ECOSYSTEM GOODS AND SERVICES IN A SEMI-ARID LANDSCAPE: AN EXAMINATION OF THE RELATIONSHIP BETWEEN ECOLOGICAL PROCESSES, LAND-USE STRATEGIES AND BIODIVERSITY CONSERVATION

Patrick John O'Farrell

University of Cape Town

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University of Cape Town

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Abstract

Biodiversity loss and the disruption and degradation of ecosystems is proceeding at unprecedented rates. Conservation areas are insufficient to protect all species and there is growing recognition of the need to promote biodiversity conservation on private land, through the adoption of biodiversity-friendly land-use practices. Conservation and ecosystem function are linked to the delivery of ecosystem goods and services, which are processes and conditions of ecosystems that benefit humans and their activities. The research focus on ecosystem goods and services to date has been at global and regional scales, and there is a paucity of research at the fine scale. Benefits need to be measured and evaluated at a fine scale if land-users are to adopt best practices. The central aim of this study was to examine the relationship between commercial agricultural land-use practices and ecosystem goods and services in a biodiversity hotspot in a semi-arid area of South Africa. The approach adopted was based on the premise that to influence management activities and land-use practices it is best to first develop an understanding of what farmers perceive to be the most important ecosystem goods and services and how they manage their landscapes according to these perceptions.

Farmers recognise and value a broad range of ecosystem goods and services that they incorporate into their farming practices, and their management framework is structured according to these in an attempt to optimise production. Ecosystem goods and services are perceived according to landscape heterogeneity which provides temporal and spatial opportunities for their exploitation.

An exploration of the effects of land-use practices on identified ecosystem goods and services showed these to be highly dependent on the incorporation of natural vegetation and the maintenance of key ecological processes. Natural vegetation is essential for the provision of goods and services related to grazing and livestock production, with different vegetation types providing different goods and services. The maintenance of the service provided by an abundance of small mammals as an alternative source of prey to livestock for medium-sized predators, was demonstrated to be highly dependent upon landscape and vegetation structure, with 82% of all mammals trapped in the most structurally diverse vegetation type, vegetation clearance resulted in a seven fold decrease in small mammal abundance. A detailed examination of rainfall infiltration and erosion in natural, transformed and managed transformed vegetation showed there to be greater infiltration, less run-off, wind speeds reduced four fold, and eight times less soil lost to wind erosion in natural vegetation compared with transformed areas. However, in managed transformed areas, rainfall infiltration was greater than in natural and transformed areas. An examination of the key ecological processes maintaining soil health showed a decline in

soil invertebrate activity with increasing distance from natural vegetation remnants. However, under managed transformed conditions earthworm populations were three times greater than in natural vegetation remnants and this may account for greater infiltration rates measured here. An exploration of the potential to develop horticultural products from the species in the area, demonstrated the importance of the retention of natural vegetation as repositories of future-use options.

In comparing farmers' perceptions, with analysed ecosystem goods and services, their perceptions were demonstrated to be generally accurate in their identification of ecosystem goods and services. While their perceptions may be correct, the value farmers place on a particular service is often not sufficient to influence farming practice. Farmers appear to misjudge the degree of magnitude that management effects have on the delivery of ecosystem goods and services. Despite farmers perceiving the general concept of future-use options, they do not perceive the repository potential of their own remnant patches of natural vegetation for ecosystem goods.

The broader objective of this thesis has been to consider the role that an understanding of ecosystem goods and services can play in promoting biodiversity conservation on private agricultural land. While scientists grapple with the conceptual issue of how diversity links to ecosystem processes, whether all species are important, and finally how these may benefit humans, farmers work at a more intuitive level trying to achieve benefits for themselves based on their experiences and perceptions, which influence land strategies. As a result, understanding farmers' perceptions and testing some of their assumptions can provide a basis for illustrating the links between biodiversity and goods and services at a farm level and in this way offer opportunities for conservation on private land.

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Table of contents

Chapter 1 1

Introduction: ecosystem goods and services in a global context

1.1 Global threat to biodiversity and conservation outside reserves 1

1.2 What are ecosystem goods and services? 2

1.3 Our understanding of general ecological processes 4

1.3.1 The rivet hypothesis 4

1.3.2 The redundant species hypothesis 4

1.3.3 Idiosyncratic response and the null hypothesis 5

1.4 Our understanding of ecological processes that benefit humans or ecosystem services 6

1.4.1 The focus and scale of existing ecosystem service research 6

1.4.2 Biodiversity conservation and ecosystem services 9

1.5 Agriculture 10

1.6 Addressing the weaknesses in our current knowledge base on ecosystem services 14

1.6.1 Gaps in the literature 14

1.6.2 How my study will fill these gaps 15

1.6.3 Thesis outline 17

Chapter 2 21

Study area: the Bokkeveld plateau

2.1 Introduction 21

2.2 Geology and soils 22

2.3 Climate 23

2.3.1 Rainfall 23

2.3.2 Temperature 25

2.3.3 Wind 25

2.4 Vegetation 26

2.5 Socio-economic characteristics 33

2.5.1 Pre-colonialism 33

2.5.2 Colonialism 34

2.5.3 Current socio-economic situation 35

Chapter 3 37

Identifying ecosystem goods and services: local ecological knowledge and land-use practices

3.1 Introduction 37
3.2 Methodology 39
3.3 Results 40
3.3.1 Interview details 40
3.3.2 Farm history and characteristics of production 40
3.3.3 Ecological perceptions of ecosystem goods, services and disservices 45
3.3.4 Conceptual model 49
3.3.5 Ecosystem services according to vegetation type 51
3.4 Discussion 52
3.4.1 Identified ecosystem goods and services 52
3.4.2 Management framework 52
3.4.3 Conservation priorities 59
3.4.4 Scientific assessment 60
3.5 Conclusion 61

Chapter 4 63

Determining the influence of ecosystem goods and services on livestock management practices

4.1 Introduction 63
4.2 Methods 65
4.2.1 Land-use strategy identification 65
4.2.2 Vegetation composition and structure 65
4.2.3 Productivity and biomass 65
4.2.4 Leaf content analysis 66
4.2.5 Phenology assessment 67
4.3 Results 67
4.3.1 Land-use and livestock management practices 67
4.3.2 Vegetation composition and structure 69
4.3.3 Productivity and biomass 72
4.3.4 Leaf content analysis 73
4.3.5 Phenology 75

4.4 Discussion 79
4.4.1 Landscape utilisation strategies 79
4.4.2 Vegetation structure and composition, productivity and biomass, and nutritive value 80
4.4.3 Matching farmers' utilisation patterns with vegetation temporal patterns 82
4.4.4 Additional factors determining utilisation strategies 84
4.5 Conclusion 87

Chapter 5 **89**

Small mammal diversity and density: implications for livestock predation
5.1 Introduction 89
5.2 Methods 90
5.2.1 Study site 90
5.2.2 Sampling methods and data analysis 92
5.3 Results 92
5.4 Discussion 94
5.5 Conclusion 97

Chapter 6 **99**

Vegetation transformation and the effect on soil erosion processes
6.1 Introduction 99
6.2 Methodology 101
6.2.1 Rainfall simulation 101
6.2.2 Wind erosion 103
6.3 Results 104
6.3.1 Rainfall simulation 104
6.3.2 Wind erosion 107
6.4 Discussion 108
6.5 Conclusion 111

Chapter 7 **113**

Vegetation transformation, functional compensation and soil health
7.1 Introduction 113
7.2 Study area 114
7.3 Methods 115

7.3.1 Mesofaunal and microbiological activity 115
7.3.2 Earthworm biomass and activity 115
7.3.3 Soil disturbance and infiltration 116
7.3.4 Soil properties 117
7.4 Results 117
7.4.1 Mesofaunal and microbiological activity 117
7.4.2 Earthworm biomass and number 119
7.4.3 Soil disturbance and infiltration 120
7.4.4 Soil properties 122
7.5 Discussion 124
7.6 Conclusion 127

Chapter 8 **129**

The development potential of a perceived ecosystem good: the viability of and issues involved with indigenous plant production

8.1 Introduction 129
8.2 Approach 131
8.3 Floriculture markets 132
8.3.1 Trends in international markets 132
8.3.2 South Africa contribution to international markets 132
8.3.3 Bulbs 133
8.3.4 Succulents 134
8.4 Trends in nurseries in South Africa 136
8.5 Species under pressure and the causes of pressure 136
8.5.1 Species in the study area recognised as under pressure 136
8.5.2 Causes of pressure 137
8.5.3 Collectors 137
8.5.4 Domestic use 138
8.5.5 Medicinal use 138
8.5.6 Grazing 139
8.5.7 Addressing pressures 139
8.6 Legislation 140
8.7 Nurseries and community projects in the study area and lessons learnt 142
8.7.1 The Nieuwoudtville bulb nursery 142
8.7.2 The Emmanuel nursery 144

8.7.3 The Cedar Tree nursery project 145
8.7.4 Tulip farming in Sutherland 145
8.7.5 Succulent nursery in Van Rhynsdorp 145
8.8 Issues and constraints 148
8.8.1 Emerging key issues 148
8.8.2 Feasibility and constraints 149
8.9 Discussion and conclusion 152
8.9.1 Development potential of a perceived ecosystem good 152
8.9.2 Remnants, biodiversity storage and future use options 153

Chapter 9 **155**

The relationship between ecological processes, land-use strategies and biodiversity conservation

9.1 Motivation for the study 155
9.2 Do farmers recognise specific ecosystem goods and services that they value for their own farming practices and do they attempt to manage their farms to optimise access to these goods and services? 156
9.3 What are the effects of land-use practices on the identified ecosystem goods and services, and is their delivery dependent on the incorporation of natural vegetation and the maintenance of key ecological processes? 157
9.4 Are farmers' perceptions about ecosystem goods and services accurate? 159
9.5 How can conservation of biodiversity on farmland benefit from increasing our understanding of ecosystem goods and services at a farm level? 161

References **167**

Chapter 1

Introduction: ecosystem goods and services in a global context

1.1 Global threat to biodiversity and conservation outside reserves

As the human population grows and associated impacts on the earth intensify, so does the threat to biodiversity (Vitousek *et al.* 1997). There is general consensus amongst biologists that a mass extinction of species is underway, with estimated losses of more than 30 000 species per year (Myers 1993a). Growing recognition of this biodiversity crisis is reflected in global and national political agendas and budgets. The Convention on Biological Diversity, signed by Member States at the United Nations Conference on Environment and Development in Rio de Janeiro 1992, and again in Johannesburg in 2002, was aimed at establishing international consensus and recognition of the need to retain global biological diversity. By adopting the 2010 conservation targets governments have explicitly recognised the value of biodiversity and its conservation (Balmford *et al.* 2005).

In the past, conservation efforts have been directed at the establishment of reserves as a means of conserving and protecting biodiversity. Conservation areas are not evenly distributed and can either under, or over represented biodiversity, with different ecosystems receiving different levels of protection (Norton 2000). Edwards and Abivardi (1998) note that reserves are important for the conservation of biodiversity, but that there is a need to shift attention to the preservation of biodiversity within the major forms of land-use. It is increasingly recognised that in order to achieve adequate conservation goals, efforts must be extended beyond the network of formally conserved areas (Desmet 1999; Wessels *et al.* 2003). This is especially true in very diverse heterogeneous areas that are recognised as biodiversity hotspots such as the Succulent Karoo and the Cape Floristic Region in South Africa (Mittermeier *et al.* 2004). Both the Succulent Karoo and Cape Floristic Region are of global botanical importance as they have high levels of plant diversity and endemism (Cowling *et al.* 1992; Cowling *et al.* 1999; van Wyk & Smith 2001).

According to the South African land surface classification, the greatest land class is natural vegetation, accounting for 77.9% of the country's surface (Statistics South Africa 2004). The majority of this land class comprises privately owned commercial agricultural

enterprises, in stark contrast to the 4.5% held in nature reserves and conservation areas (Statistics South Africa 2004). Promoting the conservation of biota on privately owned land is seen as a major future challenge to conservation (Bond 1999; Wessels *et al.* 2003). The contribution and importance of private land for biodiversity conservation has been noted in South Africa, and a number of regional conservation plans have been developed incorporating this potential (Gelderblom *et al.* 2003; SKEP 2003; Younge & Fowkes 2003). The role of private land for conservation has also been noted in New Zealand and the United States (Knight 1999; Norton 2000). In the United States nearly half of all species threatened with extinction occur on private land (Knight 1999).

While the need to shift attention towards conservation on private land is recognised, the understanding of ecological processes in these frequently modified ecosystems is limited (Norton 2000). The challenge therefore for conservation biologists is to improve the understanding of issues associated with conserving biodiversity on private lands (Norton 2000).

Biodiversity provides both direct values in the form of ecosystem goods, and indirect values in the form of ecosystem services (Myers 1996). Some global authors who support the shift in thinking away from formal reserve conservation strategies, state that attention should not be focused on conserving wilderness areas and biodiversity hotspots, but rather on conserving areas which provide the greatest ecosystem service values (Singh 2002; Batabyal *et al.* 2003). The potential economic losses due to biodiversity loss and degradation have been identified (Daily 1997c). Focusing conservation efforts on to those elements of biodiversity that have 'use' value, provides both conservation motivation and ensures the continuation of those aspects of biodiversity that are of vital importance to production and our continued survival.

1.2 What are ecosystem goods and services?

Ecosystem goods are the products created by natural ecosystems which include seafood, wild game, forage, timber, biomass fuels, natural fibres, many pharmaceuticals, industrial products and their precursors (Holdren & Ehrlich 1974). Ecosystem services are defined as processes and conditions of natural ecosystems that support human activity and sustain human life (Daily 1997a). Ecosystem goods and services are mostly biologically generated, occurring when communities of organisms carry out a diverse range of biochemical and biophysical processes (Swift *et al.* 2004). They encompass all the

benefits derived directly or indirectly, from the effective functioning of ecosystems (Costanza *et al.* 1997). Ecosystem services produce ecosystem goods, maintain biodiversity and support life through functions such as purification of air and water, generation and preservation of soils and renewal of their fertility, detoxification and decomposition of wastes, pollination of crops and natural vegetation, dispersal of seeds, cycling and movement of nutrients, control of the vast majority of potential agricultural pests, protection of coastal shores from erosion by waves, protection from the sun's harmful ultraviolet rays, partial stabilisation of climate, mitigation of droughts and floods, moderation of weather extremes and their impacts, and the provision of aesthetic beauty and intellectual stimulation that act to lift the human spirit (Holdren & Ehrlich 1974; Binning *et al.* 2001).

This detailed consideration of what ecosystem goods and services are, makes apparent the clear linkages between natural processes and ecosystem functioning, and the effective and continued productivity that benefits and sustains human life. While the demand for ecosystem services is growing, human actions are diminishing the capacity of ecosystems to meet these demands (Alcamo *et al.* 2003). Ecosystems are in decline worldwide largely due to ignorance of their value to humans and inadequate mechanisms to encourage investment to maintain them (Cork *et al.* 2001). Ecosystem services can provide a powerful motivation for the conservation of biodiversity (Daily 1997a; Jenkins 2003). Jenkins (2003) states that both the ecological and economic underpinnings of most ecosystem services are poorly understood, and this impedes their conservation and management. Drawing people's attention to and generating broader public awareness around the existence of ecosystem services has been seen as a way to promote conservation, sustainable land-use, and improve natural resource management, by incorporating the use-value of biodiversity into the socio-economic system (Cork *et al.* 2001).

The significant reduction in biodiversity currently underway should result in a subsequent loss of ecosystem services, with a major failure in ecosystem services predicted by 2050 (Jenkins 2003). This view is based on the belief that intact ecosystems will provide better services than an ecosystem that has been degraded, and stands as the basis for the notion that ecosystem services can be used as a conservation motivator. This view also assumes that there is a clear relationship between biodiversity, ecological processes and ecosystem

goods and services. However, Myers (1996) states that ecosystem services are resilient to some level of species loss and can keep supplying services even in highly modified states.

1.3 Our understanding of general ecological processes

The possible effects of biodiversity loss on ecosystem processes and function and even the definition of ecosystem function (Ghilarov 2000), have received considerable research attention during the last decade (Loreau *et al.* 2001; Naeem 2002b; Lyons *et al.* 2005). Four hypotheses concerning the role species diversity plays in ecosystem functioning and stability, have been proposed. These, reviewed below, include the rivet hypothesis, the redundant species hypothesis, the idiosyncratic response hypothesis, and the null hypothesis.

1.3.1 The rivet hypothesis

The rivet hypothesis suggests that all species make a contribution to ecosystem performance (Ehrlich & Ehrlich 1981). This key hypothesis draws on the analogy of an aeroplane being held together with rivets, suggesting that if one were to remove rivets, at some point the aeroplane would be unable to function. Proponents argue for the need to conserve all species, even the seemingly redundant species, to ensure the reliability of ecosystem functioning and the delivery of goods and services (Johnson *et al.* 1996; Naeem 1998), even in impacted systems (Folke *et al.* 1996). Biodiversity with multiple species per functional group, is viewed as providing a form of biological insurance against changes in environmental conditions, and the loss or poor performance of some species (Naeem & Li 1997; Aarts & Nienhuis 1999). A functional group is defined as a collection of species that fulfil similar roles within an ecosystem.

1.3.2 The redundant species hypothesis

The redundant species hypothesis suggests that there is a minimum level of diversity necessary for ecosystems to function properly and that most species are redundant in their roles (Walker 1992; Lawton & Brown 1993). McCann (2000) and Johnson *et al.* (1996) argue that the stability of the ecosystem and its continued function are directly related to the functional diversity of the ecosystem and are dependent on the nature of species interactions. Rosenfeld (2002) notes that the effects of species loss will depend on the range of functions and diversity of species within a functional group, the relative

partitioning of variance in functional space between and within functional groups, and the potential for functional compensation of the species within a functional group.

Schwartz *et al.* (2000) argue that there is little evidence to support the link between a full complement of biodiversity and ecosystem function, and that few empirical studies demonstrate improved function at high levels of species richness (Lawton & Brown 1993). Theoretical models indicate low levels of species richness are required to maintain ecosystem function. A possible reason cited is that a few species provide the vast majority of the community biomass (Schwartz *et al.* 2000). Vitousek and Hooper (1993) suggest that a low level of diversity is needed for ecosystems to function efficiently, and this is achieved at low numbers of species by a functional group of plants. Swift *et al.* (2004) cite the example of a monotypic perennial plant cover being as effective in controlling erosion as a diverse plant community. They suggest further that the functional role of communities may depend on the structure of vegetation and the relationships between functional groups rather than of diversity.

1.3.3 Idiosyncratic response and the null hypothesis

The idiosyncratic response hypothesis suggests that ecosystem function changes as diversity changes, but the magnitude and the direction of change is unpredictable, as the role of individual species is complex and varied (Lawton 1994). The null hypothesis suggests that ecosystem function is insensitive to the deletion or addition of species (Lawton 1994; Johnson *et al.* 1996).

The number of theories is reflective of the unresolved nature of this debate. The implementation of conservation practices based on these theories would require practices that range from the most conservative, preservationist approach to ensure against the loss of unknown roles and values of species, to those that suggest simpler systems with greater resilience are adequate. There is some consensus that a certain level of diversity needs to be retained to ensure ecosystem functioning as it is believed that biodiversity loss or a loss of ecosystem goods can result in the possible collapse of services (Mannion 1997). Simberloff (1999) states that the easiest way to ensure that processes are retained is to ensure that biodiversity is retained. The different approaches do demonstrate that the desired end, be it the preservation of one ecosystem services, such as erosion prevention,

or the realisation of the need to retain biodiversity for its future use values, will drive the argument and determine threshold levels.

1.4 Our understanding of ecological processes that benefit humans or ecosystem services

While the exact mechanisms are still being researched and the threshold levels debated, it is generally agreed that changes in biodiversity will alter ecosystem processes, affect the resilience of ecosystems (Chapin *et al.* 2000), and in turn reduce the quality of ecosystem services (Ehrlich & Wilson 1991; Alcamo *et al.* 2003). Unlike our understanding of biodiversity and ecosystem functioning, which is relatively well researched and increasingly understood, there is only a limited understanding of the links between ecosystem function and those ecological processes that are of benefit to people, i.e. ecosystem services. Few studies have examined the role of biodiversity in providing ecosystem goods and services (Kremen 2005). Kremen (2005) stated that in the past, experimental studies have focused on biodiversity and ecosystem function of communities and groups of species, which differs greatly from those communities which provide services in real landscapes. Luck *et al.* (2003) state that recent research has begun to explore and identify species-specific ecosystem services, and that this needs to be expanded to assess the theoretical and practical implications of species-specific population changes. Ecosystem service research, whilst picking up on long standing ecological and conservation research and theory, is itself relatively new to the biological sciences.

1.4.1 The focus and scale of existing ecosystem service research

Assessments of ecosystem goods and services have mostly taken place at a global or regional scale. Studies at a global scale have been fundamental in attracting attention to the field of ecosystem services (e.g. Costanza *et al.* 1997; Daily 1997a; Daily *et al.* 1997a; Balmford *et al.* 2002; Alcamo *et al.* 2003). These large-scale studies have characterised and described ecosystem goods and services, promoted public awareness of these global assets, emphasised that these services are being impaired or destroyed by human activities, and argued that our survival is linked to their continued existence. Studies have adopted either an economic approach, examining the value of ecosystem attributes as economic contributions, or an ecological approach examining ecosystem services in relation to broader ecological processes (Myers 1996), or a combination of these approaches.

The literature is replete with studies that value ecosystem services, at either a global or regional scale (e.g. Costanza *et al.* 1997; Wilson & Carpenter 1999; Chen & Zhang 2000; CSIRO 2000; Heal 2000b; Heal 2000a; Loomis *et al.* 2000; Loomis 2000; Seidl & Moraes 2000; Guo *et al.* 2001; Proctor 2001; Balmford *et al.* 2002; Boumans *et al.* 2002; Farber *et al.* 2002; Howarth & Farber 2002; Page 2002; Villa *et al.* 2002; Abel *et al.* 2003; Batabyal *et al.* 2003; Cork 2003). Studies stress the need to incorporate these non-market valued goods and services into the global economy, thereby demonstrating their monetary worth (e.g. Ehrlich & Ehrlich 1992; Balvanera *et al.* 2001; Balmford *et al.* 2002). The literature also contains much on the suitable methods for valuing ecosystem services that ranging from traditional economic approaches (e.g. Costanza *et al.* 1997; Alexander *et al.* 1998) to those focused on social equity (e.g. Wilson & Howarth 2002). In response to these studies there has also been considerable criticism of valuation and valuation techniques (Toman 1998; Turner *et al.* 1998; Turner *et al.* 2003).

Few, yet diverse methods of identifying ecosystem services have been attempted. Approaches include the inventory approach (Shelton *et al.* 2001), participatory model building (Cole 2003), interviews with individuals and focus groups (Kaplowitz 2001), and the use of satellite images to identify change in land-use, and on this basis changes in ecosystem services (Kreuter *et al.* 2001; Sutton & Costanza 2002). The lack of a standardised approach for assessing the ecological and socio-economic value of goods and services, prompted Groot *et al.* (2002) into developing a conceptual framework and typology for describing, classifying and valuing goods and services.

The majority of this ecosystem goods and services research to date, largely conducted at a regional level, encompasses a variety of habitat types and ecosystems. River catchments, watersheds and fresh water ecosystems have received attention in a variety of countries including Australia, China, South Africa and the United States (Jansson *et al.* 1999; Wilson & Carpenter 1999; Chen & Zhang 2000; CSIRO 2000; Binning *et al.* 2001; Guo *et al.* 2001; Jewitt 2002; Wu *et al.* 2002; Abel *et al.* 2003; Cork 2003; Nakamura 2003; Bohensky *et al.* 2004). All these studies demonstrated strong links between ecosystem services and human benefits in these ecosystems, at this scale. Forest ecosystems and the role they play in the watersheds of these river systems, have also been studied in respect to ecosystem goods and services, as they regulate water flow, storage and nutrient cycling (Pattanayak & Kramer 2001; Kaiser & Roumasset 2002; Guo *et al.* 2003). Riparian deforestation in turn impacts on the health and well being of riparian communities

(McClain & Cossio 2003). Water catchments, and the loss of ecosystem services by alien invasion, has received attention in South Africa resulting in a large government job creation scheme aimed at clearing infested river catchments (e.g. van Wilgen *et al.* 1996; van Wilgen *et al.* 1998; Le Maitre *et al.* 2002). Forests provide a range of other ecosystem goods and services (e.g. Myers 1997b; Guo *et al.* 2000; Guo *et al.* 2001; Wu *et al.* 2002; Hendrickson 2003), and other studies have focused on the effects of the transformation of forests causing extensive loss of biodiversity, a potential loss or impairment of goods and services (Mannion 1997), and the factors that promote deforestation (Laurance 1999). The value of remnant forest fragments and woodland for the provision of services such as pollinators have been studied as motivation for the conservation of those areas (Kremen *et al.* 2002; De Marco & Coelho 2004; Ricketts 2004).

Other biomes that have been investigated for an ecosystem goods and services perspective include mangroves, seagrass beds and coral reefs. Mangrove forests have received the most attention (Ewel *et al.* 1998; Arrow *et al.* 2000; Kaplowitz 2001). Other studies have made comparisons between the ecosystem goods and services derived from mangroves compared with shrimp farming (Sathirathai & Barbier 2001), and the trade-offs associated with fishery production and harvesting mangroves for the production of charcoal. Allen (1998) also examined the positive and negative impacts of mangroves on the ecosystem services in Hawaii where they have been introduced. Moberg and Ronnback (2003) looked at the potential for the re-establishment of ecosystem services by creating artificial reefs. They concluded that ecosystem services cannot easily be restored or replaced, and a greater understanding of the interconnectedness of ecosystems is needed. White *et al.* (2000) examined the effects of coral reef destruction on fisheries and emphasised the need for protection and potential tourism opportunities. Costanza (1999) discussed the inter-relatedness of ecological, economic, and social importance of oceans and the value of market and non-market valued ecosystem goods and services.

The ecosystem services supplied in arid and semi-arid regions have received considerably less attention than other biomes. Darkoh (2003) who examined existing literature on a number of regions in Africa, noted the impact of agriculture on biodiversity, the importance of goods and services, and stressed the need to formulate sustainable agricultural policies that integrate these concepts. Main (1999) discussed farming practices in south-western Australia, and notes how these have impacted and resulted in the loss of some ecosystem services leading to rising ground water, salinisation, erosion and soil

degradation. Al-Eisawi (2003) and Sterk *et al.* (2001) focused on the potential of biodiversity and natural vegetation in stopping degradation, desertification and preventing erosion. The specific ecosystem service of carbon sequestration in semi-arid regions has received notably more attention than other services (Glenn *et al.* 1993; Keller & Goldstein 1998; Lal 2000, 2001; Mills 2003; Lal 2004b). Sala and Paruelo (1997) investigated the services supplied specifically by the grasslands of the world, also emphasising their role in maintaining the composition of the atmosphere.

Ecosystem service research to date has largely been at a broad scale, with concerted efforts in the areas of forest, riverine and marine ecosystems and only limited work in the arid and semi-arid regions. Research has largely been aimed at influencing policy and the promotion of conservation and restoration at this broad regional scale. Biological diversity occurs at several hierarchical levels. At each of these there are important relationships between biodiversity and ecosystem processes, and the way ecosystems respond to disturbance and change (Risser 1995). While the research to date has raised international awareness of ecosystem goods and services and contributed to the development of tools there has been little investigation of ecosystem goods and services at a fine or local scale. This presents an outstanding challenge to the research community as benefits need to be measured and evaluated at this fine scale if ecosystem goods and services are going to be used as a conservation motivation amongst private land holders, where clearly demonstrated ecosystem goods and services can be used to encourage the adoption of best and most ecologically sound land-use practices.

1.4.2 Biodiversity conservation and ecosystem services

In general, some ecosystem services are of benefit at a local level, whilst other services may benefit the public as a whole, but be of little or no benefit at a local level or to the private land holder (Tilman *et al.* 2002). Studies have suggested that the private benefits of conserving natural areas do not provide sufficient incentive to protect against transformation of natural areas to more lucrative activities (Turpie *et al.* 2003). Ecosystem services tend to be site specific and it is difficult to make generalisations across areas (Myers 1996). There is a need to understand how specific changes in different ecosystem states affect social interests and values, and how these relate to ecosystem services experienced by people in particular places (Toman 1998).

Given that the scale of benefits can confound the issue of using ecosystem goods and services to promote conservation a number of authors are prudent about using this ecosystem services approach as a conservation motivator. Lerdau and Slobodkin (2002) suggest that ecosystem services have both potential and peril for conservation biologists. Where these services depend on species-specific processes, there is potential for promoting conservation. However, where services depend on processes common to many taxa, then arguments for preserving biodiversity are weaker (Lerdau & Slobodkin 2002). Schwartz *et al.* (2000) caution that given this observation, conservationists should be careful in using ecosystem services to promote the conservation ideal.

These possible confounding factors are accepted as useful criticisms, necessary to guide any academic research programme. General support, however, seen in conjunction with the global biodiversity crisis, means the notion of ecosystem goods and services as a motivator for conservation must be explored as one possible further conservation mechanism.

1.5 Agriculture

One of the greatest factors affecting the global environment is the expansion of agricultural land (Matson *et al.* 1997). Agricultural activities and intensification have had a widespread impact on a variety of habitats resulting in a loss of biodiversity across many taxa (Benton *et al.* 2003).

More than 80% of South Africa's natural vegetation is managed for livestock production (du Toit *et al.* 1991). In the last 40-50 years agriculture has been seen as a technical process, in which outputs are dependent on external inputs such as pesticides, fertiliser and fossil fuel driven technology (Pretty 1995; Edwards & Abivardi 1998; Altieri 1999; Björklund *et al.* 1999). Ecological processes, which help to promote fertility or control pests and disease have not been considered important in maintaining agricultural production (Edwards & Abivardi 1998).

