Simons

KEYWORDS:

Arid Ecosystems

Succulent Karoo

Namaqualand

Rangelands

Vegetation Change

Rehabilitation

Grazing

Galenia africana

ABSTRACT

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Heavy grazing of rangelands in the succulent karoo has placed the biodiversity of these areas at risk. In Paulshoek, overgrazing has resulted in the removal of much of the palatable vegetation from low lying areas. The remaining vegetation is dominated by *Galenia africana,* an unpalatable shrub. Loss of favourable microsites, competition from *Galenia africana*, as well as loss of seed banks, may be the cause of poor seedling establishment of palatable species. I explored how high grazing pressure has changed this system by comparing with surrounding private farms, which have a history of less concentrated grazing pressure. I found that heavy grazing increased the seed bank of *Galenia africana* in the soil and reduced that of palatable perennials. Vegetation cover was significantly lower ($p<0.0001$) under heavy grazing and consisted mainly of *Galenia africana* and few palatable perennials.

The aim of this study was to test techniques that could restore this area to a more productive palatable shrubland. I propose that rehabilitation can be used to gain an understanding of the ecological factors that may be sustaining this altered vegetation state. My methodology involved biophysical interventions to manipulate this system. Grazing pressure was removed from the study area and vegetation changes were monitored under grazed and protected regimes. No change in plant cover was found after two years. However, there was an increase in cover of palatable perennials in relation to overall cover.

I physically manipulated the environment by introducing microcatchments and brushpacks to act as traps for water, seed and organic material. These interventions resulted in few changes, however, I found higher soil moisture levels in microcatchments and under brushpacks than open positions. Cover of ephemerals was also significantly higher ($p<0.001$) in areas that had been brushpacked. In the absence of a seedbank, I tested whether the introduction of seed would result in recruitment. Seed of four palatable perennial species was sown into open, packed and tilled soil. A low number of seeds germinated in the first year and most seedlings died. Further germination occurred after a rainfall event in the second year, but still in very low numbers.

Various microhabitats were implemented to assess seedling establishment requirements. Seedlings were transplanted in microcatchments and open positions; in areas cleared of *Galenia*, under adult *Galenia* and brush packs and in bare soil. Microhabitats did not facilitate seedling establishment, and few seedlings survived. Survival of seedlings was influenced by the size of seedling at transplantation and site differences.

I conclude that the factors underlying vegetation change are complex. Individual physical and biological interventions offered no immediate change in vegetation cover and composition. However, a combination of interventions may over time and under favourable climatic conditions allow the return of a viable palatable shrubland.

March 2005

DECLARATION

I declare that REHABILITATION AS A METHOD OF UNDERSTANDING VEGETATION CHANGE IN PAULSHOEK, NAMAQUALAND is my own work, that it has not been submitted for any degree or examination in any other university, and that all the sources I have used or quoted have been indicated and acknowledged by complete reference

Liora-lee Simons March 2005

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ACKNOWLEDGEMENTS

I wish to thank the following people for their valuable contributions to this study;

My heartfelt thanks go to Dr. Nicky Allsopp for her guidance, support and advice. It has been an honour to share this time with her and I am a better researcher because of it.

Many thanks to Dr. Richard Knight for his supervision. Sincere thanks to Prof. Eugene Moll for his professional support and advice on drafts. Thanks to Mr. Frans Weitz for his editorial assistance.

Prof. M. Timm Hoffman for provision of climatic data and useful discussions. Dr. Peter Carrick for advice on seedbank methodologies and useful discussions. Prof David Ward for advice on the statistical analysis of seedling data in chapter 5.

The following programmes and organisations have provided funding for this study for which I am grateful:

National Department of Agriculture – Landcare Programme

Agricultural Research Council – Professional Development Programme

Agricultural Research Council – Range and Forage Institute

European Union: International Cooperation with Developing Countries (INCO-DC) – Project no's. ERBIC18CT970162 and ICA4-CT-2001-10050

Many thanks to the Environmental Education and Resource Unit for providing space in their glasshouse for the seedbank study, and Winston Coe for his assistance.

I am indebted to the staff and postgraduate students of the Biodiversity and Conservation Biology Department for their interest in this study and support. I would specifically like to thank the department for the provision of laboratory and office space and the use of equipment.

During the course of this study I have had the pleasure of spending a great deal of time in the Paulshoek village. My sincere thanks goes to the Paulshoek community for their kindness and allowing me to do my research in the area. I am indebted to John “Herlus” Corjeus for his assistance and the time spent with me in the hot sun and freezing cold in the veld. A special word of thanks to Magrieta “Ou Tannie” Andrews and Johannes “Oom Vonkie” Claasen for their hospitality and willingness to share their homes with me.

To my friends: Stacey Brown, Jocelyn Collins, Tammy Thring, Corinna Riginos, Cher Leetjer, Jeffrey Manual, Michiel Smet and Clement Cupido. Your friendship, encouragement and above all good humour have made this process bearable. It’s been a pleasure to share this experience with you. A special word of thanks to Henzel Saul for his love, support and encouragement.

Finally, my heartfelt gratitude goes out to my family; Mom, Joylene, Dale, Brian and Verity, and all my aunts, uncles and cousins. Your prayers, sacrifice, love and support have been the driving force behind me. I am eternally grateful to all of you.

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CHAPTER 1

INTRODUCTION

1.1. Background

The abundance of rangelands studies worldwide is indicative of their importance to the livelihoods of people and the extended urban networks they feed into. The deteriorating condition of rangelands in Africa due to grazing pressure and climate change has been the focus of much of this research (Ellis & Swift, 1988; Coppock, 1993). In South Africa, Hoffman *et al*. (1999) showed that 25% of natural rangelands are degraded. In the karoo loss of productivity of rangelands has primarily been attributed to overgrazing and agricultural practices such as ploughing (Acocks, 1953; Dean & Mcdonald, 1994).

On the communal rangelands of South Africa, overgrazing by livestock is often presumed to be inevitable and these areas are often branded as poorly managed, overstocked and degraded (Vetter, 2004). Hardin (1968) called this the tragedy of the commons and postulated that lack of ownership of resources leads to individuals maximizing animal numbers and profits at the expense of the resource and other landusers. Various role players and advisory services have attempted to address the problem through destocking schemes, camp systems and the implementation of economic units (Archer, 1989). However removal of grazing pressure does not result in the recovery of vegetation in a time frame suitable for landowners (van Rooyen, 2000). This approach to management of communal areas has received criticism (Ellis & Swift, 1988; Abel & Blaikie, 1989, Behnke & Scoones, 1993; Sullivan & Rhode, 2002) due to the underlying ecological and economic assumptions that such areas are mismanaged. Furthermore, terms such as degradation are often used too quickly and the extent and apparent irreversibility of degradation has been over estimated (Dean *et al.*, 1995). Thus the problem of identifying degradation persists as it is often difficult to distinguish between irreversible changes and short term changes in driving forces such as grazing and climate which can result in change.

Abel & Blaikie (1989) defines degradation as a permanent decline in the rate at which land yields livestock products under a given system of management. This means that natural processes will not rehabilitate the land within a time scale relevant to humans, and that capital or labour invested in rehabilitation is justified. In arid and semi arid environments degradation is said to occur when the vegetation had crossed or was at risk of crossing a critical threshold, which prevents or severely inhibits the subsequent return to a more productive state (Behnke & Scoones, 1993; Friedel, 1991). Degradation thus refers to an irreversible change within a natural system.

On the commons of Paulshoek, Namaqualand, the livelihoods of people are affected by grazing induced vegetation change of rangelands. Monotypic stands of unpalatable *Galenia africana* L. (Aizoaceae) dominate the lowlands (Todd & Hoffman, 1999). Land users are aware of the decline in rangeland condition and experience it in the subsequent reduction in animal health especially in times of drought. The permanence of this change in vegetation composition is not fully understood and the possible drivers have not been investigated. There is thus a need to investigate the processes maintaining this system in an altered state, and why transitions to more palatable states do not occur.

In 1999 the Paulshoek community received funding from the National Department of Agriculture's Landcare Programme. Landcare South Africa is a community-based programme focused on the conservation of natural resources (soil, water and vegetation) through sustainable utilisation and the creation of a conservation ethic through education and awareness (Molope, 1999). As part of this programme part of Paulshoek (255.1 ha) was fenced off and set aside as a grazing reserve for times of drought. This made Paulshoek an ideal study site to test rehabilitation treatments and to monitor vegetation in the absence of grazing over time.

1.2. Aims of study

The main aim of this study was to test rehabilitation interventions in a system altered by heavy grazing, and to develop methods of monitoring these interventions. I hypothesized that through the process of rehabilitation we could gain an understanding for the ecological processes that are maintaining grazing induced vegetation change and that may be preventing transition to a more productive shrubland. Through biophysical manipulations, I could determine which of many factors is most limiting to long term ecosystem recovery.

1.3. Thesis outline

Chapter 2 provides a historical background of the study site, and the description of study area in terms of the vegetation, climate and soil chemistry. In Chapter

3, I explore how continuous concentrated grazing pressure has changed this system by comparing heavily and lightly grazed areas in terms of vegetation composition, cover and seedbank composition. Results from this chapter provide a framework for rehabilitation interventions tested in Chapter 4 and 5. Chapter 4 investigates the use of grazing exclusion as a means of understanding vegetation dynamics within a system transformed by heavy grazing. Chapter 5 investigates the process of rehabilitation and how it can be used to gain an understanding of the ecological factors that may be sustaining this altered vegetation state. Chapter 6 provides a synthesis of this study with conclusions and recommendations

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CHAPTER 2

SITE HISTORY AND DESCRIPTION

2.1. Introduction

Present day management of natural resources in Paulshoek, Namaqualand are rooted in past events that influenced access to land. This chapter describes how past land users and policies regarding land use, have directly affected the management of this resource, and how this ultimately impacts on the current condition of this rangeland. The current physical and social environment of the study area is described; with emphasis on the effects of extended, concentrated grazing pressure on rangeland function.

2.2. Historical review of Namaqualand

2.2.1. Early History

The origin of communal land use in the coloured reserves of South Africa dates back to pre-colonial times. Prior to the arrival of the European settlers, Namaqualand was inhabited by San hunter-gatherers and the Little Namaquas, who were a Nama speaking branch of the nomadic Khoikhoi (Webley, 1984). The Khoikhoi pastoralists kept small stock and cattle, and engaged in transhumance to take advantage of seasonal differences in grazing and water resources (Hoffman *et al.*, 2000). In the area of the present day Leliefontein reserve Namaqua herders would move their stock approximately 100 km from the Kamiesberg to the "Onderveld", which had a milder climate for lambing and better grazing in winter (Webley, 1984).

The arrival of European settlers in 1652 resulted in many Khoikhoi being robbed of their herds, losing their grazing lands and the subsequent disruption of their traditional transhumance, as these early colonists moved into the interior (Webley, 1984; Boonzaaier *et al*., 1996). The resulting violent conflicts drove many Khoikhoi to slavery and serfdom, and by the 1800s little remained of their pastoralist lifestyle as many took advantage of the increased demand for wage labour in the urban and mining centres (Boonzaaier *et al*., 1996)

2.2.2. Establishment of the Leliefontein reserve

Displaced people from various tribes including the Namaquas, Khoikhoi and Basters (people of mixed descent who were excluded from colonial society) found refuge at various mission stations in the Leliefontein district of the Kamiesberg. The establishment of mission stations in the early 1800s was encouraged as a means to stabilise indigenous communities by promoting the cultivation of crops. However, some farmers continued to move with their herds in semi-nomadic patterns in the commons surrounding the mission station. Grazing in the immediate vicinity of the station soon became depleted, and smaller permanent settlements and mobile stockposts were formed at some distance from the core village (Boonzaaier *et al*., 1996).

These stockposts were to become an integral part of stock farming in the communal reserves. In 1840 the official boundaries of the Leliefontein communal reserve were laid down and a "ticket of occupation" was issued to the Namaquas, providing certainty and security with regard to their occupation of this land (SPP, 1995). However, the state never recognized their claim of ownership, and only awarded them occupational status. The existing boundaries of the reserve are still disputed as many inhabitants claim that dispossession continued even after formal recognition from the Cape Colony (SPP, 1995; May, 1997).

2.2.3.The apartheid era and after

By the 1950s schools and shops became commonplace within the reserve. The lifestyles of people in the reserves took on a more sedentary nature as they settled in core areas. As a result it became increasingly difficult for families to permanently stay with their herds without help from hired herdsman, who could stay with the livestock at stockposts scattered throughout the commonage. Furthermore, many reserve residents were using wage labour on the mines as a supplement to farming, resulting in a flow of workers from the communal villages. Upholding links with the reserve and farming was seen as a security net when retrenchments occurred on the mines (Boonzaaier, 1987).

The Rural Coloured Areas Act of 1963 separated residential and agricultural areas, forcing families to leave their stockposts and settle within villages (Archer *et al.*, 1989). The official aim of this scheme was to act as a solution to overgrazing and erosion and the development of more profitable farming practices (Boonzaaier, 1987, Archer *et al.*, 1989). In 1984, the Leliefontein reserve was subdivided into 47 economic units, ranging between 1 500 and 6 175 ha (Archer *et al.*, 1989). Thirty units were rented to individuals, while only 17 was set aside for communal use. The economic units discriminated against poorer farmers who could not afford to apply for units, restricting many to the smaller communal units.

As a result many opposed the privatisation of the land. Consequently, four communal farmers contested the issue in court and the case ended in a Supreme Court victory for them (Archer *et al*., 1989). By the late 1980s, land in the Leliefontein reserve had returned to communal tenure (Archer *et al*., 1989; SPP, 1995). After the first democratic elections in 1994, the old Land Acts were abolished and a policy of restitution and land reform was adopted resulting in the purchase of additional grazing lands. Today the Leliefontein reserve covers an area of 279 000 ha (SPP, 1995; Hoffman *et al*., 2000).

2.3. Physical environment and climate

The Leliefontein reserve extends across the Kamiesberg, from low-lying strandveld in the west to the inland border of the Bushmanland plateau (Fig. 2.1). The Kamiesberg is 980 – 1400 m above sea level and consists of gneiss hills and mountains with underlying bedrock of quartzite, which is surrounded by base-rich shallow sandy plains (Cowling *et al*., 1999). Granites and gneisses decay to form rich soils. In the south the Karoo Sequence shales and sandstones give rise to more skeletal soils (Low & Rebelo, 1996). Isolated inselbergs and koppies in the "lowlands" are a major topographic feature (Hilton-Taylor, 1994). The region falls within the Namaqualand complex of the Great Escarpment, whose combined geomorphologic diversity and changes in soils and climate, has a profound effect on plant species diversity.

The reserve receives unpredictable rainfall with the western areas receiving mostly winter rainfall (May-August) and the eastern areas summer rainfall. Paulshoek receives an estimated average of 180 mm of rain per year, though much variation occurs across the area when comparing individual rainfall events

(Fig 2.2) (M.T. Hoffman unpublished data). The prevailing wind direction is southwesterly with an average wind speed of between 2 and 6 ms^{-1} (Fig 2.3). The area is generally characterised by a moderate climate, with the maximum temperatures rarely exceeding 37 ^{o}C in summer, though the temperature is known to drop below freezing in winter (Fig 2.4) (MT. Hoffman unpublished data).

2.4. Vegetation

In the Paulshoek region, 255 plant species in 39 families have been recorded, with the dominant families being Asteraceae, Mesembryanthemaceae, Crassulaceae and Aizoaceae (Petersen, 2004). The vegetation of the region falls within the Succulent karoo biome (Low & Rebelo, 1996) and is defined as shrubland. The sandy lowlands are classified as Namaqualand broken veld (Acocks, 1953; Hilton-Taylor, 1994), which is characterised by the leaf succulent Mesembryanthemaceae family although other succulents, deciduous and perennial Asteraceae and geophytes are also common (Cowling *et al.*, 1999).

In Paulshoek, the lowland communities are dominated by *Galenia africana* and *Ruschia robusta* L. Bolus (Mesembryanthemaceae) (Todd & Hoffman, 1999; Petersen, 2004), while the uplands is characterised by *Pteronia glomerata* with pockets of mountain fynbos which merge into renosterveld vegetation on the high lying rocky areas (Hilton-Taylor, 1994; Petersen, 2004). These fynbos affinities can be recognized by the presence of typical elements from the Proteaceae, Ericaceae, Restionaceae as well as geophytes. The vegetation

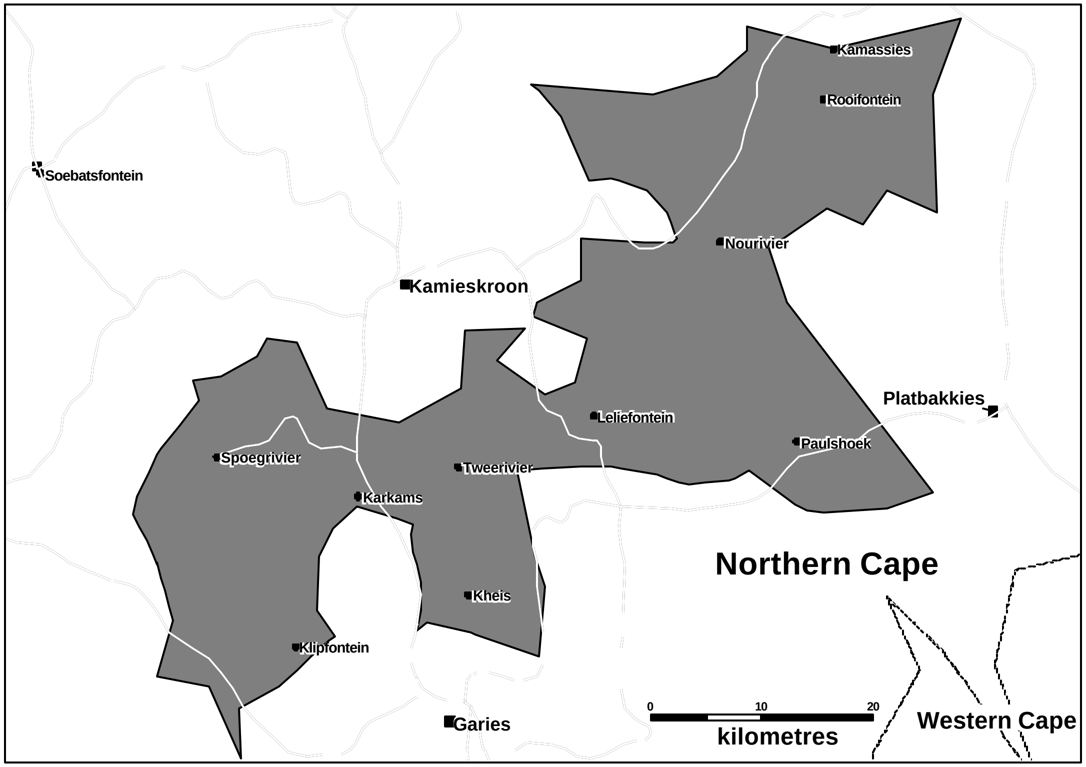

Fig. 2.1. Map of the Leliefontein reserve indicating the position of the ten villages in the commons (Rohde *et al.*, 2003).