Farmers in South Africa face a number of challenges. Political and economic changes in the country over the last ten years have resulted in numerous subsidies falling away. Costly technological inputs into the commercial farming production process are becoming harder to justify. Technological limitations are being realised and the need to develop agricultural systems that utilise functional biodiversity, or ecosystem goods and services,

to maintain production is increasingly recognised (Swift & Anderson 1993; Pretty 1995; Altieri 1999). Farmers in South Africa are realising the need to find other avenues of income generation besides traditional farming approaches which no longer benefit from government subsidies. Many farmers are looking to the biodiversity on their farms to provide marketable ecosystem goods and services (Donaldson 2002). Just as previously advantaged farmers must look for new opportunities and new methods to address reduced government support, so must the development needs of marginalised communities in these rural areas be met. Biodiversity, and associated ecosystem goods and services, and indeed disservices, could all provide development opportunities.

In light of the global biodiversity crisis and current conservation thinking, it is necessary to find ways of promoting conservation in these agricultural landscapes which account for so much of the Earth's surface. Agriculture provides a real opportunity to develop and use our understanding of ecosystem goods and services at a local scale in that agricultural activities rely inherently on natural assets or substitutes that carry a cost. This could be particularly relevant in areas which are high in biodiversity, such as in the globally recognised hotspots, and areas where there is limited formal conservation taking place (Altieri 1999; Wessels *et al.* 2003; Swift *et al.* 2004). There is some urgency in the matter as both agriculture and conservation must bear in mind that agricultural production must keep abreast of population growth, which is expected to double in the next 50 years (Ehrlich *et al.* 1993; Daily *et al.* 1998; Tilman *et al.* 2002).

Suggestions have been made as to how tackle this conundrum of increasing food production whilst maintaining biodiversity in agricultural landscapes. Green *et al.* (2005) suggest two possible approaches, either to promote wildlife-friendly farming methods, which may not meet food demands, or to focus on minimising the demand for land and its associated impacts by increasing agricultural yields. Some studies have explored the relationships between ecosystem services, biodiversity, and agriculture (Altieri 1999; Swift *et al.* 2004). In their study, Swift *et al.* (2004) suggest that important ecosystem services for agriculture are genetic diversity for animal and crop breeding, nutrient cycling, biological control of pests and disease, erosion control and sediment retention, and water regulation. The lack of awareness of the value of ecosystem services, and the conflict between short-term gain over long-term value, is a factor that can drive the conversion of natural ecosystems to human-controlled systems, at the expense of long-term economic stability.

Agricultural practices can have negative impacts on the production of ecosystem goods and services, through habitat destruction and ecosystem simplification (Björklund *et al.* 1999; Tilman *et al.* 2002). Land conversion and agricultural intensification alter the biotic interactions and patterns of resource availability in ecosystems and can have significant local, regional, and global environmental consequences (Matson *et al.* 1997). Agricultural intensification can also have negative local consequences, for example increased erosion, reduced soil fertility, pollution of ground water, the eutrophication of rivers, reduced assimilation of solar energy, and fall in net primary production (Matson *et al.* 1997; Björklund *et al.* 1999). The reduction in diversity which is often associated with modern agricultural systems could prompt strong deleterious effects (Schläpfer *et al.* 1999). Numerous farm management decisions directly impact ecological processes and stability, disrupting the functioning of ecosystems. The loss of plant species may impair ecosystem processes and reduce the ability of ecosystems to withstand and recover from extreme events (Lawton 1994). Unstable ecosystems, where biodiversity has been lost, and ecological processes disrupted, can have a negative impact on farmers. Species can have different responses to these disturbances and if negative feedback loops are established disservices can be experienced by farmers.

Agriculture, especially cultivation, typically divides up and fragments landscapes. Often remnant patches of natural vegetation are left to co-exist alongside transformed areas, either as they are of use to the farmer, for example as windbreaks, or because their habitats in some way necessitates exclusion, such as falling on rocky ground. Studies of ecosystem services in agricultural landscapes in western Poland found that a mosaic of small cultivated fields, shelterbelts, meadows and small ponds enhanced water storage, controlled groundwater chemistry, and helped maintain biological diversity (Ryszkowski 1995). Essential ecosystem services may suffer when functional groups such as pollinators and predators are affected by fragmentation (Klein *et al.* 2002). Studies reveal that pollination services are of major importance both to agriculture and natural systems, and are affected by habitat transformation and fragmentation (Rathcke & Jules 1993; Cunningham *et al.* 2002; Donaldson *et al.* 2002). A number of studies have demonstrated the value of retaining natural fragments of vegetation for maintaining pollination services (e.g. Cunningham 2000; Kremen *et al.* 2002; De Marco & Coelho 2004; Ricketts 2004). Studies indicate that positive interactions between these systems can go both ways, with

natural remnants providing ecosystem services to the agro-ecosystem, and agro-ecosystems aiding species survival (Klein *et al.* 2002; Daily *et al.* 2003).

Fragmentation of the landscape not only affects the services provided by flora and fauna, but also impacts on ecosystem services delivered by soil resources. Soils provide an array of ecosystem services that include the moderation of the hydrogen cycle, physical support of plants, retention and supply of nutrients to plants, assimilation of wastes and dead organic matter, renewal of soil fertility and the regulation of major element cycles that include carbon, nitrogen and sulphur (Daily *et al.* 1997b). Amundson *et al.* (2003) argue that undisturbed soils associated with remnant patches, warrant conservation because of the ecosystem services and associated complex interactions they have with plant communities. With the continued emission of carbon through the combustion of fossil fuels, the release of greenhouse gasses and the resultant effects on climate, carbon sequestration is becoming an increasingly important ecosystem service. Numerous studies have demonstrated the importance of the relationship between transformation and soil carbon sequestration (Thuille *et al.* 2000; Garten & Ashwood 2002; Lal 2002; Olsson & Ardo 2002; Mills 2003; King *et al.* 2004; Lal 2004a). These are all services that could be supplied by remnant patches associated with, and of importance to, agricultural landscapes.

Swift *et al.* (2004) caution that the effect of land-use change and agricultural intensification on biodiversity and associated functions are still poorly understood. There is a real paucity of studies that investigate the effects of a change in ecosystem services that results from the transformation of natural systems, where pre-transformation services are compared to post-transformation services, due to the difficulty of timing and anticipating such changes (Balmford *et al.* 2002). It is necessary to know if different ecosystem services operate when ecosystems are in different ecological states because of human-induced transformation. Similarly, it is possible that redundant species under one ecological state may become keystone species, or functionally compensate for other species under a different ecological state. Creed and Sheldon (1995) and Creed (2000) working in North American water systems demonstrated this possibility in their examinations of a herbivorous aquatic weevil, *Euhrychiopsis lecontei.* This species, regarded as a minor grazer under natural conditions, became a keystone herbivore controlling the spread of an alien watermilfoil species *Myriophyllum spicatum.* Cairns (1997) states that we neither know how many species can be eliminated and still serve as a

life support systems, nor how much fragmentation will impair adequate delivery of services. Given this uncertainty the dependable delivery of these services over large temporal and spatial dimensions requires healthy ecosystems with unimpaired integrity.

Nassauer and Westmacott (1987) state that the act of farming is the expression of ideals and values through land management decisions, and the landscape displays farmers' knowledge, their values and work ethics. It is argued that the way toward sustainable agriculture is to focus on the value farmers' place on ecosystems, as it is this value that will conserve the integrity of ecosystem services and the diversity of species that drive them (Edwards & Abivardi 1998). To change land-use practices so that they incorporate and maintain biodiversity requires an understanding of how farmers recognise and perceive ecological processes. Studies indicate that researchers and farmers have different perceptions of natural resources and ecological functioning, and that it is important to identify farmers' perceptions when developing conservation and resource management strategies at a local level (van der Meulen *et al.* 1996; Gray & Morant 2003; Desbiez *et al.* 2004; Lado 2004). Furthermore, it is important to reconcile the differences between farmers' perceptions and scientific studies, not to discredit local knowledge, but to develop an understanding of why differences have emerged (Gray & Morant 2003).

1.6 Addressing the weaknesses in our current knowledge base on ecosystem services

1.6.1 Gaps in the literature

The current body of ecosystem service research is contextually constrained in that research in arid and semi-arid regions has been limited, with far greater focus to date on mesic environments. In South Africa arid and semi-arid areas are of major conservation significance containing high levels of both plant and animal diversity (Cowling *et al.* 1999). Determining ecosystem goods and services here may help to develop conservation planning approaches and strategies.

The fact that the vast majority of research has been carried out at a broad, regional scale presents a methodological gap or challenge. The challenge is to take ecosystem goods and service research to the local scale, the motivation for this being twofold. Firstly, considerable ecological research has been conducted at the local scale, which can in turn inform ecosystem goods and service research (Loreau *et al.* 2003). Secondly, there is a need to develop an understanding of how ecological processes and ecosystem services

function at a field or paddock level, and scale up to a local landscape level as management decisions are typically made at this level (Swift *et al.* 2004).

There is a need to improve our understanding of the effects of transformation on the supply of ecosystem services. In addition, how specific species will be affected as well as the relationship between the level of transformation and the degree of ecosystem service impairment needs to be understood. Future research on functional impairment with species loss should focus on identifying which species, functional groups, and ecosystems are most vulnerable to functional impairment from species loss, so that these can be prioritised for management activities directed at maintaining ecosystem function (Rosenfeld 2002).

Studies that have assessed perceived ecosystem goods and services of the local land-user, and linked these to ecological processes, demonstrate the value of acquiring local ecological knowledge when developing conservation strategies and resource management decisions. There is a need to understand how specific changes in different ecosystem states affect social interests and values (Toman 1998). The value that rural people, in particular farmers, place on ecosystems and their functioning, needs to be incorporated into research on biodiversity, ecosystem function and ecosystem goods and services delivery. Furthermore, differences between perceived and actual ecosystem services need to be understood in order to influence land-use management practices on private land and promote conservation here.

1.6.2 How my study will fill these gaps

The broader aim of this research was to facilitate and affect future land-use change and promote biodiversity conservation through a better understanding of the links between ecosystem goods and services and land-use strategies in a commercial farming landscape. My study systematically addressed a number of the identified gaps within the ecosystem goods and services literature. I investigated the relationship between land-use practices and ecosystem goods and services at a local landscape level in a semi-arid environment. I selected a study area within a local biodiversity hotspot, which falls within the two globally recognised biodiversity hotspots of the Succulent Karoo and Cape Floristic Region.

My research focus in this study was guided by stakeholder's perceptions, achieved through a number of interviews. Interviews determined farmers perceived ecosystem goods and services, identified their management approaches and determined how management decisions and ecosystem service delivery are linked. The following question was put forward:

- Do farmers recognise and value specific ecosystem goods and services for their own farming practices and do they attempt to manage their farms to optimise access to these goods and services?

Ecological experiments were then designed and carried out to explore the effects of land-use management on these identified services, and how these linked to biodiversity and ecological processes. I explored the links between land-use practices and ecosystem goods and services available to farmers, comparing how these differed for different areas their farms incorporated, with different levels of diversity, and how these differed at different times of the year. I investigated the effects of perceived disrupted food webs and ecosystem function due to land-use strategies, examining functional group responses to land-use strategies. I examined the implications of transformation on the delivery of services, assessing whether these are affected by transformation, whether services change and whether different services are derived from a transformed state, and how functional diversity, transformation and service delivery are linked. Finally, I undertook a study assessing the potential development of a perceived ecosystem good, and investigated the value of retaining biodiversity for future use options. This was carried out in answering the question:

- What are the effects of land-use practices on the identified ecosystem goods and services, and is their delivery dependent on the incorporation of natural vegetation and the maintenance of key ecological processes?

The findings of these experiments were in turn used to explore the links between actual measured ecosystem goods and services and perceived goods and services. This approach allows for comparisons to be made between land-users objectives and how they should best manage their environments to achieve these or retain these goods and services. Here I asked:

- Are farmers' perceptions about ecosystem goods and services accurate?

This was carried out as a means of contributing to the broader debate on whether knowledge of ecosystem goods and services can be used to promote biodiversity conservation at this fine scale. The following question was put forward:

- How can conservation of biodiversity on farmland benefit from increasing our understanding of ecosystem goods and services at a farm level?

1.6.3 Thesis outline

Chapter one provides a review of the literature concerning ecosystem goods and services and outlines the aims of my thesis.

Chapter two is an introduction to the study area of Nieuwoudtville, describing its socio-economic and biophysical characteristics in relation to the ecosystem services and conservation status of the area.

Chapter three describes both the general farming characteristics and the perceived ecosystems goods and services, as identified by farmers of Nieuwoudtville. It examines how farmers' understanding of ecosystem goods and services are incorporated into their general management strategies. This data was obtained in a series of semi-structured interviews with farmers in the study area. Here I discuss the emerging ecosystem goods and services framework that governs their interactions with ecosystems.

Chapter four is an examination of the relationship between the ecosystem goods and services associated with grazing and livestock management practices within the study, with consideration of how these have changed over the last 120 years. Current livestock management practices were identified through interviews with farmers. Experiments examining the ecosystem services, vegetation structure, productivity, biomass and phenology in vegetation types available to farmers were undertaken. Comparisons were made between these ecosystem goods and services in these different vegetation types as well as how these differ on a seasonal basis.

Chapter five is focused on land-use strategies and the possible impacts of these on the perceived services of predation alternatives to livestock as provided by the abundance of small mammals. I assessed the validity of this reported ecosystem service by determining the density and diversity of small mammals in four habitat types.

Chapters six and seven examine the implications of transformation of natural vegetation on the ecosystem services of soil retention and soil health. In chapter six I undertook a series of rainfall simulations in natural vegetation and in transformed areas, comparing infiltration rates, run-off volumes and sediment loads. Similarly, aeolian loads and wind speeds were compared between natural and transformed vegetation using suspension traps and hand-held anemometers. In chapter seven I investigated mesofaunal and microbiological feeding activity, earthworm densities, biomass and soil turnover as indicators of soil health and condition in natural and transformed vegetation. I examined the effect of soil turnover by earthworms and porcupines on water infiltration, and explored the effects of transformation on soil moisture retention and soil temperature. This investigation considers the role of functional compensation in maintaining ecosystem services.

Chapter eight is a study examining the potential future use and development of an identified ecosystem good. The natural vegetation of the study area was perceived as holding great developmental potential for many plant species and future horticultural products, providing both farmers and the broader rural communities with an alternate source of income. Here the continued functioning of natural vegetation fragments and the retention of biodiversity are necessary to ensure the future use options and development of these ecosystem goods. I investigated the potential of developing nurseries producing succulents and bulbs found in the study area, for sale to the public, to promote broader community development and conservation within the study area. The role of natural vegetation remnants as repositories of biodiversity with future use values is also discussed.

Chapter nine concludes this study and discusses the links between ecological processes, land-use strategies and biodiversity conservation. In this chapter I return to the four key questions raised and highlight the role that knowledge of ecosystem services at a local level can play in biodiversity conservation.

Appendix 1 contains the questionnaire used as a guide when interviewing farmers to determine the perceived ecosystem goods and services and to develop a detailed understanding of land- use strategies in the study area.

Appendix 2 is a list of the dominant plant species used in the phenology study for six vegetation types found in the study area.

Appendix 3 contains the questionnaire used in the study to assess the future development potential of a perceived ecosystem good. The following target groups of individuals were interviewed: international horticulturalists, national horticulturalists, nurseries owners and workers in the Succulent Karoo, community development initiatives, tourism groups, conservation organisations, agricultural workers, scientists and plant interest groups.

Chapter 2

Study area: the Bokkeveld plateau

2.1 Introduction

The western regions of South Africa are globally unique in that they contain two of the 34 recognised Conservation International biodiversity hotspots (Mittermeier *et al.* 2004). These are the Succulent Karoo and the Cape Floristic Region. A hotspot is an area of exceptional concentration of endemic species which is experiencing remarkable loss of habitat (Myers *et al.* 2000). With high levels of plant diversity and endemism, both the Succulent Karoo and Cape Floristic Region are of global botanical importance (Cowling *et al.* 1992; Cowling *et al.* 1999; van Wyk & Smith 2001). These two biomes meet along the Bokkeveld Mountains, in an area known as the Bokkeveld plateau. The Bokkeveld plateau falls within the Northern Cape Province, is situated 350 km north of Cape Town, at an altitude of 800 m above sea level, and covers an area 100 km by 75 km. The Bokkeveld plateau stretches from the Bokkeveld mountains and Vanrhyn's Pass in the west, through to Calvinia in the east, and the Botterkloof pass in the south (Manning & Goldblatt 1997). The study site incorporated a portion of the Bokkeveld plateau, measuring approximately 300 km^2. The small town of Nieuwoudtville (31° 23'S, 19° 07'E) is situated at the western edge of the plateau and the study site (Fig. 2.1).

The flora of the Bokkeveld plateau is extremely diverse with approximately 1350 species (van Wyk & Smith 2001). Eighty of these species are endemic to the plateau (Manning & Goldblatt 1997), which is regarded as a local biodiversity hotspot. Apart from a small municipal nature reserve of 115 ha, this local biodiversity hotspot has no formal protection, and the bulk of the floral diversity is located on a few privately owned farms. A high level of transformation of the natural vegetation has taken place. The study area was selected in light of this fact, and the study itself driven by the need to investigate alternative options to formal conservation in this botanically important area. Identifying the ecosystem goods and services of the area was viewed as important to see whether these could be used to promote local conservation actions.

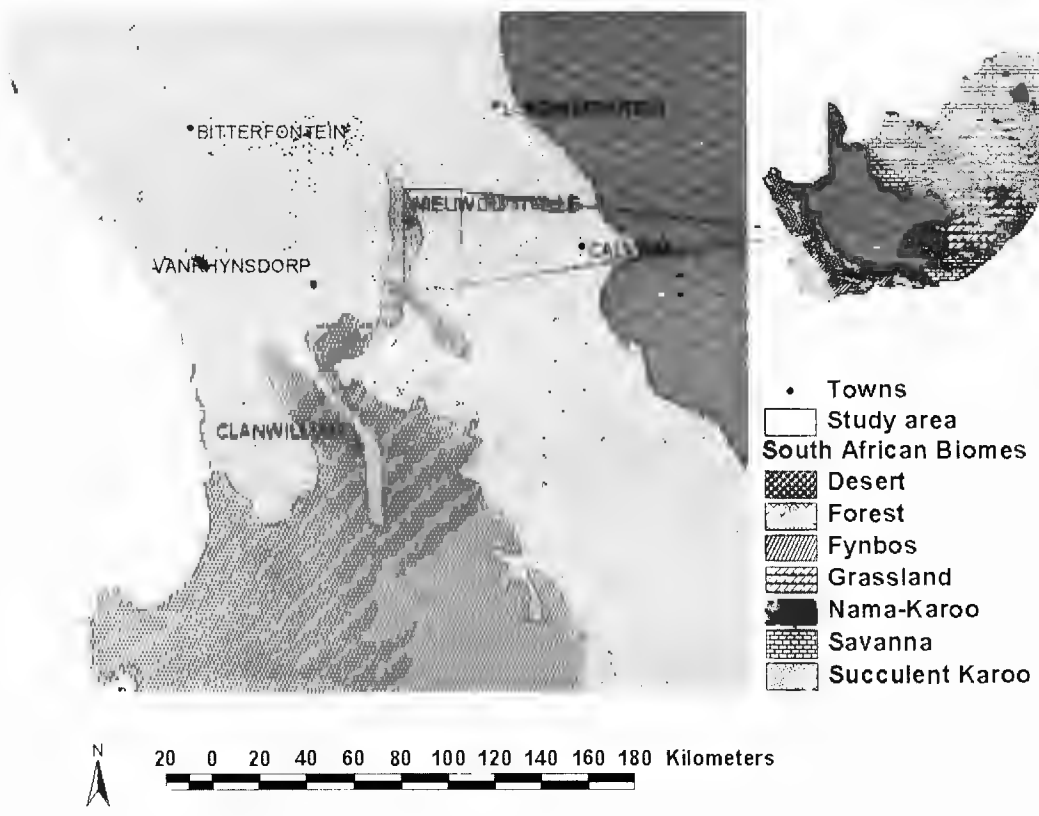

Figure 2.1 Map showing the study area, Northern Cape towns and vegetation biomes of South Africa.

2.2 Geology and soils

The Bokkeveld plateau is geologically diverse, being situated on a convergence zone of parallel bands of Table Mountain sandstone (TMS), dwyka sediments and dolerite (Fig. 2.2). At the western extreme of the Bokkeveld plateau, at the greatest altitude, TMS is exposed. Moving eastwards the TMS ridge is covered by dwyka tillite sediments. Dwyka rocks formed approximately 300 million years ago when the area was covered by a glacier. Intruded into the dwyka tillite sediments is a dolerite sill.

The TMS has weathered to form a sandy, acidic, nutrient-poor soil. The dwyka sediments have weathered to form highly fertile, yellow tillite soils with a very high clay content. The dolerite sill has weathered to form a deep self-mulching vertisol, due to its ability to shrink and swell under alternate dry and wet periods. In places the intruded sill is still evident forming an exposed rocky ridge. To the east of the dolerite the tillite soils are once again exposed. Beyond the tillite soils an Ecca Shale derived substrate occurs that covers large areas of the Karoo.

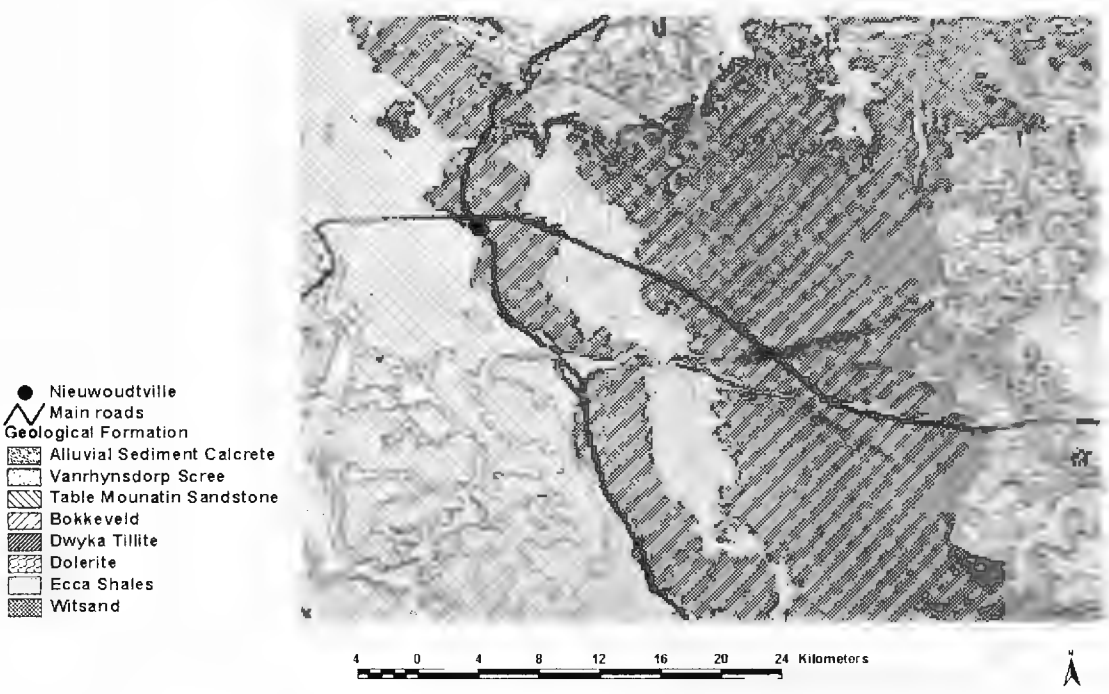

Figure 2.2 Map showing the geological formation of the study area (Geological Survey 1980).

2.3 Climate

The climate of the study area is typically Mediterranean, with dry, hot summers and cool, wet winters. Being close to the edge of the winter rainfall region, occasional summer thunderstorms are also experienced. Rainfall data was analysed from the South African Weather Bureau, whilst temperature and wind speed and direction were collected in the field during the 2002–2003.

2.3.1 Rainfall

The rainfall varies from over 500 mm at the edge of the escarpment in the west, to 300 mm near Calvinia in the east. For the town of Nieuwoudtville, mean annual rainfall is 350 mm with a CV of 33% (Figs. 2.3 & 2.4). Rainfall is strongly seasonal with most of the rainfall falling in the winter months between May to August. This is a result of cold fronts, moving from west to east, extending further northward in the winter, bringing cold, wet conditions.

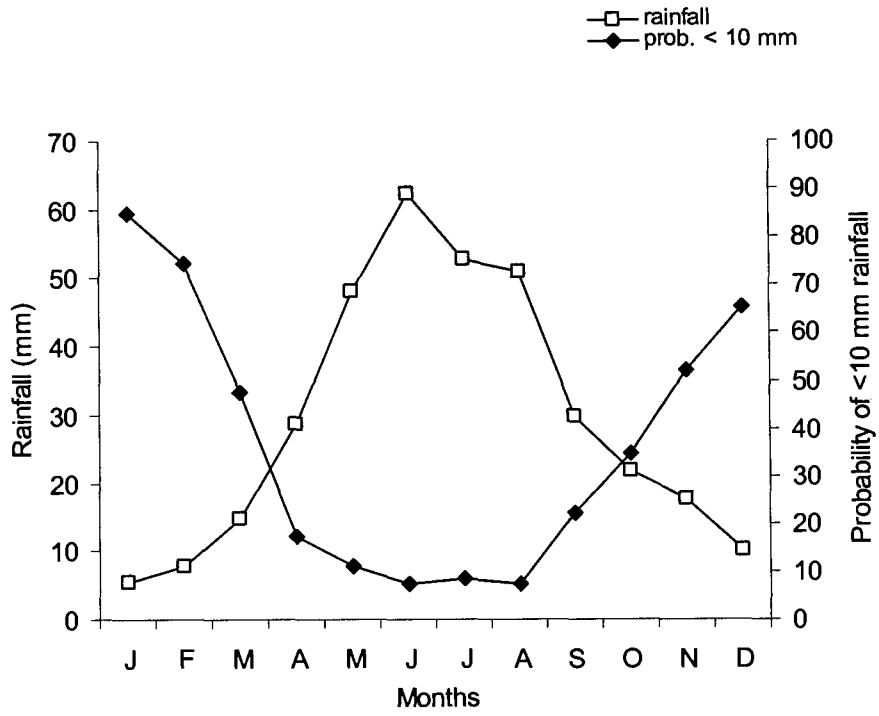

Figure 2.3 Mean monthly rainfall and the probability of receiving less than 10 mm of rainfall in a month for the town of Nieuwoudtville (1913–2000).

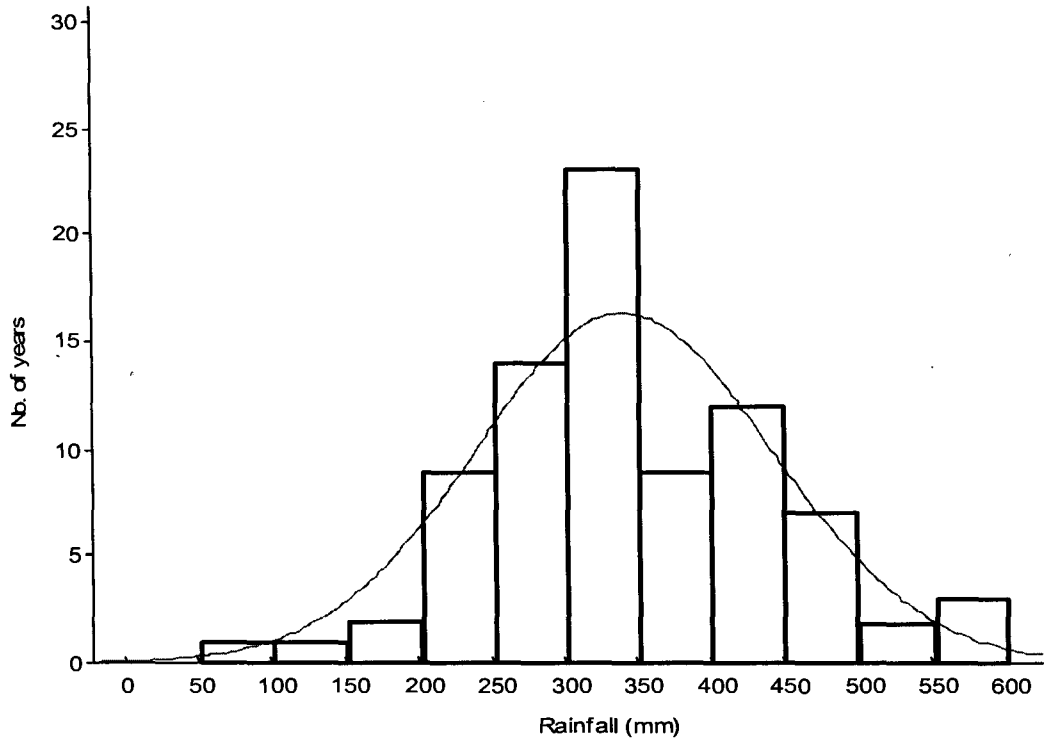

Figure 2.4 Frequency distribution of annual rainfall totals (mm) (histogram) for the period 1913–2000, and the expected normal distribution (line) for the town of Nieuwoudtville.

2.3.2 Temperature

Temperature data was recorded using a MCS 486T Temperature Data Logger. Temperature data was collected on the farm Glenlyon 2 km south of the town of Nieuwoudtville. Temperature was found to be strongly seasonal with the highest temperatures recorded in February, with an average maximum temperature of 31° C, and the coldest in June with an average minimum temperature of 4° C (Fig. 2.5).

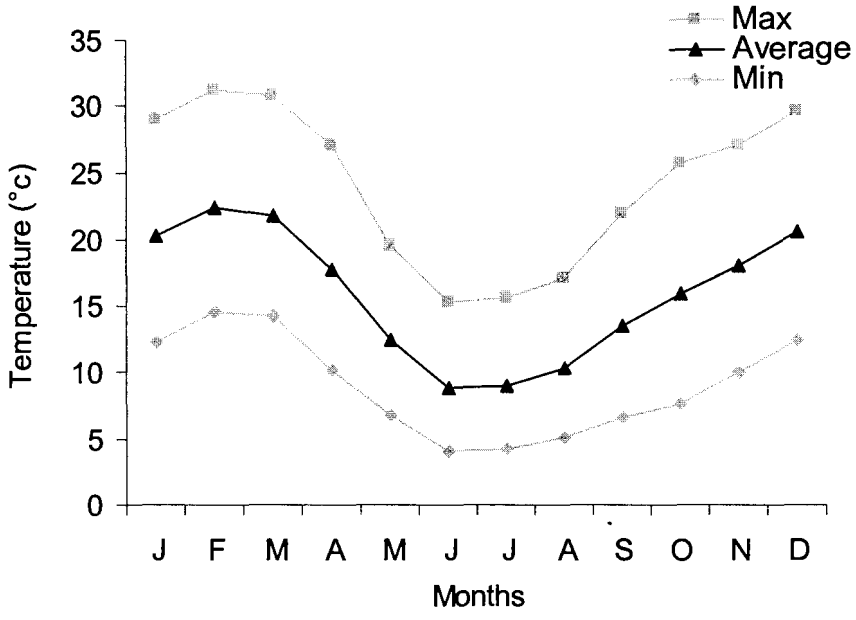

Figure 2.5 The mean monthly temperature (°C) for the period 2001–2003, as well as the average, maximum and minimum temperature for this period.

2.3.3 Wind

Wind speed and wind direction data were recorded with a WatchDog Model 700 Weather Station, during the period 2002–2003. Wind data was collected on the farm Glenlyon 2 km south of the town of Nieuwoudtville. Results show that the study area received wind predominantly from a south-westerly direction, which also blows strongest from this direction (Fig. 2.6). The strongest wind speeds were recorded in the afternoon, with the wind speed decreasing to its lowest point in the early morning (Fig. 2.7).

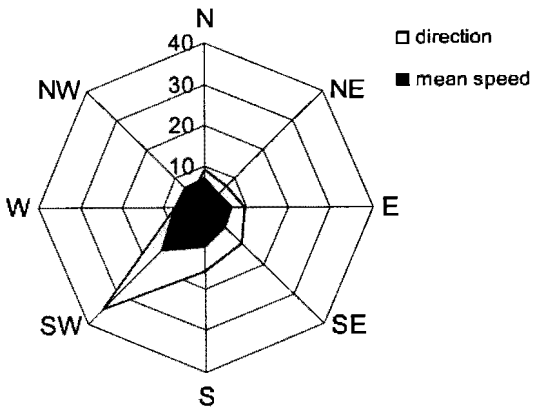

Figure 2.6 Wind direction as a percentage from that direction, and mean wind speed (km/hr) recorded for the period 2002–2003.

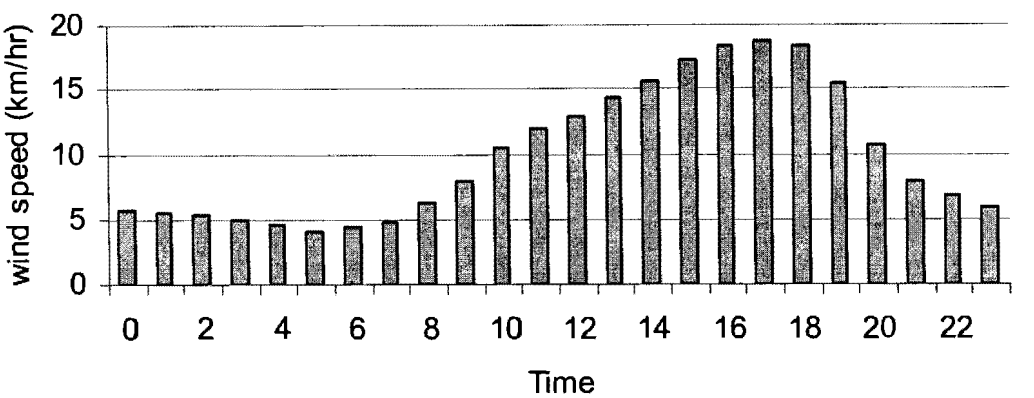

Figure 2.7 Mean wind speed (km/hr) (2002–2003).

2.4 Vegetation

There are five dominant vegetation types found within the study area (Fig 2.8). These are attributable to the varied geology, altitude and rainfall. Fynbos is found on TMS, renosterveld occurs on the Dwyka tillite, two dolerite specific vegetation types are found on dolerite plains and dolerite ridges, and karoo veld is found on Dwyka tillite, and Ecca shales. These vegetation types define the boundary between the Cape Floristic Region and the Succulent Karoo. The fynbos and renosterveld fall within the Cape Floristic Region and the dolerite vegetation and the karoo veld fall into the Succulent Karoo. Each of these vegetation types has recognisable characteristics, being structurally and botanically different (Snijman & Perry 1987). The renosterveld and the dolerite plains have been transformed and fragmented by agricultural activity, creating two additional vegetation types: transformed renosterveld and transformed dolerite vegetation.

Fynbos is recognisable by the presence of proteas and leucadendrons, ericas and other low shrubs and restios (Fig. 2.9). *Protea laurifolia* grows up to 8 m in height, with *P. glabra* dominant in the rocky areas (Manning & Goldblatt 1997).

Renosterveld is a low scrubby vegetation, named after the renosterbos, *Dicerothamnus rhinocerotis*, a grey-green bush approximately 1 m in height (Fig. 2.10). Other dominant elements of this vegetation type are the shrub *Eriocephalus purpureus*, and the tall bunch grass *Merxmuellera stricta* (Manning & Goldblatt 1997). The understory has a rich diversity of annuals and geophytes. The highly fertile tillite soils on which renosterveld is found are regarded as suitable for growing crops (Hoffman 1997), and 50% of the renosterveld in this area has been transformed. Renosterveld is characterised by remnant patches of varying size and degree of disturbance scattered amongst transformed renosterveld vegetation. This latter vegetation type refers to transformed areas that are no longer actively used for wheat production but as grazing lands for livestock (Fig. 2.11). The transformed renosterveld vegetation is found typically on flat uniform areas. It is dominated by annual species and some geophytes, resulting in a structurally homogenous vegetation type that is only visible in winter and spring. This vegetation type is dominated by weedy species such as *Erodium cicutarium*, *E. botrys*, *Avena fatua*, *Cotula microglossa*, *Medicago sp.*, and *Oxalis sp.*

The dolerite plains are best known for geophytes. *Bulbinella latifolia* var. *doleritica* and *Romulea monodelpha* are two characteristic geophyte species (Manning & Goldblatt 1997), but *Lotononis hirsuta, Emelia sp., Avena fatua,* and *Medicago sp.* are the dominant plant species found here (Fig. 2.12). This vegetation type is structurally lacking in diversity as shrub species are absent, possibly due to current or past land-use. The dolerite ridges are distinct from the dolerite plains, with rocky outcrops providing different habitats from the dolerite plains (Fig. 2.13). The most noticeable species include *Pentzia incana*, *Eriocephalus sp., Rhus undulata* and *Olea europea* subsp. *africana* (Manning & Goldblatt 1997). Geophytes such as *Crossyne flava*, *Hexaglottis lewisiae,* and *Cyanella lutea* are also common here. Like the renosterveld, the natural dolerite plains have also been transformed for the production of wheat, although to a lesser degree with 70% of the natural vegetation remaining (Fig. 2.14). The transformed dolerite refers to transformed areas that are not actively used for wheat production, the cultivating of other commercial crops or animal feeds but as grazing lands for livestock. The dominant species on this

vegetation type are typically weedy and include *Erodium cicutarium, Avena fatua, Brachypodium distachyon*, *Bromus pectinatus*, and *Tribolium brachystachyum.*

The karoo veld found further to the north, south and east, is also a low scrubby vegetation, found on flat land, and shares many species with the renosterveld, and the dolerite ridges (Fig. 2.15). It has a higher proportion of succulents such as *Ruschia spinosa, R. caroli* and *Drosanthemum latipetalum.*

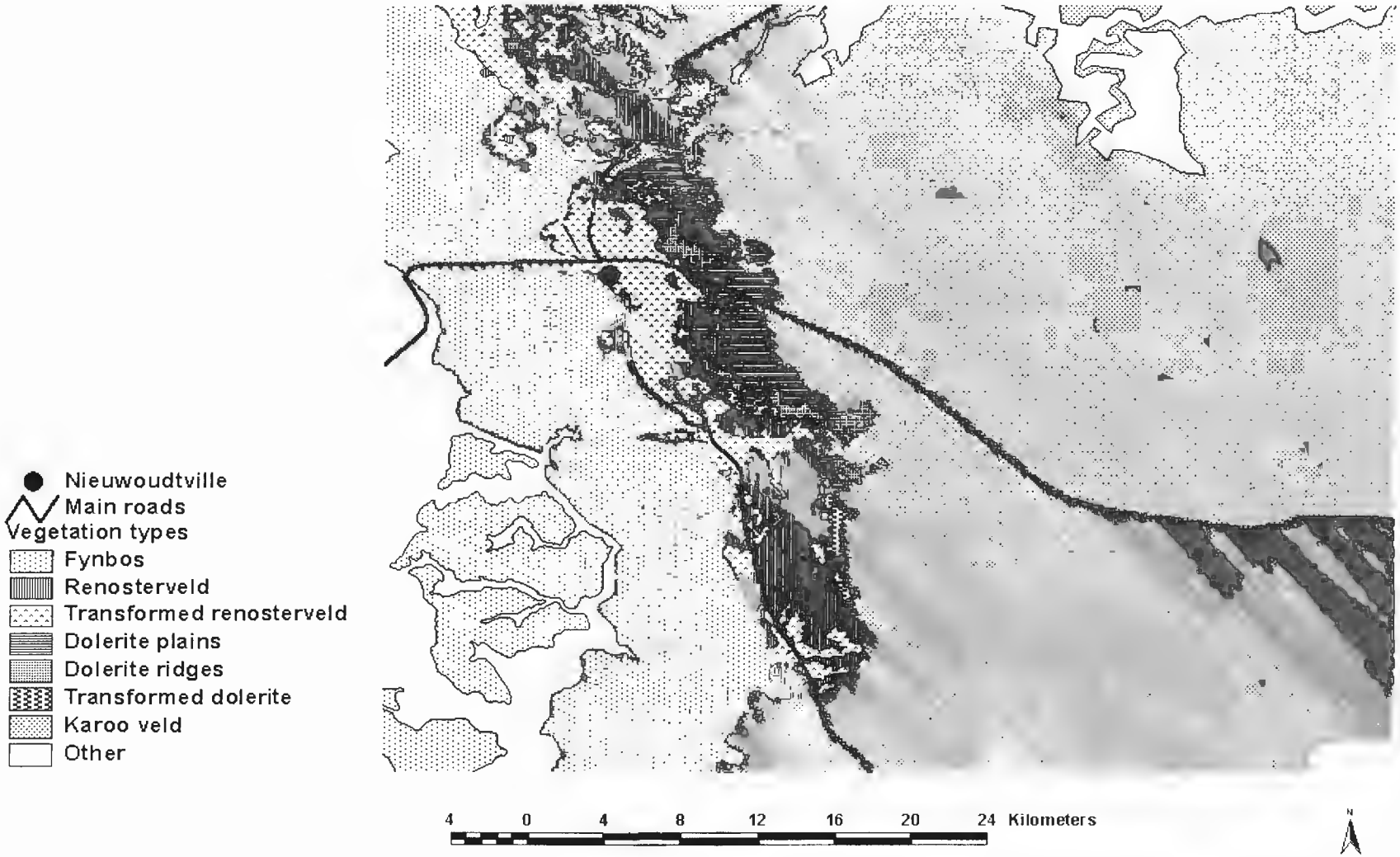

Figure 2.8 Map showing the seven dominant vegetation types found in the study area, adapted from Mucina and Rutherford (2004).

Figure 2.9 Fynbos vegetation growing on TMS soils is recognisable by the presence of protea species. *Protea laurifolia* one of the dominant species in the study area is pictured in the foreground.

Figure 2.10 Renosterveld vegetation growing on Dwyka tillite soils is dominated by the shrub species *Dicerothamnus rhinocerotis* pictured here. The dominant grass species in the area *Merxmuellera stricta* is visible in the bottom right corner.

Figure 2.11 Transformed renosterveld vegetation is typically dominated by annual species for example *Cotula microglossa* pictured here.

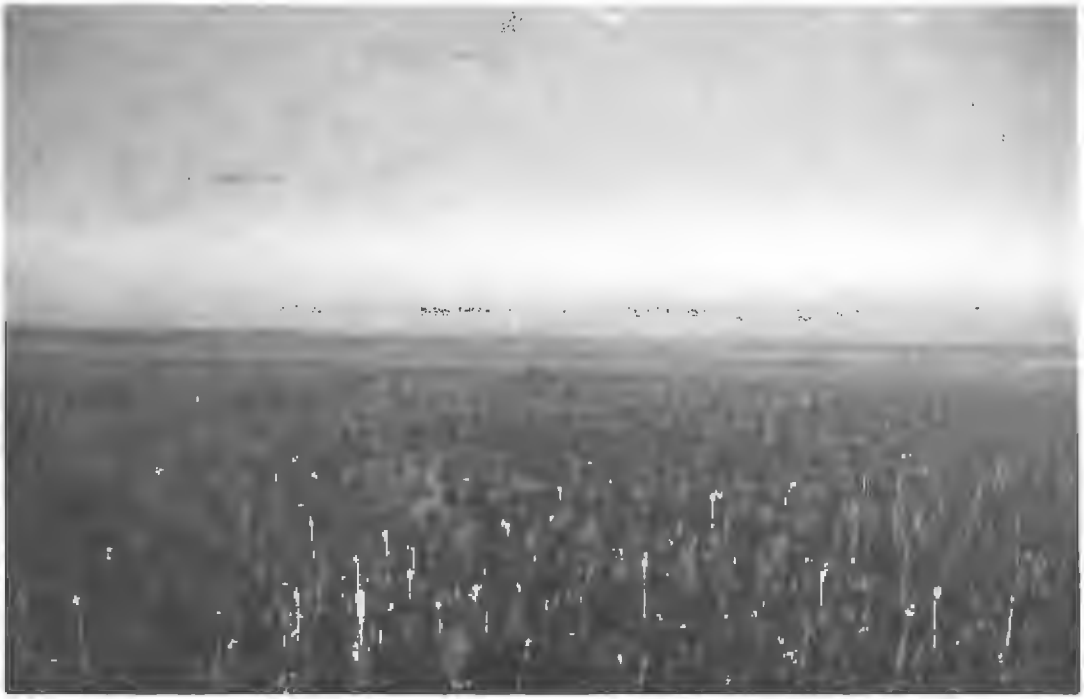

Figure 2.12 Dolerite plains vegetation has a wealth of geophyte and annual species. The noteworthy geophyte species *Bulbinella latifolia* var. *doleritica* can be seen here growing on deep red dolerite soils.

Figure 2.13 The dolerite ridges vegetation is characterised an exposed rocky outcrop, and dominated by *Pentzia incana*, *Eriocephalus sp.* and *Rhus undulata*.

Figure 2.14 The transformed dolerite vegetation is dominated by grass species, notable *Avena fatua* pictured here.

Figure 2.15 Karoo veld vegetation, found on Dwyka tillite and Ecca shales, is a low scrubby vegetation dominated by shrubs and succulents. The succulent species *Ruschia spinosa* and the shrub species *Eriocephalus namaquensis* are pictured here.

2.5 Socio-economic characteristics

2.5.1 Pre-colonialism

The appearance of modern people (*Homo sapiens sapiens*) in southern Africa can be traced back to about 40 000 years (Smith 1999). The original indigenous inhabitants of this area were San hunter-gatherers. About 2000 years ago the Khoikhoi arrived in the region (Penn 1986). They were a nomadic pastoralist society, with domestic sheep, who had adopted a transhumance lifestyle, moving seasonally between different vegetation types ensuring all year round access to grazing and water. Their production activities were focused on herding sheep and goats, hunting and gathering (Hoffman *et al.* 1999). Underground corms of the Iridaceae were also used seasonally as an important carbohydrate source (Smith 1999). Penn (1986) argues that there are five focal regions in western South Africa where a transhumance lifestyle is possible. The Bokkeveld escarpment is described as one of these regions. The escarpment is close to the division between the summer and winter rainfall area, and has a number of springs and could have acted as a focal point for a transhumance cycle. Regions further to the east, Bushmanland and the Great Karoo have too little water.

2.5.2 Colonialism

The strategic importance of the ecological resources of this region for pastoralism is reflected in the intensity of the resistance by the Khoikhoi to the invasion of the 'trekboers', or colonial settlers, into this region with the expansion of the northern frontier during the period 1770 to 1790 (Penn 1986). Trekboers had superior strength with guns, horses and commandos (Penn 1986). The Khoikhoi suffered military defeat, were dispossessed of their livestock, decimated by smallpox and forced to enter into relations of slavery or serfdom.

Once they controlled the area, the trekboers themselves were forced to adopt a transhumance lifestyle within this agriculturally marginal environment (Penn 1986). Land tenure for the trekboers initially comprised short-term grazing leases which allowed the licensee to graze as much as they needed in a vaguely defined area of unalienated land (Talbot 1961). In 1808 grazing licences were replaced by the loan farm system. For the farmers in the study area this entailed winter grazing on a farm on the Bokkeveld escarpment and then trekking to a loan farm or a 'legplaats' just north of Loeriesfontein, where they paid no rent, for summer grazing (van der Merwe 1945). This provided some measure of security of tenure over ecological resources and facilitated the continuation of transhumance grazing practices (Talbot 1961).

In 1813 perpetual-quitrent tenure, which afforded all the rights of freehold tenure on a surveyed area in exchange for an annual rental came into being (Talbot 1961). Changes to this legislation in 1878 enabled farmers to purchase property entrenching freehold tenure rights (Talbot 1961). The transhumance grazing system of the trekboers gradually collapsed towards the late 1800s with the influx of settlers and the extension of private land ownership on both the Bokkeveld plateau and in Bushmanland and increased competition for ecological resources (van der Merwe 1945).

During the early part of the 1800s, churches established mission stations to protect the indigenous Khoikhoi populations from further dispossession of their land (Hoffman *et al.* 1999). By the end of the nineteenth century the Northern Cape province was dominated by private property ownership and commercial livestock production, with small pockets of communal tenure surrounded by commercial farms.

2.5.3 Current socio-economic situation

South Africa has a paucity of areas of high agricultural value, and the Northern Cape is regarded as an area of low agricultural potential (Fox 2000). The rural landscape still typically consists of large white-owned commercial farms surrounding a small service centre or town. The agricultural sector here is characterised by low levels of employment. This hampers the economic growth and development of closely located small towns (Fox 2000). Farmers generally employ a few 'coloured' labourers who live on the farm (the term coloured is used to describe people of mixed origin, and is incorporated so as to highlight the racial economic divide that is still present in South Africa).

Poverty in South Africa in general is predominantly a rural phenomenon, with 70% of the country's poor living in these areas (Mather 2002). The rural towns of the Northern Cape have relatively large populations of unemployed poor coloured people who have been previously disadvantaged by apartheid policies. Towns provide few employment opportunities. Coloured communities, being landless, have very little access to natural resources or ecosystem goods and services. Despite the strong position of commercial agriculture during the apartheid era, in recent years state support to white commercial farmers has declined and various market boards have been dissolved with the introduction of legislation in 1996 (Mather 2002).

Farming activities within the study area are dominated by livestock production, predominantly dual purpose sheep producing both wool and mutton, for their respective markets (Hoffman *et al.* 1999). The fertile tillite soils on which renosterveld grows is ideal for pasture and wheat production and much of the natural vegetation has been converted for cropping. Between 1930 and 1980 wheat production was carried out on a large scale, but production emphasis on this crop has decreased in the last couple of decades mostly due to crop failure and prohibitive capital investment costs required for production. Farmers have diversified their production activities and are engaged in a number of other activities. These include flower harvesting, tea production, and eco-tourism.

Chapter 3

Identifying ecosystem goods and services: local ecological knowledge and land-use practices

3.1 Introduction

The initial step in any examination of the relationship between ecosystem goods and services, and land-use strategies requires the identification of these services (Daily 1997c). Scientists have developed a number of different conceptual frameworks or categories for considering ecosystem goods and services (Alcamo *et al.* 2003). Daily (1999), for example, suggested that there are five categories into which ecosystem goods and services fall, these being production processes, regeneration processes, stabilisation processes, life-fulfilling functions, and the preservation of options. The Millennium Ecosystem Assessment identified four major categories of ecosystem services which are, provisioning services, regulating services, cultural services, and supporting services. de Groot *et al.* (2002) describe four categories or functional groupings of services related to regulation, production, habitat, and information. Norberg (1999) categorises services as those dependent on the maintenance of populations of certain species, species that provide filtration services, and inherent selection processes that create organisation of biological units. Moberg and Folke (1999) in their examination of the ecosystem goods and services associated with coral reef ecosystems, classified these according to renewable and non-renewable resources, physical structures, biotic services, biogeochemical services, information services and social and cultural services. These categories all provide a useful way for scientists to define and explain ecosystem goods and services. However, people living within an area or ecosystem, who are dependent on the natural resources surrounding them, have their own ecological knowledge of these ecosystem goods (Gadgil *et al.* 1993). Their experiences shape their understanding of the functioning of ecological process and ecosystem changes, which are often different from those developed by scientists (Berkes *et al.* 1998).

Ecosystem services are by their nature important to farmers. Identifying and understanding these services, and the benefits they derive from them, is complex, as the values placed on certain elements of ecosystems and their condition, are dependent on an individual's perspective which subsequently influences the long-term delivery of these services

(Bingham *et al.* 1995). Local ecological knowledge is a fundamental component in the development of natural resource management strategies (Gadgil *et al.* 1993; Silvano *et al.* 2005). However, it is the combination of local knowledge combined with supporting scientific evidence, that has proved most useful in the management of ecosystems (Robertson *et al.* 2000; Gray & Morant 2003; Silvano *et al.* 2005). Studies also indicate that researchers and farmers have different perceptions of natural resources and ecological functioning, and that it is important to identify their perceptions when developing conservation and resource management strategies at a local level (van der Meulen *et al.* 1996; Desbiez *et al.* 2004; Lado 2004). Rigid, scientific prescriptions for the conservation management of an area can be less effective than the more flexible and sensitive practices which farmers often use themselves (Burgess *et al.* 2000). Combining an understanding of the distinct way in which land-users perceive the ecosystem goods and services provided by their environment, with actual measured and scientifically investigated ecosystem goods and services, is important for the future development of biodiversity-compatible and sustainable land-use practices, both through awareness-raising and in designing future management strategies.

This chapter represents a starting point in this examination. Here I ascertain how local land-users identify and perceive ecosystem goods and services, and how these relate to their land-use strategies. This establishes the basis for this thesis, whereby perceptions and views, which would essentially be the raw material available in initiating any conservation-motivated land-use changes, are ascertained. In order for any ecosystem service-motivated approach to be encouraged or discouraged, it is essential to start the process with a detailed knowledge of local perceptions. It is in this light of finding a common ground initially, that this perceptions-based approach is adopted. In turn, the meeting of local and scientific knowledge are drawn together in subsequent chapters in the testing of these perceptions. This approach to ecosystem studies differs from those adopted in purely scientific studies, and the significance of this is reviewed in the discussion.

This chapter identifies land-use activities and perceived ecosystem goods and services and disservices, and develops an understanding of how farmers manage their ecosystems, within the identified study area of Nieuwoudtville. The study area is characterised by a diversity of vegetation types as outlined in chapter 2. My aim was to identify and interview all of those farmers who owned a portion of renosterveld and dolerite plains

vegetation. These vegetation types, which form the focus of this study, are already highly transformed and fragmented, the remaining fragments are currently under threat of transformation, and are of conservation significance. Farmers were interviewed to develop an understanding of their view of the ecosystem services and ecological processes required for the various farming practices taking place here. A conceptual model that displayed the perceived linkages between ecological processes and production objectives was constructed.

The results presented here show that farmers perceive ecosystem goods and services to fall into the following categories: structural services, information services, production and regeneration services, provisioning services, and cultural services. Farmers use this framework or these perceptions to make their management decisions. I discuss how and why management activities take place within this framework, and argue for the need to consider this framework when introducing new landscape level conservation initiatives.

3.2 Methodology

To achieve an in-depth understanding of the perceived ecological functioning from the perspective of the farmers, a semi-structured interview technique (Patton 1990; Pretty 1995) was adopted with the farmers in the study area. Farmers who owned land containing natural vegetation fragments of renosterveld and dolerite vegetation, were interviewed. Only one farmer per property was interviewed. For reasons of requested anonymity and confidentiality, no farmer, farm names or specific geographic farm areas have been made explicit in this study. Questions focused on farming history, resource identification, livestock management, cultivation practices, perceived ecological costs and benefits, and vegetation management practices. This involved the preparation of a set of pre-determined questions that were explored during the interviews (a copy of the questionnaire can be found in Appendix 1). These questions served as a checklist and guided the interview process, ensuring that the same information was obtained from all interviewees (Marshall & Rossman 1999; Huysamen 2001). This approach was used, as it allowed a number of different persons to be systematically and comprehensively interviewed by delimiting the issues under discussion, and was simultaneously flexible, allowing the interviewer to pursue certain questions in greater depth when farmers identified related issues (Patton 1990; Marshall & Rossman 1999; Huysamen 2001). Further anecdotal information was gained through two farmers' workshops, organised by the National Botanical Institute, held within the study area, broadening the level of understanding. These workshops were

informal information sessions providing researchers working within the study area with an opportunity to meet and interact with farmers and and the broader community.

From these data a general understanding of farming activities was established along with an inventory of relevant ecosystem services and disservices identified by the farmers that impact on production. A conceptual model was developed based on the interview data demonstrating the linkages between the land-use or production objectives and ecosystem goods and services. Geographical information system (GIS) data supplied by the South African National Biodiversity Institute, which included farm boundaries and vegetation types, was used to assess vegetation ratios according to farms.

3.3 Results

3.3.1 Interview details

A total of ten farmers within the study area were willing to be interviewed and participated in the study. These farmers collectively own approximately 92% of the remaining natural dolerite plains and 72% of the remaining renosterveld vegetation. Persons interviewed lived on the farms and were responsible for the day-to-day management of the farm. The length of time they had spent in this position varied from two years to fifty years. All the farmers interviewed were male. The time taken to complete an interviewed differed, ranging from two hours to ten hours.

3.3.2 Farm history and characteristics of production

Nine of the farms had been in family possession since the mid-1800s to mid-1900s, and had been passed down the patriarchal line. Only one farm had been purchased within the last ten years (Table 3.1). All farms, excluding the most recently purchased, were farmed by family members. While all farmers maintained farm records, the degree of detail and length of record varied.

Farm size differed considerably, with the largest being just under 15500 ha, and the smallest just over 2200ha (Table 3.1). Average farm size was 7160 ha. Farms typically consisted of discontinuous pieces of different vegetation types. Figure 3.1 is a map showing the boundaries of the ten farms and the vegetation types contained within these boundaries, which form the study area. Farms contained on average six of the seven vegetation types. Six of the ten farmers interviewed had farms comprised of all seven

vegetation types. Farm layout or arrangement of paddocks, has generally not changed since the 1930s, when most of these farms were initially fenced. Farmers attributed this lack of change to the prohibitive cost of fencing and other infrastructure. Four of the farmers have made some changes. Two of these farmers stated that they are constantly trying to create more paddocks, whilst the other two re-fenced their farms once according to vegetation types.

Table 3.1 Farm sizes, number of small stock units (SSU), ha/SSU, percentage of the farm transformed, number of vegetation types (max = 7), length of farming experience of the interviewee in the study area, and the number of years the farm has been owned by a single family.

Farm No.	Farm size (ha)	No. SSU	Ha/SSU	% trans-formed	No. vegetation types	Farming experience (years)	No. years in family
1	15500	2200	7	4	7	24	130
2	9600	1800	5	7	7	30	130
3	8900	2000	4	13	7	15	100
4	8400	2000	4	11	5	18	180
5	7800	1800	4	22	7	40	170
6	6900	1200	6	18	6	17	100
7	6300	3100	2	10	7	42	110
8	3200	750	4	11	7	48	110
9	2800	1500	2	10	3	42	5
10	2200	600	4	4	4	10	100
Mean	7160	1675	4	11	6	29	114

Farming activities were dominated by livestock production. Mutton Merinos and Dorper sheep were the preferred breeds with the majority of farmers (Table 3.2). A single farmer kept flocks of wool Merinos, with wool being of greater emphasis in his production system. One other farmer maintained flocks of Damara sheep. Three of the farmers maintained small herds of cattle, either Herefords or Charolais cattle. A single farmer kept a flock of 10 ostriches, while two other farmers had also farmed with ostriches in the past. Two farmers also reported keeping springbok and blesbok. Stocking rates for farmers varied from two to seven ha/SSU, depending on vegetation types and cultivation activities (Table 3.1).