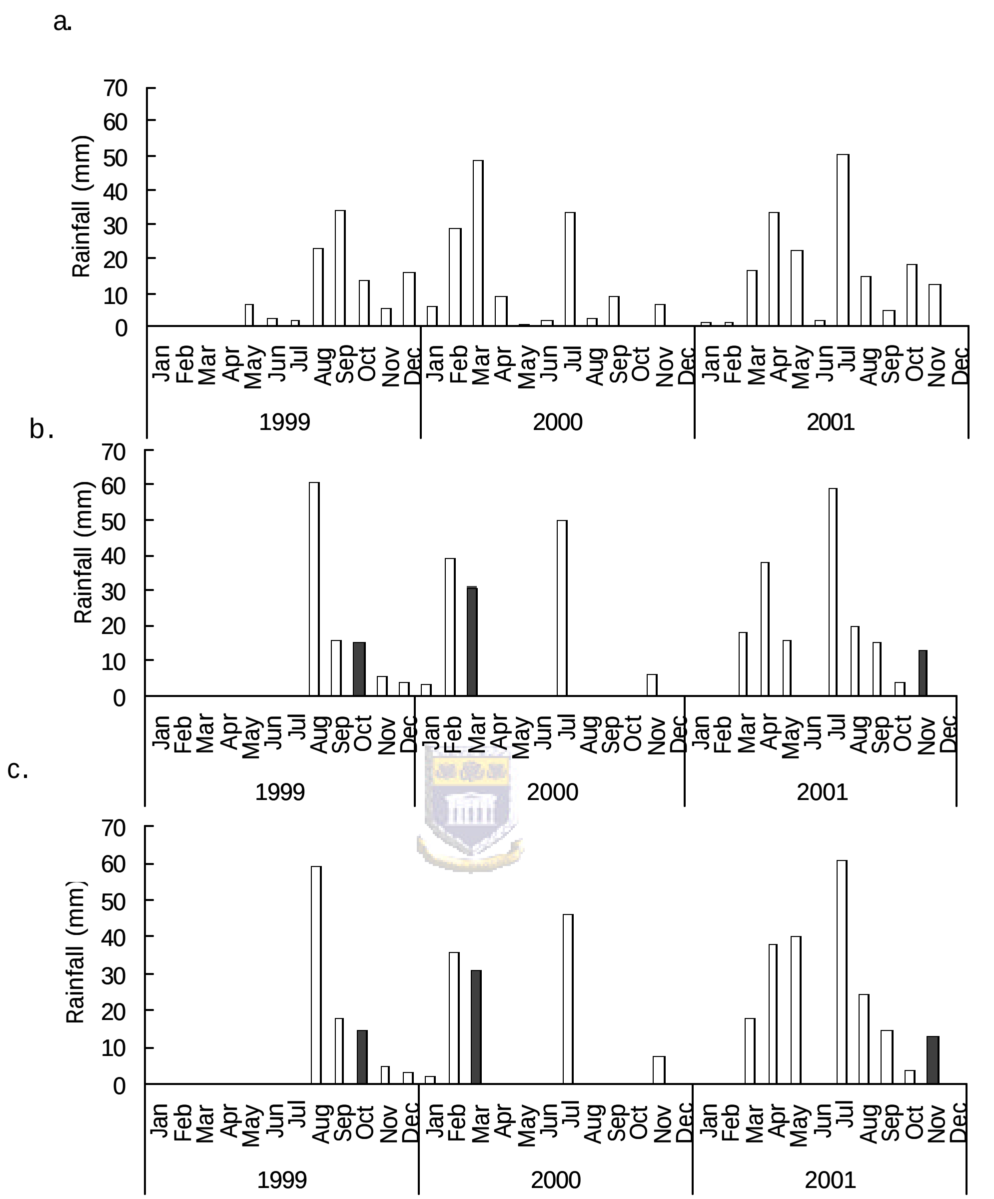

Fig. 2.2. Rainfall for Site 1 (a), Site 2 (b) and Site 3 (c) for the years 1999, 2000 and 2001. Shaded bars indicate average rainfall for the greater Paulshoek region to replace missing data points (MT. Hoffman unpublished data).

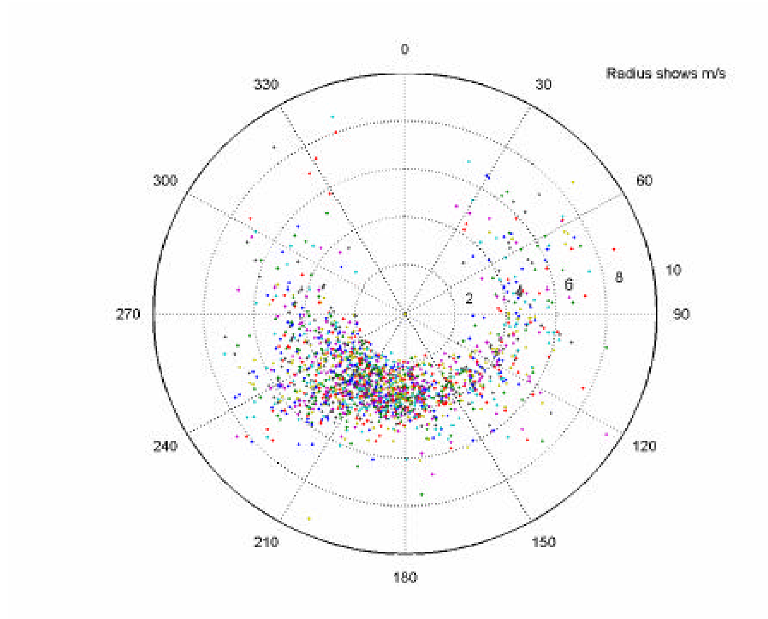

Fig. 2.3. Polar plot showing daily prevailing wind direction (angle: 0^0 = north) and wind speed (radius: m/s) for Paulshoek calculated over 54 months (July 1999 – December 2003) (MT. Hoffmann unpublished data)

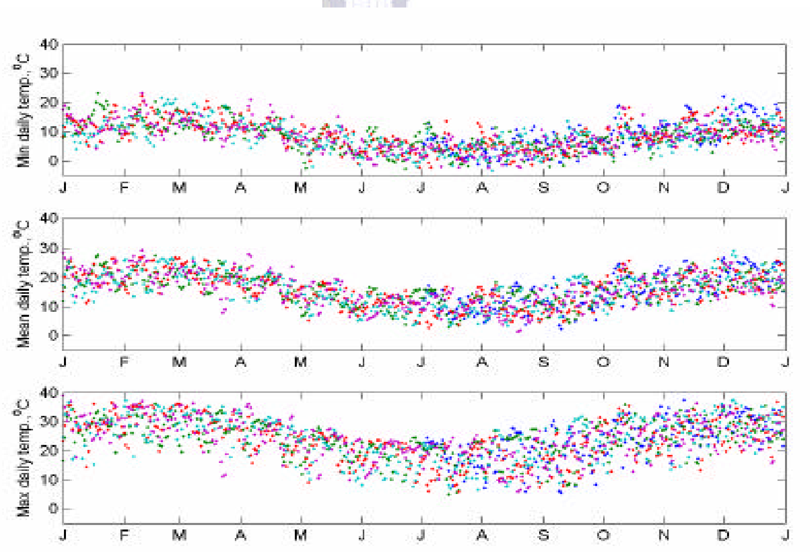

Fig. 2.4. Daily temperatures (minimum, mean, maximun) for Paulshoek calculated over 54 months (July 1999 – December 2003) (MT. Hoffman unpublished data).

ranges between 0.5 m and 1 m high and is slightly higher on rocky areas than on plains.

2.5. Livelihoods and land use practices

The main reliable sources of income for households in Paulshoek are disability grants and state pensions (May, 1997). Mines, commercial farms and larger towns such as Springbok, Vredendal and as far as Cape Town, offer the main source of employment to people from the Leliefontein reserve. Potential earnings from mining and commercial agriculture are not reliable, as much of this work is on a contract basis or seasonal and the future of these industries in the province is very uncertain (May, 1997; Anseeuw, 2000).

Small livestock production and cultivation of oats, wheat, rye and barley are the main agricultural activities in Paulshoek (Hoffman *et al*., 2000; Anseeuw, 2000). Production of crops is dependent on rainfall, and crop failures are frequent and returns are variable. Crop farming constitutes a very small part of livelihoods in Paulshoek, with fewer than 15 households sowing in the last five years (Hoffman *et al*., 2000). Animal production is mainly aimed at household consumption and exchange within families, and serves a savings function with few livestock owners selling animals on commercial markets (Anseeuw, 2000).

Paulshoek is one of the smaller villages (22 000 ha) in the Leliefontein reserve (Fig 2.1), with a population of approximately 600-800 people, consisting of 130 households within the village and 28 stockposts in the commons surrounding the primary settlement (Hoffman *et al*., 2000; Rohde, Hoffman & Allsopp, 2003) (Fig

2.5). In the 1930s, a group of displaced people settled in the area known as Moedverloor within Paulshoek, and practiced small scale cropping as well as livestock farming. This area is flatter than the surrounding grazing areas and, until 1998, was heavily utilised by stock as it was easily accessed from the village. Reports from elderly members of the community confirm that between 1920 and 1960 nearly all land capable of being cultivated had been ploughed at some time (Rohde *et al.*, 2003). Such large scale disturbance combined with over utilisation by small stock of this area has resulted in the removal of much of the palatable vegetation. The remaining vegetation is dominated by *Galenia africana*, which is toxic to livestock. Today it is hard to distinguish between changes in the vegetation brought about by ploughing compared to heavy grazing.

In Paulshoek, livestock farming is based on a communal tenure system, which allows all inhabitants access to natural resources. Regulations and mutual arrangements between livestock farmers do exist to control land use (May, 1997; Debeaudoin, 2002). However, no formal written controls are in place with regard to stock numbers or movement (May, 1997). Herds comprise of goats and sheep, which are herded by day and kraaled at night at stockposts. Boer goats and a hybrid mix of Karakul, Persian, Dorper and indigenous Afrikaner sheep are kept in a ratio of two goats to one sheep, though this may vary between individual herds (Rohde *et al.*, 2000). The mean sizes of herds between the 28 stockposts are generally low with less than 100 sheep and goats per herd (Todd & Hoffman, 2000). However this excludes a large population of donkeys, which is estimated at 230 donkeys (MT. Hoffman pers comm). Stocking rates vary greatly with rainfall, dropping below 1000 goats and sheep in a drought year and exceeding 6000 animals following exceptionally good rainfall years (MT. Hoffman pers comm). Though the term "grazing" will be used throughout this thesis, the study area is defined as a shrubland (Low & Rebelo, 1996) and thus grazing and grazing areas comprises browsing and browse material.

The stocking rate in Paulshoek for the past 30 years has been twice that recommended by the South African Department of Agriculture (Todd & Hoffman, 1999). Effects of trampling and grazing are most clearly seen around stockposts and watering points. This problem is compounded by the size of the Paulshoek commons relative to the number of landusers and stockposts not moving regularly, with some occupying the same position for over 20 years (Solomon, 2000; Todd & Hoffman, 2000). The effect of livestock on rangeland ecology will be discussed in Chapter 3.

2.6. Site selection

In 1999, the Paulshoek community received funding from the National Department of Agriculture's Landcare Program, to protect and improve their natural resources. As part of this program part of the Moedverloor area (255.1 ha) in Paulshoek was fenced off and set aside as grazing reserve for times of drought. This made Moedverloor an ideal study site to test rehabilitation treatments and to monitor vegetation in the absence of grazing over time.

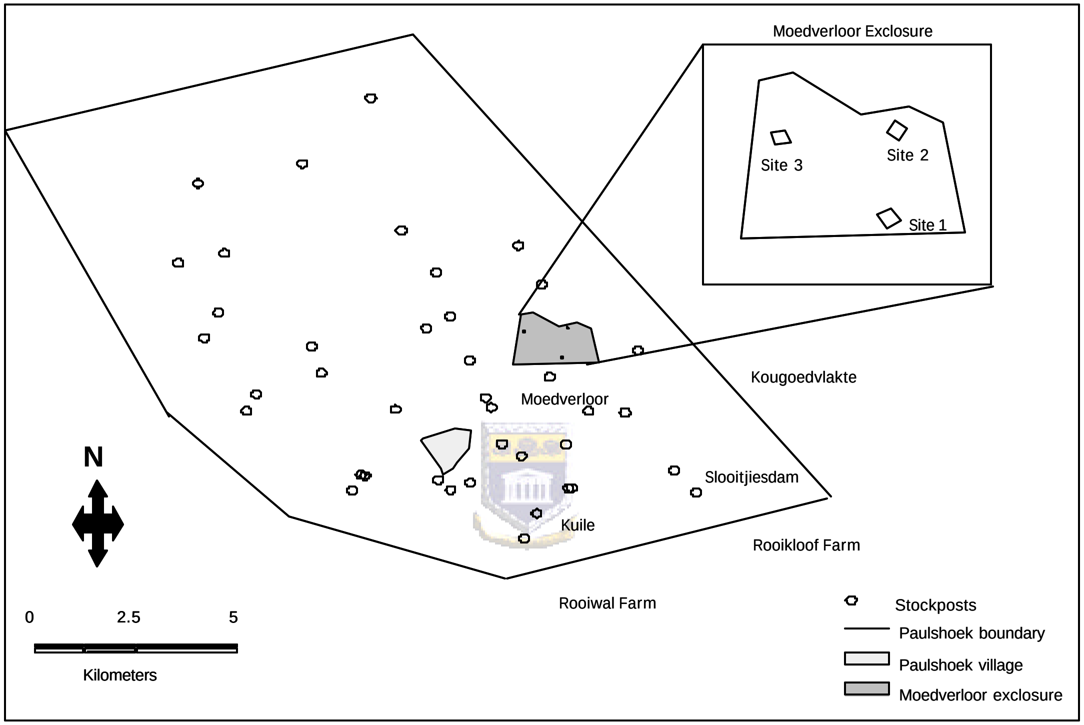

Fig. 2.5. Map of Paulshoek indicating the position of the village, stockposts in the surrounding commons and the position of the Moedverloor grazing exclosure where the rehabilitation trials were carried out (Samuels, 2005).

Three 50 x 50 m sites were chosen in the Moedverloor area of Paulshoek (Fig. 2.5). Each site was further subdivided into 36 plots, which are approximately 7 m x 7 m in size with one meter paths between each plot. Moedverloor lies on the boundary of summer and winter rainfall regions, receiving most of its rain in winter, with occasional thunderstorms in summer. The short term average rainfall for this area is 50 mm less than surrounding areas (Fig. 2.2) (MT. Hoffman unpublished data).

2.7. Site description

2.7.1. Physical analysis

The physical properties of the soil vary slightly between the three study sites. Site 1 has significantly deeper soils ($p<0.001$) than Site 2 and 3 (Table 2.1). The soil surface at Site 3 is significantly harder ($p<0.0001$) than Site 1 and Site 2, however there were no difference in water infiltration rates between the three sites (Table 2.1). Methods and statistical analysis are outlined in Appendix A.

Table 2.1: Physical properties of soils collected at the three study sites in Moedverloor. Means and standard errors shown. Different letters follows values which are significantly different ($p<0.05$).

	Site 1	Site 2	Site 3
Soil Depth (cm)	44.58 ± 3.08a	33.63 ± 3.28b	36.83 ± 5.02b
Soil Hardness (kg.cm^2)	1.10 ± 0.17b	1.39 ± 0.18b	2.90 ± 0.29a
Water Infiltration (sec)	259:49 ± 101.94a	340:51 ± 79.17a	503:84 ± 92.39a

2.7.2. Soil chemical analysis

Soil pH varied significantly ($p<0.0001$) between the study areas and ranged between 6.5 and 7.4 (Table 2.2). Organic matter levels in the soil were low with a mean of 1.53 % for Sites 1 and 2, and significantly higher levels ($P<0.0001$) at 1.90 % for Site 3 (Table 2.2). At Site 3, total soil phosphorus was significantly higher ($p<0.0001$) than Sites 1 and 2. On average, total soil nitrogen was 249 µg g^{-1} for the three study areas with significant variations ($p<0.05$) between the them. Soils measured at 5 – 20 cm below the soil surface contained significantly ($p<0.001$) lower nitrogen levels at 205 µg g^{-1}.

Methods and statistical analysis are outlined in Appendix A.

Table 2.2: Chemical properties of soils collected at the three study sites within the Moedverloor grazing exclosure at two depths. Means and standard errors shown.

	Site 1		Site 2		Site 3	
	0 - 5cm	5 -20cm	0 - 5cm	5 -20cm	0 - 5cm	5 -20cm
pH	6.96 ± 0.11	7.17 ± 0.10	6.52 ± 0.12	6.62 ± 0.17	7.35 ± 0.09	7.54 ± 0.09
OM (%)	1.49 ± 0.06	1.51 ± 0.04	1.58 ± 0.14	1.35 ± 0.08	1.91 ± 0.18	1.84 ± 0.16
Total N ($\mu g.g^{-1}$)	237.72 ± 16.46	190.72 ± 11.31	240.52 ± 18.09	190.64 ± 18.36	267.82 ± 18.11	236.23 ± 20.57
Total P ($\mu g.g^{-1}$)	83.32 ± 7.21	84.71 ± 4.13	69.13 ± 2.82	69.08 ± 3.46	226.92 ± 16.43	219.99 ± 17.91

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CHAPTER 3

THE IMPACT OF HEAVY GRAZING ON RANGELAND COMPOSITION AND FUNCTION

3.1. Introduction

Vegetation of many rangelands in arid environments has been transformed to a less palatable state as a result of high grazing pressure and disturbances such as ploughing. This altered vegetation state may result in loss of productivity and a possible decrease in biodiversity of these areas. In Paulshoek, Namaqualand, heavy grazing has led to a reduction in palatable shrubs and the dominance of the unpalatable, toxic shrub *Galenia africana*, as well as reduced flower productions and seedling recruitment of palatable shrubs (Todd & Hoffman, 1999). The decrease in shrub density brought about by heavy grazing and ploughing ultimately affects soil processes resulting in a depletion of nutrients on a landscape scale (Allsopp, 1999). The effect of trampling and grazing are most clearly seen in the sandy bottom plains and around stockposts and watering points (Riginos & Hoffman, 2003).

In this chapter, I explore how continuous concentrated grazing pressure has changed this system by comparing the Moedverloor area in Paulshoek with surrounding private farms, which have a history of less intense grazing pressure in recent decades. The lighter grazed private farms of Rooikloof and Rooiwal adjacent to Kuile and Slooitjiesdam (Chapter 2: Fig.2.5) respectively were used as comparison for the vegetation cover and composition and soil condition in Moedverloor. The seed bank study compared germination of seeds from soil collected at Moedverloor and the private farms adjacent to Kuile, Slooitjiesdam and Kougoedvlakte. The results of these baseline studies of the state of the vegetation will assist us in recognising the factors that may be maintaining the present rangeland state. This knowledge will contribute to planning aimed at restoring ecosystem integrity.

3.2. Materials and methods

3.2.1. Site description

The study was carried out in Paulshoek, Namaqualand. A detailed description of the location, history, climate and vegetation of the area is found in Chapter 2.