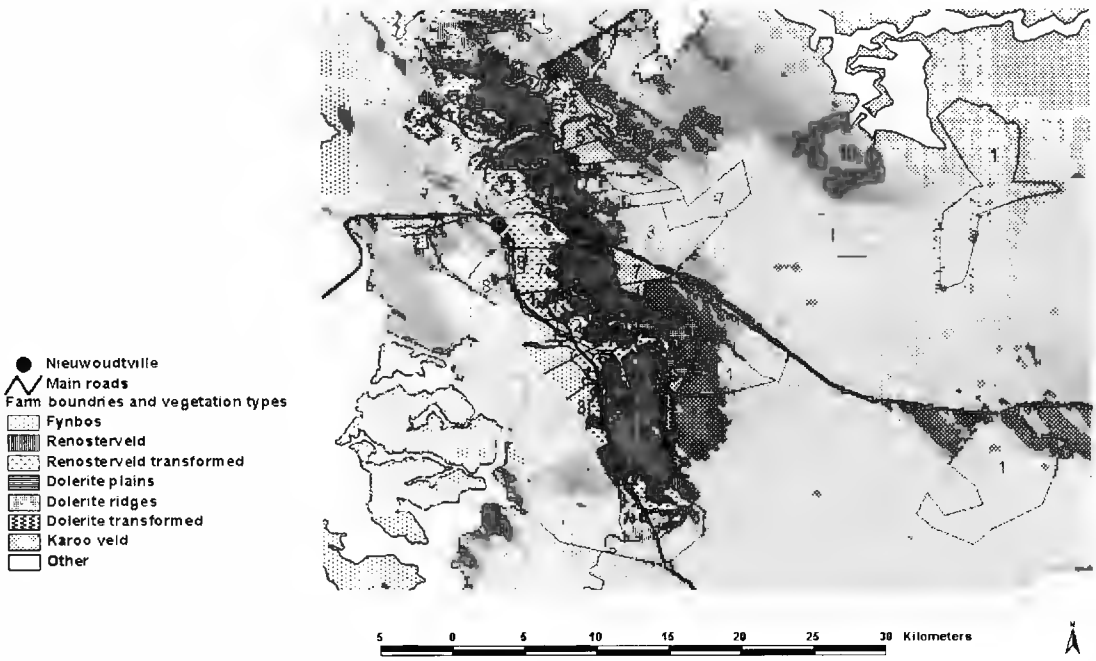

Figure 3.1 Map showing the majority of farm boundaries, farm number, and the vegetation types they incorporate. Farms were typically made up of discontinuous pieces of different vegetation types. For reasons of anonymity farm names have not been included.

Table 3.2 Animal types and breeds, the number of farmers currently farming with this animal, as well as the number of farmers who had in previous years farmed with this animal.

Animal Type/ Breed	No. of farmers presently farming with this animal	No. of farmers previously farming with this animal
Sheep – Merino	3	1
Sheep – Dual purpose Merino	7	0
Sheep – Dorper	4	2
Sheep Damara	1	0
Goats – Angora	0	1
Cattle – Charolais	1	0
Cattle – Herefords	2	2
Springbok	1	0
Blesbok	1	0
Ostrich	1	1

Lambing success is the cornerstone of the livestock production process in the study area. Generally, the colder months of May and June are regarded as the best time for lambing. One farmer lambs all year round. Farmers did not express similar general preferences for specific lambing areas. One farmer suggested bushy areas, another regarded proximity to the homestead as important, and yet another regarded open areas as most suitable. There was very little consensus amongst farmers as to the major causes of premature mortality. Perceived reasons included, weather, particularly cold, lack of food, predators, stock theft, and poisoning by plants. There was no apparent correlation between perceived causes of premature mortality and vegetation types making up the farms. The two farmers with the highest percentage of open vegetation cited cold as the primary reason for premature stock loss.

Grazing strategies varied between farmers according to breeds, number of paddocks, and paddock sizes. There was general consensus in movement of livestock between vegetation types, with a trend for winter grazing in the karoo veld and summer grazing in renosterveld and dolerite vegetation. An in-depth discussion of grazing strategy follows in chapter four. Eight of the farmers interviewed provided additional feed during the late summer months when grazing is poor. Only two of the farmers interviewed provided mineral supplements for livestock. Providing additional feed did not correlate with farm composition according to vegetation types, or with stocking rates.

All farmers interviewed produce wool and this is derived mostly from dual-purpose Merinos. Shearing takes place in September and October. Three of the farmers interviewed have in the last two years started shearing in March as well, as a strategy to avoid breaks in their wool, which results from malnutrition. These farmers are stocking above the average stocking rate for the farms included in this study.

Eight of the farmers interviewed actively engage in cultivation (Table 3.3). The degree of effort and contribution to farm production varies, but the percentage contribution of cultivation to stock production never exceeds 40/60% respectively to overall farm production. Seven of these farmers produce wheat for commercial sale. All eight produce fodder crops that include medics, lucerne, and oats. Rooibos tea is a tea made from the dried fine needle-like leaves and twigs of the *Aspalathus linearis* shrub, and is produced by five of the farmers, all of whom have access to TMS-derived sandy soils. A single

farmer also produces potatoes. Of the ten farmers interviewed, eight stated that they would not increase cultivation, even with an increase in the value of a cultivated item. Farmers were content with the status quo on their farms and shared the view that they would like to increase their grazing potential, by improving the availability of palatable plants or grass on their natural veld.

Table 3.3 Fodder crop and commercial crop types, the number of farmers cultivating this crop, and the number of farmers who have previously planted the crop but are no longer cultivating it.

Species under cultivation	**No. of farmers who presently cultivate this crop**	**No. of farmers who have previously cultivated this crop**
Animal feed		
Medics	7	0
Lucerne	7	0
Lupins	2	1
Teff	1	0
Oats	7	0
Saltbush	7	0
Commercial crops		
Wheat*	7	3
Rooibos	5	1
Potatoes	2	0
Canola	0	1

* Wheat is also used as an animal feed if rains fail and the crop is viewed as not worth harvesting.

Four of the farmers surveyed use fire as a management tool to enhance grazing in the renosterveld and fynbos vegetation types. All of the farmers have actively engaged in the removal of perceived undesirable plants, particularly poisonous plants such as *Tylecodon wallichii*. There is limited use of herbicides and pesticides, four farmers having previously used these and two still use chemical sprays but in very limited quantities. Species that are targeted are the alien grasses *Hordium vulgarae* and *Bromus tectorum* because they have sharp awns that irritate sheep, particularly around the face. Farmers also employ grazing strategies to help reduce the impact of undesirable plants, by grazing them whilst they set seed.

Farmers' water management strategies are typical of those in other semi-arid regions, where ground water is vital to production. Farmers utilise ground water by combinations of windmills and reservoirs. Five of the eight farmers who actively cultivate commercial

crops rely on irrigation for cultivation. There is a lack of consensus on whether erosion is a problem in this area. Seven of the ten farmers perceive it to be a problem. Contours have been constructed on cultivated areas, to prevent erosion. Vegetation cover was identified as a further control of erosion. River frontage and exposed areas, and areas that have been heavily grazed, are regarded as areas prone to erosion. Farmers' perceptions of erosion were not evidently related to cultivation practices nor the proportions of vegetation types available to them.

3.3.3 Ecological perceptions of ecosystem goods, services and disservices

Farmers were specifically asked to identify the costs and benefits that natural ecosystems contributed to their farming systems. Ecosystem goods and services were categories based on farmers' responses. Their responses have been grouped according to environmental factors, natural vegetation, and indigenous fauna (Table 3.4). The ecosystem disservices, or those ecological processes or elements negatively affecting production, have also been grouped according to these categories (Table 3.5).

Climate, rainfall and infiltration are regarded as the key elements driving the ecology and production of their environments. Ground water was also stated as important for irrigation and providing drinking water for livestock and human consumption.

There was little consensus amongst farmers as to the most productive elements of the landscape. Areas of especially fertile soils, such as river frontage and watercourses, were recognised as particularly good areas by those farmers whose farms incorporated these landscape elements. Farmers also listed dolerite vegetation and medicago pastures as being especially favourable in terms of ecosystem goods and services associated with grazing. The fynbos and TMS soils were noted as having potential for the increased production of rooibos tea. The general environmental aesthetics were also regarded as important to farmers, who frequently stated that the aesthetics provide a form of environmental therapy, and the potential for an increase in future tourism.

Across all vegetation types the natural vegetation was also identified as providing benefits to farmers. Natural vegetation provides a diverse and varied diet for livestock, supplying them with different ranges of nutrients and chemicals. Eight of the ten farmers had a detailed knowledge of plant names and the relative palatability of the plants growing on

their farms. Farmers assess vegetation according to a reference group of a few highly palatable plant species, such as *Tripteris sinuatum, Arctotus sp.* and *Pentzia incana*. They monitor the condition of their vegetation and grazing impacts according to this reference group of palatable species.

Table 3.4 Summary of ecosystem goods and services as identified by the 10 farmers interviewed, according to environmental factors, natural vegetation, and indigenous fauna, and the broader ecosystem goods and services framework categories into which they fall.

Ecosystem goods and services	**Categories based on farmers' perceptions**
Environmental factors	
Climate	Structural services
Rainfall	Structural services
Ground water	Production and regeneration services
Fertile soils	Production and regeneration services
Aesthetic beauty	Cultural services
Natural vegetation	
Grazing (palatable plants)	Information services
Nutrition (diversity of diet)	Production and regeneration services
Vegetation regeneration	Production and regeneration services
Rainfall infiltration and soil moisture	Structural services
Soil retention and erosion control	Structural services
Windbreak and shelter for livestock	Structural services
Garden plants	Provisioning services
Flower displays for tourism	Provisioning services
Wildflowers for cut production	Provisioning services
Firewood	Provisioning services
Medicinal plants	Provisioning services
Indigenous fauna	
Alternative food sources for predators	Production and regeneration services
Soil turnover and rainfall infiltration	Production and regeneration services
Healthy soil and nutrient cycling	Production and regeneration services
Pest control	Production and regeneration services
Recreational activities (hunting)	Cultural services
Food products (meat, honey)	Provisioning services

Bushes are perceived to act as seed traps, and are viewed as important in retaining seeds and vegetation productivity in the landscape, facilitating the re-establishment, re-growth, maintenance and recovery of vegetation after grazing. General plant cover is important for soil retention, stability and infiltration. Farmers believe that renosterveld vegetation on flat areas with its shallow root system cannot hold water, and this leads to soils becoming hard, dry and grey. All the farmers regarded natural renosterveld vegetation as being of poor grazing value. However, it was regarded as important for acting as a windbreak and

providing shelter for livestock in colder months. Two of the farmers stated the importance of retaining renosterveld patches in and around the perimeter of paddocks for this reason and in this instance is seen as a goods service provider.

Wood is used as a fuel source, although much of this comes from alien plants, such as the alien invasive tree *Prosopis glandulosa*. Farmers had mixed feelings about this species, perceiving it as a threat to grazing in that it creates dense impenetrable stands. However, it also provides highly palatable seed pods during the months when there is very little other grazing available to livestock.

Natural vegetation is viewed as having great developmental potential. Plant diversity and spring flower displays attract tourists to the region which is an additional source of income for six of the farmers interviewed. Activities include flower tours, provision of accommodation, hiking, 4X4 trails, and the sale of farm produce at farm stalls. Farmers feel that tourism activities could be expanded to take greater advantage of flower displays. Farmers perceive the natural vegetation to have horticultural potential and believe there are a number of species which could be sold as garden plants, especially to tourists visiting the area. Wild flowers, particularly *Protea repens*, are currently harvested for the cut and dried flower market. Natural vegetation contains medicinal plants that are still used today, though to a lesser degree than in the past. An example cited is the use of *Sutherlandia frutescens* as a cure for stomach pain. The extraction of essential oils, new varieties of cooking herbs and further medicinal applications are all perceived as ecosystem goods available in the natural vegetation with future development potential.

Farmers ascribed a number of benefits attributable to various animals on their farms. Indigenous fauna reportedly keep certain pest species in check, for example, birds eat caterpillars that consume valuable pasture. The burrowing and digging activities of porcupines, aardvarks, crows and soil organisms are cited as acting as natural ploughs, turning the soil over, maintaining soil health and facilitating rainfall infiltration. Larger mammals provide a source of meat and recreational hunting opportunities. Other food sources, such as honey, are also exploited.

Two farmers reported that bird populations and small mammals are an alternative food source to predators who might otherwise prey on livestock if this was not available. No

correlations could be detected between this reported ecosystem service and farm size, stocking rate, nor vegetation type characteristics for each farm.

Eight farmers stated that they suffer stock loss due to predation by jackal (*Canis mesomelas*) and caracal (*Felis caracal)*, and estimated that they spend up to 5% of their income controlling these predators. Farmers suffer crop loss through predation and destruction by baboon (*Papio ursinus*) and porcupine (*Hystrix africaeaustralis*). Large tracts of grazing lands are rendered useless through excessive animal diggings. Infrastructure, such as roads, fences and water pipes are dug up and destroyed by aardvark (*Orycteropus afer*) and porcupine (*Hystrix africaeaustralis*). A number of these species are hunted and trapped as part of these farm management strategies. Indigenous herbivores compete for grazing with livestock. Rodents and caterpillars were also identified by a single farmer as problem animals because they denude areas creating large bare patches.

Natural vegetation contains a number of poisonous plants, for example *Tylecodon wallichii*, *Cotyledon orbiculata*, *Galenia africana*, and *Ornithogalum conicum* that affect livestock health and can even cause death. Farmers have programmes to actively remove a number of these species. However, eight of the farmers interviewed described how they use these toxic species as indicators to assess their farm's vegetation condition. Farmers stated that if their management was sound, these plants are not problematic as sheep avoid them when other grazing is abundant.

Table 3.5 Summary of ecosystem disservices identified by the 10 farmers interviewed, according to environmental factors, natural vegetation, and indigenous fauna and the broader ecosystem goods and services framework categories into which they fall.

Ecosystem disservices	**Categories based on farmers' perceptions**
Environmental factors	
Climate variability	Production and regeneration services
Natural vegetation	
Contaminated wool (seeds, sticks)	Production and regeneration services
Poisoned livestock	Production and regeneration services
Indigenous fauna	
Predated livestock	Production and regeneration services
Destroyed crops	Production and regeneration services
Grazing by indigenous herbivores	Production and regeneration services
Destruction of infrastructure	Production and regeneration services

Farmers also noted that vegetation, twigs, leaves and seeds, stick in the wool of sheep, lowering its retail value. The variability in rainfall, attributed by farmers to global climate change, was also regarded as an ecological cost.

3.3.4 Conceptual model

Ecosystem goods and services are perceived to play a key role in farmers' production activities. Figure 3.2 shows how the ecosystem goods and services relate to land-use and production, and the ecological linkages that farmers identified, demonstrating where these perceived benefits lie, and how they are utilised. Natural vegetation has been generalised for the sake of clarity.

Farmers believe that vegetation cover and soil turnover influence rainfall infiltration, and that these in turn prevent soil erosion. Stable and moist soils are seen to provide the required nutrients and moisture necessary for the production of crops, pasture and natural vegetation. Natural vegetation provides windbreaks for livestock. Vegetation regeneration and seed production processes are both seen as beneficial, but also provide the ecosystem disservices of wool contaminants, and toxic plants. Pasture and natural vegetation provide nutrition for livestock necessary for the production of quality wool and mutton. Natural vegetation also attracts tourists to the area, as well as providing garden plants and species with developmental potential, medicinal plants and firewood. Natural vegetation provides habitat for prey species for predators. Predators prey on either livestock or prey species, depending on the amount of food available. Indigenous fauna also damage crops, destroy infrastructure, and consume grazing that would otherwise be utilised by livestock. Indigenous fauna are also said to provide pest control for crops, pasture and livestock, turn soil over, are a food source and provide recreation in the form of hunting.

The conceptual model clearly demonstrates that farmers have a clear idea of how their farming objectives are linked to ecological processes, as well as how ecosystem goods and services are interlinked to one another. This implies that a change or impact on one ecological process could have corresponding impacts on other processes.

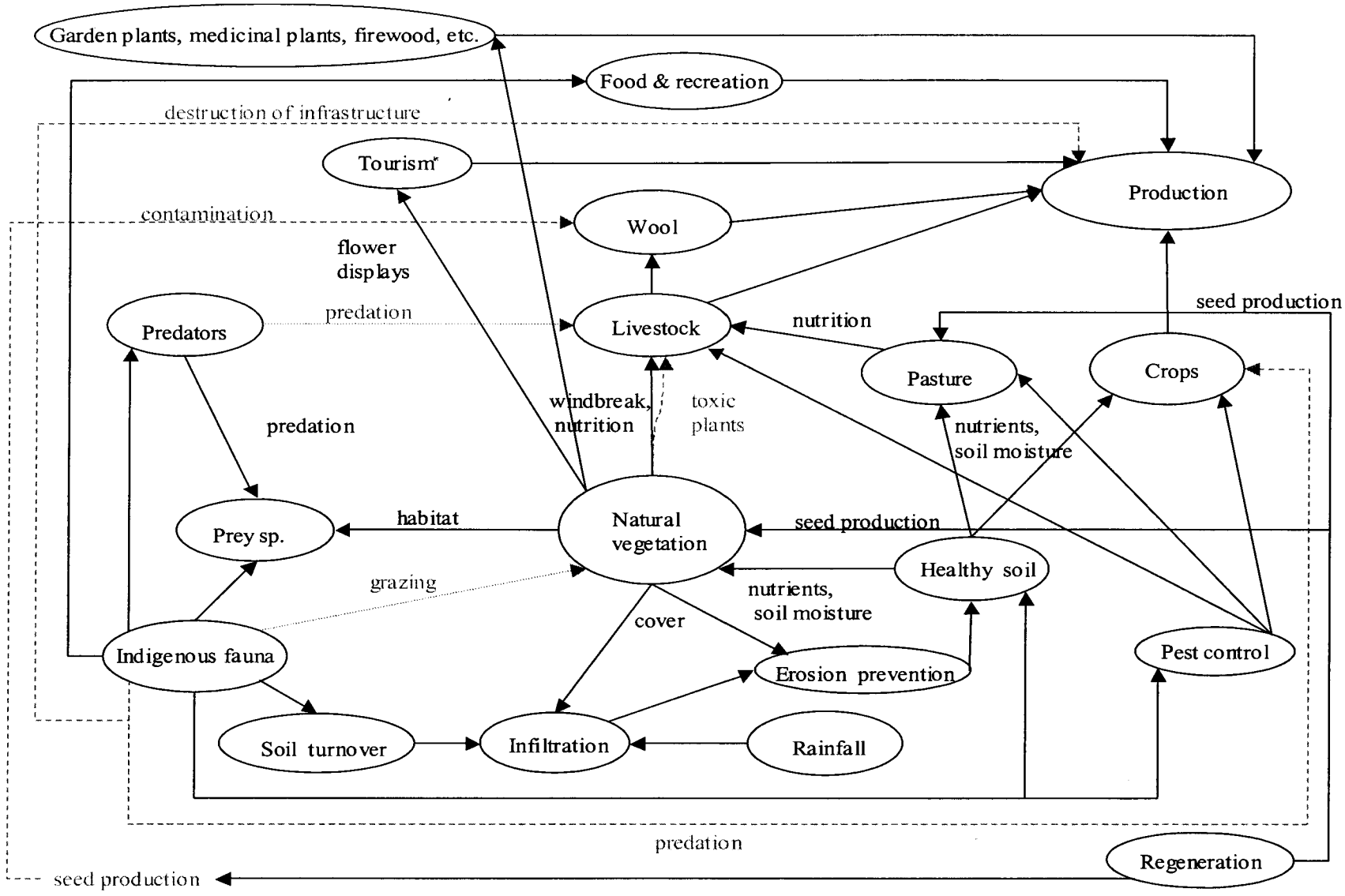

Figure 3.2 Conceptual model showing agricultural activities, ecological variables, ecosystem services (solid) and ecosystem disservices (dashed) as perceived by farmers in the Nieuwoudtville area.

3.3.5 Ecosystem services according to vegetation type

Different vegetation types are perceived to offer farmers different ecosystem goods and services, and disservices. These have been tabulated against vegetation types to clearly show where these occur in the landscape (Tables 3.6 & 3.7). Of the services and disservices identified by farmers, marginally fewer services and slightly more disservices are experienced on transformed vegetation types compared with natural vegetation.

Table 3.6 Ecosystem services identified, and tabulated according to occurrence in vegetation types, and totalled for each vegetation type. Vegetation types are FB – fynbos, R – renosterveld, RT – renosterveld transformed, DP – dolerite plains, DR – dolerite ridges, DT – dolerite transformed, and K – karoo veld.

Ecosystem Service	**FB**	**R**	**RT**	**DP**	**DR**	**DT**	**K**
Environmental factors							
Ground water	√	√	√	√	√	√	√
Fertile soils			√			√	
Aesthetic beauty	√	√	√	√	√	√	√
Natural vegetation							
Grazing (palatable plants)		√	√	√	√	√	√
Nutrition (diversity of diet)		√	√	√	√	√	√
Vegetation regeneration		√	√	√	√	√	√
Rainfall infiltration and soil moisture	√	√	√	√	√	√	√
Soil retention and erosion control	√	√	√	√	√	√	√
Windbreaks and shelter for livestock		√					√
Garden plants	√	√		√	√		√
Flower displays for tourism		√	√	√	√	√	
Wildflowers for cut production	√						
Firewood	√		√				√
Medicinal plants	√	√			√		√
Indigenous fauna							
Alternative food source for predators	√	√		√	√		√
Soil turnover and rainfall infiltration	√	√	√	√	√	√	√
Healthy soil nutrient cycling	√	√	√	√	√	√	√
Pest control	√	√	√	√	√	√	√
Recreational activities (hunting)	√	√	√	√	√	√	√
Food products (honey, meat)	√						√
Total no. services	14	16	14	14	15	13	17

Table 3.7 Ecosystem disservices identified, tabulated according to presence in vegetation types, and totalled for each vegetation type. Vegetation types are FB – fynbos, R – renosterveld, RT – renosterveld transformed, DP – dolerite plains, DR – dolerite ridges, DT – dolerite transformed, and K – karoo veld.

Ecosystem disservice	FB	R	RT	DP	DR	DT	K
Natural vegetation							
Contaminated wool (seeds, sticks)			√				√
Poisoned livestock		√	√	√	√	√	√
Indigenous fauna							
Predated livestock	√	√		√	√	√	√
Destroyed crops	√		√			√	
Grazing by indigenous herbivores			√				
Destruction of infrastructure	√	√	√	√	√	√	√
Total no. disservices	3	3	5	3	3	4	4

3.4 Discussion

3.4.1 Identified ecosystem goods and services

From the interview process it was clear that farmers perceive a variety of ecosystem goods and services available to them, and that these are intimately linked to their management activities. Ecosystem goods and services play an important role in the production processes of the farms examined, enhancing farming activities and providing a variety of opportunities for diversifying economic activities. Farmers found it easier to identify ecosystem goods than ecosystem services. The adopted interview technique did not ask farmers to identify ecosystems services directly. Farmers had to demonstrate their ecological knowledge by identifying the links between ecosystem goods and ecosystem services. On the whole they were aware of a range of goods and services, and could to some extent describe ecological processes and demonstrate how they incorporated them into their land-use decisions. A number of other studies concur with this finding (Gadgil *et al.* 1993; Silvano *et al.* 2005). Farmers' ecological knowledge can be attributed to the long time these families have lived on the Bokkeveld plateau and the farming experience of the individuals who were interviewed for their ecological knowledge.

3.4.2 Management framework

Scientists have developed numerous conceptual frameworks for grouping and describing ecosystem goods and services and these provide a useful tool for other scientists working

in this field (e.g.Daily 1999; Moberg & Folke 1999; Norberg 1999; de Groot *et al.* 2002; Alcamo *et al.* 2003). All the services identified by farmers could be placed into one of the ecosystem service framework categories in the above studies. Berkes *et al.* (1998) point out that traditional knowledge and frameworks are different from scientific frameworks. The value of qualitative research at a local level in assessing ecosystem services has been demonstrated by Kaplowitz (2001) who explored the local use of mangroves by interviewing focus groups and individuals. In this study it is evident that farmers have their own framework for ecosystem goods and services, and manage their environments according to five broad categories, some of which overlap with previous scientific studies, particularly the Millennium Ecosystem Assessment (Alcamo *et al.* 2003). These are: structural services, information services, production and regeneration services, provisioning services, and cultural services. They use this framework for making land-use decisions. Therefore, while this study recognises the importance of the work of these authors and is guided by it, the discussion and the approach taken in this thesis follows the framework established by the farmers in the study area. This is viewed as appropriate, given the purpose of the study, which was to identify and assess perceived ecosystem goods and services, explore the links between what farmers want from their environments, and how they should best manage their environments to achieve this. The broader aim of this research was to affect future land-use change and promote biodiversity conservation by providing a better understanding of the links between biodiversity conservation and ecosystem services.

Structural services

Structural services are those benefits that farmers derive from structural characteristics of their farms. These relate to both landscape structure and vegetation structure, and farmers' management strategies are strongly influenced by these services.

Farmers all stressed that climate was the controlling factor in production. Unable to control climate, they have developed management practices comparable to a transhumance grazing strategy, moving between vegetation types according to season and rainfall. Decisions on cultivation activities are based largely on the previous years' rainfall, with consideration to both timing and amount.

Decisions about the spatial arrangement of the whole farm and level of transformation desired, are considered at a landscape scale. An integral part of understanding the

ecosystem services provided by landscape structure in a farming context is understanding landscape heterogeneity. The identification of key resource areas, and what determines these areas of above average productivity, is an important component of understanding land-use management. An example of a key resource area is the specific vegetation growing in areas of higher soil moisture along drainage lines or riparian areas (Illius & O'Connor 1999).

The selected study area is considered particularly heterogeneous with four distinct geological formations and associated soil types, and seven distinct vegetation types. The landscape contains other geomorphological features such as river courses. These provide variable goods and service which provide farmers with opportunities for producing a variety of different products, such as potatoes and rooibos tea. Maintaining a diversity of vegetation types appears to be fundamentally important to farmers. My findings indicate that a more heterogeneous environment provides a greater diversity of ecosystem goods and services and farmers engage in a number of production activities taking advantage of this landscape heterogeneity, ranging from tourism to tea production. The different environments or vegetation types were found to provide the same perceived ecosystem goods and services in some instances as well as goods and services unique to specific vegetation types. Farmers also perceive a temporal component to the delivery of ecosystem goods and services. An example of this is the livestock grazing strategies that have been developed where livestock are rotated between different vegetation types at different time of the year. Farmers perceive very few negative consequences of having transformed areas on their farms but rather view this as another vegetation type which provides important ecosystem goods and services for grazing. This is contrary to my findings which contrasted the goods, services and disservices attained from each vegetation type. These indicated that transformed renosterveld provides a greater number of disservices. This points to a potential weakness in the approach adopted in this study in not having quantitative data, the cost of disservices may be small relative to the benefits of services. Farmers hold the perception that numerous services flow from a diverse resource base, and their management decision are governed by the vegetation types they have access to.

Variable vegetation structure and the way in which these different vegetation types differ architecturally, is another component of structural services and a contributing factor to the landscape heterogeneity of the study area. These vegetation structural elements are also

incorporated into a farmer's management strategy adding a three-dimensional element to their view of the landscape. This in turn feeds into decisions about both transformation and utilisation time of specific vegetation types. Scientists state that farming practices and land-use management which drastically alter vegetation structure are likely to disrupt the delivery of ecosystem services (Swift *et al.* 2004). Grazing practices, vegetation burning and large-scale clearing activities that significantly alter natural vegetation structure could increase run-off, promote soil erosion and prompt the loss of resources from the production system. Farmers valued transformed areas as one highly productive part of a complex mosaic. However, they do perceive that transformation may result in soil erosion. The effects of vegetation transformation on the ecosystem service soil retention are examined in detail in chapter 6.

Conflicting views over the value of structural services of the landscape point to a combination of farmers who use these structural ecosystem services, those who have perhaps forfeited them, and those who do not perceive them. Studies in Australia (Burk 1998) show that by reducing wind speed through the provision of shelter, lambing mortality is reduced and there is an increased conversion of feed to meat and wool. In this study some farmers stated that natural vegetation acts as a windbreak, sheltering livestock in the winter lambing season, something that pasture and cropland cannot provide. However, they also state that sheep prefer to lamb in open areas where threats are visible, as opposed to dense vegetation. Farmers noted the ideal situation would be natural vegetation boundaries, or patches of natural vegetation in amongst pasture. This points to variable perceptions with some farmers incorporating vegetation structure and its associated ecological dynamics into their management systems while others have possibly forfeited these ecosystem services, or do not perceive them. Again there is a clear preference for a patterned and variable landscape.

Information services

Information services are provided to farmers predominantly through what they regard as key indicator species which provide information to them about their management strategies and allows them to gauge and direct their management actions. Indicator species have long been used for managing landscapes from both a production and conservation perspective. Landres *et al.* (1988) define an indicator species as an organism whose characteristics are used as an index of attributes too difficult, inconvenient or expensive to

measure for other species or environmental conditions of interest. Noss (1990) describes indicators as measurable surrogates for environmental end points.

The continued productivity and persistence of palatable vegetation in grazed areas is a fundamental ecosystem service to all livestock farmers. Toxic plants, however, are regarded, as a disservice. A large amount of farming effort is directed at increasing or promoting desirable species, ecosystem goods and services, and trying to either avoid or eliminate less favourable species or ecosystem disservices. Taylor and Ralphs (1992) state that correct stocking rate, combinations of animal species, and the grazing system employed by a farmer can be used to minimise the livestock death attributable to poisonous plants. Whilst farmers in the study area agree with this statement they actively remove toxic plants.

Farmers assess vegetation according to reference groups of a few highly palatable and toxic plant species, and are continually evaluating their grazing strategy according to the persistence of these groups of indicator species in the landscape. Key palatable and toxic species provide farmers with a quick and easy measure of the condition of their vegetation. Furthermore, they use them as directional and end points indicators to assess vegetation condition. The accuracy of selected indicators is unknown, but those farmers interviewed use the same set of species as indicators. In this way indicator species provide a service to farmers, who in turn base their management decisions on their presence or absence. Landres *et al.* (1988) also note that indicator species may not accurately assess population trends of other species, and whilst selected indicators may thrive, general environmental quality degenerates (Noss 1990). Despite these caveats, there is a move to construct farm level indicators that provide a measure of progress towards sustainable development (Rigby *et al.* 2001).

Production and regeneration services

Production and regeneration services are those services that are the mainstay of agricultural activities. Farmers perceive functional groups of species being linked to production and regeneration services. There is growing evidence that ecosystem stability is directly related to the functional diversity of the ecosystem and is dependent on the nature of species interactions (Johnson *et al.* 1996; McCann 2000). In keeping with this view unstable ecosystems, where biodiversity has been lost and ecological processes disrupted, should be comparatively dysfunctional (Schläpfer *et al.* 1999). In some cases

the loss of species may result in a negative feedback loop being established where farmers continually experience disservices. A possible example of this is the predation of livestock by medium-sized predators in the study area.