3.2.2. Vegetation

Cover of perennial plants was measured along four 50 m transects at each of the three rehabilitation sites within the Moedverloor area which have experienced heavy grazing. Five 50 m line transects were sampled at each of the two lighter grazed sites on private farms (Rooiwal and Rooikloof) adjacent to Paulshoek. All perennial plants intercepted by transects were identified.

3.2.3. Seed bank study

In April 1999, soil was sampled from under large adult shrubs and from adjacent open areas between shrubs to determine the composition of the seed bank and if microhabitat influence in anyway. Soils were collected under large shrubs in Moedverloor and at the three private farms to establish the influence of grazing intensity on the seedbank. Soils were only sampled under *Galenia africana* at Moedverloor as this was the only large shrub species. The top 5 cm of soil and litter from open and under shrubs at each site was collected. Ten samples for each microhabitat were bulked at each sampling area.

Six hundred grams of sample was spread over 5 cm deep river sand in seedling punnets (16 cm x 20 cm x 6 cm) and a thin layer of river sand placed over the top. There were four replicate punnets for each of the soil samples. Four control punnets consisting only of river sand were used to identify any seedlings that might establish from seeds blown in or in the river sand. Punnets were placed in a green house at ambient temperatures and watered once a day initially and twice weekly as evaporation decreased in the cooler months. Punnets were inspected weekly and new seedlings counted and identified over a period of 6 months.

3.2.4. Landscape function analysis

Landscape function analysis (LFA) was developed for generic use in Australian rangelands in response to the need to include soil productive potential as an integral part of the assessments (Tongway & Hindley, 1999). The functional analysis is based on the assumption that as a system becomes more dysfunctional it looses increasing amounts of resources such as soil nutrients and water. Rangeland condition was assessed along line transects using indicators of soil surface processes to infer the status of a landscape on a function/dysfunction basis (Tongway & Hindley, 1997). In this context, function describes how a landscape works to capture, store and utilise important natural resources within the local system. There are two principle steps in quantifying this process namely: a) characterising the selected area in terms of the spatial patterns of soil and vegetation along a transect b) assessing the soil surface condition along these transects based on a 1 m x 1 m quadrat observation system.

Firstly, areas of resource loss and gain in the landscape were assessed by calculating the number and width of all obstructions to water flow along a 50 m transect. Obstructions include all perennial plants, rocks, sticks or any relatively immovable and long-lived object that could intercept raindrops (Tongway & Hindley, 1995). Three parameters are measured to characterise the functional status of the selected area namely: 1) the number of obstructions per 50 m transect, 2) the width of each obstruction, 3) the percentage cover of vegetation (Tongway and Hindley 1995).

Five, 1 m^2 quadrats were selected along each 50 m transect. Where possible, each 1 m^2 quadrat represented a different patch type e.g. sandy or rocky soil along the transect. Nine soil surface indicators were used to explain the effect of rangeland use on ecosystem processes. These indicators include the percentage soil cover i.e. the amount of plant material covering the soil, amount of litter cover, cryptogram cover, crust brokenness, soil erosion features, deposited material, soil micro topography and soil surface nature and a slake test which test for the crust's stability when wet (Tongway & Hindley, 1995).

During the assessment, each feature in each quadrat is assigned a score out of four with the exception of soil cover and litter cover, which are scored out of six. Three indices are derived from grouping the indicators namely: soil stability, how soil partitions rainfall into soil water and runoff, and the nutrient cycling status of the soil. As these three categories do not necessarily change uniformly, the strengths and weaknesses of a site can be identified. The condition of the soil can also be directly compared with vegetation data to give an understanding of the overall site condition.

3.2 .5. Statistical analysis

Analysis of variance was used to statistically analyse data. All percentage data were arcsine transformed to avoid deviation from normality for very small or large percentage values (Zar, 1996). Tukey's test was used to distinguish between means where applicable.

3.3. Results

3.3.1. Vegetation

Vegetation cover was significantly lower ($p<0.0001$) on heavily than lightly grazed areas (Fig. 3.1). Vegetation composition differed between heavy and lightly grazed areas, with a significantly higher percentage ($p<0.0001$) of *Galenia africana* in the heavily grazed area and a low percentage in lightly grazed areas. Cover of palatable perennials was higher under light grazing with very low cover under heavily grazed areas (Fig. 3.1).

3.3.2. Sæd bank study

Seed germination was higher in soil from the heavily grazed site than from the lighter grazed private farms ($p<0.05$) (Fig. 3.2). The position where soil was collected, i.e. in the open or under shrubs had no influence on germination patterns. The number of *Galenia africana* seeds that germinated was significantly higher ($p<0.001$) under heavy grazing with almost no germination under lower grazing pressure. Conversely, germination of annuals ($p<0.05$) and palatable

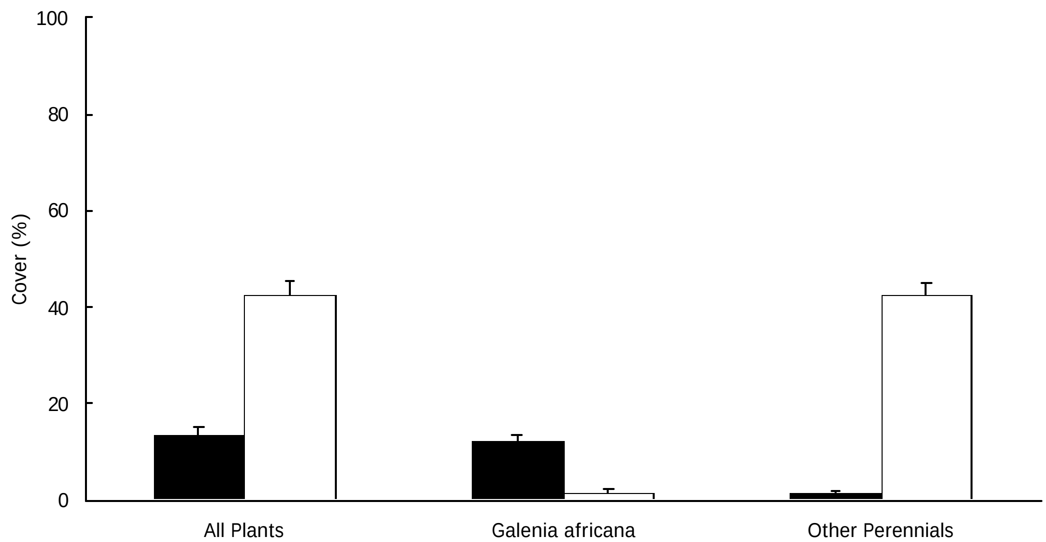

Fig. 3.1. Comparison of plant cover and composition between heavy grazed (Dark Bars) sites and adjacent lighter grazed areas (Light Bars). Standard errors are shown.

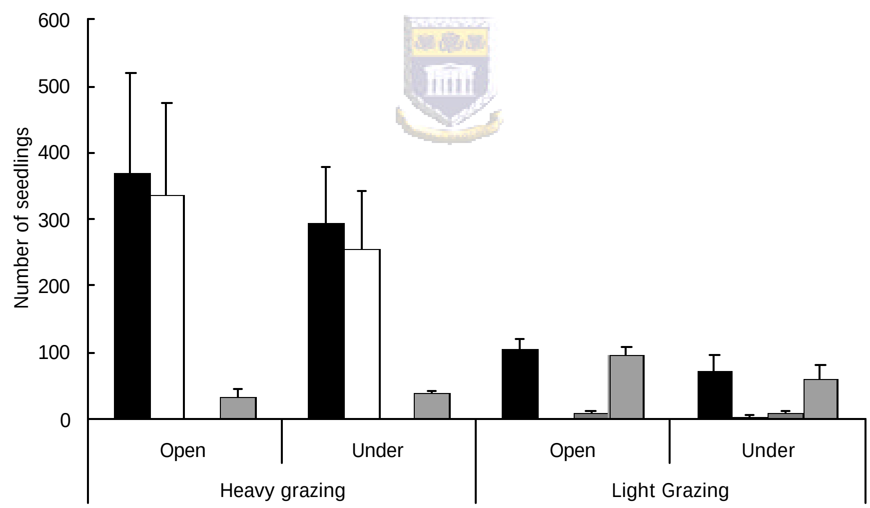

Fig. 3.2. Number of seedlings emerging from soil collected from heavy and lightly grazed areas and from open and under shrubs respectively. (dark bars = all seedlings, light bars= *Galenia africana*, checker bars = other perennials, striped bars = annuals). Standard errors are show.

perennials (p<0.001) was significantly higher under light grazing with little and no germination of these under heavy grazing.

3.3.3 Landscape Function Analysis

Grazing intensity did not affect soil stability (Table 3.1). The infiltration/runoff index and nutrient cycling status of soil was significantly higher (p>0.05) at the lightly grazed farms compared to the heavily grazed Moedverloor area (Table 3.1). Heavily grazed areas had an average of 28 obstructions per 50 m transect, which was significantly (p<0.0001) lower than the average 57 obstructions per transect at the lighter grazed areas (Table 3.1). The mean size of individual obstructions was also larger (mean = 36 cm) under lighter grazing compared to the heavily grazed areas (mean = 24 cm).

Table 3.1: Comparison of landscape function analysis indices under lighter grazing and heavy g razing in the Paulshoek rangelands and surrounding farms. Means and standard errors shown. Significant differences (p<0.05) indicated by a and b in rows.

	Heavy Grazing	Light Grazing
Soil Stability (%)	54.56 ± 1.16a	56.13 ± 1.85a
Infiltration/Runoff (%)	35.32 ± 2.61a	41.38 ± 1.05b
Nutrient Cycling (%)	26.01 ± 1.09a	36.45 ± 0.78b
No of Obstructions per 50m	28.50 ± 7.87a	57.20 ± 2.06b
Size of Obstructions (cm)	23.87 ± 2.74a	36.01 ± 2.38b

3.4. Discussion

The large difference in number of *Galenia africana* seedlings emerging from the soil seedbank and cover of this unpalatable shrub between the different grazing regimes suggests that recruitment and growth of *Galenia africana* seedlings is favoured by heavy grazing. Selective grazing may lead to abundant recruitment of unpalatable shrubs (Milton, 1994) and this continued grazing pressure might result in the local extinction of highly palatable shrubs (Hunt, 2001). In arid environments heavy grazing is typically associated with a shift in vegetation composition from palatable vegetation to one that is unpalatable and toxic to livestock (Noy-Meir *et al*., 1989; O'Connor & Pickett, 1992; Meissner & Facelli, 1999). Plants such as *Galenia africana* that become dominant may establish soil conditions which contribute to their persistence and may deter the establishment of palatable perennial shrubs (Allsopp, 1999; Schlesinger *et al*., 1990).

Comparison of soil stored seedbanks of heavy and lightly grazed areas shows dominance of *Galenia africana* seedlings under heavy grazing with noticeably higher germination of palatable perennials and annuals under light grazing. Heavy grazing pressure has not only reduced the seed bank of palatable perennials, but favours the establishment of *Galenia africana* and annual seedlings.

It has been postulated that reduced seed production of palatable perennials under heavy grazing may be one of the factors limiting recruitment in this system (Todd & Hoffman, 1999; Carrick, 2001). The reduction in vegetation cover and number of obstructions under heavy grazing may also limit the number of favourable recruitment sites suitable for palatable perennial shrubs.

From the landscape function analysis, it appears that the study area has retained some ability to withstand soil and wind erosion, as the soil stability index is similar to that of the adjacent lightly grazed area. However signs of dysfunction can be seen in the lower infiltration/runoff and nutrient cycling indices. Rainfall on the lightly grazed areas has a higher probability of infiltrating the soil and becoming available for plant use than on the heavily grazed areas. Rainfall on heavily grazed areas is more readily lost by the system through runoff, which in turn may transport litter and seed away. The areas under lighter grazing pressure are more efficient at recycling organic matter into the soil than the sites under heavy grazing pressure.

The results of this study highlighted the following factors which may be maintaining the lowlands of Paulshoek rangelands as a monospecific stand of *Galenia africana* and preventing transition to a multi-species shrubland. Firstly, the landscape function analysis indicates that this system maybe dysfunctional in that it has lost the ability to trap or control resources such as water, nutrients and seed. Secondly, there may be an absence of a viable palatable perennial seed bank. Thirdly, the dominance of *Galenia africana,* which may have altered soil properties to the detriment of palatable perennial shrubs that further facilitates establishment of *Galenia africana* seedlings (Allsopp, 1999). Finally, there may be a lack of possible safe sites that trap seed of palatable shrubs and this may deter recruitment of seedlings. Chapter 4 and 5 will deal with testing various biophysical interventions and manipulations that will attempt to facilitate the return of these key functional processes to this system.

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CHAPTER 4

UNDERSTANDING ECOLOGICAL FACTORS MAINTAINING GRAZING INDUCED VEGETATION CHANGE

4.1. Introduction

Rangelands worldwide are often moderately or severely transformed, primarily as a result of overcultivation and overgrazing (Grainger, 1990). In South Africa, the loss of vegetation cover and change in species composition are perceived as the most important types of rangeland degradation associated with grazing (Todd & Hoffman , 1999). This change in species composition is usually attributed to selective grazing by livestock which can reduce the reproductive output of preferred forage species such as *Tripteris sinuatum* (Milton, 1992) and *Ruschia robusta* (Riginos & Hoffman, 2003) favouring the establishment of toxic and unpalatable shrubs (Milton & Dean, 1990; Noy-Meir *et al*., 1989) such as *Galenia africana* (Todd & Hoffman, 1999; Carrick, 2001) in the karoo. The result of such changes is a suppression of recruitment and establishment of palatable shrubs (Milton, 1994; Todd, 2000), which ultimately lowers the production potential of rangelands (Dean & Macdonald, 1994).

Conventional grazing management practices recommended by agricultural advisory services recommend the removal of grazing pressure from areas where grazing has transformed the vegetation to what is deemed a less productive state. This follows the equilibrium theory that suggests that in the absence of disturbances such as grazing, fire or drought the vegetation of an area develops through succession to reach a single persistent climax state, which is perceived as pristine (Hoffman, 1989; Westoby *et al.*, 1989). The loss of vegetation cover or change in species composition due to grazing will thus result in a shift down the successional sequence to a less productive state. When an area has been heavily grazed, the removal of grazing pressure should therefore result in the overgrazed plant community reverting to one dominated by palatable perennial shrubs. The range succession model has received much criticism (Westoby *et al.*, 1989; Friedel, 1991; Milton & Hoffman, 1994) as grazing induced vegetation change has often been found not to be continuous, reversible or consistent especially in more arid areas. Where rest does result in recovery, it is often not in a time scale suitable for land users (Walker, 1993; v an Rooyen, 2000).

In the last thirty years, there has been a revision in range science theory with new models to explain rangeland dynamics coming to the fore. Most notably has been the introduction of the cyclic and stochastic models (Milton & Hoffman, 1994). The cyclic or non-equilibrium model is based on the principle that plant and animal dynamics are largely independent of each other and are instead driven by abiotic factors such as rainfall (Ellis & Swift, 1988; Behnke & Scoones, 1993). Consequently, overgrazing by animals should have no effect on plant production, since periodic deaths of stock during droughts will keep numbers below equilibrium. The reduction of stock numbers on heavily grazed lands is thus not seen as a worthwhile intervention (Ellis & Swift, 1988). This model does not account for changes in vegetation states observed under grazing at different intensities.

The stochastic or non-equilibrium models, including the state and transition model (Westoby *et al*., 1989), propose the management of rangelands by using catalogues of alternative states and possible transitions between these states. Transitions between states are brought about through changes in climatic conditions and through management action such as grazing or fire. Transitions are not always reversible (Walker, 1993). Using this premise, it can be argued that changes in vegetation as a result of grazing in arid systems are caused by a disturbance resulting in a shift in state. This shift in state may be due to the loss of key functional components in a system, and rest from grazing on its own may not be enough to allow the return of the original state (Milton & Hoffman, 1994).

In the Namaqualand region of the succulent karoo, heavy grazing of low-lying areas has resulted in the reduction of palatable perennial shrubs and the dominance of the unpalatable shrub, *Galenia africana* (Todd & Hoffman, 1999). When compared with adjacent areas under low grazing pressure, it was found that heavy grazing has increased the seed bank of *Galenia africana* in the soil and reduced that of palatable perennials (Chapter 3).

Low vegetation cover under heavy grazing has resulted in an increase in exposed soil which has been highlighted as an indicator of system dysfunction (Tongway & Ludwig, 1997). The lower vegetation cover reduces the efficiency with which resources such as water, organic material and nutrients are trapped. In such a dysfunctional system, longer distances between plants (fetches) allows for the acceleration of soil, water and wind erosion and resultant losses in resources

(Rietkerk & van de Koppel, 1997; Tongway & Ludwig, 1997). These factors can serve to maintain vegetation in a specific state.

This chapter investigates the use of grazing exclusion as a means to understanding vegetation dynamics within a system transformed by heavy grazing. In the process I aim to address the apparent conflict between the various rangeland models and how they can be applied to the rangelands of the succulent karoo. My investigation is driven by the following questions:

a. Is the change in vegetation from a palatable to unpalatable shrubland a transient or permanent state?
b. Can this grazing induced vegetation change be reversed, and if yes what ecological factors are needed to bring about this change?
c. How appropriate is short-term rest as a possible management strategy and rehabilitation tool?

4.2. Materials and method

4.2.1. Site description

The study was carried out in Paulshoek, Namaqualand. A detailed description of the location, history, climate and vegetation of the study area is found in Chapter 2.

4.2.2. Sampling method

Vegetation dynamics in the absence of grazing were monitored in two ways. Vegetation cover and composition was monitored for two years, in plots from which grazing was excluded, to study vegetation dynamics under ambient climatic conditions. Grazed and ungrazed vegetation adjacent to the fence enclosing Moedverloor was compared to assess the impact of grazing on vegetation dynamics. This would also provide insights on how the removal of grazing pressure influences vegetation dominated by unpalatable species.

4.2.2.1. Vegetation dynamics

Four, 7x7 m plots were randomly selected within each of three 50 x 50 m sites within the Moedverloor enclosure (Fig. 4.1). The position of all perennial shrubs in the plots was mapped. All shrubs were identified and their height and diameter along two axes at 90^{o} to each other were recorded. Volume of shrubs was calculated as if the shrub canopies were ellipsoid in shape. Plants were measured in June or July of 1999, 2000 and 2001. Seedlings of perennial shrubs were mapped and recorded from the second year. Owing to the dominance of *Galenia africana,* individuals of this species were divided into seven size classes based on canopy volume to gain insight into their population dynamics over the two year monitoring period.