Livestock predation is a well-recognised problem amongst stock farmers in South Africa. Studies conducted in Kwazulu Natal, South Africa, estimated that a total of 3% of sheep and lambs were lost to predators annually, with a value of over R3 million (Lawson 1989). Livestock predation was raised as an issue in the interview process. The majority of farmers interviewed actively remove predators from their ecosystems. However, a number of farmers perceive the service of an alternative food supply to predators in place of livestock. They stated that if there is an abundance of small mammals, birds and rodents on the farm, they did not lose stock to predators. Similar experiences in Europe provide some validation for this perception where European wolves (*Canis lupus*) kill domestic livestock (Cozza *et al.* 1996; Meriggi & Lovari 1996). Meriggi and Lovari (1996) argue that the simultaneous re-introduction of several wild ungulate species is likely to reduce predation on livestock. Farmers perceive the retention of a functional group of prey species as a beneficial ecosystem service directly related to their production activities. This perceived ecosystem service will be explored in greater detail in chapter 5.

One view regarding the relationship between species diversity and ecosystem function proposes that the fewer close substitutes a species has in terms of its function in an ecosystem, the more damaging to ecosystem function its loss will be (Rosenfeld 2002). On this basis it could be argued that for these agricultural systems to continue to function and provide ecosystem goods and services, farmers need to ensure that this functional diversity is retained within their production systems. Farmers appear to understand some of the links between the functional groups and the services they provide, and management activities are in some cases directed at promoting the continued existence of those particular functional groups. An example of this relates to the functional groups of species that are responsible for soil turnover and rainfall infiltration.

Infiltration potential and resultant soil moisture are vital for soil health (Van Bruggen & Semenov 2000), vegetation regeneration (Breman & De Wet 1983), and also the prevention of erosion (Hendrix 2000). Farmers identified a functional group of species, which included porcupines, aardvarks, crows, and general soil organisms, as important in increasing rainfall infiltration through soil turnover. Soil moisture is also essential for the

maintenance of natural vegetation, growth of pasture and crop production. Whilst porcupines are hunted to limit their number because of the negative impact they have on farming infrastructure, other members of this functional group are perceived to be maintaining this important ecosystem service. The effects of transformation on these functional groups will be explored in chapter 7.

Provisioning services

Provisioning services include all the products farmers obtain from the ecosystems on their farms. These include products that are harvested or with collected from the environment and used on the farm such as firewood, garden and medicinal plants; products that are sold such as meat, honey and cut flowers; and products that generate income for farmers base on their existence on farms such as flowers which attract tourists. These also included potential future products such as the development of garden plants for sale to tourists and the broader public.

Provisioning services play a vital role in farm production. They enable farmers to diversify their income generation sources. Little *et al.* (2001) and Valdivia *et al.* (1996), working in east Africa and the Andes respectively, both found the diversification of income sources in rural communities was an important risk management strategy. It is argued that the farmers of the Bokkeveld plateau also regard diversification as a risk management strategy, as this reduces their dependence on the production of agricultural inputs.

Cultural services

Cultural services are typically regarded as those non-material benefits that people derive from ecosystems, and these are integrally linked to human values and behaviour. (Alcamo *et al.* 2003). The farmers of the Bokkeveld plateau regard landscape aesthetics as important, both for themselves and perceive general aesthetics as a key draw card for tourists. They described the landscape as important for 'environmental therapy', allowing visitors space to reflect. Farmers also recognise recreational activities associated with natural ecosystems and describe hunting both for meat and to eliminate predators as recreational activities.

3.4.3 Conservation priorities

Maintaining species diversity on farms and within the production processes is expected to give rise to ecosystem stability and enhance productivity (Johnson *et al.* 1996; Tilman 1999). It has been argued that the loss of plant species may impair ecosystem processes and reduce the ability of ecosystems to withstand and recover from extreme events (Lawton 1994; Tilman 1999). Farmers do perceive benefits from retaining natural vegetation on farms, but stated that they did not want farms comprised of only natural vegetation. In a study in Switzerland examining the preferences for forest re-growth in agricultural areas, both locals and tourists agreed that partial re-growth was most favourable and that homogenous stretches of natural vegetation alone were not preferential (Hunziker 1995). All the farmers in the study area held the same view that landscape diversity is considered most favourable and for this reason they value retaining a variety of vegetation types, both natural and transformed. Benton *et al.* (2003) argue that generally agricultural practices in the past have eroded heterogeneity at a variety of spatial and temporal scales, and that it is this loss of heterogeneity that has had major impacts on the biodiversity in agricultural landscapes. Given that farmers value heterogeneity, conserving biodiversity within the study should prove simpler than where farmers do not perceive the value of heterogeneity.

This perception of heterogeneity makes a clear starting point for any conservation considerations within this landscape. Given that variable states of a vegetation type, natural and transformed, are favoured, the question arises as to what ecosystem goods and services does each state provide to the farmers. Answers here could provide the motivation for the retention of natural fragments, both in that they provide goods and services directly, and because they are possibly linked to the supplying of ecosystem services in transformed areas as well.

Farmers state that natural vegetation, although having a lower carrying capacity than pasture, provides sheep with a diverse diet, and that sheep thrive under conditions where there is choice of species to graze. Natural vegetation is important for eco-tourism. Nieuwoudtville is a very popular flower-viewing destination. Tourists come to see both the mass displays of annuals and seek out specific geophyte species found in great diversity in the area (Turpie & Joubert in press). These species generate income for both farmers and the broader community, from direct and indirect sales.

Clearly certain species as well as the diversity of species play a role in farmers' production processes. Despite the recognised benefits of retaining the diversity of plant species, the majority of farmers have a far greater interest in maintaining and promoting palatable plant species. To retain these species, management needs to be directed at those regeneration processes responsible for ecosystem stability and resilience. The redundancy species hypothesis argues that not all species are vital in ecological processes either and there is a certain amount of ecological redundancy, or overlap in the role that different species play in ecosystems (Walker 1995). Some farmers agree with Costanza *et al.* (1997) in suggesting that a minimum level of ecosystem infrastructure is necessary for ecosystem stability and the production of ecosystem services, and much management effort is focused on the retention of certain key palatable species.

A number of authors note the importance of incorporating local knowledge into scientific investigations and in the development of natural resource management plans (Berkes *et al.* 1998; Burgess *et al.* 2000; Desbiez *et al.* 2004). Farmers have an established framework for managing the ecosystem goods, services and disservices on their farms. It is believed that conservation actions to encourage conservation on private land should incorporate, or take into account this framework, as these are the parameters in which the current custodians of this land work.

3.4.4 Scientific assessment

It was evident in the interview process that farmers perceived a number of ecosystem services and had some ecological knowledge. It was clear that farmers' knowledge of ecosystem services was incomplete in that they failed to identify all known ecosystem services, such a carbon sequestration. When identifying an ecosystem good or service farmers were sometimes unaware of the species involved, and in those instances where they were aware, they appeared to have a narrow understanding of the biology and ecology of these species. This is not surprising or unreasonable given that in many instances of ecosystem service identification there has been little or no scientific research on the ecological processes that are associated with ecosystem goods and services (Kremen 2005). This raises an important issue. While this study seeks to understand farmers' perceptions and the basis for implementing ecosystem service-motivated land-use change, the scientific relevance of these perceptions must also be explored and where possible validated.

This chapter is the first stage in such a study comparing local technical knowledge and scientific experimental research. From the list of ecosystem services that farmers identified as important to them, I selected a number of these to study in detail. This selection process was based on the principle of trying to be as inclusive as possible, designing studies that incorporaded the greatest number of these services within set time and budgetary constrainsts. Chapters four, five, six, and seven involve the measurement some of the identified ecosystem services, both as a means of validating local knowledge and in order to gain a deeper understanding of the ecological processes involving ecosystem goods and services in this arid farming landscape. The eighth chapter adopts a different approach. Whilst still focused on validating local knowledge it adopts a social analytical approach drawing on technical expert opinion to assess the validity of a perceived ecosystem good identified by farmers. These studies incorporate four of the five ecosystem categories: structural services, information services, production and regeneration services, and provisioning services.

3.5 Conclusion

Ecosystems services play a crucial and diverse role in agricultural production within the study area. Farmers perceive some of the ecosystem goods and services available to them, and these they incorporate into their production systems. Conserving the floral diversity of the study area is not a priority for farm management. Few services are perceived to flow from retaining biodiversity, but many are perceived to flow from retaining landscape diversity. Farmers make management decisions based on a framework consisting of structural services, information services, production and regeneration services, provisioning services, and cultural services. This is of great significance to biodiversity conservation initiatives on private land, demonstrating both the potential and limitations of the views and perceptions of farmers, but acknowledging that any private land conservation initiatives would need to work within this framework in order to succeed.

Chapter 4

Determining the influence of ecosystem goods and services on livestock management practices

4.1 Introduction

The primary economic activity on the Bokkeveld plateau is livestock production. The management of grazing resources is ultimately the management of ecosystem goods and services required for the provision of this resource. The ecosystem goods and services that are necessary for livestock production include: vegetation productivity, plant structure, biomass and the production of grazing, the nutrient availability within grazed vegetation, and the seasonal regeneration of vegetation. Farmers and pastoralists have developed grazing systems that make use of these ecosystem goods and services on offer in a way that best meets their end goals.

The seasonal movement of livestock between different vegetation types, or transhumance, has been practiced in the arid western regions of southern Africa for at least 2000 years (Smith 1983). Penn (1986) has argued that the best strategy for a pastoralist society in semi-arid areas is to control an area containing a variety of natural resources that are subject to different seasonal characteristics, as this ensures year-round access to water and grazing. He goes further to state that the Bokkeveld escarpment is one of a select number of regions in western South Africa where transhumance lifestyles are necessary. The escarpment, while situated in the winter rainfall area, borders the summer rainfall area to the east and this close proximity means farmers can benefit from summer and winter rainfall. In addition, the Bokkeveld plateau has a number of springs and, therefore, could provide the necessary ecological services to support a transhumance lifestyle.

The strategic importance of the Bokkeveld region for pastoralism is reflected in the intensity of the resistance by the Khoikhoi, the indigenous inhabitants of this region, to the invasion by trekboers or colonial settlers with the expansion of the northern frontier during the period 1770 to 1790 (Penn 1986). The trekboers defeated the Khoikhoi, and once in control of this area, they were also forced to adopt a transhumance lifestyle (Penn 1986). Typically this involved winter grazing on a farm on the Bokkeveld escarpment, and then

trekking to a summer grazing loan-farm or a 'legplaats', just north of Loeriesfontein were farmers could find summer grazing, rent-free (van der Merwe 1945).

This transhumance grazing system of the trekboers gradually collapsed towards the late 1800s. Factors contributing to this collapse included the influx of settlers and the extension of private land ownership on both the Bokkeveld plateau and in Bushmanland (van der Merwe 1945; Talbot 1961). Technological innovations such as windmills and wire fencing further enabled farmers to settle permanently on the land (Archer 2000).

Today, virtually no farmers of the Bokkeveld plateau trek to Bushmanland, but graze livestock in close proximity to the plateau all year round. The Bokkeveld plateau is a very heterogeneous environment with a variety of different vegetation types each with a suite of ecosystem goods and services that influence grazing and livestock production (see chapter 2). Compared with the diversity of publications regarding grazing practices in the Nama Karoo, there is no published evidence of any grazing trials conducted in the winter rainfall Succulent Karoo, of which the Bokkeveld plateau is a part (Archer & Hoffman 1989). There are no accounts of the strategies farmers have developed now that the transhumance system of moving between winter and summer rainfall areas has largely collapsed.

How farmers choose to utilise their landscape directly relates to how they identify and perceive the goods and services available to them. I identified and investigated the dominant grazing strategy within this heterogeneous study area to determine how, when and where the available ecosystem goods and services necessary for livestock production (vegetation productivity, biomass, composition and structure, nutrient availability and vegetation phenology), are being utilised. I determined whether these ecosystem goods and services differed between available vegetation types. My primary interest was in determining whether farmers' utilisation strategies have evolved to utilise different vegetation types to secure novel or different ecosystem services for livestock, or whether they obtain the same ecosystem goods and services from different vegetation types, but at different times of the year. The effects of transformation on the supply of these grazing goods and services was examined. I also explored the scientific rationale for the chosen land-use strategy as a means of testing farmers' perceptions of these ecosystem goods and services.

4.2 Methods

4.2.1 Land-use strategy identification

Semi-structured interviews (see Appendix 1) were conducted with ten farmers in the study area in October 2000. Farmers were questioned on history of ownership, land-use practices, both past and present, the resources available to them and their utilisation strategies, and which plant species they viewed as most palatable and most toxic. This information was synthesised and discussed in chapter 3.

4.2.2 Vegetation composition and structure

Vegetation composition and structure of renosterveld, transformed renosterveld, dolerite plains, dolerite ridges, transformed dolerite, and karoo veld was assessed. Three sites in each vegetation type were selected, based on patch scale, the researcher's view of what constitutes typical, and with consideration to avoiding human infrastructure which could influence results. Plant biodiversity was recorded and vegetation cover was visually estimated in 16 randomly located 1 m^2 quadrats at each site, this sample number was selected based on statistical considerations and time constraints. Species were then assigned to the growth form categories: annual, forb, geophyte, grass, shrub, and succulent. Simon Todd, who carried out a vegetation biodiversity assessment of the study area for the Conservation Farming Project, using Modified Whittaker plots (Stohlgren *et al.* 1995), collected the dolerite ridge data used in this analysis (see Todd 2003). This provided consistent data as Modified Whittaker plots are sampled at a 1 m^2 scale. Mean vegetation height was also estimated based on species dominance (Germishuizen & Meyer 2003).

4.2.3 Productivity and biomass

Differences in productivity and biomass were compared between renosterveld, transformed renosterveld, dolerite plains, dolerite ridges, transformed dolerite, and karoo veld. To eliminate the effects of grazing, 36, 1 m^2 exclosures were constructed, six in each of the six vegetation types in mid summer before the start of the growing season. Again sites were selected based on patch scale, the researcher's view of what constitutes typical, and with consideration to avoiding human infrastructure which could influence results. Sample number was based on statistical considerations and financial constraints. All

grasses, annuals and geophytes were cleared from the exclosures by cutting them at ground level, and removing them from the site. Some of the exclosures contained shrubs and succulents. Twenty shoots were selected on each shrub and succulent and marked with a small tag at 10 cm from the tip of the shoot.

Exclosures were re-examined the following summer. All grasses, annuals and geophytes were collected in the exclosures by cutting them at ground level. Marked shrub and succulent shoots were re-measured, and a new growth mean for each shrub and succulent calculated. Twenty five percent of all new growth was then collected for each individual shrub and succulent, within an exclosure, using the calculated growth mean. The remaining shrub and succulent biomass was then cut to ground level and collected separately, thus all biomass was cleared from the exclosure, and measures of standing crop and productivity obtained.

In order to increase the sample size of the standing crop, the biomass in a further six 1 m^2 plots in each of the six vegetation types was collected and divided into grasses, geophytes, annuals, shrubs and succulents. These plots were selected by throwing a quadrat from each existing exclosure. All the biomass from these 72, 1 m^2 plots was dried in a 60° C oven for 72 hours and weighed to determine the total standing crop. Differences in productivity for vegetation types were compared using Kruskal-Wallis ANOVA and a post-hoc test was performed using a multiple comparison of mean ranks for all groups. The differences in biomass of each vegetation type were assessed using a One Way ANOVA and a Tukey honest significant difference post-hoc comparison as this data was normally distributed.

4.2.4 Leaf content analysis

A standard leaf analysis measuring N, P, K, Ca, Mg, Na, Mn, Fe, Cu, Zn, and B was carried out by an independent laboratory, Bemlab, to determine the mineral element composition for each vegetation type. A lumped leaf sample, consisting of 10 sub-samples, was collected from each of 72 biomass plots that had been oven dried. Total nitrogen (%) was determined on dried milled samples and analysed in a LECO FP-528 nitrogen analyser (Nelson & Sommers 1982). Other all element concentrations were determined using dried milled samples, by dry ashing in a muffle furnace at 450 °C and dissolving in (50%) Hydrochloric Acid. These were then analysed on a Inductive Coupled Plasma Emission Spectrometer.

The differences in the mineral element composition of each vegetation type were assessed using a one way ANOVA and a Tukey test for normally distributed data for K, Fe and CU, or a Kruskal-Wallis ANOVA and a multiple comparison of mean ranks for non-parametric data for the remaining mineral elements N, Na, P, Mn, Ca, Mg, Zn and B.

4.2.5 Phenology assessment

The phenology study compared all six vegetation types according to a range of plant phenophases. These included: leaf growth, shoot growth, flowering, fruit, seed set, and leaf abscission. Twelve sites, that consisted of two replicates of all six vegetation types, were sampled on a monthly basis for a year, using a random walk technique that lasted 30 minutes, recording the phenophase of select species. The species selected were the most dominant species that constituted 80% of the vegetation cover in each of the vegetation types, which was derived from the vegetation composition and structure assessment. In the interviews, farmers identified ten toxic plants that by their estimates have the greatest effect on grazing. The phenology of these toxic plants was also tracked for each of the vegetation types. Monthly rainfall at Nieuwoudtville, for the study period March 2001–March 2002, was provided by the South African Weather Bureau and examined in conjunction with phenology data.

4.3 Results

4.3.1 Land-use and livestock management practices

Farms were found to comprise a number of disjointed pieces of land covering a variety of vegetation types. Farms in the study area typically comprised six vegetation types. Table 4.1 shows the vegetation composition of the ten farms that were investigated (see chapter 3).

This table makes explicit the level of fragmentation and the diversity of land holding within the study area. Farmers use six of the seven dominant vegetation types available to them on the Bokkeveld plateau for livestock production. These include renosterveld, transformed renosterveld, dolerite plains, dolerite ridges, transformed dolerite and karoo veld (see chapter 2). Fynbos is not used for grazing and has therefore been excluded from further analysis. Farmers employ different land-use strategies depending on the

combination of vegetation types they own and the condition of the vegetation. Overall farmers owned more karoo veld than other vegetation types.

Table 4.1 The vegetation composition of all ten farms shown as a percentage of the total farm area. Vegetation types included here are FB – fynbos, R – renosterveld, TR – transformed renosterveld, DP – dolerite plains, DR – dolerite ridges, TD – transformed dolerite, and K – karoo veld, and other vegetation.

Farm No.	FB	R	TR	DP	DR	TD	K	Other
1	43	25	16	0	0	2	14	0
2	11	2	10	18	3	1	55	0
3	0	0	0	7	4	4	78	7
4	16	4	5	2	1	1	52	19
5	19	4	9	15	0	1	50	2
6	5	1	3	3	1	0	66	21
7	3	15	6	4	5	2	28	37
8	89	1	10	0	0	0	0	0
9	25	8	16	5	0	2	26	18
10	7	11	9	0	1	0	54	18
Mean	22	7	8	5	2	1	42	12

Farmers typically use the karoo veld as their winter grazing area as they believe this is the best time to graze this vegetation type (Fig. 4.1). Where farmers cultivate wheat on transformed dolerite and renosterveld sites, sheep are moved off these areas in winter to allow crops to grow. However, this also applies to farmers who do not produce wheat or other crops. Farmers move their stock into the karoo vegetation between May and July, usually two weeks after the first winter rains. Here the stock remains until November, when they are moved onto the transformed dolerite and, or transformed renosterveld to graze wheat stubble, medicago pasture or other annual vegetation depending in access to these vegetation types. In December some sheep are also moved into renosterveld, and, or dolerite plains and, or dolerite ridges where they will remain for the rest of the summer months, also dependent on access to these vegetation types. One farmer did not have access to karoo veld, and stated that he kept livestock on transformed renosterveld throughout the year.

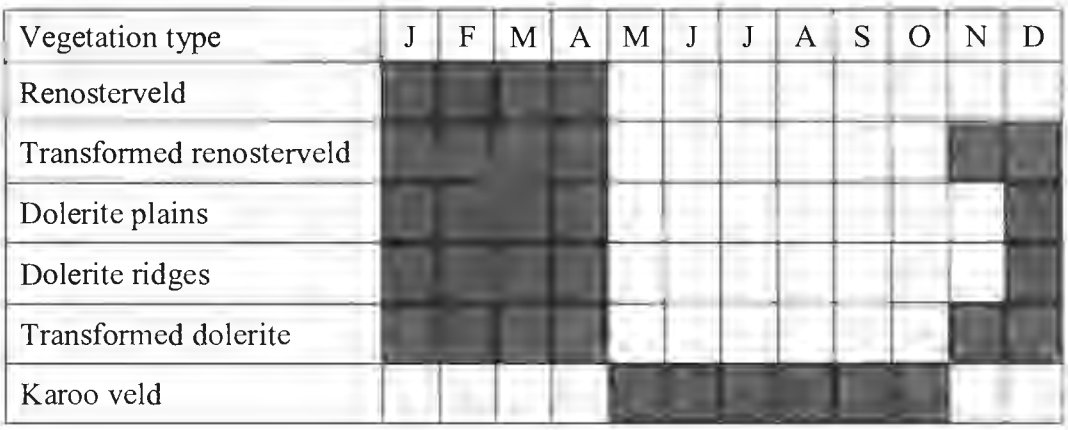

Figure 4.1 Diagram showing monthly utilisation of vegetation types in the study area followed by the majority of farmers. The diagram represents a generalised perspective derived from semi-structured interviews with ten farmers in the region.

4.3.2 Vegetation composition and structure

Vegetation composition, structure and cover was found to be different for each of the vegetation types compared (Fig. 4.2 & 4.3). The renosterveld is predominantly a woody shrub vegetation, with a considerable annual and geophyte component in the form of an understorey. The transformed renosterveld consisted overwhelmingly of annuals. The dolerite plains had a high proportion of annuals, grasses and geophytes. The dolerite ridges had a high cover of shrubs, grasses, annuals and geophytes. Grass dominated the transformed dolerite, and the karoo veld was found to consist mostly of succulents and shrubs.

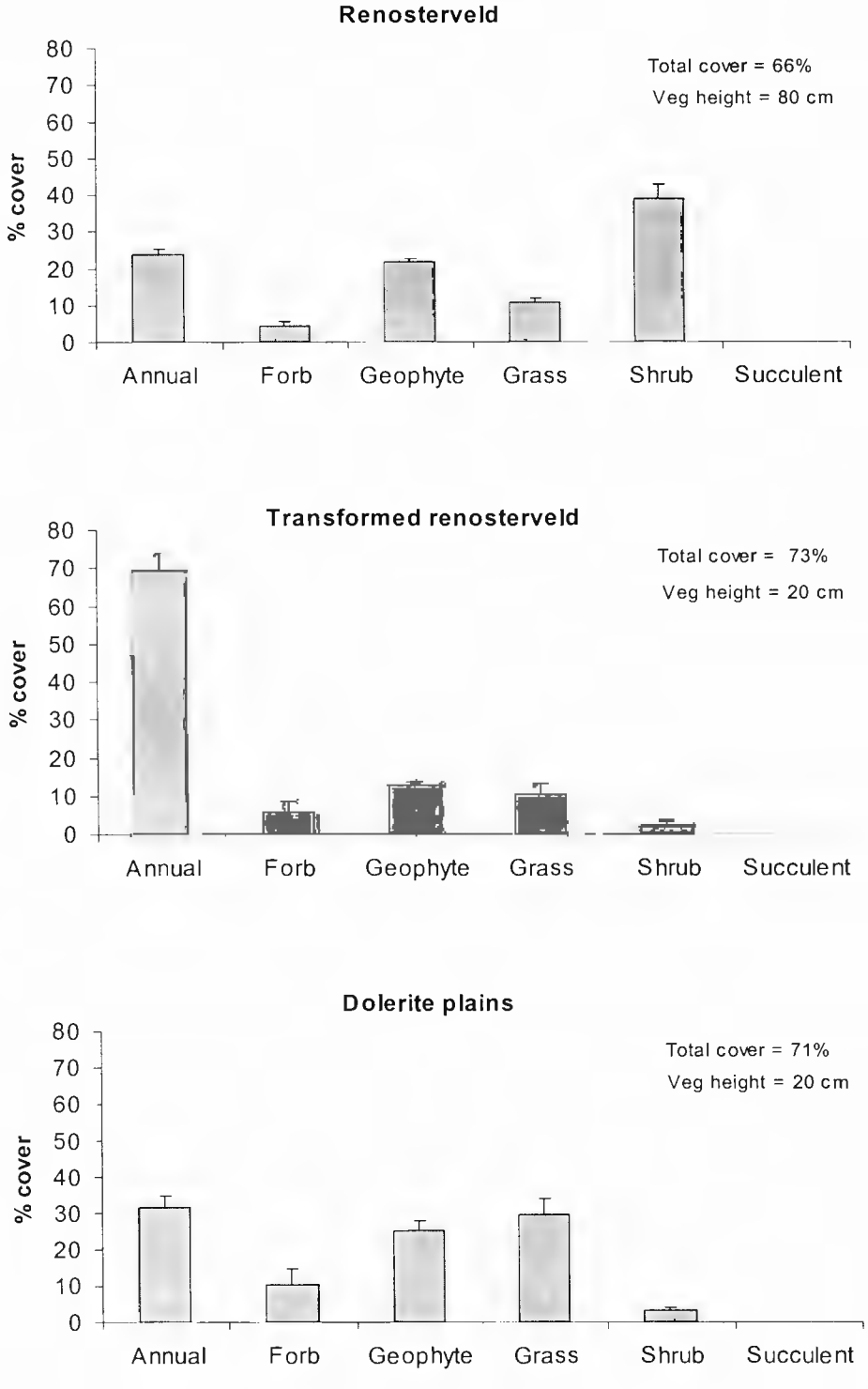

Figure 4.2 The growth form composition and standard deviations of the renosterveld, transformed renosterveld, and dolerite plains vegetation types according to the growth forms, annuals, forbs, geophytes, grass, shrub, and succulent demonstrating the composition and structure of these vegetation types.

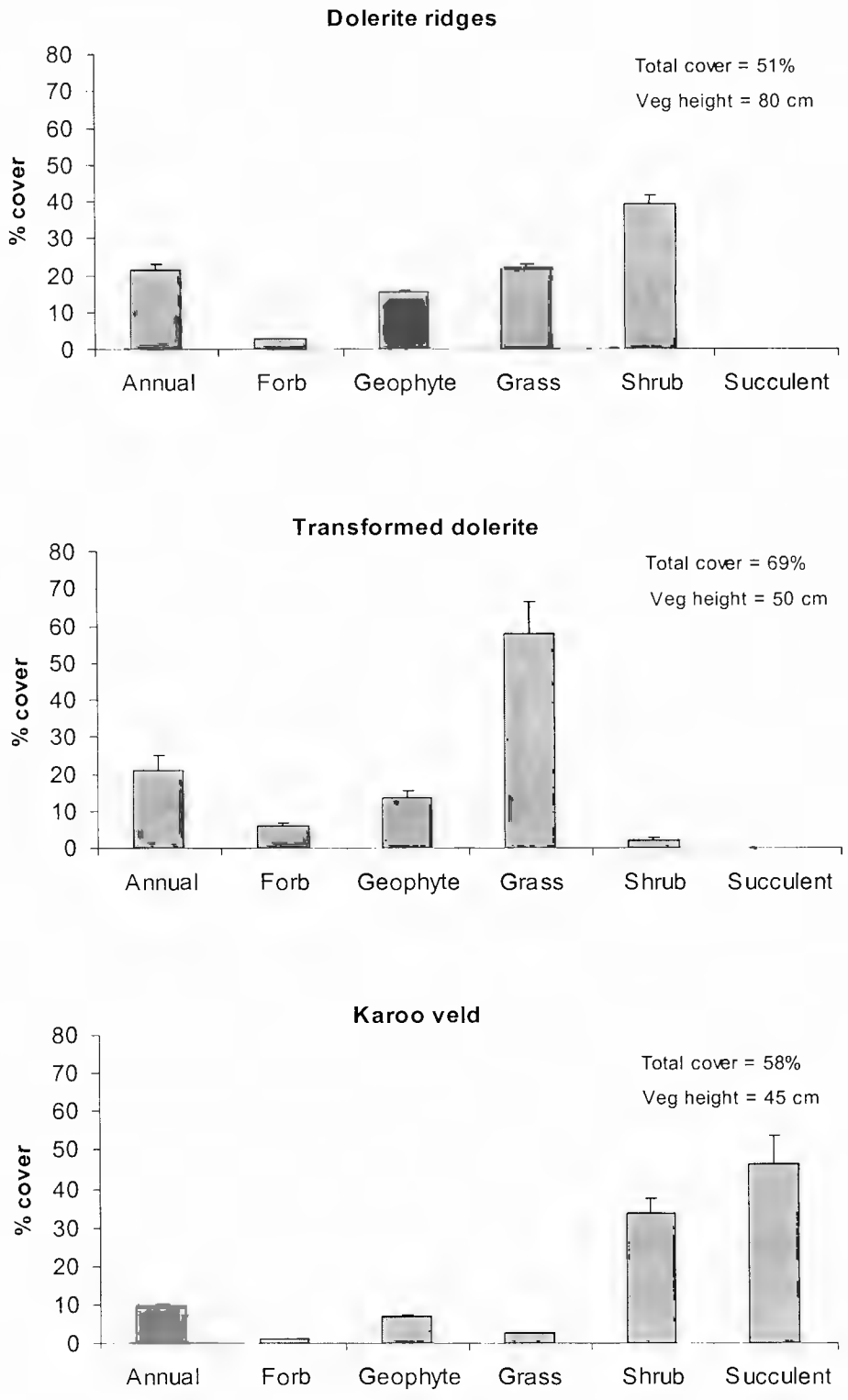

Figure 4.3 The growth form composition and standard deviations of the dolerite ridges, transformed dolerite, and karoo veld vegetation types according to the growth forms, annuals, forbs, geophytes, grass, shrub, and succulent demonstrating the composition and structure of these vegetation types.