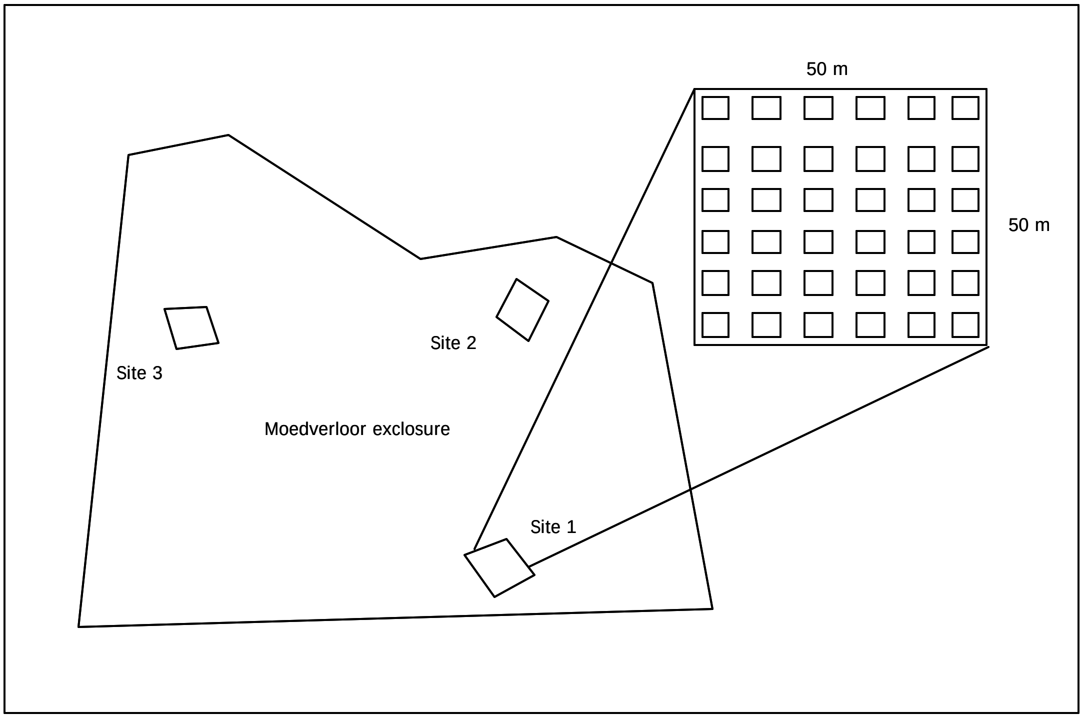

Fig. 4.1. Layout of individual 50 m x 50m sites with 36, 7 m x 7 m plots in each within the Moedverloor grazing exclosure.

4.2.2.2. Impact of grazing on vegetation dynamics

Ten paired 50 m line transects were set up on the inside and outside perimeter of the fenced area in Moedverloor. Transects ran parallel or perpendicular to the fence, and were set up in areas where slope and vegetation were similar on both sides of the fence. Transects were set up at a distance of at least 5 m from the fence to avoid disturbances caused when it was erected as well as livestock trampling caused by any funneling effect the fence may have on animal movement.

Perennial vegetation cover was determined as a proportion of the 50 m transect which intercepted plant canopies. Transects were used to assess areas of resource loss and gain in the landscape by calculating the number and width of all obstructions to water flow (Tongway and Hindley 1995). Transects were monitored in October 1999, 2000 and 2001 following the winter rainfall season.

The soil surface was assessed based on the method outlined in Tongway and Hindley (1995). Nine soil surface indicators were used to explain the effect of rangeland use on surface and ecosystem processes. These indicators include the degree of litter cover, cryptogram cover, crust brokenness, soil erosion features, deposited material, soil microtopography and soil surface nature (Tongway & Hindley 1995). Three indices were derived from grouping the indicators namely; soil stability, how soil partitions rainfall into soil water and runoff, and the nutrient cycling status of the soil.

4.3. Statistical Analysis

Paired sample t-tests were used to test for statistical differences in vegetation cover and composition between paired transects on the inside and outside of the exclusion fence. Data collected from the three grazing exclusion sites, are considered repeated measures i.e. data collected cannot be compared between years, and therefore cannot be statistically analysed using ANOVA (Zar 1989). Data was thus descriptively analysed and presented as graphs showing number, canopy area and volume of shrubs per 100 m^2.

4.4. Results

4.4.1. Vegetation Dynamics

No change in vegetation composition was seen at the three sites in the absence of grazing, with *Galenia africana* remaining the dominant species with low numbers of palatable perennial shrubs (Fig. 4.2) Though site one had a higher number of plants than site two and three, all sites showed higher plant numbers in 2000, compared to 1999. Plant numbers decreased in 2001 to numbers similar to that of 1999, largely as a result of change in *Galenia africana* numbers (Fig. 4.2).

Shrub canopy area or cover increased in 2000 at all three sites, and though a reduction in shrub canopy area was seen in 2001, cover was greater than in 1999 (Fig. 4.3). An increase in shrub canopy volume was seen from 1999 to 2000, and remained stable in 2001 (Fig. 4.4)

The *Galenia africana* populations were different at each of the three sites in terms of total numbers (Fig. 4.2) and distribution between size classes (Fig. 4.5). All three sites showed smaller numbers within the smallest and largest size class, with the majority in intermediate size classes. In 1999 the majority of individuals at site one, fell within the smaller size categories, with numbers decreasing as the shrub canopy volume increased (Fig. 4.5a). Shrub size increased from 1999 to 2001 at site one. The increase in shrubs size was not as obvious at site two and three. Most of the seedlings recruiting over the two years at all three sites died rather than entering larger size classes.

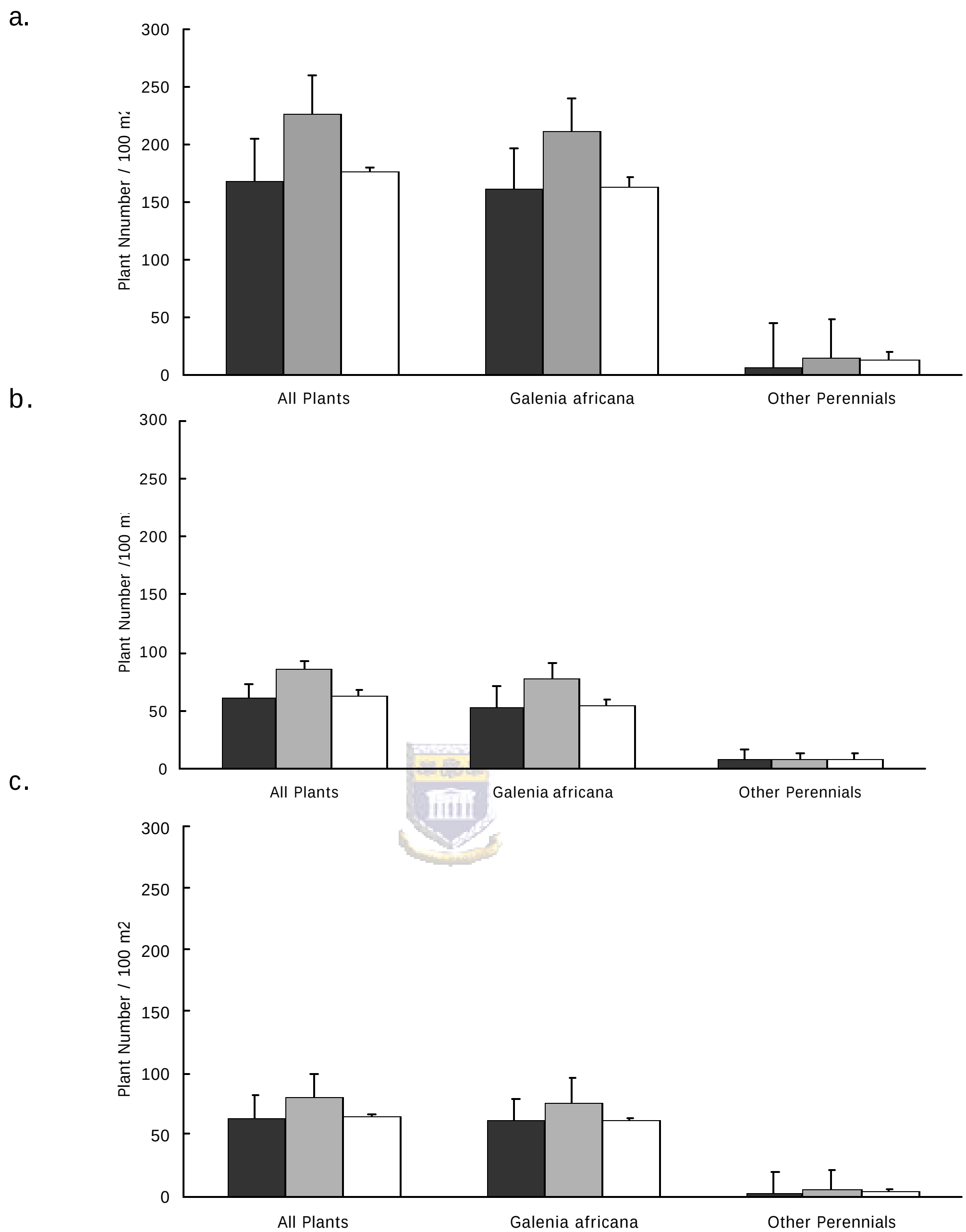

Fig. 4.2. Number of shrubs per 100 m^2 for the selected guilds in 1999 (dark bar), 2000 (striped bar) and 2001 (light bar) at Site 1 (a), Site 2 (b) and Site 3 (c). Standard error bars are shown.

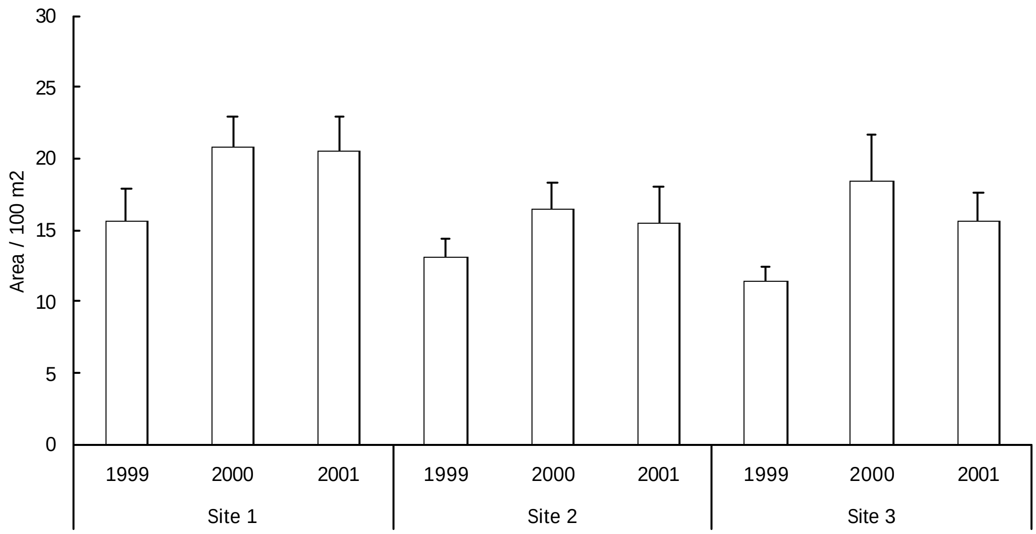

Fig. 4.3. Vegetation cover per 100 m^2 for three years at site one, two and three. Standard error bars indicated.

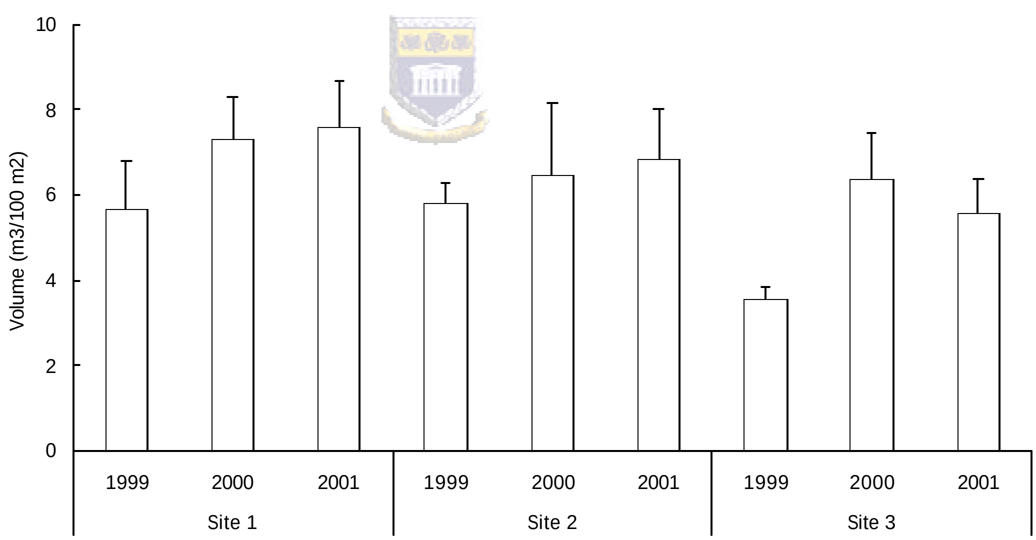

Fig. 4.4. Shrub canopy volume per 100 m^2 for 1999, 2000 and 2001 for the three exclusion sites. Standard error bars indicated

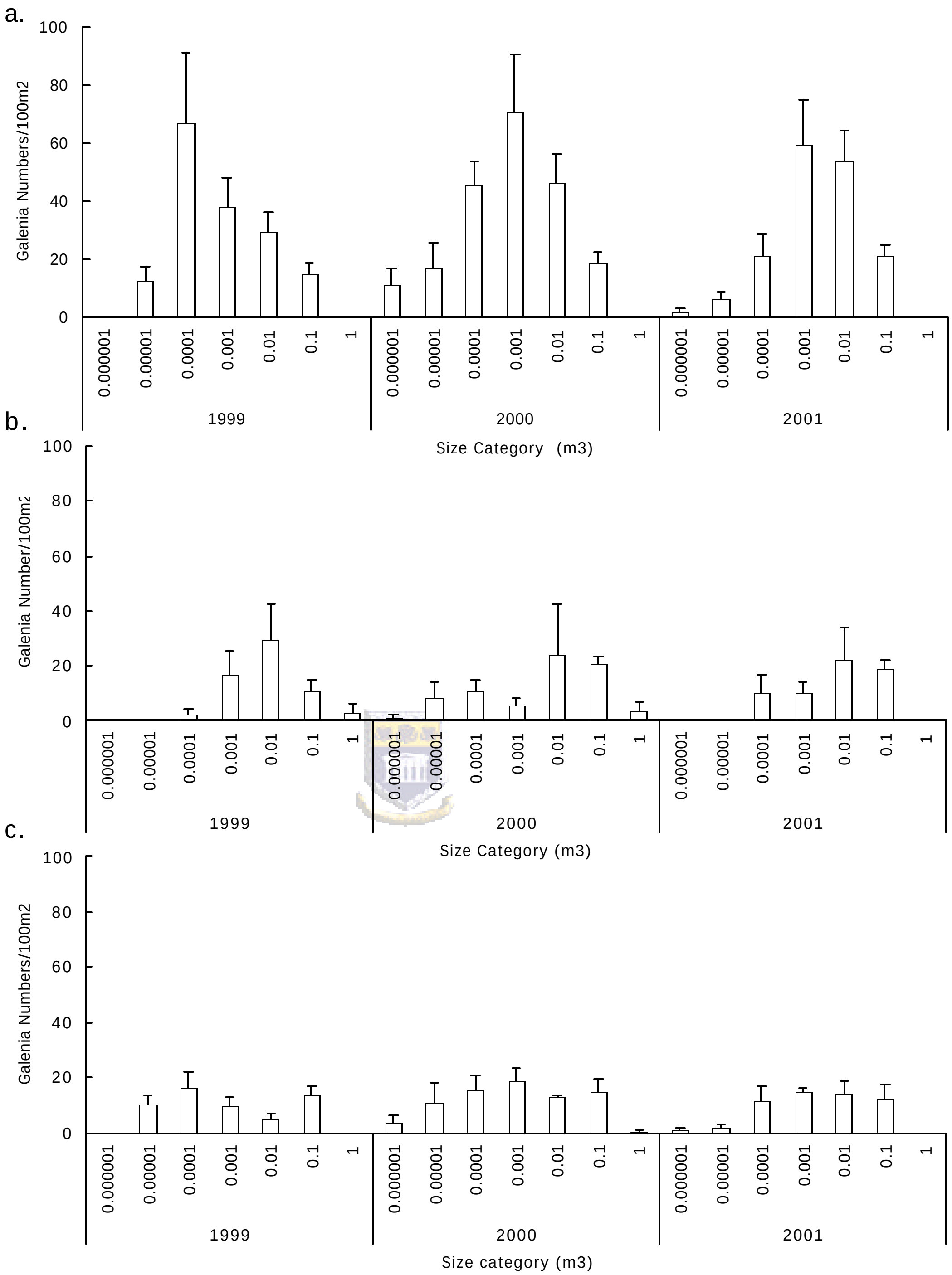

Fig. 4.5. Number of *Galenia africana* individuals per 100 m^2 in five size categories divided according to shrub canopy volume at site one (a), two (b) and three (c). Standard error bars indicated.

4.4.2. Impact of grazing on vegetation dynamics

Vegetation cover remained below 30 % inside and outside of the fence after two years of grazing exclusion (Fig. 4.6). Plant cover was significantly higher ($p<0.05$) inside than outside the fence for the two years following grazing exclusion (Fig. 4.6). Cover of *Galenia africana* was significantly higher ($p<0.05$) on the inside of the exclusion fence for 1999 and 2000, with no difference in cov er inside and outside during the third year. With the exception of the increased cover of palatable perennials inside the fence for 2001, cover of palatable perennials showed no difference in cover on the inside and outside of the fence (Fig. 4.6)

The period 1999-2000 showed an overall increase in cover on both sides of the exclusion fence for all guilds (Fig. 4.7). In the subsequent year, 2000–2001, exclusion from grazing showed no change in cover of all plants, a decrease in *Galenia africana* and increase of palatable perennials. The grazed side of the fence for this period showed a decrease in cover of all plants with no change in cover of *Galenia africana* but a marked decline of palatable perennial cover (Fig. 4.7). The pattern from 1999-2001 shows an overall increase in cover of all plants on both the inside and outside of the fence. The increase in cover of rested veld is largely attributable to the increase in cover of palatable perennials rather than *Galenia africana* (Fig. 4.7).

There were no consistent changes in soil indices over the two years of grazing exclusion (Table 4.1). The number of obstructions was significantly higher in the absence of grazing by the second year though the size of obstructions was not affected by protection from grazing (Table 4.1).

The pattern of rainfall between the sites indicates a gradient from higher less frequent rainfall at sites two and three, to lower but more frequent rainfall at site one (Refer to Chapter 2: Fig. 2.2). This may be owing to the collection methodology as rainfall data at site one was collected by an automatic weather station, while rain gauges were used at site two and three. This presents a problem, as rainfall was not always measured immediately after rainfall events. Data for these months were replaced by averages from the gauges in the greater Paulshoek area. Overall, 1999 was considered a dry year for this region with the rainfall improving in 2000 and 2001.

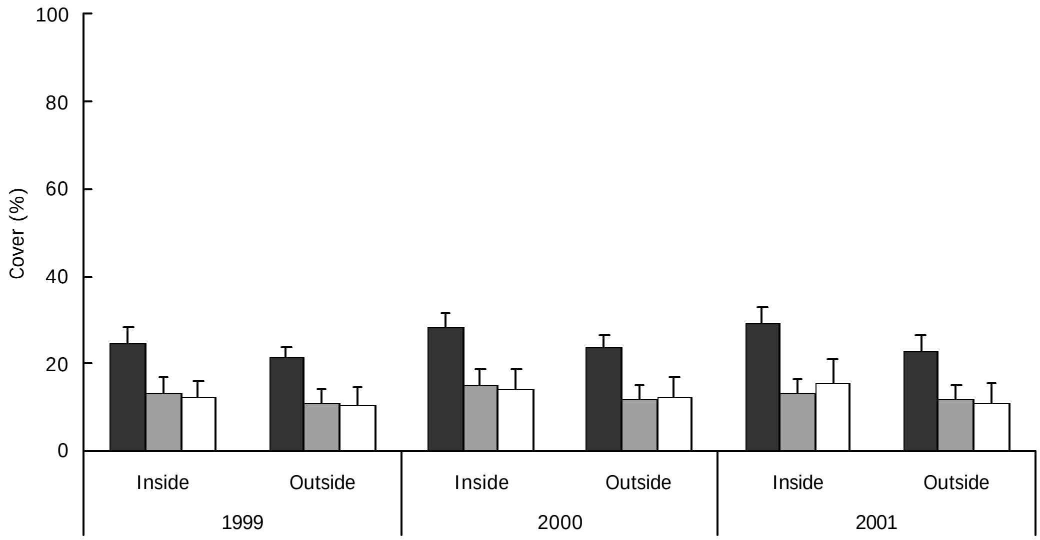

Fig. 4.6. Cover of all plants (dark bars), *Galenia africana* (striped bars) and palatable perennials (light bars) on the inside and outside of the exclusion fence for the years 1999, 2000 and 2001. Standard error bars are indicated.

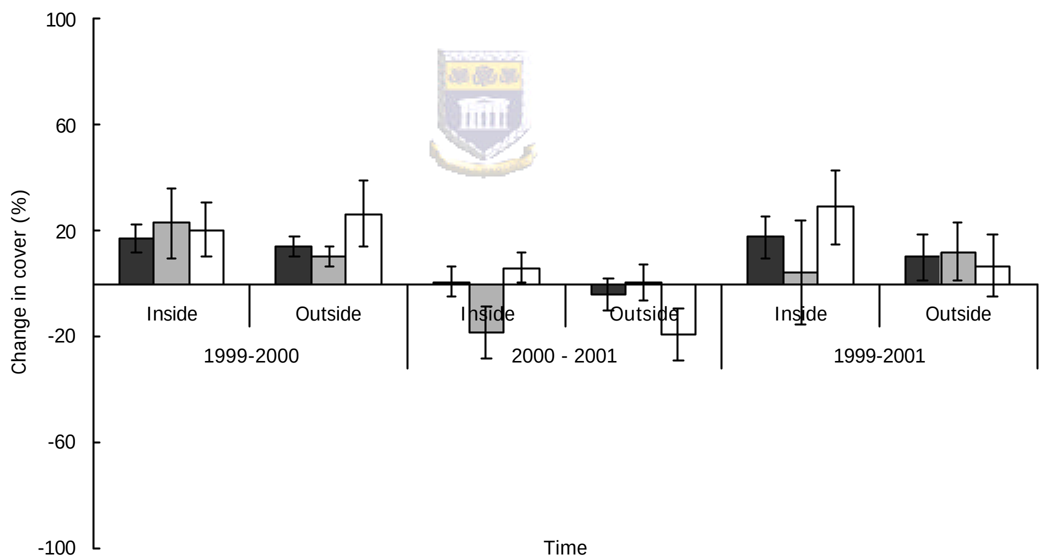

Fig. 4.7. Change in percentage cover of all plants (dark bars), cover of *Galenia africana* (striped bars) and cover of palatable perennials (light bars) on the inside and outside of the exclusion fence for the time period 1999 to 2000, 2000 to 2001 and 1999 to 2001.Standard error bars are indicated.

Table 4.1: Comparison of landscape function analysis indices across a grazing exclusion fence for two years. Values are means ± Standard errors. Letters indicate significant difference (p<0.05).

	1999		2000		2001	
	Inside	Outside	Inside	Outside	Inside	Outside
Soil Stability (%)	52.0 ± 1.6a	53.6 ± 2.4a	53.8 ± 1.9a	57.4 ± 1.7b	51.8 ± 1.5a	52.5 ± 1.5a
Infiltration/Runoff (%)	37.3 ± 0.8a	39.2 ± 0.8b	38.6 ± 1.7a	43.5 ± 1.6b	40.8 ± 1.5a	42.6 ± 2.0a
Nutrient Cycling (%)	32.4 ± 0.9a	31.4 ± 0.8a	30.1 ± 0.5a	28.1 ± 0.9b	31.8 ± 0.8a	31.1 ± 1.1a
No. of Obstructions per 50m	27.5 ± 4.4a	20.4 ± 5.1a	38.7 ± 5.4a	27.8 ± 6.7a	36.6 ± 6.3a	25.7 ± 6.3b
Size of Obstructions (cm)	34.5 ± 3.4a	36.7 ± 2.7a	32.8 ± 3.4a	38.3 ± 3.8a	41.2 ± 5.6a	48.1 ± 4.1a

4.5. Discussion

In this study, two years of grazing exclusion show that in the absence of grazing vegetation cover increased. However most fluctuations in plant cover can be ascribed to rainfall. No recruitment of preferred grazing species occured in the time period of this study. Although this study did not effectively report on recruitment of palatable perennials, Gabriels *et al.*, (2003) found that the removal of grazing pressure positively influenced the recruitment of palatable perennials especially on rocky areas along the same transects as used in this study. However, grazing exclusion did not change vegetation composition as *Galenia africana* maintained its dominance after two years.

The continued dominance of *Galenia africana* suggests that heavy grazing and or ploughing has resulted in a shift in state. Friedel (1991) explains that such a system has crossed a threshold into a new state, and this shift may not be reversible on a practical time scale without substantial external intervention. This shift to a *Galenia africana* state is maintained by this plant's strategy of recruiting high numbers of seedlings from possibly higher numbers of seed to ensure survival of the species (Chapter 3). This linked with *Galenia africana*'s preference of recruiting in open areas (Moinde, 1998) where other shrubs have been removed by grazing (Carrick, 2001) can facilitate its dominance in flat open sandy areas.

Allsopp (1999) found that *Galenia africana* forms areas of nutrient enrichment under its canopy with associated increases in soil pH and a depletion of soil moisture. It can be hypothesised that this change in soil chemistry could benefit establishment of *Galenia africana* seedlings and continued prevalence of adults.

It therefore follows that new vegetation states cannot always be reversed by succession since the new dominant shrubs and local extinction of species maintain the state (Westoby *et al.*, 1989; Walker, 1993). This implies that the removal of grazing pressure alone might not be enough to dislodge this system from its inertia.

Milton (1992) has shown that the lack of an adequate supply of seed of palatable perennial species can prevent transition from a system dominated by unpalatable plants to a mixed assemblage. Furthermore, a reduction in vegetation cover, and the subsequent reduction in favourable microsites where seeds can be trapped and seedlings establish, may also maintain a system in an unproductive state.

Vegetation dynamics of arid systems are closely linked to climatic events and have led to the understanding that plant populations are driven by a cycle of climatic events (O' Connor & Roux, 1999; Esler *et al.*, 1999). The results of this grazing exclusion study seem to support the theory of climate driven vegetation dynamics. This is seen in the fluctuations of shrub size and number in response to the amount of rainfall that fell each year. This would affirm that abiotic factors, specifically rainfall, could override the effects of grazing pressure on vegetation dynamics. This agrees with the non-equilibrium theory of event driven change in systems (Ellis & Swift, 1988; Walker, 1993). However state and transition dynamics seem to prevail in maintaining vegetation in specific states.

Though it is important to assess vegetation change given the climatic variability, in the case of Paulshoek, grazing has been suggested to be an equally important driver that can influence vegetation composition. Todd & Hoffman (1999) reduced size, flower production and seedling recruitment of palatable species and increased density and recruitment of unpalatable shrubs under heavy grazing in an exceptionally high rainfall year.

From this two year study it is impossible to conclude as to the permanence and reversibility of this altered vegetation state under long-term exclusion of grazing. It is clear that grazing exclusion alone may not be an effective short-term rehabilitation tool in the succulent karoo. Recommendations by agricultural advisory services and other service providers that the heavily grazed commons of Namaqualand will benefit from short term rest, or stock reduction, will not result in a change in rangeland condition. Recommendations of this kind, especially since they require additional inputs in terms of fencing, management and reduction of herd sizes, cannot be justified on the basis of this study. Interventions of this type are unlikely to result in change because they fail to address the underlying ecological processes and therefore the system will not change from its current state without some, as yet unresolved event or intervention.

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CHAPTER 5

UNDERSTANDING VEGETATION DYNAMICS USING BIOPHYSICAL MANIPULATIONS

5.1. Introduction

An understanding of vegetation dynamics is an essential prerequisite to understanding and predicting the responses of a system to disturbance and ultimately to the underlying forces that shape communities (Goldberg & Turner 1986). In degraded systems, such knowledge could contribute to planning aimed at restoring ecosystem integrity.

Past attempts to address the issue of degraded rangelands have been dominated by pragmatic studies that fail to address the underlying ecological processes that maintain these altered systems (Call & Roundy, 1991). When rehabilitation focuses on re-establishing a functioning system, recapturing the dynamics of systems may be dependent on ensuring that the appropriate processes are returned. This requires understanding of the extent to which processes or events in the past were important in regulating the system, and whether they can be re-established at restored sites.

The need for rehabilitation of rangelands has increased with the noticeable decrease in range condition associated with intensive use by livestock (Call & Roundy, 1991). This need is reinforced by the realisation that natural recovery does not occur in a time frame acceptable to land users. In my study, two years of grazing exclusion had no significant effect on reversing grazing induced vegetation change (Chapter 4). The inability to revert degraded rangelands to former productive states by only removing grazing pressure (Walker, 1993; Westoby *et al*., 1989; van Rooyen, 2000) has necessitated the use of a more active approach to the rehabilitation of rangelands.

In Paulshoek, Namaqualand, heavy grazing of low-lying areas has resulted in the reduction of palatable perennial shrubs and the dominance of the unpalatable shrub, *Galenia africana* (Todd & Hoffman, 1999). When compared with adjacent areas under low grazing pressure, it was found that heavy grazing has increased the seed bank of *Galenia africana* in the soil and reduced that of palatable perennials (Chapter 3).

Increases in exposed soil as seen in Paulshoek (Chapter 3; Allsopp, 1999) is perceived as an indicator of system dysfunction (Tongway & Ludwig, 1997). Lower vegetation cover reduces the efficiency with which resources such as water, organic material and nutrients are trapped. Therefore, landscapes become increasingly dysfunctional, as their ability to capture and store resources decrease, resulting in a loss of accumulated reserves. Such an environment is not conducive to successful recruitment and establishment of seedlings. Interventions that improve capture of resources may enable systems to recover.

In the succulent karoo, changes in the demographic structure of shrub populations are a function of seed availability (Milton, 1994a). Grazing can thus determine the relative abundance of seedlings by selectively reducing the size and reproductive success of preferred forage plants while giving unpalatable species a competitive advantage (Milton, 1994a; Hoffman *et al,*. 2003). In the southern Karoo, it has been shown that where herbivory is sufficient to prevent seeding of palatable shrubs, these shrubs could be replaced by unpalatable shrubs such as *Galenia africana* and *Pteronia pallens* (Milton, 1992).

The timing of flowering, seed set, dispersal and germination in arid systems is vital because the occurrence of times suitable for these processes is highly uncertain (Noy-Meir, 1973). The synchronizing of events such as flowering and seed set with grazing is critical in determining which species persist in the ecosystem. Factors such as the introduction of propagules into favourable microhabitats when sufficient soil moisture is available can optimise the probability of germination and establishment.

Stock *et al*., (1999) and Allsopp (1999) found that shrubs in succulent karoo ecosystems develop areas of nutrient enrichment under their canopies, which can lead to the formation of fertile islands. These zones of nutrient enrichment are formed through the deposition and subsequent stabilization of windborne soil particles under plant canopies as well as litter deposition from the shrub canopy (Carillo-Garcia *et al*., 1999). As a result of these zones of enrichment, associations form between adult shrubs and seedlings that recruit under their canopies (Humberto *et al*., 1996).

Adult plants can facilitate seedling establishment by reducing high temperatures near the soil surface as well as providing a microhabitat with a higher soil nutrient content (Humberto *et al*., 1996). Turner *et al*., (1966) found that shade is essential to seedling survival of *Saguaro* seedlings, with 100 % mortality of seedlings in unshaded compared to 65 % in shaded conditions. However, shading and competition for water with the adult plant can also reduce the growth of associated seedlings (Franco & Nobel, 1989).

It has been suggested that an opportunistic management approach, which includes reseeding and stock withdrawal from overgrazed areas, could optimise the restoration potential of degraded rangelands (Milton, 1994b). The introduction of seed and seedlings into overgrazed rangelands could therefore re-establish forage species in an area which in turn can increase the plant species diversity. However, the success of artificially introduced propagules relies strongly on a sound understanding of their recruitment and establishment requirements.

The creation of favourable microhabitats for seed entrapment, germination and seedling establishment could assist in the rehabilitation of grazing induced vegetation change. It has been suggested that the presence of *Galenia africana* enriches and stabilizes soils under its canopy, and that this change in soil condition may contribute to its persistence on heavily grazed areas (Allsopp 1999). Shrubs introduced into areas previously occupied by *Galenia africana* might be assisted in their re-establishment by this enrichment.

Artificially created safe sites such as brushpacks can act as traps of water, sediments, litter and seed resulting in the formation of fertile patches (Noble *et al.*, 1997) which facilitate the establishment of seedlings. While brushpacks act as natural barriers and nurse sites that capture resources and stimulate biotic activity, they do not compete with emerging seedlings (Brown *et al*., 1999).

This chapter investigates the process of rehabilitation and how it can be used to gain an understanding of the ecological factors that may be sustaining this altered vegetation states. The choice of rehabilitation methods was based on their ability to answer these questions:

1. What is the influence of removing *Galenia africana* on soil movement and soil nutrients?
2. Will the introduction of artificially created microhabitats improve resource control of this system and facilitate natural recruitment?
3. What influence will created microhabitats have on seedling emergence?
4. What are the conditions required for the successful establishment and survival of seedlings?

5.2. Materials and method

5.2.1. Site description

This study took place in the communal rangeland of Paulshoek, Namaqualand. A description of the location, history, climate and vegetation of the study area can be found in Chapter 2.

5.2.2. Sampling method

Three, 50 m x 50 m sites was selected in the enclosed Moedverloor area. Each site was further subdivided into 36 plots, which were approximately 7 m x 7 m in size with 1 m spaces between them. Rehabilitation treatments were randomly allocated to plots. All treatment plots were replicated twice within each site.

5.2.3. Physical Interventions

5.2.3.1. Removal of *Galenia africana*

Galenia africana is regarded as an undesirable species and is often cleared from rangelands and old fields. The effect of removing *Galenia africana* on enriched soil nutrient patches and soil movement was investigated. In June 1999, six plots (two replicates per site) were cleared of all vegetation excluding perennial palatable shrubs.

5.2.3.2. Monitoring the effect of removing *Galenia africana*

a. Soil movement

Iron stakes (50 cm long, 0.5 cm in diameter) was placed centrally in patches where six large adult *Galenia africana* shrubs had been removed at each site. The stakes were inserted until the height above ground equalled 30 cm. Stakes were measured every month to determine soil movement.

Statistical differences of absolute cumulative movement at each site was tested using a one way analysis of variance test. Tukey's test was applied to distinguish between means.

b. Soil analysis

Soil was collected to a depth of 5 cm from areas cleared of adult *Galenia africana* shrubs and adjacent areas. Samples were used to determine the effect *Galenia africana* has on soil nutrient status and if this effect will be sustained over time when the adult shrub is removed. Samples were air dried and sieved through a 2 mm sieve before being analysed for the following; pH, organic matter, total nitrogen and total phosphorus.

Soil pH was determined in 0.01M $CaCl_2$ (Conyers & Davey, 1988). Soil organic matter was measured after combustion at 450 ^oC for 16 hours. Total nitrogen was determined by kjeldahl digestion followed by distillation and titration (Allen, 1989). Total phosphorus was measured using a molybdenum blue colour development using a spectrophotometer after digestion in concentrated hydrochloric acid (Murphy & Riley, 1962).

Paired student t-tests were used to test for statistical differences in soil chemistry between areas cleared of *Galenia africana* and adjacent control sites.

5.2.3.3. Methods of improving resource capture

a. Microcatchments

In April 1999, 12 to 16 triangularly shaped microcatchments were dug in 6 plots at each of the three sites. Each microcatchment was 75 cm x 75 cm x 75 cm in size and tapered to a depth of 10 cm (Fig. 5.1). Existing vegetation and rocks were not removed. The microcatchments were aligned with the slope and placement of microcatchments in rows was such as to alternate with those in adjacent rows to ensure maximum trapping of runoff water.

Fig. 5.1. Microcatchments

b. Microcatchments and Brushpacking

The microcatchments in two of the plots at each site (Fig. 5.2) were packed with thick mats of branches from *Galenia africana* shrubs.

Fig. 5.2. Microcatchment with *Galenia africana* branches as brushpacking.

c. Brushpacks

Galenia africana shrubs were packed onto two plots at each site in June 1999 (Fig. 5.3). Existing vegetation was not removed from the sites. The *Galenia africana* packs were made up of overlapping shrubs in order to cover the entire area of each plot. *Galenia africana* shrubs were obtained from croplands that had been cleared for sowing.

Fig. 5.3. Brushpack made of *Galenia africana* shrubs to cover a 7 x 7 m area.

5.2.3.4. Monitoring the efficiency of resource capture treatments

a. Soil Analysis

Soil samples were collected to a depth of 10 cm four months after rain in November 2000, immediately after good rainfall in May 2001, and one month after rain in August 2001. Soils were collected from controls i.e. plots receiving no treatment, under brushpacks made with *Galenia africana* shrubs and in microcatchments. Samples were air dried and sieved through a 2 mm sieve before being analysed for pH, organic matter, total nitrogen and total phosphorus.

Soil pH was determined in 0.01M $CaCl_2$ (Conyers & Davey, 1988). Soil organic matter was measured after combustion at 450 °C for 16 hours. Total nitrogen was determined by kjeldahl digestion followed by distillation and titration (Allen, 1989). Total phosphorus was measured using a molybdenum blue colour development using a spectrophotometer after digestion in concentrated hydrochloric acid (Murphy & Riley, 1962).

In addition to the soils collected for chemical analysis, soils were also collected from under *Galenia africana* shrubs. All soils were analysed for soil moisture content after drying at 100 ºC overnight.

Analysis of variance was used to test for statistical differences in soil chemistry due to treatment. Tukey's test was applied *post hoc* to distinguish between means.

b. Natural recruitment

Natural recruitment of perennial seedlings and ephemeral cover was measured under the extensive brush packs and the triangularly shaped microcatchments, which had been left empty or packed with *Galenia africana* brush. Cover of ephemerals was calculated by placing a 75 cm x 75 cm x 75 cm triangular grid drawn on clear plastic film placed within the following microhabitats: randomly selected microcatchments, microcatchments with brushpacks or areas within brushpacks and control plots.