4.3.3 Productivity and biomass

Productivity, or new growth accumulation in a single growth season, showed that transformed renosterveld, transformed dolerite and the dolerite plains have the highest growth rates (Fig. 4.4). New growth was significantly greater than karoo veld. Grasses, annuals and geophytes made up the majority of the new growth in all vegetation types, excluding the karoo veld where succulent and shrub growth accounted for the majority of the new growth.

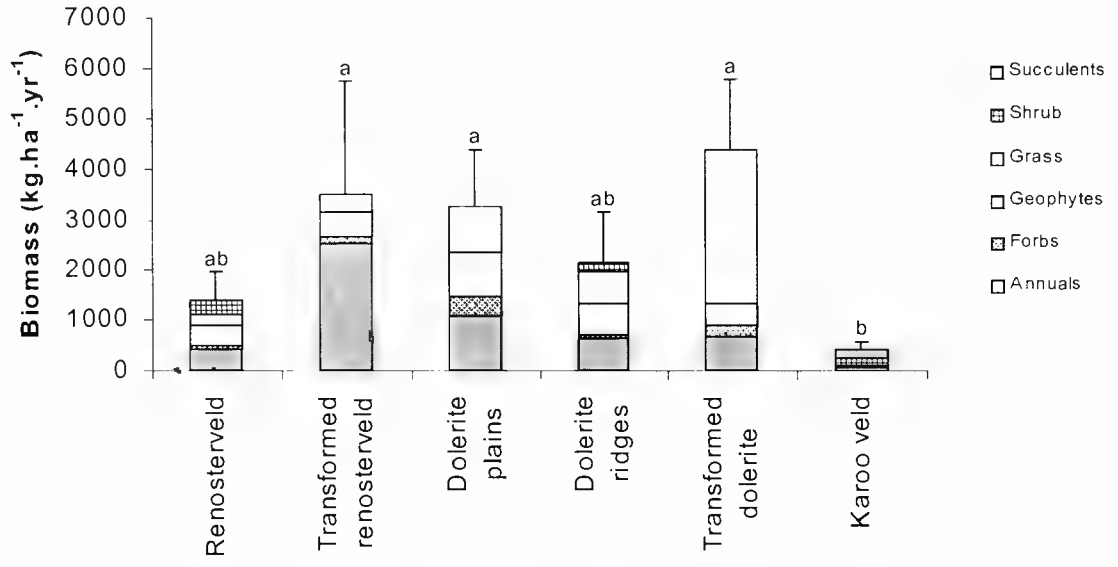

Figure 4.4 Mean new growth accumulation and standard deviations for all exclosures, according to the different vegetation types over the period of a single year ($H = 24.6$, $p < 0.001$, $n = 36$). Superscript denotes significant differences at the $p < 0.001$ level.

An analysis of standing crop revealed that the karoo veld and the renosterveld have significantly more biomass than the other vegetation types included in the study (Fig. 4.5). The shrubs in the case of renosterveld and shrubs and succulents in the case of the karoo veld form the bulk of the biomass in these vegetation types.

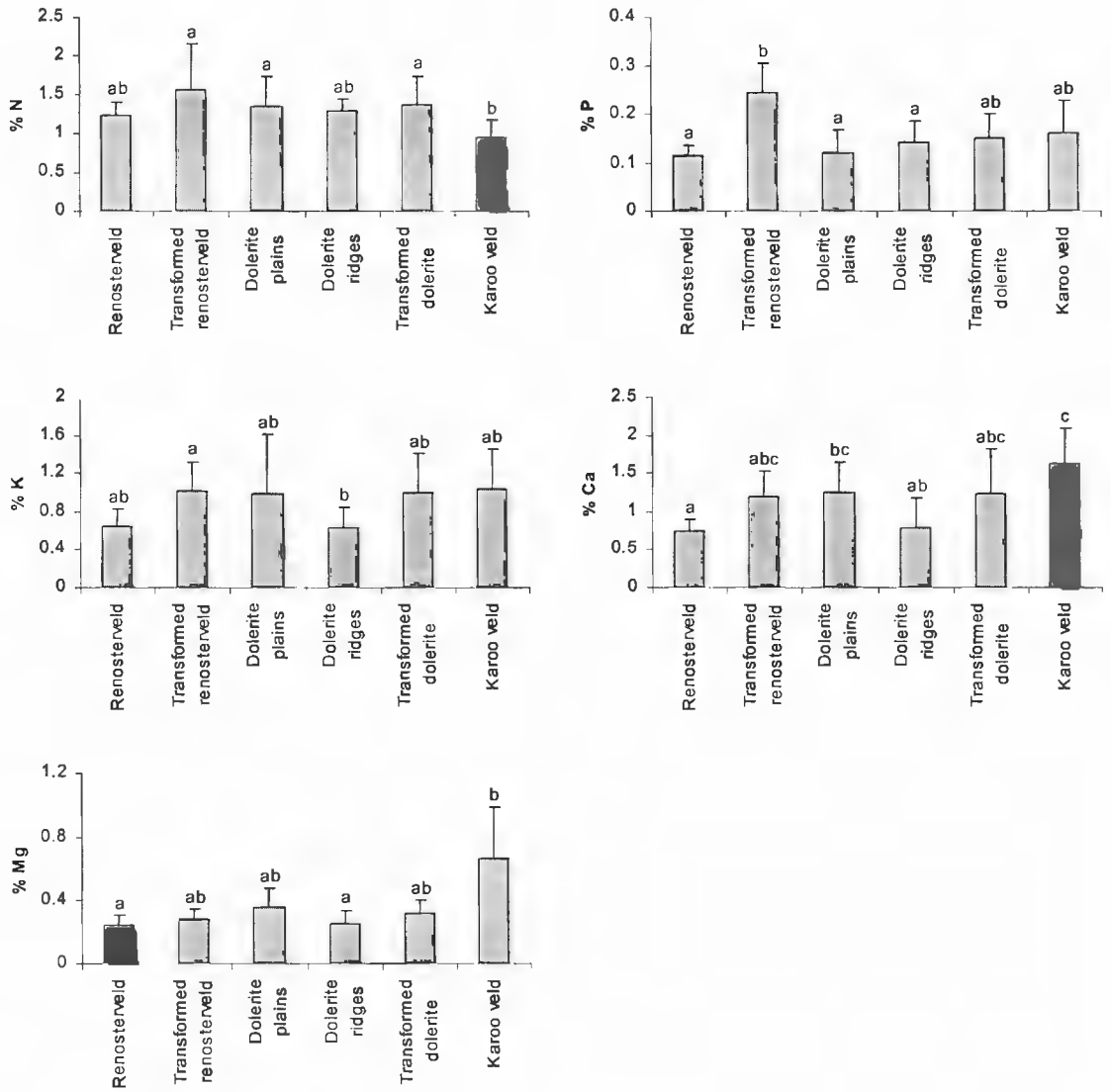

Figure 4.6 Mineral content of leaf samples for six vegetation types expressed as a percentage of dry mass (± SD), for the elements N, P, K, Ca, and Mg. Superscript denotes significant differences at the $p < 0.05$ level, $n = 72$.

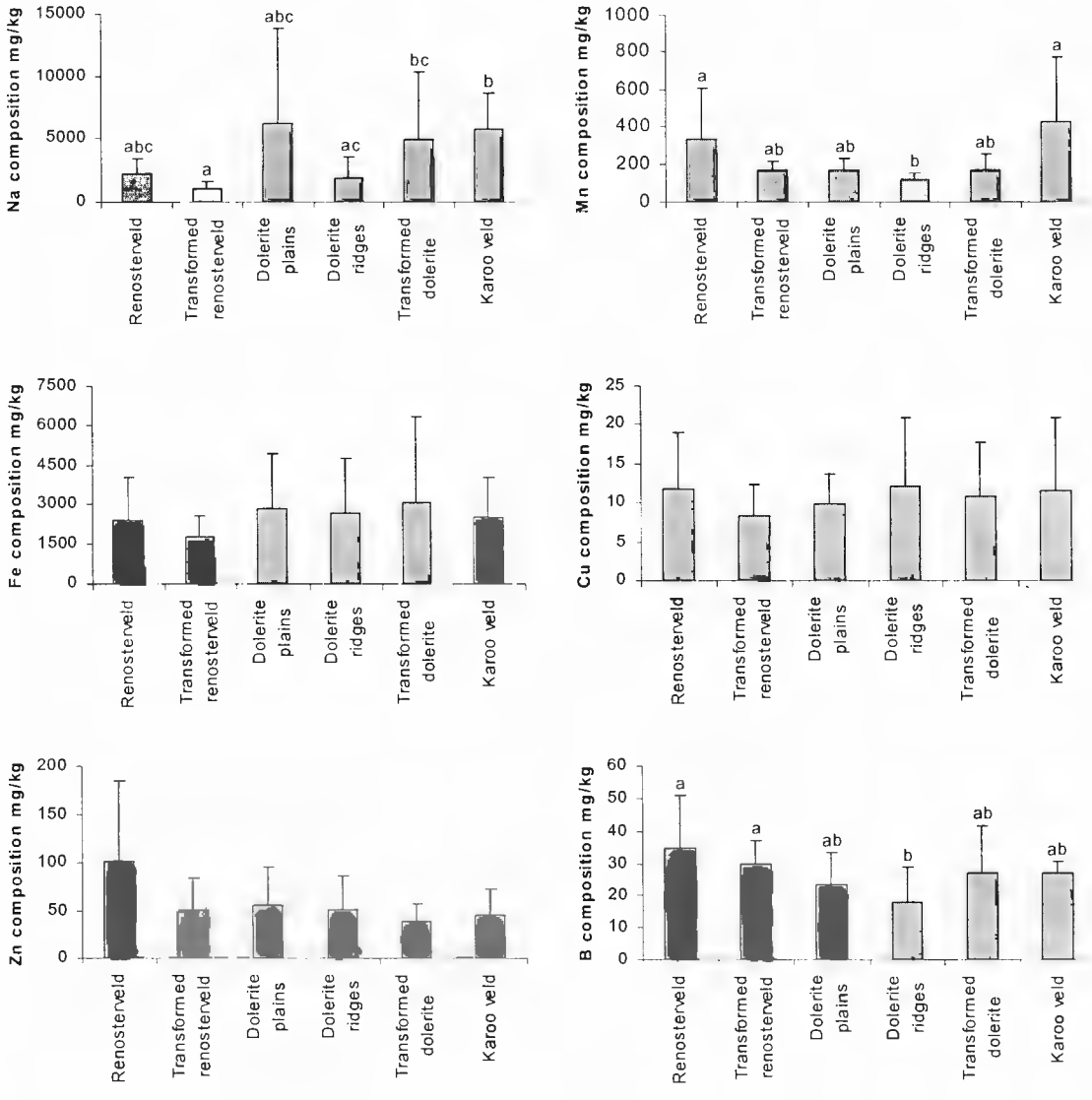

Figure 4.7 Mineral content of leaf samples for six vegetation types expressed in mg/kg of dry mass (± SD), for the elements Na, Mn, Fe, Cu, Zn, and B. Superscript denoted significant differences at the $p < 0.01$ level, $n = 72$.

4.3.5 Phenology

The number of species that accounted for 80% of the vegetation cover varied for each vegetation type. The phenology of a total of 61 species was recorded (Appendix 2). There were overlaps in dominant species across vegetation types. The number of species for which phenology was recorded in each vegetation type was: renosterveld 25, renosterveld transformed 9, dolerite plains 9, dolerite ridges 29, dolerite transformed 6, and karoo veld 14. Phenology results showed that leaf growth and shoot growth track rainfall in all vegetation types (Fig. 4.8). Both leaf growth and shoot growth occurred predominantly between April and September. The transformed renosterveld was the most sensitive to

rainfall, with shoot growth responding strongly to a drop in rainfall in June and recovering slowly thereafter. Leaf loss was less consistent when comparing vegetation types (Fig. 4.8). The dominant species on the dolerite plains and transformed dolerite lost leaves in November. The majority of flowering in 2001 took place in July, August and September (Fig. 4.9). Very little flowering took place before April and after October for all vegetation types. The renosterveld and karoo veld flowered earliest with a number of species flowering in April and May. The transformed dolerite had the shortest flowering period with all flowering restricted to July, August and September. Fruiting and seed set closely tracked flowering patterns and peaked a month after flowering in all vegetation types (Fig. 4.9).

As with the dominant species, the phenology of 10 poisonous species associated with specific vegetation types exhibited similar temporal responses (Fig. 4.10) (Appendix 2). Leaf growth of the poisonous species generally occurred before the majority of the dominant species in May, June and July. Similarly leaf loss occurred slightly earlier than the dominant species between September and November.

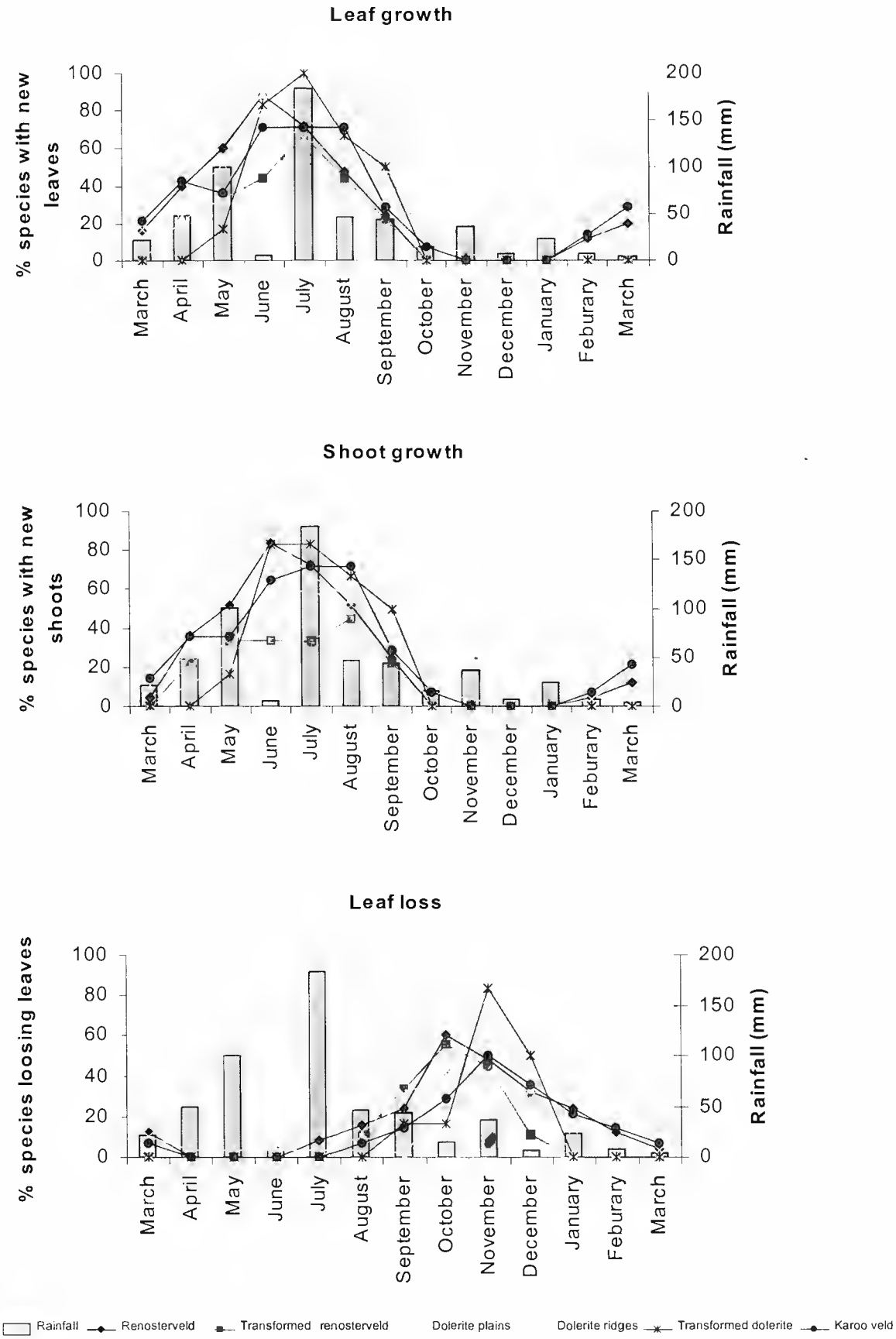

Figure 4.8 The percentage of species with leaf growth, shoot growth and leaf loss according to vegetation type and rainfall, for the period March 2001–March 2002.

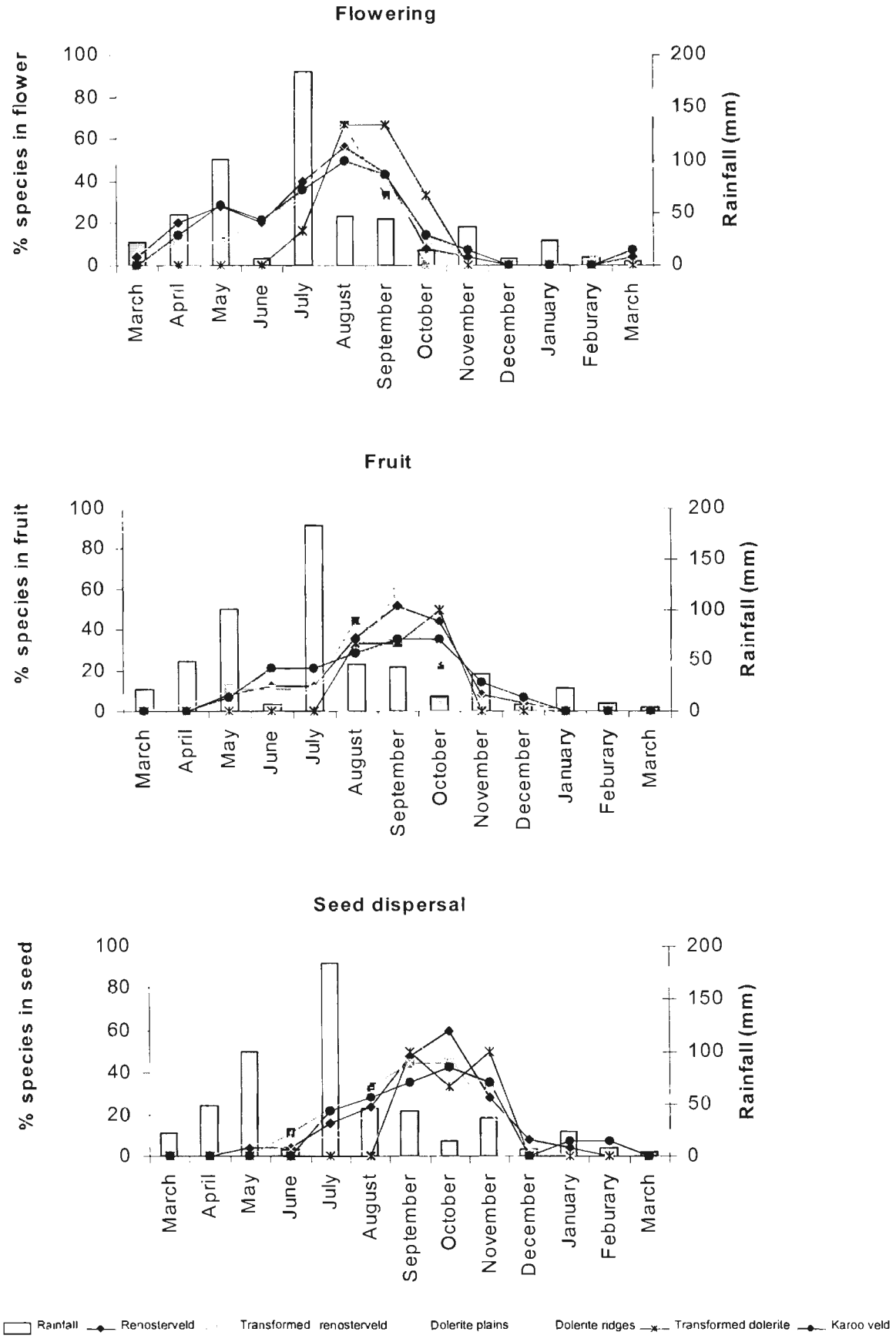

Figure 4.9 The percentage of species flowering, in fruit, and dispersing seed according to vegetation type and rainfall, for the period March 2001–March 2002.

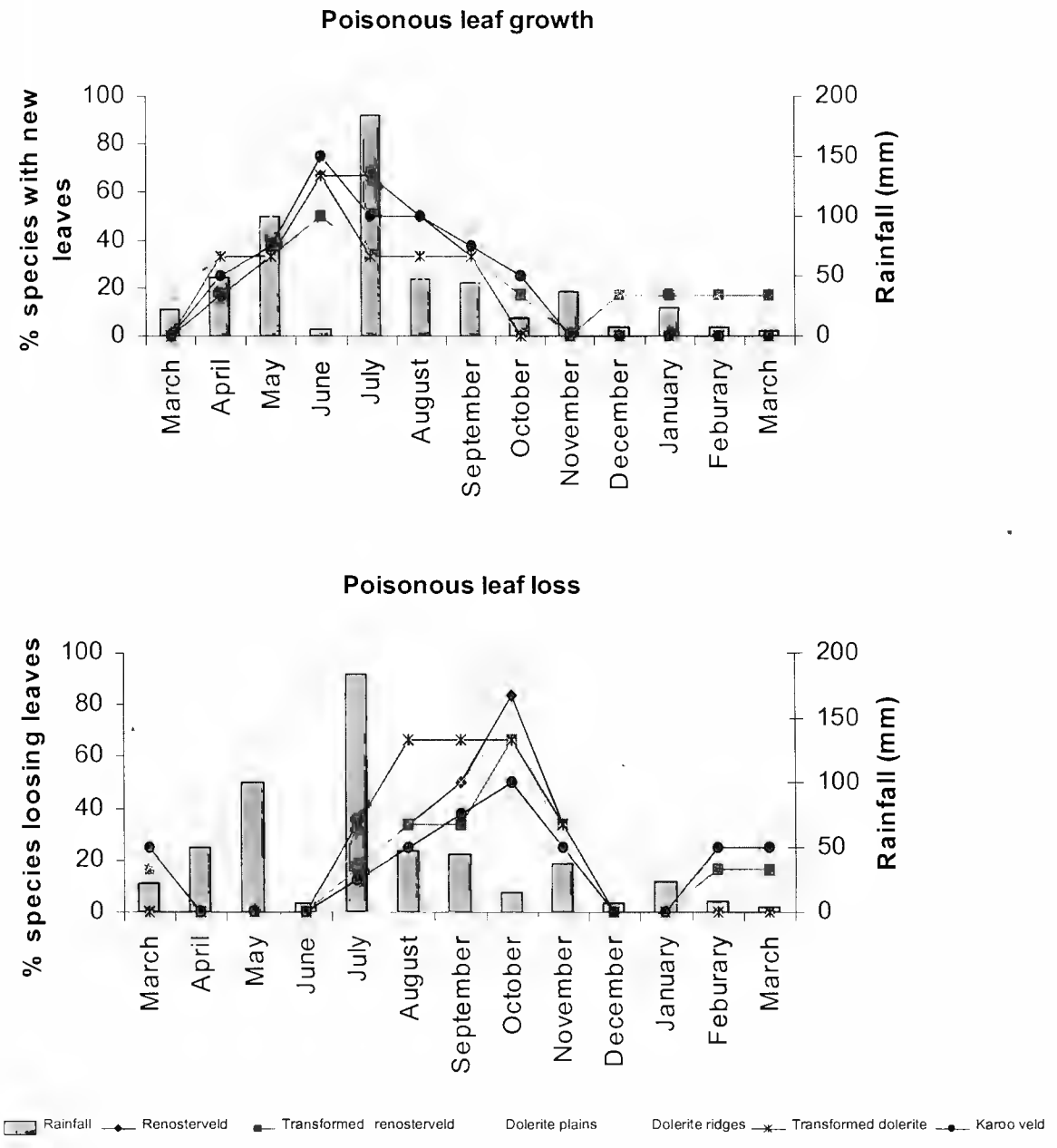

Figure 4.10 The percentage of poisonous plant species with leaf growth and leaf loss according to vegetation type and rainfall, for the period March 2001–March 2002.

4.4 Discussion

4.4.1 Landscape utilisation strategies

It was hypothesised that differences in the ecosystem goods and services associated with different vegetation types, either temporally or spatially, provide a basis for livestock management and grazing strategies on the Bokkeveld plateau. The majority of farmers in the study area have adopted a grazing strategy which involves moving livestock between

different vegetation types. This appears to mimic historical patterns of transhumance in which livestock were moved between summer and winter rainfall areas. The Bokkeveld plateau farmers are, however, restricted within the winter rainfall area, and they move between what they perceive to be summer grazing on the renosterveld and dolerite vegetation types, and winter grazing in the karoo veld. They have also drawn on conventional grazing system theory which evolved from the results of large integrated trials in more homogenous areas of South Africa. Three dominant grazing systems are non-selective grazing, short duration grazing and the group camp system, all of which involve the movement of stock between paddocks over varying time periods (Hoffman 1988). This study set out to determine whether farmers have adopted this livestock management strategy simply to increase their overall forage reserve, or whether they are deriving additional benefits from the diversity at a landscape level.

4.4.2 Vegetation structure and composition, productivity and biomass, and nutritive value

Farmers see vegetation primarily as potential grazing, with vegetation composition, biomass and productivity having implications for carrying capacity and animal production. Farmers correctly perceived the differences in vegetation types with these varying according to structural form, composition, biomass and productivity. These differences are largely interlinked. Vegetation structural differences are reflected in biomass with the renosterveld and karoo veld having greater standing biomass with large shrub and succulent components. The transformed renosterveld and dolerite, and the dolerite plains, dominated by fast growing grasses, annuals and geophytes had the highest productivity in contrast to the shrubs and succulents in the karoo veld, which had significantly lower productivity than these vegetation types. Farmers generally have a higher proportion of karoo veld than other vegetation types possibly to accommodate for this difference in productivity and given the limited area of the other vegetation types. Furthermore, the rainfall gradient of the Bokkeveld plateau, which decreases from west to east, also influences productivity. Karoo veld is the most easterly vegetation type and has the lowest productivity of all vegetation types studied.

Mineral elements are essential for the higher forms of animal life, comprising structural components of organs, tissues, fluids and acting as the catalysts in enzymes and hormone systems (Underwood 1981). The mineral composition of plants in turn depend on the

different vegetation types. This appears to mimic historical patterns of transhumance in which livestock were moved between summer and winter rainfall areas. The Bokkeveld plateau farmers are, however, restricted within the winter rainfall area, and they move between what they perceive to be summer grazing on the renosterveld and dolerite vegetation types, and winter grazing in the karoo veld. They have also drawn on conventional grazing system theory which evolved from the results of large integrated trials in more homogenous areas of South Africa. Three dominant grazing systems are non-selective grazing, short duration grazing and the group camp system, all of which involve the movement of stock between paddocks over varying time periods (Hoffman 1988). This study set out to determine whether farmers have adopted this livestock management strategy simply to increase their overall forage reserve, or whether they are deriving additional benefits from the diversity at a landscape level.

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Mineral elements are essential for the higher forms of animal life, comprising structural components of organs, tissues, fluids and acting as the catalysts in enzymes and hormone systems (Underwood 1981). The mineral composition of plants in turn depend on the

species and maturity of a plant, the type of soil it is growing in, and the climatic and seasonal conditions (Underwood 1981).

The leaf content analysis results indicate that farmers' perceptions of a nutritional diversity between vegetation types was correct. There are clear differences in the mineral content of the different vegetation types. The results indicate that transformed renosterveld and karoo veld are the most important vegetation types in the supply of these essential mineral elements. There are clearly potential nutritional benefits from owning a diversity of vegetation types, as each contributes to different aspects of required animal nutrition.

Phosphorus is often regarded as the key mineral element in the nutritional physiology of livestock. Every physiological event involving gain or loss of energy and energy exchange in cells includes the making or breaking of phosphate bonds (Underwood 1981). The higher phosphorus content of vegetation grown on transformed lands, compared with renosterveld, dolerite plains and dolerite ridges, is possibly attributable to the historical use of fertilisers. Phosphorus levels are important as deficiencies result in declining reproductive rates for livestock (Grant *et al.* 2001). All farmers keep their stock on the transformed renosterveld during the summer months when ewes are pregnant, taking advantage of these higher phosphorus levels. Potassium which is vital in maintaining nerve and muscle excitability and in water and acid-base balance of the body (Underwood 1981), were also found to be higher in this vegetation type compared with the dolerite ridges.

Transformed renosterveld, dolerite plains, and transformed dolerite had significantly higher nitrogen levels than the karoo veld vegetation type. This is possibly due to the number and volume of legume species found in these vegetation types. Transformed dolerite and transformed renosterveld are occasionally sown with *Medicago sp.* to increase their grazing value (see chapter 2). These areas are utilised later in the summer when there is very little vegetation cover, and the supply of medicago seed pods on the ground provides a high protein source for sheep at this time when little else is growing.

The karoo veld, despite having the greatest biomass, is possibly the least palatable and lowest in protein, as indicated by the leaf nitrogen content. The best time to utilise this veld would be during the wet winter season, whilst vegetation is green. Vegetation loses much of its nutritive value with age (Underwood 1981). However, this vegetation appears

particularly important in that it has significantly higher levels of Ca and Mg, compared to renosterveld and dolerite ridges, Mn compared to dolerite ridges and Na compared to transformed renosterveld. These elements are important for the development of teeth and bones, the metabolism of carbohydrates, reproductive development and maintaining osmotic pressure and metabolism in tissues (Underwood 1981).

4.4.3 Matching farmers' utilisation patterns with vegetation temporal patterns

The seasonal variation in the phenology of different vegetation types, which farmers perceive as important, was not substantiated by the phenology study. The phenology data indicates that the different vegetation types have similar phenological responses to environmental drivers. Rainfall and moisture availability are the major factors influencing plant phenology in a region. A further confounding factor is that vegetation types share species and functional types, such as geophytes and annuals which flower in spring.

Struck (1994) notes that short and copious blooming is a characteristic feature of many arid and semi-arid areas. Van Rooyen *et al.* (1979) working in Namaqualand, South Africa, found that in this winter rainfall area, plant growth begins in autumn and flowering occurs from late winter to spring. Fox *et al.* (in press), also working in Namaqualand used the Normalised Difference Vegetation Index (NDVI) to analyse vegetation patterns and found that the regions' distinctly different vegetation types generally responded at the same time and that rainfall was the driving factor. My findings concur with these results, as all vegetation types in this study track rainfall through the year. The impact of below average rainfall for the month of June is notable in both the flowering and leaf growth phenophases, demonstrating the importance of rainfall as a key driver of ecosystem function in the area. Arguments put forward by Behnke and Scoones (1993) in favour of herd mobility in order to minimise fluctuations in vegetation productivity, do not apply to the Bokkeveld plateau given that the available grazing resources are mostly subjected to the same rainfall periodicity, and the perceived heterogeneity is constrained by this seasonality.

Leaf growth and leaf loss of poisonous plants are the phenophases of the most interest to farmers as these determine when an area can and cannot be grazed. Farmers stated that temporal patterns of specific species impose certain constraints on them. The flowering of certain poisonous geophytes, for example *Ornithogalum conicum*, during spring and early

summer, limits the use of an area and the movement of sheep at certain times. Livestock have to be kept away from the areas where it occurs until this plant has dried out. My study, however, indicated that all vegetation types have poisonous plants following the same phenological pattern. It appears that farmers make decisions based on a hierarchy of toxic species, and where toxic species are most prolific. Management relating to toxic plants largely involves avoidance and eradication, with little consideration to maniputating vegetation composition.

Ecosystem resilience and the continued productivity and persistence of vegetation in grazed areas is a fundamental service which the farmers in the study area identified. If resilience declines then ecosystem services can also be expected to decline (Myers 1996). Various studies, using small controlled species mixes, have shown that a decline in the number of plant species leads to a corresponding decline in the productivity and stability of ecosystems (Naeem *et al.* 1994; Tilman 1996; Tilman *et al.* 1997). The loss of plant species and functional groups of plants, may impair ecosystem processes (Tilman *et al.* 1997), and reduce the ability of ecosystems to withstand and recover from extreme events; an important component of ecosystem resilience (Lawton 1994). The most sound grazing strategy in terms of resilience should ensure that the least amount of grazing within a vegetation type takes place during the flowering and seed-set phenophases. Milton (1994) working in the Prince Albert area, South Africa, demonstrated that grazing affects the abundance of new seedlings of preferred forage plants. Todd (1999) working in Namaqualand, South Africa, demonstrated that stocking rates have an impact on seed production of palatable plant species. Therefore, to maintain grazing resources careful utilisation choices need to be made. The bulk of species recorded across vegetation types flower between June and October. As the removal of flowers means less regeneration and in turn degradation of the vegetation, a fine-tuned rotation strategy during the flowering phenophase is necessary to allow for effective regeneration.

Despite farmers' recognition of the need to retain the services of regeneration and resilience, farmers repeatedly keep livestock in the karoo veld during the flowering phenophase period. This vegetation is likely to be more severely impacted in the long term by this management strategy, resulting in reduced regeneration potential and ultimately degraded vegetation. Grazing the other vegetation types at this time would have the same effect on resilience. However, dolerite soils have a high clay content and are very adhesive when wet, rendering this vegetation type inaccessible during the winter months as sheep

can get trapped in the clay soils and die. Renosterveld could be utilised but with the increase in eco-tourism, renosterveld is possibly best left ungrazed during the flower season to maximise the flower displays and tourism benefits.

4.4.4 Additional factors determining utilisation strategies

Heterogeneity valued

Heterogeneous landscapes typically have different vegetation types, ecological zones and habitats, varying ecological diversity and differing levels of agricultural productivity. Areas which are naturally more productive than others may arise along a drainage line or riparian area where an increase in soil moisture may result in more productive vegetation, or a specific favourable species composition (Illius & O'Connor 2000). Human activities have also created variability in the landscape. The creation of lands, roads, diverse farming practices and the planting of different crops, all generate a diversity of habitats (Ghersa & Leon 1999). The effect of landscape diversity on the provision of ecosystem services is largely unknown. Swift *et al.* (2004) hypothesise that ecosystems services at the landscape scale are optimised by a diversity of land-uses, but the number that are required for optimisation are relatively small. Here I hypothesise that a diversity of vegetation types allows for a closer to optimal grazing strategy. Swift *et al.* (2004) also state that the nature of the plant community influences the ecosystem service provided here.

Although farms on the Bokkeveld plateau have been divided and portions sold, farmers have consciously chosen to retain a diversity of vegetation types over the consolidation of farms within vegetation types, which would be more economical in terms of transport costs. Farmers recognise and value the heterogeneity of their landscape. They recognise areas of high productivity and consciously choose to hold a diversity of vegetation types. The results of this study support this perception. Farmers have determined for themselves that a variety of vegetation types can result in better nutrition for livestock and the analysis of leaf nutrition lends support for this conclusion. Holding combinations of vegetation types clearly does expose livestock to different concentrations of essential nutrients, which in this area, no single vegetation can provide.

Risk avoidance

Farmer preference for risk avoidance continues to shape the landscape and drive management decisions. Arid and semi-arid areas are generally considered marginal

environments for agriculture. As a result farmers are exposed to a certain degree of risk which is determined by the options and choices available to them. Management opportunities increase as diversity in physical structure of a landscape increases (Swift *et al.* 2004). Typically, risk is minimised by spreading or diversifying your management and production options.

Farmers in the Nieuwoudtville area have a range of management options and activities that they can engage in but are constrained by their access to different vegetation and soil types. Farmers with access to only a few vegetation types are constrained in their choices and ability to adapt to climatic and economic conditions increasing their risk exposure Swift *et al.* (2004) state that a farmer's risks depend on farm level diversity rather than plot level diversity. A variety of vegetation types also allows for minimising risk with regards to grazing. A diversity of grazing resources with their differences in composition, structure and functional groups may respond differently under different environmental management conditions. The single farmer in the study who does not have access to karoo veld is forced to graze livestock on transformed renosterveld which has a poor vegetation cover in the summer months and is highly dependant on rainfall given that this vegetation composition is dominated by annuals, as discussed below.

Agricultural approaches in the past, typically those which promoted the green revolution, encouraged the homogeneity of the landscape, of farmers' goals, practice and behaviour (Swift *et al.* 2004). Swift *et al.* (2004) stated that under monocultures farmers had to have access to risk buffering mechanisms such as insurance and agricultural subsidies, whilst other farming systems such as integrated livestock-arable systems typically maintained a diversity of functional groups above a mono cropping level. This ensured greater functional stability and wider spread of risk associated with more diverse products. On the Bokkeveld plateau different areas can be used all year round, both for grazing and pursuing other activities simultaneously, thus maximising the use of ecosystem services. Farmers wishing to produce both mutton and wheat, require access to transformed renosterveld or dolerite soils and winter grazing for their livestock. These farmers are not as impacted by the price fluctuations of their products as a farmer who produces only mutton or wheat. Flower tours, grazing and crop production can be carried out at the same time, on the same vegetation type, but not within a single paddock. Little *et al.* (2001) who examined processes of livelihood diversification and risk management strategies amongst east African herders also found that herders who become sedentary tend to diversify

income sources to reduce risk, cultivating crops and seeking employment. Valdivia *et al.* (1996) working in semi-arid regions in the Andes, also found that the diversification of sources of income amongst households was the main risk management strategy. Swift *et al.* (2004) take this point further, arguing that the success in maintaining biodiversity and ecosystem services outside of reserves lies in promoting diversity of land-use at the landscape and farm level rather than at the field scale, and that this requires an economic and policy-climate that favours a diversity of land-uses.

The transformation of vegetation also carries risks for the farmer. Transformation of vegetation and continued disturbances tend to favour annual species, which are readily able to colonise open spaces (Todd & Hoffman 1999). In this study, annual species were found to dominate, in terms of both biomass and productivity in the transformed renosterveld. Annual species are highly dependent on rainfall. Where farmers have large areas of transformed vegetation, and rely on these for grazing, their production system becomes closely coupled with annual rainfall. Given the variable nature of rainfall between years, and climate change predictions for the area, which suggest a reduction in rainfall in the western regions of South Africa (Midgley *et al.* 2001), these farmers are potentially at greater risk to environmental variability in the future.

Social and historical factors

The legacy of transhumance grazing patterns persists in how farmers use the variable vegetation types on the Bokkeveld plateau today. There is an entrenched belief in the value and utilisation period of different vegetation types. There is also a certain amount of pressure on farmers to continue using the landscape in this manner. One farmer interviewed stated that he would like to shift this paradigm of only grazing the karoo veld in winter, and he intended to graze this vegetation type in the following summer. Kaur *et al.* (2004) state that values related to cultural heritage and past practices play a critical role in landscape arrangements. Other studies have also noted the importance of social issues in grazing strategies and the movement of livestock. Baker and Hoffman (in press) investigating herding strategies in communal rangelands in Namaqualand, South Africa, could detect no livestock production advantages of having a mobile grazing strategy over that of a sedentary grazing strategy. They found that non-environmental factors, such as the individual herders' personal social and economic situation, governed their grazing strategy. On the Bokkeveld plateau, non-environmental factors and a historically

entrenched belief in the value of moving livestock may also be contributing to decisions made regarding livestock management practices here.

4.5 Conclusion

The current grazing and land-use strategies on the Bokkeveld plateau are a modified transhumance grazing strategy. Livestock are moved between different vegetation types on the plateau but these movements are restricted to the winter rainfall region. Farmers describe vegetation types as being either summer or winter grazing. Farmers' perceptions were found to be correct in that there are important spatial differences in goods and services between vegetation types relating to, structure, productivity, biomass, and nutritional content. The expected ecosystem goods and service differences in vegetation type phenology realised in farmers' movement patterns, could not be explained in terms of temporal differences in growth and reproduction of these different vegetation types. Grazing strategies do appear to assist farmers in securing different ecosystem services at different times of the year. Farmers keep their stock on transformed renosterveld during the summer months when ewes are pregnant, taking advantage of the high phosphorous and nitrogen levels in this vegetation type. Farmers also avoid dolerite soils with a high clay content in winter to avoid stock losses due to bogging. The current grazing strategy, which always grazes the karoo veld vegetation type during the flowering phenophase is likely to affect the regeneration and resilience of this vegetation type in the long term. These are both important ecosystem goods and services identified by the farmers. Farmers see the value in retaining a diversity of vegetation types. Landscape diversity and the management options that flow from this heterogeneity reduce risk by presenting farmers with a variety of opportunities. Management and utilisation strategies have evolved to maximise the benefits that farmers can derive from, as well as incorporate the constraints imposed by, the diversity of vegetation types within this area. Social factors, pressure to conform, and a legacy of this transhumance mindset are further factors that have entrenched this livestock management strategy.

Chapter 5

Small mammal diversity and density: implications for livestock predation

5.1 Introduction

Farmers in the study area spend up to 5% of their income on controlling livestock predators (chapter 3). A number of farmers interviewed believe that stock losses are linked to the amount and variety of alternative prey sources available on farms. They argued that, amongst other benefits, small mammals provide an alternative food source for predators that typically prey on sheep. Farmers recognise the ecological processes involved in the predator-prey relationship, and see the diversion of predators away from sheep due to an abundance of prey species as an ecosystem service.

Earlier studies have indicated that small mammals form an important component of predators' diets. For example, Avenant and Nel (2002) found that caracal (*Felis caracal)* are generalist feeders, and utilise a wide range of species, concentrating on the most abundant species which they found to be rodents. An examination of predator-prey relationships was beyond the scope of this study. However, it is possible to examine the availability of prey and to test the assumption that prey availability is influenced by land-use and landscape heterogeneity.

Other studies have suggested that habitat complexity has an important influence on the species diversity of mammals (August 1983). Schweiger *et al.* (2000), working in Kansas, compared the density and distribution of four small mammal species across two succession phases of old lands. Their results emphasised the role that landscape structure plays in small mammal communities, with different species responding in different ways to succession. Joubert *et al.* (1999) compared two rangelands in Namaqualand, South Africa, with contrasting land tenure systems and found that rangelands used for commercial agriculture supported a larger and more diverse assemblage of small mammals compared with rangelands managed communally, and that diversity depended on a minimum level of cover. Eccard *et al.* (2000) compared grazed with ungrazed commercial rangelands in the Karoo, South Africa, and found that both species number and abundance were higher in ungrazed areas.

The main objective of this study was to assess the distribution and abundance of small mammals in relation to different vegetation types and different land-uses. I determined the diversity and density of small mammals on four structurally distinct vegetation types in the study area in an attempt to understand how prey abundance may be influenced by landscape structure, habitat structure and management decisions.

5.2 Methods

5.2.1 Study site

The study was conducted across four habitat types in the study area, namely renosterveld; transformed renosterveld, which had not been cultivated for at least 10 years and was used for grazing, natural dolerite plains, and dolerite ridges (Fig. 5.1). For a description of the vegetation types see chapter 2, and for a breakdown of vegetation structure see chapter 4. These four habitat types were selected because they are both the most valuable from a conservation prespective and because they are most heavily impacted by agricultural practices that involve transformation of the natural vegetation.

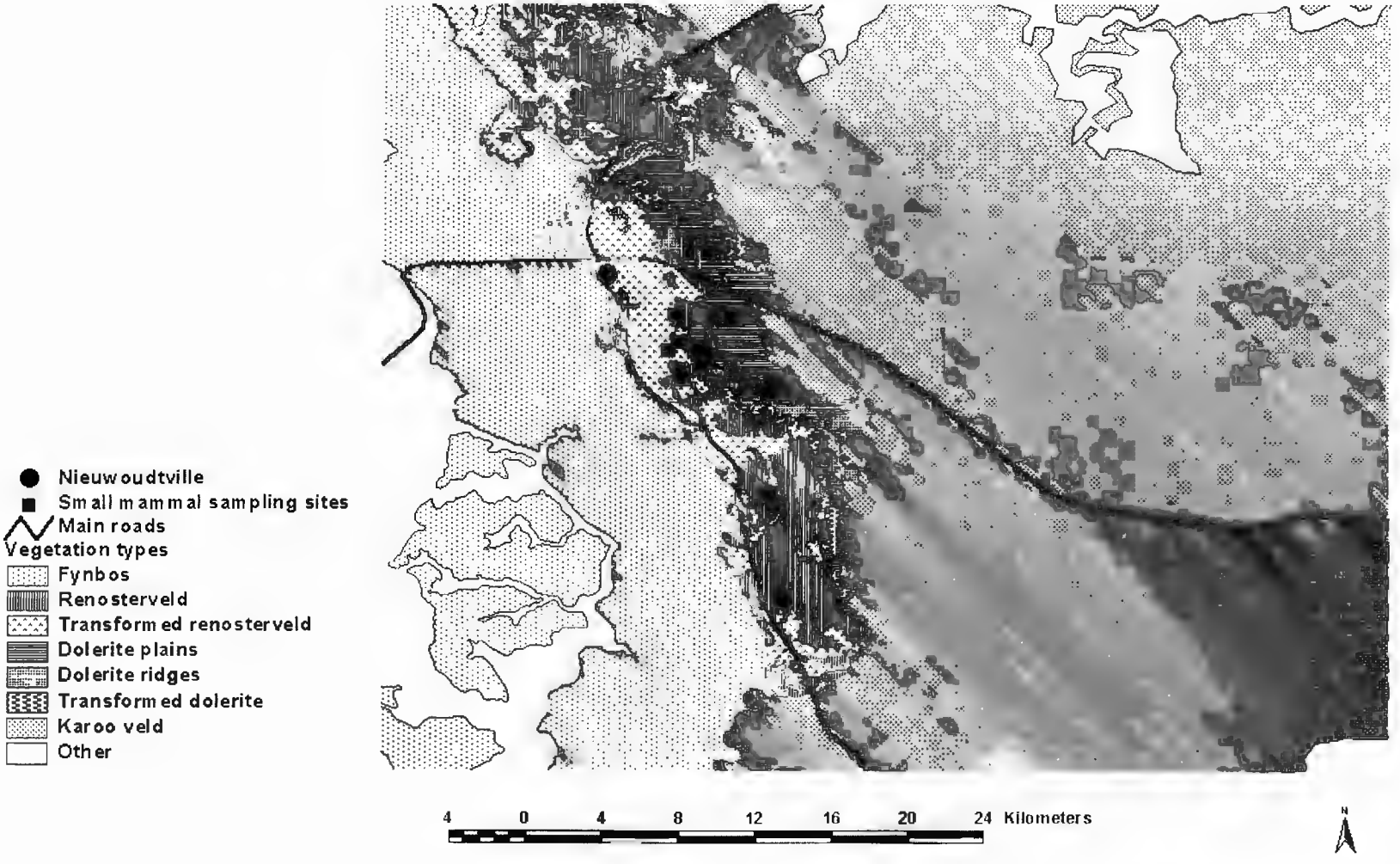

Figure 5.1 Map of the study area on the Bokkeveld plateau near Nieuwoudtville showing the four habitat types where the 20 rodent sampling sites were located.

5.2.2 Sampling methods and data analysis

The study area incorporated six farms where two surveys (one in the winter month of June 2002, and the other in the summer month of November 2002), were carried out. Sherman traps were used to catch small mammals. For each three-day period, a trapping grid of five by six traps, totalling 30 traps, were laid out at 10 m intervals in each of these four different habitat types. A total of 20 sites were investigated over a period of 15 nights. Trapping took place during the last and first quarter of the moon. During the winter trapping session, traps were left open both day and night, for 12 hours at a time. In the summer session, only night trapping took place as day-time temperatures were high and animals were at risk of overheating in the traps once caught. The total trapping effort was 3600 trap nights. The term trap night describes one trap set for a 24-hour period (Rowe-Rowe & Meester 1982). Traps were baited with a mixture of peanut butter, rolled oats, and 'marmite', a yeast based savoury spread. Trapped individuals were identified to species level, marked with a non-toxic white marking fluid and released.

All data was analysed using Statistica (StatSoft 2003). Kruskal Wallis Anova and Mann-Whitney U tests were used to compare the differences in individual and species numbers across the habitat types. A Sign test for non-parametric data where two measures or variable are involved, was used to compare differences in individual numbers caught between summer and winter (Zar 1996).

5.3 Results

A total of 219 individuals, representing 10 species, were recorded during this survey of 3600 trap nights, which gave a total trap success rate of 6.1% (small mammals captured per 100 trap nights). Of the 10 species caught, three were shrews and seven were rodents (Table 5.1). The vast majority of individuals were captured in the dolerite ridges, and consisted predominantly of one species, the Namaqua rock mouse (*Aethomys namaquensis*).

Unique species were recorded in all vegetation types (Table 5.1). The dolerite ridges had the greatest diversity of species. Significantly more species were recorded in the dolerite ridges compared to dolerite plains ($U = 3$, $n = 10$, $p < 0.05$). Comparisons between the number of species recorded in the renosterveld and in adjacent transformed renosterveld showed renosterveld to have significantly more species ($U = 4$, $n = 10$, $p < 0.05$). Species

composition was distinct, with three species (*Gerbillurus paeba, Macroscelides proboscedeus and Rhabdomys pumilio*) recorded in renosterveld and only one species, *Desmodillus auricularis* recorded in transformed renosterveld. Three species are listed in the IUCN Red Data List of Threatened Species as Vulnerable. These three species are the Cape Rock Elephant-shrew (*Elephantulus edwardii*), the Round-eared Elephant-shrew (*M. proboscideus*), and the White-tailed Mouse (*Mystromys albicaudatus*) recorded in the ridges, the renosterveld and on the natural dolerite, respectively.

Table 5.1 Species trapped in each habitat type and number of individuals caught for both summer and winter (recaptures excluded). Vegetation types included here are, R – renosterveld, TR – transformed renosterveld, DP – dolerite plains, and DR – dolerite ridges. * Indicates that the species is an IUCN Red Data List species.

Species	Common Name (Stuart & Stuart 1997)	R	TR	DP	DR	Total # Individuals
Macroscelides proboscideus*	Round-eared Elephant-shrew	2	-	-	-	2
Elephantulus edwardii*	Cape Rock Elephant-shrew	-	-	-	1	1
Crocidura cyanea	Reddish-grey Musk Shrew	-	-	-	5	5
Mystromys albicaudatus*	White-tailed Mouse	-	-	2	-	2
Steatomys krebsii	Krebs's Fat Mouse	-	-	6	2	8
Desmodillus auricularis	Short-tailed Gerbil	-	2	-	-	2
Gerbillurus paeba	Hairy-footed Gerbil	4	-	-	2	6
Tatera afra	Cape Gerbil	-	-	4	-	4
Aethomys namaquensis	Namaqua Rock Mouse	-	-	-	165	165
Rhabdomys pumilio	Striped Mouse	17	-	3	4	24
Number of individuals captured by habitat type		23	2	15	179	219
Number of species captured by habitat type		3	1	4	6	14
Number of species unique to habitat type		1	1	2	3	7

Seasonal effects were evident, with significantly more individuals caught during the night trapping in winter than in summer across all sites ($Z = 2.1$, $n = 20$, $p < 0.05$). In winter significantly more species were caught in the dolerite ridges than on transformed renosterveld and dolerite plains ($H = 14.5$, $n = 20$, $p < 0.01$), compared with summer trapping events where the dolerite ridges were found to be significantly different to transformed renosterveld ($H = 13.7$, $n = 20$, $p < 0.01$). During the winter day-trapping session no significant differences were recorded in the number of individuals and species caught for the different vegetation types ($H = 2.8$, $n = 20$, $p = ns$).

The density (#.ha^{-1}) and biomass (g.ha^{-1}) of small mammals in the four habitat types are shown in Table 5.2. Mean weights according to species were derived from Skinner and Smithers (1990). These differed significantly for the different habitat types. The dolerite ridges had significantly greater biomass ($H = 25.5$, $n = 40$, $p < 0.001$) and density ($H = 26.2$, $n = 40$, $p < 0.001$).

Table 5.2 Small mammal density (number.ha^{-1}) and biomass (g.ha^{-1}) in four habitat types in winter and summer.

	Winter		**Summer**
Density (#.ha^{-1})	**Day**	**Night**	**Night**
Renosterveld	11	8	4
Transformed renosterveld	0	2	0
Dolerite plains	3	11	2
Dolerite ridges	4	90	85
Mean density	4.5	27.8	22.8
Biomass (g.ha^{-1})			
Renosterveld	528	274	130.4
Transformed renosterveld	0	104.6	0
Dolerite plains	185.1	629.3	24
Dolerite ridges	176	4364.5	3916.2
Mean biomass	222.4	1343.1	1017.7

5.4 Discussion

Livestock predation is considered a major issue in South Africa. Through interviews with farmers, Lawson (1989) found predators to have a significant negative effect on the sheep industry. On the Bokkeveld plateau stock losses due to medium-size predators such as caracal and jackal, were also identified by farmers as one of the main problems in the region. The control of medium-size predators is one of the main costs incurred by stock farmers. A number of farmers stated that stock losses are linked to the amount and variety of alternative prey sources available on farms. They argued that alternative natural prey sources supply an ecosystem service. Meriggi and Lovari (1996) put forward similar conclusions in their examination of dietary preferences of European wolves (*Canis lupus*) in Europe. They found that the simultaneous re-introduction of natural prey species was likely to reduce wolf predation on livestock.

Caro (2001) noted that agricultural practices need not be devastating on small mammal communities, as they found greater diversity and abundance in agricultural areas compared with adjacent reserves. Like Kerley (1992) and Bond *et al.* (1980), this study found that small mammal species richness and abundance are strongly correlated with vegetation and landscape structure and complexity, and negatively correlated with land transformation. The most structurally complex habitat in this study was the dolerite ridges, with a diverse vegetation structure and topographical heterogeneity. This habitat type had the greatest small mammal diversity, density and biomass, compared with the other habitat types. The structural diversity of this habitat provides suitable nest sites, shelter, and refugia for a number of small mammal species. The renosterveld has a low structural diversity as it is dominated by a single shrub species, *Dicerothamnus rhinocerotis*. Renosterveld fragments, however, typically placed within a matrix of transformed areas, increases the structural diversity at a landscape level. Yahner (1983), who found that species richness of small mammals is associated with the size of a shelterbelt, recommended management practices that do not reduce the stratification of vegetation and called for the establishment of shelterbelts as large as possible.

Small mammal density and diversity are adversely affected by management decisions, in particular vegetation transformation. These findings are in keeping with numerous other studies which have also demonstrated the relationship between rodent abundance and micro-habitat features such as vegetation structure and cover (Taitt & Krebs 1983; Maccracken *et al.* 1985; Peles & Barrett 1996; Monadjem & Perrin 1998). Transformation can result in the removal of all vegetation cover, resulting in higher risk of predation and lower food availability. Small mammals appear restricted to natural vegetation fragments and limited capture in transformed habitats is attributable to the preference of *Desmodillus auricularis* for open areas and hard ground for burrowing. Although not captured, personal observations within transformed renosterveld revealed that the Cape Gerbil, *Tatera afra,* also make extensive use of these transformed lands. Both individuals and colony burrows were observed. Despite having a very low vegetation structure, the soil surface of the dolerite plains has large cracks in the summer, which increases the structural diversity of habitat type. This was expected to increase abundance and diversity during summer. Small mammals were observed to shelter in these cracks, taking advantage of this structural phenomenon, but only in very low numbers.

Small mammals constitute the first link in the food chain for many carnivores and raptors (Avenant 1997). They are a natural alternative prey source to livestock for predators such as jackal (*Canis mesomelas*) and caracal (*Felis caracal*). Rodents have been found to be the most abundant component in caracal scat, with diet correlating to rodent density and biomass suggesting they rely heavily on rodents as prey throughout the year (Avenant & Nel 1997). Caracal spend most of their time foraging in areas where rodents were most plentiful (Avenant & Nel 1998). These studies were conducted in Strandveld vegetation. Of the four rodent species most frequently caught by caracal as recorded by Avenant and Nel (1997), two (*Rhabdomys pumilio* and *Gerbilluris paeba*) were among the most frequently recorded in this study in renosterveld.

Comparisons with other studies shows the density of rodents within the study area to be low, with mean densities recorded by Avenant and Nel (1998) on average six times higher than densities recorded in this study. These differences are possibly due to slight differences in vegetation structure and habitat variables in the study areas. Although speculative, it is argued that small mammals at the densities recorded in this study are still capable of supporting predators. Predator weights are between 6–8 kg for jackal, and 10–16 kg for caracal (Skinner & Smithers 1990). Grobler (1981) found that adult caracal consume on average 1 kg of meat per day. This is dependent on age, activity levels, ambient temperatures, sex, and the reproductive status of individual animals. At the lowest mean biomass levels of 1 kg per ha, and assuming a predation rate of 5%, then approximately 7300 ha are required to support a predator for a year. The ridges which have a small mammal biomass of 4.5 kg per ha, and are approximately 800 ha in extent, are sufficient to support a predator for a year given these conditions. Additional factors such as small mammal reproductive rates, predation rates for both small mammals and other prey species such as birds and reptiles, need to be factored into this equation. Furthermore, Avenant and Nel (1997) found that rodent species were not all consumed in equal numbers with some species being favoured over others.

The highest number of small mammals was recorded at night during the winter months, at the time lambing takes place, when an alternative food source for predators would be most beneficial to farmers. The potential for this service is linked to the structural heterogeneity. The dolerite ridges appear to be the best area for the provision of this service, and cautious management of this area is vital in ensuring structural components are maintained. There are potential links between the preservation of natural vegetation

and the provision of ecosystems services. Management practices which incorporate natural vegetation patches, and preserve structural diversity of both vegetation types and the broader landscape are more likely to benefit from this reported service. Further research into predation, possibly radio tracking predators and analysing predator scat, would strengthen the argument for conservation initiatives.

5.5 Conclusion

Farmers are aware of the ecological process that involve predator-prey relationships. They perceive an ecosystem service when the abundance of prey species is sufficient to sustain medium-size predators, so that predation on livestock is avoided. Density of rodents in the study area was lower than found in similar studies undertaken elsewhere. Despite this it is argued that they are sufficient to support the medium-size predators found in the study area. Vegetation transformation was found to have a negative impact on small mammal density and diversity. The most structurally diverse vegetation type, the dolerite ridges, had the highest density and diversity of small mammals. This area is possibly less sensitive to management impacts as its physical structure ensures that it cannot easily be transformed, however careful management here is vital for the provision of this service. Land-use practices which include the retention of natural vegetation fragments and maintain landscape heterogeneity are more likely to benefit from this ecosystem service. Continued habitat destruction and fragmentation threaten vulnerable species with local extinction. My findings point to the need for the conservation of these small mammal populations from both a conservation perspective and to maintain this valuable ecosystem service which they provide.

Chapter 6

Vegetation transformation and the effect on soil erosion processes

6.1 Introduction

Soil erosion is the removal of soil material which includes soil particles, nutrients and organic matter, at rates in excess of soil formation and is primarily attributed to human activities (Evans 1980; Visser *et al.* 2004). The loss of topsoil through erosion is described as one of the world's greatest environmental and agricultural problems (Skidmore 1994). It is believed that as much as 75 billion metric tonnes is lost across the globe every year, with an associated cost of US$400 billion (Myers 1993b; Pimentel *et al.* 1995). This removal of topsoil typically exposes bedrock and promotes the formation of gullies, but also affects areas down valley or down wind, where sediments are deposited, blanketing areas with silt and sand, clogging reservoirs and canals with sediments (Morgan 1986).

Processes and conditions of natural ecosystems that are responsible for the retention of soil and the prevention of soil erosion are a major ecosystem service in agricultural areas. In South Africa, soil erosion has been regarded as a major ecological and economic impact and combating this has been vigorously pursued with both legislation and management action. The Soil Erosion Advisory Council was established in 1930 and provided subsidies to farmers engaged in anti-erosion projects. The Soil Conservation Act of 1946 provided the legislative framework for enforcing soil conservation on farms (Donaldson 2002). The ecosystem services which are responsible for soil retention, enhancing rainfall infiltration, and reducing wind speeds, are of major importance in South African agricultural landscapes.