A triangular shape matching the shape and size of the microcatchments was selected for uniformity of monitoring. The triangle was divided into a grid of 200 (2.5 cm x 2.5 cm) blocks. Cover of three guilds of ephemerals, namely dicotyledons, grass and geophytes were calculated by counting the number of blocks they occupied within the grid. From this the area that each guild occupied could be calculated. Data was collected in August of 2001, after the main winter rainfall season.

The total number of perennial seedlings within each triangular grid were counted and grouped into succulent species, non-succulent species and *Galenia africana* seedlings.

Analysis of variance was used to test for statistical difference in ephemeral cover and total number of perennial seedlings due to treatment. Tukey's test was applied to distinguish between means.

5.2.4. Biological interventions

5.2.4.1. Influence of microhabitat on seedling emergence

Seed of four palatable species, *Hirpicium alienatum* (Thunb) Druce (Asteraceae), *Ruschia robusta* L. Bolus (Mesembryanthemaceae), *Hermannia amoena* Dinter ex Friedr.-Holzh (Sterculiaceae) and *Tripterus sinuatum* DC. var. *sinuate* (Asteraceae) was introduced in August 2000 into microsites, namely: bare soil, under brushpacks and disturbed soil, to test the requirements of seed germination and establishment. The microsites were 1 m x 1 m and seed of each species was spread in its own microsite. This was replicated twice at each site. Seeds of all four species were viable (N Gabriels pers. comm). *Ruschia robusta* seed was introduced in two ways: as inflorescences stalks with capsules attached or as a similar number of capsules removed from inflorescences. Sixteen inflorescences were placed upright in each 1 m x 1 m microsite to simulate their orientation on bushes. The purpose of this was to ensure that seed release mimicked the release from capsules on bushes following a rainfall event. Fifty *Hermannia amoena* and *Hirpicium alienatum* seeds, forty five *Tripterus sinuatum* seeds and approximately five hundred *Ruschia robusta* seeds were sown into each microsite at each of the three sites.

Data were statistically analysed using a Chi-square test to calculate the measure of agreement between number of seeds germinated and not germinated.

5.2.4.2. Testing conditions required for seedling establishment

The effect of microenvironments on the growth and survival of seedlings was tested by introducing seedlings of *Ruschia robusta* (a palatable, leaf succulent shrub) into various natural and artificially created microhabitats. These microhabitats included the transplanting of seedlings into triangularly shaped dug microcatchments, under the canopies of *Galenia africana*, in areas cleared of *Galenia africana* and under packed material made from *Galenia africana* shrubs and into open positions i.e. undisturbed locations.

Microhabitats were chosen based on the hypothesis that they should enhance seedling establishment by trapping resources, act as nurse sites to growing seedlings and provide protection from climatic conditions. At the time of transplantation, *Ruschia robusta* seedling sizes varied between 10 mm and 160 mm. Seedling growth and survival was monitored on a monthly basis from August 1999 to August 2001.

Data were statistically analysed using Chi-square tests to calculate the measure of agreement between number of seedlings dead and alive in each treatment in August 2001.

5.3. Results

5.3.1. Physical Interventions

5.3.1.1. Removal of *Galenia africana*

a. Soil movement

Absolute cumulative soil movement is used to show the total soil movement over the monitoring period irrespective of whether soil is lost or gained. Soil movement was relatively minor for the first year until day 364 (Fig. 5.4.). Thereafter, all three sites saw more movement in soil. This took the form of steady increments in soil loss or gain at sites one and three (Fig. 5.4.a & b). At site two (Fig. 5.4.c), following major soil movement from day 364 to 418, further movement was slight until after day 693 when large quantities of soil moved around two of the stakes.

Net average monthly soil movement around six stakes at each site over the monitoring period, takes gains and losses of soil into account. A negative slope is thus an indication of net soil loss and a positive slope an indication of soil gain for the site. Site one (Fig. 5.5a) experienced net soil loss for the first year before steadily regaining soil between day 334 and day 418. From day 418 till 855 slight fluctuations in soil loss and gain occurred. However, the large standard errors between days 449 and 553 are an indication of major movement at individual stakes at this time.

Site two saw net soil loss over the first year (Fig. 5.5b). The next year saw a cycle of steady loss between day 398 and 483 and then again between days 511 to 651. This was followed by a gain in soil around day 693 before soil loss again in the following months. There was increased loss and gain of soil at individual stakes at site two around days 398 and 418 and at day 720 and 806 as seen by the high standard errors.

The pattern at site three (Fig. 5.5c) was one of minimal net soil loss or gain. As for site one and two, the first year saw a slight net loss. From day 334 to 449 there was both loss and gain of soil. From day 449 there was little net soil movement and little movement around individual stakes as reflected in the relatively low standard errors. The overall trend is one of little loss or gain over an 842 day period.

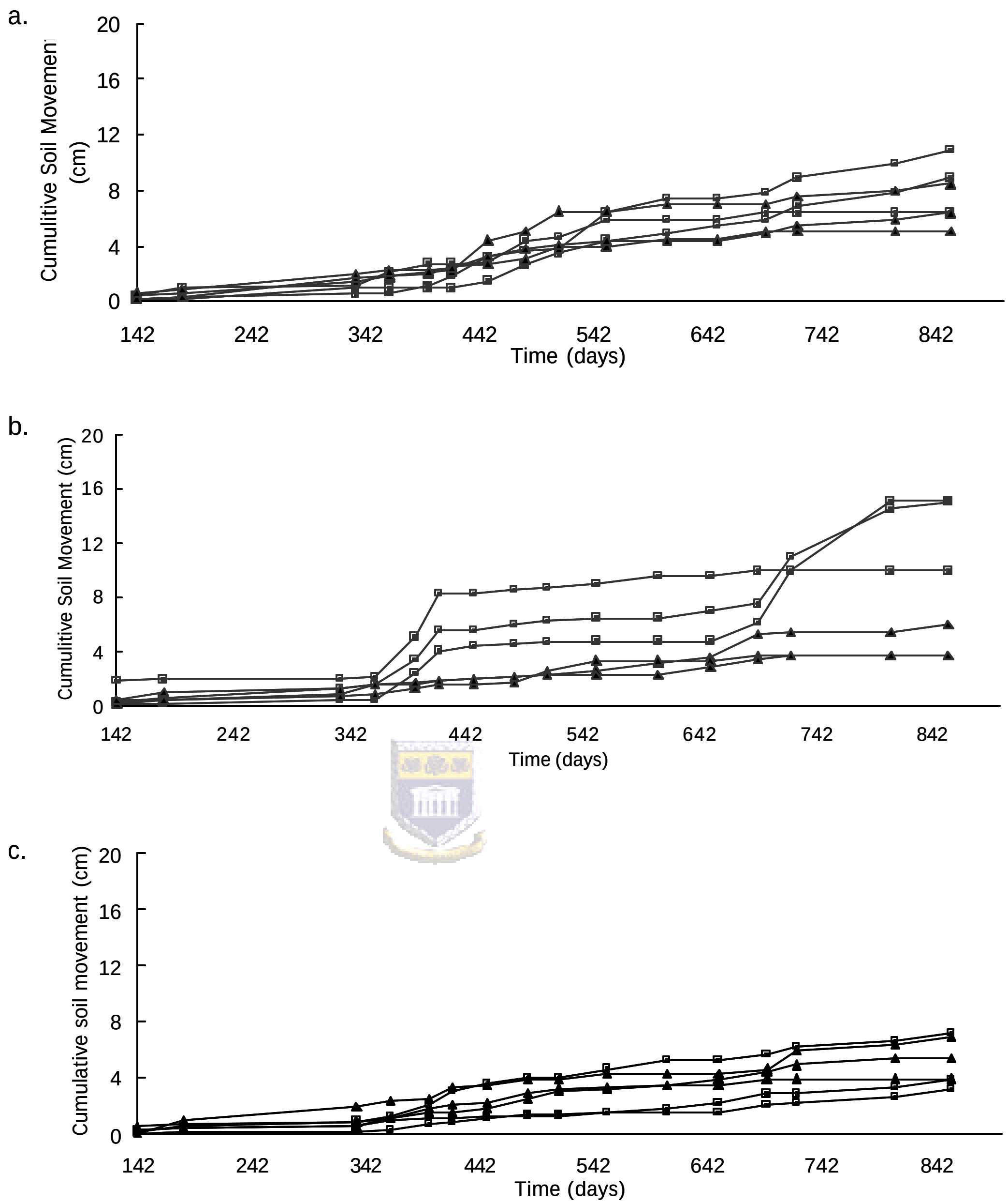

Fig. 5.4. Absolute cumulative soil movement over time at site 1 (a), site 2 (b) and site 3 (c) measured relative to permanently placed stakes. (■) and (▲) differentiate between stakes within two plots.

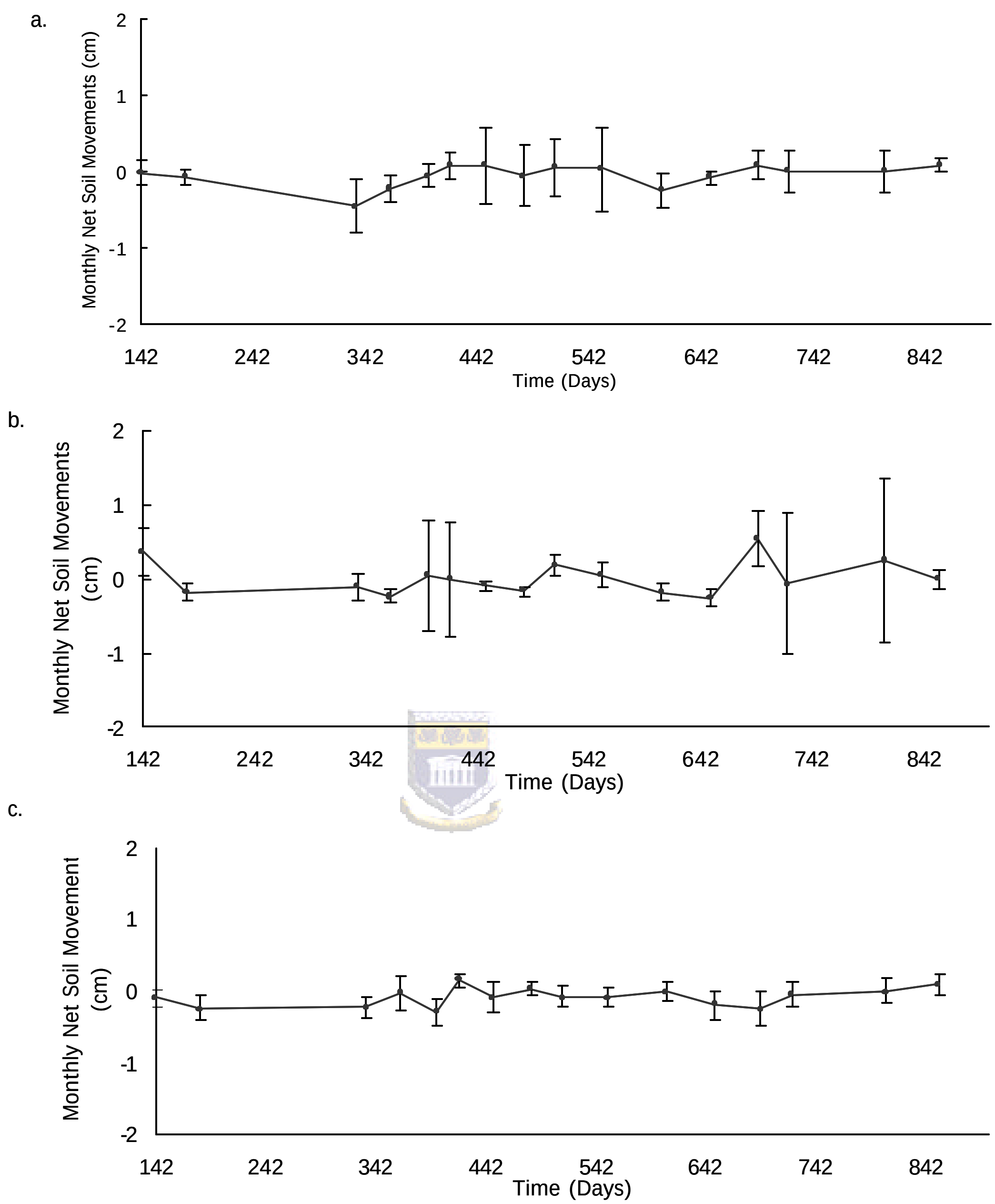

Fig. 5.5. Average net monthly soil movement measured around six stakes at site 1 (a), site 2 (b) and site 3 (c). Bars indicate standard errors of the mean.

b. Soil Analysis

Soil from areas cleared of *Galenia africana* showed significantly higher ($p<0.05$) organic matter levels than adjacent areas in the first year immediately after clearing at site one and two but there were no difference at site three (Table 5.1). In 2000, only site one showed higher organic matter levels in the areas cleared of *Galenia africana.* By 2001 no difference in organic matter was seen between areas cleared of *Galenia africana* and adjacent areas at any of the sites.

In 1999, site one and two had higher levels ($p<0.05$) of nitrogen in cleared areas than in adjacent areas not previously under *Galenia africana* canopies, with no differences at site three (Table 5.1). In the following year, site one and three still showed higher levels of nitrogen from patches cleared of *Galenia africana* with no difference at site two. By 2001 there were no statistically discernable differences in nitrogen levels due to treatment at site one and three while nitrogen levels in areas cleared of *Galenia africana* dropped below that of open soil at site two.

Soil pH levels were consistently higher ($p<0.05$) in areas cleared of *Galenia africana* than the adjacent areas for all three years at all three sites with the exception of site three in 2001 (Table 5.1).

Table 5.1: Changes in soil chemistry in areas cleared of *Galenia africana* and uncleared adjacent open areas at three rehabilitation sites.

Different letters indicate that significant differences ($p<0.05$) exist between means at any one site. Means ± standard errors shown.

	Site 1		**Site 2**		**Site 3**	
	Open Soil	**Cleared**	**Open Soil**	**Cleared**	**Open Soil**	**Cleared**
1999						
Organic matter (%)	1.54 ± 0.16a	2.03 ± 0.16b	1.50 ± 0.07a	2.57 ± 0.17b	1.77 ± 0.08a	2.05 ± 0.10a
Nitrogen (µg/g)	291.77 ±13.70a	402.50 ± 52.27b	277.87 ±47.64a	465.37 ±86.98b	307.29 ±33.95a	387.28 ±30.38a
pH	6.40 ± 0.10a	7.78 ± 0.16b	6.62 ± 0.11a	8.12 ± 0.11b	7.10 ± 0.09a	7.68 ± 0.10b
Phosphorus (µg/g)	67.36 ± 5.10a	94.60 ± 14.76b	87.03 ± 23.61a	128.35 ± 28.33b	137.68 ±15.06a	121.71 ± 28.60a
2000						
Organic matter (%)	1.33 ± 0.07a	1.70 ± 0.10b	1.59 ± 0.09a	2.10 ± 0.42a	1.76 ± 0.13a	2.33 ± 0.27a
Nitrogen (µg/g)	269.35 ±24.75a	385.17 ±34.01b	286.75 ±36.83a	376.47 ±55.42a	310.22 ±16.21a	400.30 ±47.50b
pH	6.33 ± 0.23a	7.10 ± 0.20b	6.27 ± 0.17a	7.21 ± 0.03b	6.60 ± 0.12a	7.05 ± 0.12b
Phosphorus (µg/g)	79.42 ± 6.58a	153.24 ± 33.28a	123.65 ± 23.13a	117.39 ± 28.02a	115.99 ± 28.61a	93.95 ± 7.58a
2001						
Organic matter (%)	1.34 ± 0.04a	1.51 ± 0.08a	1.16 ± 0.03a	1.87 ± 0.51a	1.81 ± 0.32a	1.80 ± 0.27a
Nitrogen (µg/g)	245.58 ±25.94a	307.75 ±43.73a	200.53 ± 26.79a	163.49 ± 10.86b	250.87 ±21.58a	219.30 ± 25.04a
pH	6.30 ± 0.06 a	7.20 ± 0.12b	6.55 ± 0.17a	7.04 ± 0.20b	6.73 ± 0.06a	6.94 ± 0.13a
Phosphorus (µg/g)	89.49 ± 13.27a	101.75 ± 22.72a	167.11 ± 27.88a	84.94 ± 11.45b	95.71 ± 16.18a	126.75 ± 20.50a

Phosphorus levels were higher in areas cleared of *Galenia africana* in 1999, at site one and two, with no difference at site three. Areas cleared of *Galenia africana* showed no difference in phosphorus levels at all three sites for 2000. In 2001, areas cleared of *Galenia africana* showed no difference in soil phosphorus levels at site one and three with adjacent areas showing significantly higher levels than cleared areas at site two (Table 5.1).

5.3.1.2. Influence of resource capture methods

a. Soil Analysis

Generally, interventions did not influence soil organic matter, pH, nitrogen and phosphorus relative to undisturbed (Table 5.2) soil except in the following instances: At site two significantly higher ($p<0.05$) organic matter levels were measured in catchments compared to the control and brushpack treatments in November 2000. However, treatment did not influence organic matter levels in May and August 2001 (Table 5.2).

Soil pH was higher in microcatchments at site two in November 2000 than in the control and brushpack treatment. Treatment had no effect on soil pH in May 2001. In August 2001 pH levels were significantly higher in the control treatment than in microcatchments, but was not significantly different to pH levels under brushpacks ($p>0.05$).

Table 5.2: The effect of microhabitats on soil chemistry at three sites over time. Letters indicate significant differences between treatments at any one site ($p<0.05$). Means ± standard errors shown.

	Open Soil	**Catchments**	**Packed**
November 2000		**Site 1**	
Organic matter (%)	1.36 ± 0.08a	1.24 ± 0.05a	1.35 ± 0.05a
pH	6.07 ± 0.09a	6.37 ± 0.09a	6.28 ± 0.16a
Nitrogen (µg/g)	205.44 ± 48.32a	198.97 ± 29.96a	252.20 ± 57.14a
Phosphorus (µg/g)	105.54 ± 24.81a	143.63 ± 26.02a	95.46 ± 19.76a
May 2001			
Organic matter (%)	1.27 ± 0.08a	1.36 ± 0.07a	1.39 ± 0.15a
pH	6.62 ± 0.16a	6.39 ± 0 .19a	6.69 ± 0.16a
Nitrogen (µg/g)	225.92 ± 13.95a	155.04 ± 11.65a	215.35 ± 39.45a
Phosphorus (µg/g)	104.00 ± 38.78a	112.21 ± 12.49a	89.55 ±21.18a
August 2001			
Organic matter (%)	1.32 ± 0.06a	1.33 ± 0.06a	1.49 ± 0.10a
pH	6.61 ± 0.07a	6.50 ± 0.13a	6.48 ± 0.06a
Nitrogen (µg/g)	208.42 ±18.28a	160.96 ± 17.73a	167.56 ± 27.06a
Phosphorus (µg/g)	112.15 ± 10.30a	96.59 ± 18.58a	117.70 ± 22.39a
November 2000		**Site 2**	
Organic matter (%)	1.18 ± 0.03a	1.80 ± 0.09b	1.40 ± 0.10a
pH	6.00 ± 0.08a	7.03 ± 0.10b	6.43 ± 0.07a
Nitrogen (µg/g)	191.35 ± 30.16a	240.95 ± 14.17a	256.99 ± 19.30a
Phosphorus (µg/g)	80.79 ± 5.23a	116.63 ± 28.37a	162.55 ± 25.41a
May 2001			
Organic matter (%)	1.30 ± 0.03a	1.68 ± 0.16a	1.57 ± 0.38a
pH	6.19 ± 0.11a	6.79 ± 0.15a	6.17 ± 0.46a
Nitrogen (µg/g)	141.13 ± 8.62a	152.68 ± 12.86a	142.45 ± 3.10a
Phosphorus (µg/g)	80.37 ± 8.19a	100.72 ± 31.53a	115.51 ± 16.73a
August 2001			
Organic matter (%)	1.25 ± 0.04a	1.60 ± 0.09a	1.32 ± 0.14a
pH	6.16 ± 0.05a	6.85 ± 0.11b	6.75 ± 0.12b
Nitrogen (µg/g)	129.18 ± 13.33a	146.94 ± 14.02a	129.15 ± 11.20a
Phosphorus (µg/g)	97.49 ± 12.80a	114.71 ± 21.17a	83.03 ± 13.27a
November 2000		**Site 3**	
Organic matter (%)	1.58 ± 0.13a	1.34 ± 0.07a	1.59 ± 0.10a
pH	6.54 ± 0.07a	6.57 ± 0.14a	6.22 ± 0.06a
Nitrogen (µg/g)	234.44 ± 57.23a	263.22 ± 43.60a	315.27 ± 29.78a
Phosphorus (µg/g)	108.82 ± 34.75a	187.11 ± 63.37a	114.49 ± 14.57a
May 2001			
Organic matter (%)	1.53 ± 0.06a	1.34 ± 0.07a	1.53 ± 0.08a
pH	6.76 ± 0.09a	6.85 ± 0.16a	6.46 ± 0.05a
Nitrogen (µg/g)	224.04 ± 14.48a	194.08 ± 29.02a	249.47 ± 14.79a
Phosphorus (µg/g)	135.89 ± 29.42a	149.28 ± 25.78a	84.03 ± 13.83a
August 2001			
Organic matter (%)	1.37 ± 0.06a	1.47 ± 0.12a	1.38 ± 0.06a
pH	6.95 ± 0.13a	6.92 ± 0.13a	6.57 ± 0.10a
Nitrogen (µg/g)	165.58 ± 9.07a	179.57 ± 13.19a	193.17 ± 13.23a
Phosphorus (µg/g)	156.29 ± 39.65a	193.90 ± 55.00a	112.38 ± 30.97a

b. Soil moisture

Significantly higher soil moisture levels ($p<0.05$) were recorded under *Galenia africana* shrubs than any other microhabitat at site one and three for November 2000 (Table 5.3). At site two, soil moisture levels were significantly higher under *Galenia africana* shrubs than with no treatment applied and brushpack treatments, with no significant difference to the microcatchment treatment ($p>0.05$).

Table 5.3: Moisture content of soil for implemented treatments at three sites over time. Different letters indicate significant differences ($p<0.05$) between treatments at any one site.

	Treatments			
	No Treatment	**Catchments**	**Packed**	**Under *Galenia***
Site 1				
November 2000	0.30 ± 0.04a	0.38 ± 0.04a	0.38 ± 0.00a	0.48 ± 0.03b
May 2001	5.63 ± 0.37a	5.97 ± 0.32a	4.90 ± 0.22a	5.72 ± 0.32a
August 2001	2.50 ± 0.23a	2.98 ± 0.33a	2.41 ± 0.15a	2.25 ± 0.30a
Site 2				
November 2000	0.19 ± 0.02a	0.46 ± 0.06b	0.23 ± 0.03a	0.49 ± 0.04b
May 2001	5.58 ± 0.43ab	6.58 ± 0.41a	5.89 ± 0.25ab	4.28 ± 0.49b
August 2001	3.10 ± 0.33a	2.88 ± 0.33a	2.96 ± 0.28a	2.99 ± 0.26a
Site 3				
November 2000	0.40 ± 0.04a	0.40 ± 0.03a	0.38 ± 0.03a	1.14 ± 0.04b
May 2001	6.69 ± 0.34a	6.28 ± 0.06a	7.58 ± 0.53a	6.65 ± 0.34a
August 2001	3.21 ± 0.15ab	2.60 ± 0.25b	4.21 ± 0.61a	2.37 ± 0.19ab

Soil moisture levels were not influenced by treatment at site one and three in May 2001 (Table 5.3). At site two, moisture levels followed the following trends, under under *Galenia africana* = Open = Packed = Catchment.

Three months later, microhabitats had no influence on soil moisture levels at sites (Table 5.3). No significant difference was found between the control and any of the treatments at site 3. However, soil moisture levels in the brushpack treatment were significantly higher ($P<0.05$) than the microcatchment and under shrub treatment.

c. Natural recruitment

Cover of all ephemerals was significantly higher under the brushpack treatment at site one and three (Fig. 5.6). At site two, the undisturbed open soil had significantly lower cover for all ephemerals but all three interventions resulted in high ephemeral cover. Since the majority of ephemerals recorded fell within the dicotyledons guild, this group followed the same pattern as for total ephemeral cover.

Cover of grasses was not influenced by treatment at site one and three, but showed significantly higher ($p<0.05$) cover under the brushpack treatment at site two (Fig. 5.6). Cover of geophytes could only be compared at site one, as they were not found within the sample grids at site two and three. At site one geophyte cover was significantly higher in open areas than the microcatchment and combination microcatchment/brushpack treatment. No difference was found between the brushpacks and open areas for geophytes.

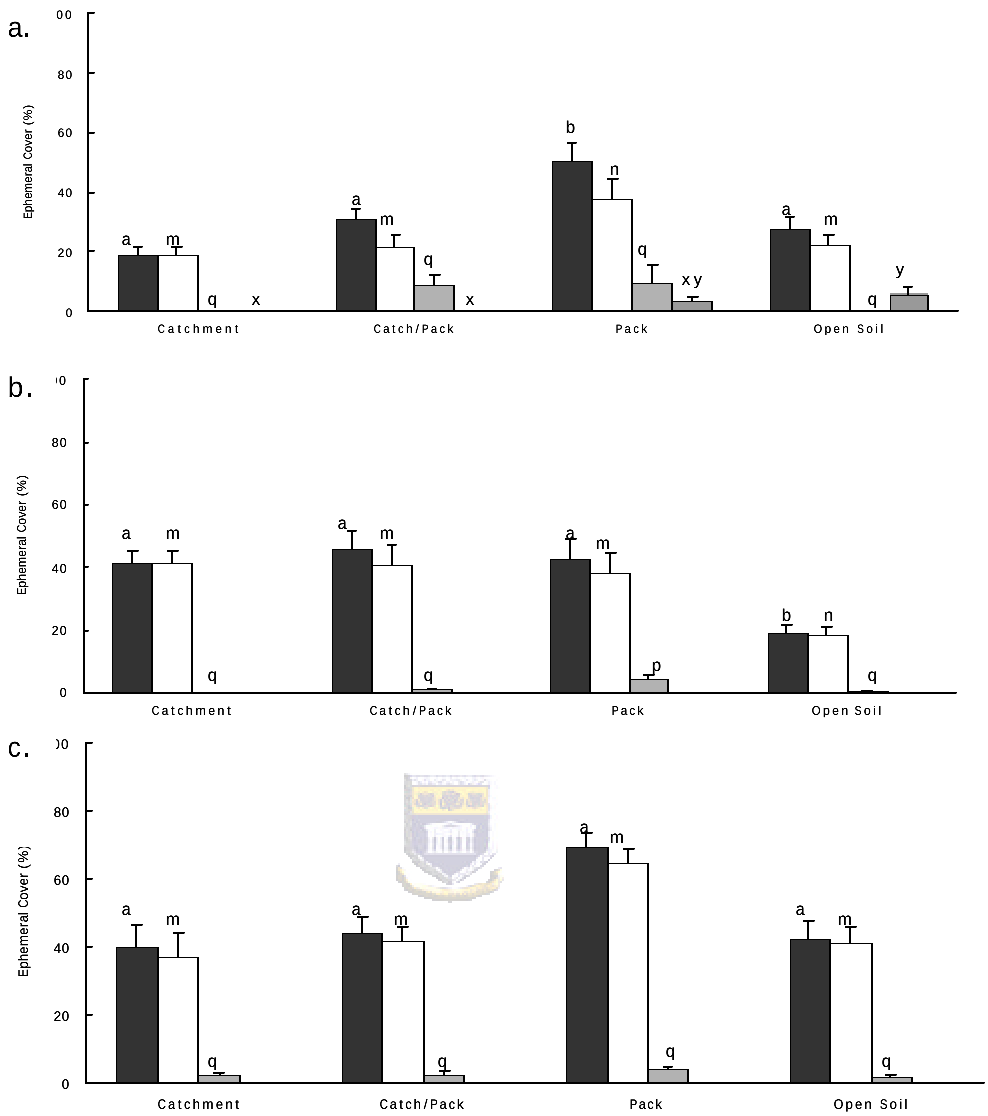

Fig. 5.6. Cover of ephemeral species at site 1 (a), site 2 (b) and site 3 (c) under introduced microhabitats. Dark bars = total cover, Light bars = cover of dicotyledons, Striped bars = grass cover, Checker bars = geophyte cover. Different letters indicate that there are significant differences in cover within guilds ($p<0.05$). Letter sequence a,b; m,n; p,q and x,y are used to distinguish between significantly different cover values for all, dicot, grass and geophyte ephemerals respectively between treatments.

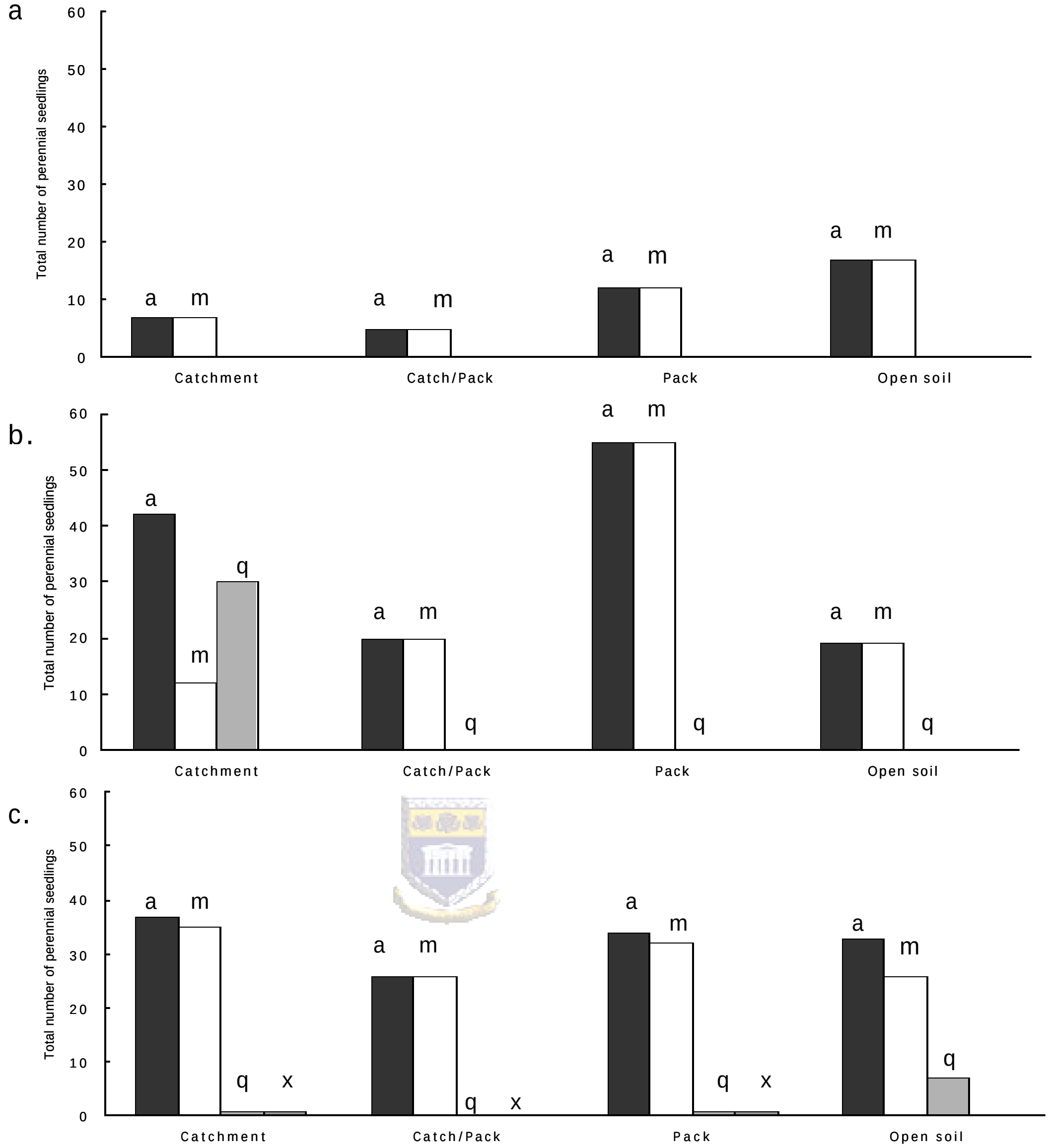

Fig. 5.7. Total number of all perennial seedlings at site 1 (a), site 2 (b) and site 3 (c) under introduced microhabitats. Dark bars = All seedlings, Light bars = *Galenia africana*, Striped bars = Succulent species, Checker bars = Non succulent species. Different letters indicate that there are significant differences in seedling numbers between treatments ($p<0.05$). Letter sequence a,b; m,n; p,q and x,y are used to distinguish between significantly different seedling numbers for all, *Galenia africana*, succulent and non succulent perennials seedlings respectively between treatments.

Galenia africana made up the largest proportion of perennial seedlings, followed by those of succulent species and a small number of non-succulent seedlings (Fig. 5.7). Treatment had no statistically significant influence on establishment of perennial seedlings (Fig. 5.7).

5.3.2. Biological Interventions

5.3.2.1. The influence of microhabitat on seedling emergence

Few seedlings emerged in the first year and all these seedlings died by the end of this year (Table 5.4). Germination occurred again in the second year of the study after a rainfall event. However, from approximately 20 000 seeds sown, only 90 seedlings emerged (Table 5.4).

5.3.2.2. Testing conditions required for seedling establishment

Seedling survival varied between 100 % and 0 % for specific treatments at individual sites (Fig. 5.8 and 5.9). Survival of seedlings was higher ($p<0.05$) when transplanted into unmodified open areas than the microcatchment treatment at site one (Fig. 5.8 a). Treatment did not influence seedlings survival at site two and three (Fig. 5.8 b and c).

Significantly more seedlings survived under *Galenia africana* shrubs than in open areas, brushpack and cleared treatments at site one ($p<0.01$) (Fig. 5.9a) and three ($p<0.05$) (Fig 5.9 c) with no difference due to treatment at site two (Fig. 5.9b).

Table 5.4: Number of seedlings that emerged from seeds of four species sown into different microhabitats.

Treatment	Species	Seed Sown	Seedlings emerged 2000	2001
Bare Soil	*Hermannia amoena*	300	0	1
Bare Soil	*Hirpicium alienatum*	300	0	1
Bare Soil	*Ruschia robusta* capsules	3000	0	18
Bare Soil	*Ruschia robusta* inflorescen ce	3000	0	8
Bare Soil	*Tripteris sinuatum*	270	0	1
Under Brush	*Hermannia amoena*	300	0	2
Under Brush	*Hirpicium alienatum*	300	1	1
Under Brush	*Ruschia robusta* capsules	3000	0	6
Under Brush	*Ruschia robusta* inflorescence	3000	0	10
Under Brush	*Tripteris sinuatum*	270	0	1
Disturbed soil	*Hermannia amoena*	300	0	0
Disturbed soil	*Hirpicium alienatum*	300	2	0
Disturbed soil	*Ruschia robusta* capsules	3000	1	9
Disturbed soil	*Ruschia robusta* inflorescence	3000	0	13
Disturbed soil	*Tripteris sinuatum*	270	9	6

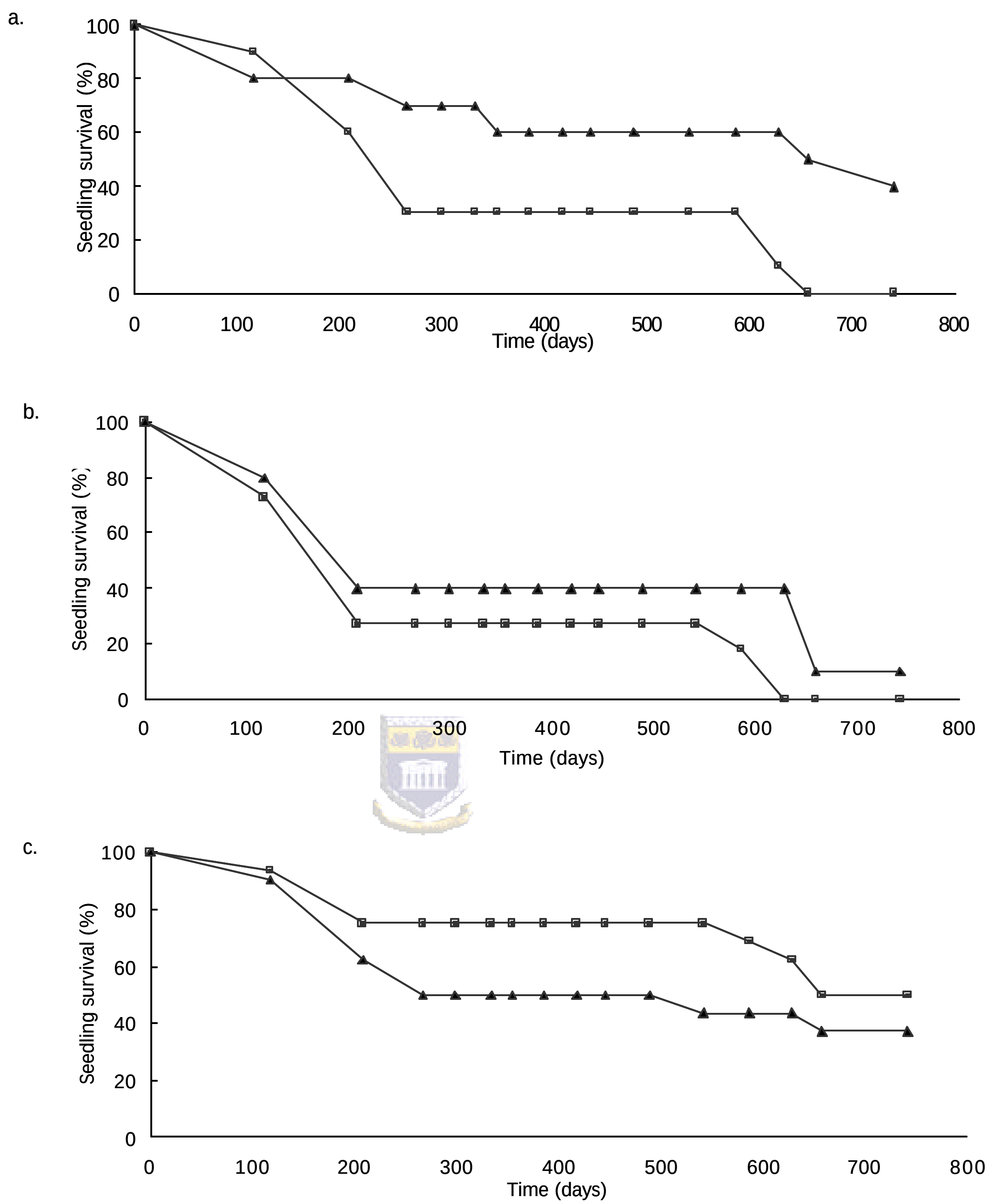

Fig. 5.8. Survival of transplanted seedlings of *Ruschia robusta* over time at site 1 (a), site 2 (b) and site 3 (c) in microcatchments (■) and in unmodified areas (▲).

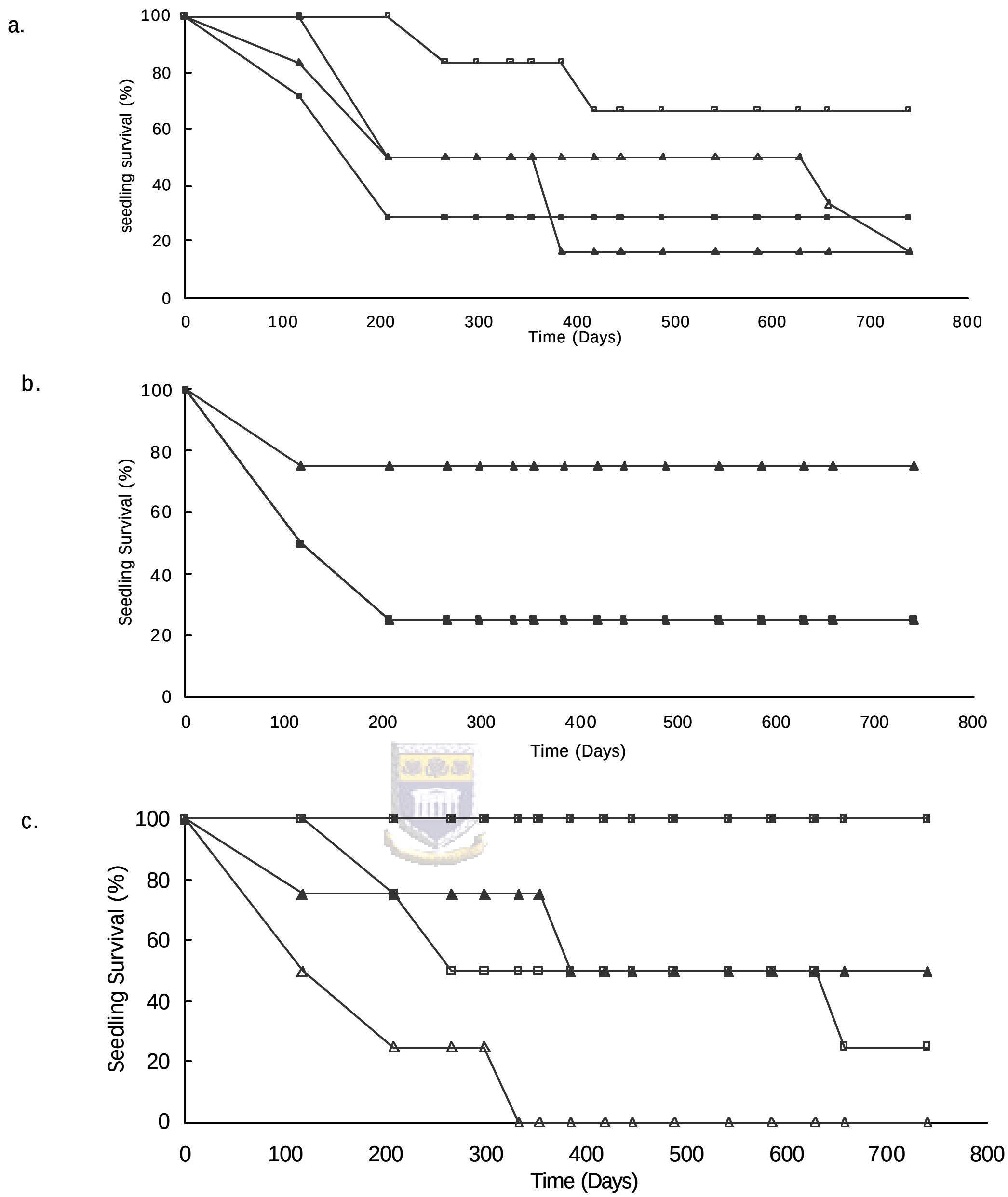

Fig. 5.9. Survival of seedlings over time at site 1 (a), site 2 (b) and site 3 (c) in four microhabitats. Seedlings transplanted in areas cleared of *Galenia africana* (□), under *Galenia africana* (■), in *Galenia africana* brushpacks (▲), in unmodified areas (△).

5.4. Discussion

In this two year study, various physical and biological interventions were followed at an arid site transformed by grazing. Soil analysis carried out on areas previously occupied by *Galenia africana* confirms that this shrub alters soil chemistry. Soil analysis shows that areas cleared of *Galenia africana* have higher nutrient status than adjacent soil. This elevated nutrient status is most pronounced immediately after clearing with measurement in subsequent years equilibrating between cleared and adjacent areas. This would indicate that fertile islands caused by *Galenia africana* are not permanent features for the soil nutrients measured.

However, soil pH levels remained higher in areas cleared of *Galenia africana* for two years after the shrub had been removed. This agrees with Allsopp (1999) who also found elevated soil pH levels under *Galenia africana* compared to open areas. Soil enrichment in areas cleared of *Galenia africana* did not seem to enhance establishment of *Ruschia robusta* seedlings though they were transplanted directly after clearing. It would thus seem that changes in soil chemistry due to the presence of *Galenia africana* could influence the success of establishment of other shrubs under its canopy.

Soil movement around stakes placed in areas cleared of *Galenia africana* showed that the majority of movement occurred between May and August. This corresponds with the main rainfall season for this area. It can therefore be postulated that soil movement patterns are linked to seasonal rainfall, which could account for the seasonal increases in movement. In the Kalahari duneveld, it has been shown that soil mobility is a function of vegetation cover and wind intensity (van Rooyen, 2000), with soil mobility increasing with increasing wind intensity and reduced vegetation cover.

Vegetation cover is significantly lower in heavily grazed areas of Paulshoek, it could be suggested that this reduction in cover could lead to increased sand mobility as plants would act as traps for soil. The localised movement of soil may result in the loss of nutrients, which are associated with small soil particles (van Rooyen, 2000). Large scale clearing of *Galenia africana* would therefore not be recommended as this would aggravate problems of soil loss and soil nutrient depletion.

In Paulshoek, increased soil mobility is probably not a primary factor affecting seedling establishment as it is in wind driven systems like the Kalahari (van Rooyen , 2000). On a landscape scale soil in this system seems stable, though seasonal increases in runoff may bury or wash away seedlings and seeds on a localised level. Burial may be advantages to seeds as it could protect seeds from extreme surface summer temperatures and could also act as a deterrent for predation (Esler, 1999).

In this study, my methodology focused on returning functionality to the ecosystem in terms of improving resource capture and ameliorating the environment for seedling establishment. For this study, it would seem that created microhabitats did not affect soil chemistry. But, soil sampled from under

Galenia africana and within microcatchment treatments retained the more moisture compared to the controls.

It has been shown that the accumulation of seed in depressions and in litter can result in increased germination due to improved moisture availability (Esler, 1999). Microcatchments mimic the role of natural depressions and act as zones of increased soil moisture. Elevated soil moisture levels under *Galenia africana* are also encouraging as this suggests that these shrubs help to maintain resources such as water within the system, preventing it from being lost as runoff. However, Allsopp (1999) found higher soil moisture levels in open areas than under *Galenia africana* in an exceptionally good rainfall year. This would suggest that soil moisture content in relation to microhabitats is variable. To establish a pattern for shrub associated soil moisture for this system would require continued monitoring.

The presence of brushpacks or microcatchments did not influence natural recruitment and establishment of perennial seedlings in the two years of this study. The emergence of large numbers of *Galenia africana* seedlings is an indication of the pervasiveness of this species within the seed bank (Chapter 3) as seed production depends largely on the abundance of the species present in the population. Milton (1992) has shown that the lack of an adequate supply of seed of palatable perennial species can prevent transition from a system dominated by unpalatable plants to a mixed assemblage. The persistence of *Galenia africana*, would indicate that new vegetation states cannot always be reversed by succession due to dominance of less palatable shrubs and associated local extinction of more palatable species (Walker, 1993; Westoby *et al.*, 1989).

Overall, cover of annual herbaceous plants was higher under the brushpacks compared to the other treatments. This would suggest that brushpacks provide a more favourable environment for seed entrapment and establishment. The majority of annuals observed were dicotyledons, with less grass and geophyte cover. Geophyte cover was restricted to the brushpack and control treatments. This may be because these treatments were the least disruptive to the soil surface since the digging of microcatchments may have uprooted geophyte bulbs. The presence of brushpacks alone, and in combination with microcatchments, promoted grass cover in relation to the microcatchment and control treatments. The promotion of growth of annual species in microhabitats, but not of perennial species, may be attributed to the fast growing opportunistic nature of ephemeral species. The establishment of annuals could serve as further protection for exposed soil, and may also create conditions, which in future facilitate the establishment of palatable perennials.

In the two years of this study, seed emergence was positively influenced by microhabitats, specifically in disturbed soil. However, from approximately 20 000 seeds sown, only 90 seedlings emerged indicating that the factors concerning seed entrapment and germination are multifaceted. Physical factors that determine the fate of a seed when it enters a system such as the size of the seed, the roughness of the ground surface, and the wind speeds that occur in the area can play an important role in its germination and establishment success

(Johnson & Fryer, 1992). This study tried to address some of these physical factors but results proved not conclusive and instead seem to show that there must be other factors involved, not all of which I can explain within this study. However, the importance of follow up rainfall after dispersal in arid systems to ensure seedling establishment has also been recognized and may explain poor emergence and survival of seedlings in this study (Esler & Phillips, 1994; Gabriels, Allsopp & Hoffman, 2003).

The introduction of *Ruschia robusta* seedling into created microhabitats proved to have an effect on seedling survival. Two out of three rehabilitation sites showed higher seedling survival under the canopies of *Galenia africana* shrubs. This would indicate that soil enrichment and increased soil moisture under these shrubs might have benefited seedling survival. Control treatments showed better seedling survival than microcatchment. Poor seedling survival in microcatchments could be attributed to the removal of fertile topsoil when these sites were created. However, analysis of soil chemistry over time showed no difference between microcatchment and control treatments. Drought stress may also factor into the mortality of seedlings since there was poor follow up rainfall after the time of transplanting.

It has been shown that other succulent karoo species like *Tripterus sinuatum* form positive associations with refuge plants like *Ruschia robusta* in grazed systems (Todd 1998). However, Todd (1998) speculated that these associations were driven by the ability of shrubs like the spiny *Lyceum ferocissimum* to act as protection from grazing and not because of any microclimate they create.

Although no particular treatment favoured *Ruschia robusta*, the survival of many of the seedlings beyond the time scale of this study suggest that conditions have not changed so much in the system as to prevent their continued growth.

Clearing of *Galenia africana* is not a recommended intervention for this system. The introduction of microcatchments may not be the best intervention to improve soil nutrient status and may have a negative effect on geophyte species. Microcatchments are however good traps for run off water and may in time facilitate further biotic activity. Natural recruitment was positively affected by the presence of brushpacks, though their presence did not improve soil nutrient status or moisture content. Brushpacks are not as effective as shrubs in terms of trapping nutrients or promoting seedling survival. However, the protective function that brushpacks offer could still be more beneficial to developing seedlings and to protect bare soil from scalding and prevent soil loss.

Conditions under *Galenia africana* shrubs seem most ideal for seedling establishment and survival as it provides nutrient enrichment and protection. However continued monitoring of this treatment may bring to light competitive effects *Galenia africana* has with the seedlings it nurses. Continued monitoring would also show if *Ruschia robusta* seedlings could in time out compete their nurses.

Combinations of physical and biological processes have been interfered with during vegetation change. The time frame of this study may be too short to fully report on the successes and failures of the interventions implemented. However, the study does suggest that it is difficult to rebuild a transformed system by bringing back only a few processes. Furthermore, issues such as climate patterns may yet prove to be dominant controller although other factors, such as loss of seed or resource control, may be crucial to determining the direction of vegetation when it rains. I propose that a combination of interventions may over time and under favourable climatic conditions conditions facilitate the return of a palatable perennial shrubland.

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CHAPTER 6

GENERAL DISCUSSION

6.1. Discussion

The main aim of this thesis was to test rehabilitation interventions in a system altered by heavy grazing and to develop methods of monitoring these interventions. I hypothesized that through the process of rehabilitation we could gain an understanding for the ecological processes that are maintaining grazing induced vegetation change and that may be preventing transition to a more productive shrubland. Through biophysical manipulations, I could determine which of many factors is most limiting to long term ecosystem recovery.

In chapter 3, I established how continuous concentrated grazing pressure has changed this system in terms of vegetation cover and composition and the composition of the seedbanks. These baseline studies assisted in identifying factors that were maintaining the present rangeland state. Heavy grazing significantly lowers vegetation cover in this system and is primarily composed of *Galenia africana*. Heavy grazing also resulted in the reduction of palatable perennial seedbanks with a high occurrence of *Galenia africana* seeds.

This knowledge contributed to the formulation and testing of rehabilitation interventions for this system (Chapter 4 and 5). From here rehabilitation takes two-sided approach. Chapter 4 investigated the merits of passive rehabilitation through removal of grazing pressure alone within the equilibrium vs. non-equilibrium ecological model framework. Chapter 5 addressed active rehabilitation through the testing of biophysical interventions.

I determined that short term rest, in this case two years, was not an effective method of rehabilitation and will not lead to the recovery of heavily grazed rangelands (chapter 4). Rainfall and grazing was found to be important drivers of vegetation dynamics in Namaqualand, indicating that both equilibrium and non-equilibrium processes are functioning in this system.

When incorporating biophysical intervention in rehabilitation (chapter 5) I found that it is difficult to rebuild a transformed system by bringing back only a few processes. A combination of interventions is suggested to maximize chance of success though the importance of rainfall after introduction of seed and seedlings should not be ignored. Where a system has been transformed and dominated by monotypic stands of *Galenia africana*, I emphasise the importance of gaining an understanding of this plant's ecological role in the system and base interventions to ameliorate impact on this knowledge.

6.2. Methodology and monitoring

Many past attempts to address the issue of degraded rangelands have been dominated by pragmatic studies that provide information about what can or cannot work under certain conditions, but fails to address the underlying ecological processes that maintain these altered systems (Call & Roundy, 1991). This study focused on rehabilitation that would re-establish a functioning system and therefore aimed to not only test rehabilitation interventions, but to do so on ecologically sound principles. This requires a understanding of the extent to which external processes or events in the past were important in regulating the system, and whether they can be re-established at restored sites.

A number of rehabilitation studies in the past have focused on quick results, favouring the establishment of fast growing exotic grasses rather than establishing a persistent biologically diverse plant community (Call & Roundy, 1991). Often these foreign species are not suited to environments they attempt to rehabilate resulting in possible greater future ecological harm. During this study I have attempted to avoid these problems by using seeds and seedlings collected in Paulshoek or propagated from local seed. Interventions were purposefully kept inexpensive and could be done by hand and can readily be reproduced on a larger scale. This was done to ensure sustainability of the rehabilitation project in a community where funds are not always available. This would serve to prevent problems where projects often fail as the methodologies were inapropriate for the circumstances of the users.

One of the main problems in assessing rangelands is knowing how to monitor change in efficient ways (Pickup, 1989). During this study great emphasis was placed on the monitoring of interventions implemented over time. This would seem to be a logical step, but is often ignored in rehabilitation projects, as sucess of projects is mistakenly measured by initial inputs and costs and not actual outcomes. Monitoring also provides record of workable solutions to problems experienced, which can be shared and adds to sustainability and knowledge transfer.

6.3. Recommendations and conclusions

The transformation of certain rural areas act (TRANCRAA), act 94 of 1998 aims to transfer ownership of 23 rural areas (18 000 km^2) in four provinces to to residents or acountable local institutions (Wisborg & Rhode, 2003). TRANCRAA has been implemented in six rural areas of Namaqualand, including Leliefontein from 2001. This Act along with the land redistribution programme has allowed for the addition of private farms to what was traditionally communal land in the Leliefontein reserve.

Though the aquisition of this land and the administration thereof remains a contentious issue, it was hoped that the "new land" would eleviate grazing pressure within the commons allowing for the resting of veld. This study would caution against using short term rest and/or stock reduction schemes as quick fix in the context of the TRANCRAA/land redistribution process within Namaqualand, as it will not result in a change in rangeland condition.

This study aimed to use rehabilitation as a tool to gain greater understanding of ecological factors maintaining the rangelands of Paulshoek, Namaqualand in a transformed state. I believe that my results have achieved this and have led to greater insight and understanding into the drivers and processeses maintaining grazing induced vegetation change in Namaqualand.

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APPENDIX A

Soil Physical Parameters

Soil depth and hardness was measured in April 1999. Soil hardness was measured using a soil penetrometer and soil depth determined by hammering a metal stake into the ground until it hit bedrock. Samples were taken at 4 points along four 50m transects at each of the three rehabilitation sites. Infiltration rates were measured at the 0, 25 and 50 m mark along four 50 m transects at each site. Measurements were taken in open areas closest to each transects. At each point 600 ml of water was carefully decanted in a tube (diameter 12.7 cm), placed firmly on the soil surface, and time of total infiltration of water recorded.

Soil chemical analysis

The top 20 cm of soil was collected at ten-meter intervals along four 50 m transects at each of the three sites. These soils were divided into two depths, the top (0- 5 cm) and the deeper (5-20 cm). Soils were sieved through a 2 mm mesh sieve and sub sampled for various analysis.

Soil pH was determined in 0.01M $CaCl_2$ (Conyers & Davey, 1988). Soil organic matter was measured after combustion at 450 ^{o}C. Total nitrogen was determined by kjeldahl digestion followed by distillation (Allen, 1989). Total phosphorus was measured on acid digested samples using a molybdenum blue colour development, which was measured using a spectrophotometer (Murphy & Riley 1962).

Statistical analysis

Analysis of variance was used to test for statistical differences between rehabilitation sites. All percentage data was arcsine transformed to avoid deviation from normality for very small or large percentage values (Zar, 1996). Tukey's test was applied where applicable, to distinguish between means.