Renosterveld is a small-leaved, grassy shrubland of the Cape Floristic Region (Low & Rebelo 1996). This vegetation type is dominated by the shrubs *Dicerothamnus rhinocerotis, Eriocephalus purpureus*, and the grass *Merxmuellera stricta*. The understory has a rich diversity of geophytes (Cowling 1990). The shale-derived tillite soil on which this diverse vegetation type grows is highly suitable for cereal cultivation (Hoffman 1997). As a result, this vegetation type has become highly fragmented due to transformation for cultivation. On the west and south west coast over 80% of the land area originally covered by renosterveld has been transformed (Mcdowell 1988; Kemper *et al.* 2000). Only 5% of

this vegetation type has been formally conserved, with the remainder being held by private landowners. Renosterveld is regarded as a conservation priority given its plant species diversity, the limited area of natural vegetation remaining, and the fact that what little remains is highly fragmented and under further threat of transformation. Kemper *et al.* (1999), demonstrated that small fragments, despite being disturbed by grazing, trampling, crop spraying and frequent fires, retained a similar community structure to large fragments, and that all renosterveld fragments should be considered conservation-worthy. Conservation planning and the provision of formal reserves are difficult in highly fragmented landscapes. If important ecosystem services and benefits, derived from the retention and wise management of the remaining renosterveld fragments, can be demonstrated at a farm scale, then this would act as an additional motivation for their conservation (Edwards & Abivardi 1998; Kemper *et al.* 1999). However, if the same ecosystem services are derived from transformed areas then using these services to promote conservation becomes less relevant.

In Australia, natural vegetation fragments supply important ecosystem services by providing soil stability and by maintaining hydrological processes (Hobbs 1992). Natural vegetation fragments, in particular renosterveld was identified by farmers of the Bokkeveld plateau as providing soil stability and acting as a windbreak. They, however, described rainfall infiltration in renosterveld vegetation as poor compared with transformed renosterveld areas that had been sown with an annual *Medicago sp*, and managed to enhance the growth of this annual through the application of fertiliser.

The aim of this study was to contrast the soil retention and water infiltration potential of natural renosterveld fragments with transformed renosterveld. It was hypothesised that renosterveld remnants are better at holding soil, are areas of higher rainfall infiltration, and reduce wind speeds. If correct this would demonstrate some of the value of conserving renosterveld fragments at the farm-scale in order to maintain these services. Farmers with more natural renosterveld fragments, and those with strategically located fragments were expected to benefit more from this ecosystem service than farmers who had small fragments of renosterveld.

I examined both the erosion and hydrological processes in renosterveld fragments and in transformed renosterveld. I carried out rainfall simulations on either side of a natural renosterveld/transformed renosterveld boundary, examining infiltration rates, run-off

volumes and sediment loads. I also investigated differences in wind speeds and aeolian sediment loads in renosterveld, and transformed renosterveld.

6.2 Methodology

This study was carried out on five farms and the municipal reserve in the study area. Natural renosterveld fragments and transformed renosterveld areas were investigated. Transformed renosterveld was defined as croplands that have been abandoned for more than 10 years (see chapter 2). For the purposes of this study these were further subdivided into two land-use classes: transformed renosterveld that received no management inputs and transformed renosterveld that is actively managed as a medicago pasture. Management activities primarily consist of the initial sowing of pasture, and the application of a fertiliser, double superphosphate (P_2O_5), which is applied every second year as a top dressing in March and April before the first winter rains. This requires a substantial investment of between R100 and R300 per ha (Donaldson 2002). Transformed lands are hereafter referred to as transformed renosterveld, and managed transformed renosterveld. The transformed renosterveld was dominated by the annuals *Rhynchopsidium pumilum* and *Cotula naudicaulis*, and soil surfaces have a hard capped appearance. Managed transformed renosterveld was typically dominated by *Medicago sp.*, and the alien grasses *Avena fatua* and *Bromus pectinatus.* Soil surfaces here were not capped and there was extensive evidence of soil invertebrate activity.

6.2.1 Rainfall simulation

A rainfall simulator was used to simulate rainfall events in September and October 2002, in renosterveld, transformed renosterveld and managed transformed renosterveld (Fig 6.1). A rainfall simulator was selected based on the findings of Boers *et al.* (1992) who compared infiltration and erosion rates using an infiltrometer, a rainfall simulator and a permeameter. They concluded that rainfall simulators are the most suitable method for research on soil erosion and infiltration as conditions are close to those under natural conditions and results are realistic. Ten pairs of sites were selected along a renosterveld and managed transformed renosterveld interface, and seven pairs of sites were selected along a renosterveld and transformed renosterveld interface along a fence line. Fence line contrasts were used so as to minimise the environmental variables, such as slope, which was controlled for using an abney level.

Figure 6.1 Single nozzle rainfall simulator used to simulate winter rainfall in September and October 2002 pictured here in managed transformed renosterveld.

The simulator was set to generate rainfall of 1 mm every minute, within an area of 1 m^2. A UniJet spray-nozzle tip of 1.3 mm, and a drop height of 2 m were used to simulate winter rainfall conditions that occur between May and October. This was considered appropriate given the intensity of recorded rainfall events in the study area, and the need to generate a large enough rainfall event to ensure run-off. The simulation continued for 30 minutes once run-off had been achieved, with time to run-off recorded. A water run-off sample from the outlet point of the plot was taken every two minutes for ten seconds over a 30 minute period. Water volumes were measured and the samples were oven-dried at 80 °C, and the remaining sediment weighed. Vegetation cover was estimated from above as a percentage of the total 1 m^2 area. Three soil depth measurements and a 10 cm soil core sample were taken at each site. Soil samples were analysed for total soil carbon, total nitrogen, and soil texture. Total carbon was determined using the Walkley-Black method and total nitrogen was determined by digestion in a LECO FP-528 nitrogen analyser (Nelson & Sommers 1982) (BemLab, Somerset-West). Soil texture was analysed using the Bouyoucos particle size method (Bouyoucos 1962).

Paired sites of renosterveld and transformed renosterveld, and renosterveld and managed transformed renosterveld were compared using a paired Wilcoxon signed rank test. The relationship amongst the biophysical variables and infiltration measurements was

established using a Pearson Correlation matrix containing all measured variables for all sites.

6.2.2 Wind erosion

Hand-held anemometers were used to measure relative wind speeds in renosterveld and adjacent, transformed renosterveld and managed transformed renosterveld. Wind speeds were recorded at 20 cm above the ground. A total of 320 readings were taken over a three-day period in November 2002, in the three vegetation types.

Suspension sediment bottles were erected to catch wind blown or suspended material from all four major wind directions (Fig. 6.2). These were largely based on the Modified Wilson and Cook sampler (Wilson & Cooke 1980). These were set up at 110 sites, and divided between the renosterveld (55 sites), transformed renosterveld (28 sites), and managed transformed renosterveld (26 sites). At each site two traps were fixed to a metal stake in the ground. One trap was positioned at 10 cm above ground level and the other at 80 cm above ground level. Traps were set up at the start of the summer in early November 2002 and emptied in March 2003 and the sediment weighed.

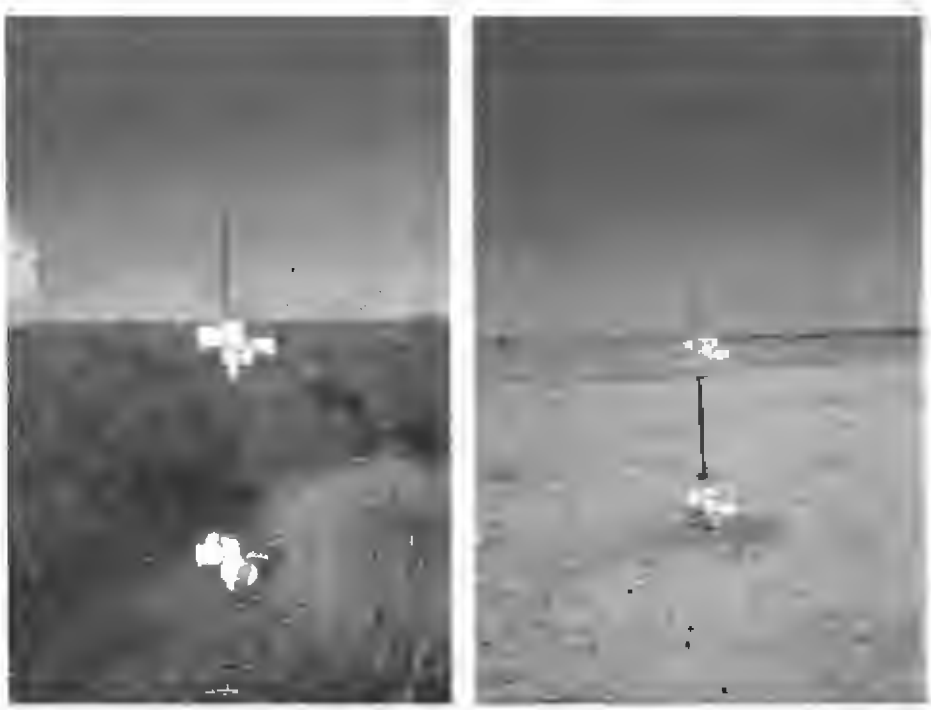

Figure 6.2 Sediment traps to capture wind suspended sediments at 10 cm and 80 cm above ground level in renosterveld (left) and on transformed renosterveld (right), between October 2002 and March 2003.

Recorded wind velocities and sediment volume differences for each vegetation type were compared using Kruskal-Wallis ANOVA and a post-hoc test was performed using a multiple comparison of mean ranks for all groups.

6.3 Results

6.3.1 Rainfall simulation

The rainfall simulation experiment demonstrated that rain water infiltrated faster in the soil of renosterveld compared with transformed renosterveld (Table 6.1). Furthermore, water infiltrated the soil for a longer time period before run-off was achieved compared with the transformed renosterveld. The vegetation cover was also found to be significantly greater in renosterveld. No significant differences in the volume of soil sediments collected, or any of the other soil properties measured between these vegetation types was found.

Table 6.1 The mean (±SE) values of infiltration and erosion measurements, on remnant renosterveld and in transformed renosterveld. Significant differences tested using a Wilcoxon paired test, Z values and significance levels are given.

	Renosterveld	Transformed renosterveld	Z	p (n = 14)
Time before run-off (min)	22.7 ±5.2	9.5 ±2.4	2.37	0.05
Infiltration rate (mm/hr)	40.9 ±5.9	27.0 ±2.9	2.37	0.05
Sediment collected (g)	626.3 ±391.2	697.1 ±557.6	0.34	NS
Soil depth (cm)	13.0 ±1.0	12.0 ±1.8	0.68	NS
Vegetation cover (%)	50.0 ±6.2	27.0 ±2.9	2.37	0.05
Soil nitrogen (%)	0.06 ±0.01	0.06 ±0.01	1.01	NS
Soil carbon (%)	0.8 ±0.1	0.7 ±0.04	1.26	NS
Clay (%)	9.8 ±1.4	8.4 ±1.1	1.86	NS
Silt (%)	15.7 ±1.4	16.8 ±2.0	0.31	NS
Fine sand (%)	47.0 ±1.6	48.2 ±1.3	1.18	NS
Medium sand (%)	13.2 ±0.9	13.3 ±0.9	0.17	NS
Course sand (%)	14.3 ±1.6	13.2 ±2.1	0.00	NS

In contrast, when comparing renosterveld and managed transformed renosterveld, the latter was found to perform better than the renosterveld. The amount of time passed before run-off was achieved and the rainfall infiltration rates were found to be significantly higher on the managed transformed renosterveld compared with renosterveld (Table 6.2). Both soil nitrogen and soil carbon were found to be significantly higher on the managed

transformed renosterveld. The percentage clay content of soil samples was significantly higher in the renosterveld than the managed transformed renosterveld. The reverse was true for the medium sand percentage, which was significantly higher in managed transformed renosterveld.

Table 6.2 The mean (±SE) values of infiltration and erosion measurements, on remnant renosterveld and in managed transformed renosterveld. Significant differences tested using a Wilcoxon paired test, Z values and significance levels are given.

	Renosterveld	Managed transformed renosterveld	Z	p (n = 18)
Time before run-off (min)	16.5 ±2.8	64.6 ±11.2	2.66	0.01
Infiltration rate (mm/hr)	36.0 ±2.6	85.0 ±10.2	2.66	0.01
Sediment collected (g)	1173.8 ±481.6	1072.0 ±565.2	1.24	NS
Soil depth (cm)	13.1 ±1.0	19.1 ±0.6	0.95	NS
Vegetation cover (%)	53.2 ±3.3	61 ±5.1	1.18	NS
Soil nitrogen (%)	0.06 ±0.01	0.12 ±0.01	2.55	0.05
Soil carbon (%)	0.9 ±0.12	1.4 ±0.12	2.31	0.05
Clay (%)	9.1 ±0.6	7.0 ±1.0	2.31	0.5
Silt (%)	17.0 ±1.0	15.7 ±0.8	1.26	NS
Fine sand (%)	42.9 ±1.8	45.5 ±1.3	1.42	NS
Medium sand (%)	12.8 ±0.5	15.5 ±0.7	2.67	0.01
Course sand (%)	18.2 ±2.0	16.2 ±1.7	1.48	NS

The Spearman Rank Correlation showed that time before run-off and infiltration rate were strongly positively correlated with each other, vegetation cover, soil nitrogen, soil carbon, and percentage medium sand content, but were negatively correlated with percentage clay content (Table 6.3). Soil sediment loads collected from run-off samples showed that the volume of sediment was negatively correlated with percentage medium sand content. Vegetation cover was positively correlated with soil nitrogen and carbon. Soil nitrogen was positively correlated with soil carbon and soil depth. Percentage clay content was negatively correlated with fine and medium sand. Both silt and fine sand were strongly negatively correlated with course sand.

Table 6.3 Spearman Rank correlation matrix for all variables investigated for all sites. Significant correlations are indicated as *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.

	Time to runoff (min)											
Infiltration rate (mm/h)	0.97**	Infiltration rate (mm/h)										
Soil sediment (g/ml)	0.45**	0.38*	Soil sediment (g/ml)									
Soil sediment (g)	0.04	-0.04	0.04*	Soil sediment (g)								
Mean Depth (cm)	0.17	0.17	0.2	0.03	Mean Depth (cm)							
Vegetation cover (%)	0.77***	0.77***	0.5**	0.07	0.19	Vegetation cover (%)						
Soil nitrogen (%)	0.59***	0.56***	0.22	0.13	0.37*	0.38*	Soil nitrogen (%)					
Soil carbon (%)	0.64***	0.62***	0.3	0.08	0.35	0.43*	0.87***	Soil carbon (%)				
Clay (%)	-0.56***	-0.57***	0.1	0.27	0.12	-0.29	-0.11	-0.3	Clay (%)			
Silt (%)	0.11	0.07	0.05	0.03	0.15	0.11	0.03	0.32	-0.08	Silt (%)		
Fine Sand (%)	0.05	0.1	-0.15	-0.27	-0.13	-0.04	-0.27	-0.2	-0.44*	-0.06	Fine Sand (%)	
Medium Sand (%)	0.44*	0.5**	-0.09	-0.38*	-0.14	0.21	0.06	0.5	-0.55**	-0.26	0.27	Medium Sand (%)
Course Sand (%)	0.04	0.03	0.1	0.27	0.01	0.08	0.28	0.13	0.08	-0.46**	-0.68***	-0.16

6.3.2 Wind erosion

Wind velocity

Localised wind speeds recorded with a hand-held anemometer at 20 cm above the ground showed renosterveld to have significantly lower wind speeds, because of its structure, when compared with both the transformed renosterveld and managed transformed renosterveld (Fig. 6.3).

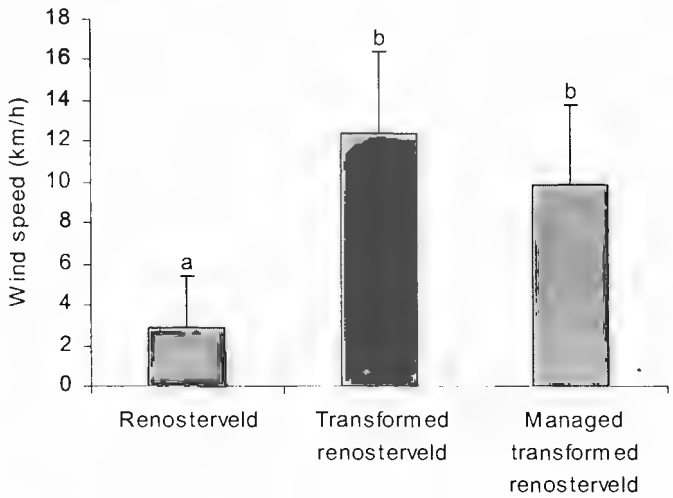

Figure 6.3 Mean wind speeds and standard deviations recorded in renosterveld, transformed renosterveld and managed transformed renosterveld, over three days in November 2002, ($H = 207.8$, $p < 0.01$, $n = 320$).

Wind-borne sediment

Suspension sediment bottles registered significant differences in the amount of wind-borne sediment in transformed renosterveld and managed transformed renosterveld when compared to renosterveld, with twelve times more sediment being captured in transformed renosterveld at 10 cm above ground level (Fig. 6.4). No differences were found in sediment loads captured at 80 cm above the ground.

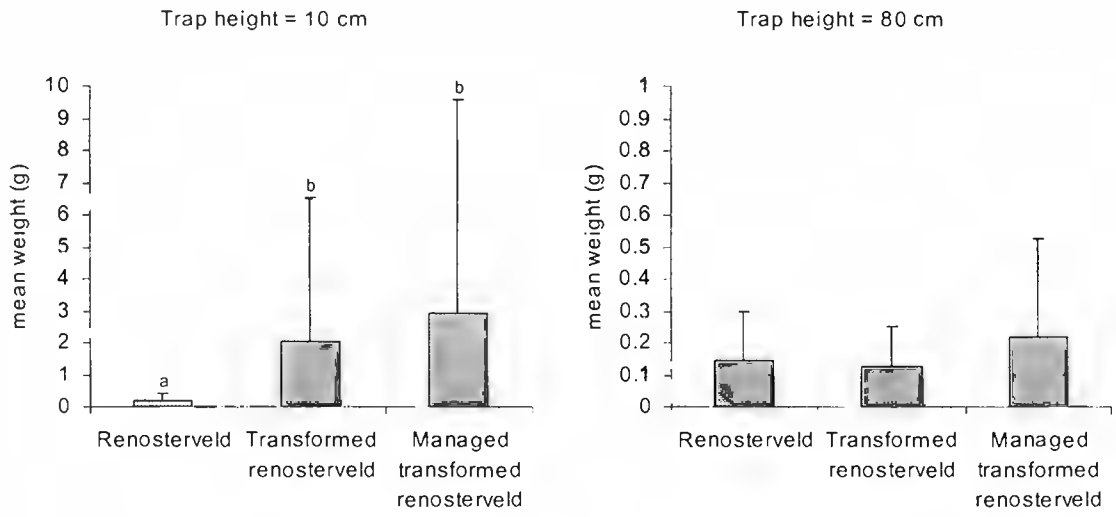

Figure 6.4 Mean sediment (± SD), trapped at 10 cm ($H = 43.4$, $p < 0.001$, $n = 110$), and 80 cm ($H = 1.7$, p = ns, $n = 110$) above ground level, for renosterveld, transformed renosterveld and managed transformed renosterveld. Superscript denotes significant differences at the $p < 0.01$ level.

6.4 Discussion

The transformation of renosterveld impacts significantly on hydrological processes on the Bokkeveld plateau. My study demonstrated that transformation of renosterveld typically decreased the rainfall infiltration potential, as reflected by the infiltration rate and time before run-off under transformed conditions. Increasing vegetation cover and soil fertility, however, can recapture this service by increasing infiltration rates above those measured in renosterveld. This experiment supported the majority view of the Bokkeveld plateau farmers, that managed transformed renosterveld had the best rainfall infiltration. In the managed transformed renosterveld farmers have increased vegetation cover by sowing annual medicago pasture and applying phosphate which stimulates root development and increases productivity. Vegetation has a major influence on soil infiltration and the relationship between plant cover and soil moisture is well established (Wilcox *et al.* 1988; Martinez-Fernandez *et al.* 1995; Woo *et al.* 1997; Casermeiro *et al.* 2004). Meeuwig (1969) also notes the importance of vegetative cover in maintaining soil stability and permeability, with plant cover and litter accounting for 73% of the variance in the amount of water retained by study plots during a 30 minute simulated rainfall test. Transformed renosterveld was found to be dominated by annual cover which is strongly influenced by seasonal rainfall, with low rainfall resulting in less cover than in high rainfall years. In the

year the rainfall simulations were carried out, above-average rainfall resulted in a proliferation of annuals and grasses, which facilitated infiltration during late spring when this experiment was conducted. These transformed renosterveld areas, however, are usually completely devoid of plant cover by the end of summer. If this experiment was to be carried out under drier conditions the differences in infiltration rates would have been greater.

The sediment load in run-off samples from the rainfall simulations were not significantly different between the vegetation types compared in this study. However, they would be expected to be significantly higher for the transformed renosterveld than the perennially dominated renosterveld at the outset of the wet season in April and May given that at this time the transformed renosterveld is completely devoid of vegetation cover. Water erosion happens when soil particles are detached from the soil mass and then transported (Morgan 1986). Rain splash is the most important detaching agent (Morgan 1986). Raindrops compact soil as they land and then disperse from the point of impact (Morgan 1986). The compaction of soil has the effect of forming a surface crust, just a few millimetres thick which clogs soil pores. Crusts therefore reduce infiltration capacity and promote greater surface run-off (Morgan 1986). Mills and Fey (2004) working at the same study site on the Bokkeveld plateau found that soil crusting was significantly greater on exposed soils compared with soils covered with vegetation. They attributed crusting to lower soluble salt and labile carbon content linked to increased clay dispersion. Morgan *et al.* (1997) demonstrated that soil loss decreased exponentially with increasing vegetation cover. They suggested that vegetation exerts an important hydrological control by increasing the infiltration capacity of the soil and the time to, and duration of, run-off. Similarly Cerda (1997), in his examination of *Stipa tenacissima* mosaics in south-east Spain, found higher surface run-off and erosion in bare patches and better infiltration in vegetated patches. Rainfall interception is cited as one of the main reasons for the enhanced infiltration and reduced run-off experienced in vegetated areas (Woo *et al.* 1997; Casermeiro *et al.* 2004). Transformed renosterveld, originally cleared for cereal production is free of obstacles such as boulders, rocks and organic matter, which would act to decelerate the flow of water. The soil of tilled lands is described as fragile and vulnerable to erosion (Martinez-Fernandez *et al.* 1995). Once soils have started to erode, other soil properties are affected. Rostagno (1989) found that eroded soils in Patagonia, Argentina were not able to store water as effectively as stable soils and produced greater run-off volumes. The Bokkeveld study site is on the cusp of the summer rainfall area and occasionally receives summer

thunderstorms. These rainfall events, which coincide with low annual vegetation cover, could result in significant erosion.

Soil texture also appeared to influence infiltration and erosion in this study, with infiltration rates being positively correlated with medium sand and negatively correlated with clay. Mills (2003) also found medium sand to be strongly correlated with infiltration rates in the laboratory. Takar *et al.* (1990) working in Somalia, also noted the effects of soil texture on erosion. Infiltration rate and interrill erosion on sand were found to be significantly higher than on clay, irrespective of cover and season. Soils with a high percentage of clay are considered coherent and form stable aggregates that are resistant to raindrop impact and splash erosion (Evans 1980). The soil textural analysis in this study indicated that clay percentages were not as high a described by Evans (1980) but appeared coherent and resistant to erosion. Soil texture differences were found when comparing the renosterveld with the managed transformed renosterveld, and these correlated with infiltration rates. The influence of soil invertebrates on rainfall infiltration rates has been demonstrated by Bouche and Al-Addan (1997). Given the overwhelming observational evidence of soil invertebrate activity in the managed transformed renosterveld this was further investigated to determine whether soil invertebrate activity, number and biomass differed between these vegetation types (see chapter 7).

In arid and semi-arid regions, wind erosion frequently exceeds water erosion due to the infrequency of rainfall events. Wind erosion is the principal source of atmospheric dust which is closely connected to major climate changes and is exacerbated by human induced land-use change (Gomes *et al.* 2003). Wind erosion is a selective process in which the finest soil particles, that contain a disproportionally high amount of plant nutrients are removed, degrading soil structure, reducing soil moisture and crop productivity (Gomes *et al.* 2003).

Wind erosion experiments, carried out during the late summer months, show transformed renosterveld and managed transformed renosterveld both to be more vulnerable to wind erosion than renosterveld. Live vegetation cover has long been recognised as protecting soil against wind erosion (Miller & Donahue 1990; Skidmore 1994). Of the vegetation types considered, renosterveld is the only perennial-dominated vegetation type that provides cover throughout the year. The main factor in wind erosion is the velocity of moving air (Morgan 1986). The analysis of wind speeds in renosterveld and transformed

renosterveld shows that renosterveld does act as a windbreak, providing a vital service to farmers in arresting wind erosion and holding soil during the dry summer months when soil surfaces are most susceptible to wind erosion, as well as providing shelter for livestock. Given that the mean height of renosterveld is 80 cm high (see chapter 4) this wind break service is likely to extend 20 to 30 m from a renosterveld strip. Boldes *et al.* (2002) demonstrated that windbreaks also serve to improve wheat crop yield and quality. The existing service provided by renosterveld could be enhanced through the establishment of *D. rhinocerotis* windbreaks adjacent to croplands, serving as a motivation for the retention or restoration of renosterveld patches in the area.

Soil erosion is a major threat to sustainable agriculture (Visser *et al.* 2004), influencing the characteristics and productivity of arid and semi-arid plant communities. Furthermore, crop production yields are also affected by erosion. Verity and Anderson (1990) demonstrated that grain yields are effected by erosion, with yields being lowest in areas experiencing the greatest amount of erosion, and that yields could be increased by adding topsoil. The maintenance of topsoil and hydrological processes are vital to farmers as they affect soil moisture and fertility influencing plant growth and forage production (Knight 1991), and affect ground water recharge. Natural renosterveld vegetation fragments provide these soil ecosystem services and should be incorporated into land-use management decisions.

6.5 Conclusion

Renosterveld supplies rainfall infiltration services, provides an effective windbreak, reduces wind speeds, and holds topsoil throughout the year. Transformation of renosterveld with no further intervention results in significantly less rainfall infiltration and significantly greater volumes of wind-borne sediment. Inputs into production may improve rainfall infiltration by increasing vegetation cover during the wet season. These inputs of seed and fertiliser are expensive and provide insight into the value of this service provided by the natural vegetation. Management practices to improve vegetation cover and productivity, however, do not prevent wind erosion. The transformation of renosterveld results in the loss of topsoil especially during the dry summer months when vegetation cover on both transformed renosterveld and managed transformed renosterveld is negligible. Farm management and planning should recognise the role that natural vegetation plays in the provision of these ecosystem services, retaining natural vegetation

fragments where applicable and encouraging the re-establishment of natural vegetation in areas where these services are most required.

Chapter 7

Vegetation transformation, functional compensation and soil health

7.1 Introduction

Living organisms in soils contribute to a range of ecosystem services, including clean water, food supply, substrate fertility, bioremediation of pollutants, and breakdown of organic matter (Wall *et al.* 1998). Soil health is considered an ecological characteristic determined more by soil organisms than by soil chemistry (Van Bruggen & Semenov 2000). Soil organisms are responsible for the decomposition of organic matter, nutrient cycling, bioturbation of the soil, the suppression of soil-borne disease and the slow release of nitrogen during decomposition (Wood 1991; Brussaard *et al.* 1997; Madong & Nkolbisson 1999; Davidson 2001). Ecosystem processes that promote soil fertility, stability, good water-infiltration capacity, as well as land-use practices that ensure the continued existence of these services are therefore important. Farmers in the study area perceive rainfall infiltration and healthy soil as dependent on a functional group of animals, comprised in particular, of porcupines and soil organisms, that are responsible for soil turnover and rainfall infiltration and for maintaining healthy soil through nutrient cycling processes (see chapter 3).

There is clear evidence that soil organism communities are significantly affected by human activities, in most cases resulting in their decline in abundance or disappearance (Baker 1998; Abawi & Widmer 2000). Following this, there should be an associated collapse or loss of the ecosystem services they provide, generally termed soil health. I hypothesised that similar results should be obtained when comparing renosterveld with transformed areas, with a decline in soil organism populations expected in the transformed areas. Furthermore, it was predicted that there may be possible edge effects of natural fragments extending into transformed areas, possibly due recolonisation activity taking place from the natual remnant into the transformed area, or with increased mortality of soil biota as distance from the natural habitat increased.

The findings of the previous chapter (chapter 6) indicate that despite a loss of above ground biodiversity through transformation, rainfall infiltration, an important component of soil health, in managed transformed renosterveld was significantly greater than in the

natural renosterveld fragments. However, Bragg *et al.* (2005), found that there were significantly more porcupine diggings and associated soil turnover in natural renosterveld compared with managed transformed renosterveld at the same study site. My observations indicated that in the managed transformed renosterveld, earthworms appeared to be driving infiltration and associated soil health processes, compared with the renosterveld where combinations of species such as porcupines, earthworms and other species, which appeared to have overlapping functional niches, were jointly maintaining soil health. I hypothesised that due to increase in population size, earthworms have functionally compensated for the reduced activity of other species under managed transformed conditions, and in doing so have ensured the delivery of important goods and services on managed transformed renosterveld. This seemingly functionally less significant species in renosterveld has become functionally significant in managed transformed renosterveld in terms of its contribution to soil health.

In this study I set out to examine the effects of vegetation transformation on soil health and explore the importance of functional compensation in maintaining and producing ecosystem goods and services associated with soil health. I examined the effect of vegetation transformation on the activity patterns of soil invertebrates using bait-lamina strips placed across a renosterveld and a managed transformed renosterveld interface. I investigated the influence of earthworm and porcupine activity on water infiltration rates, and determined if there were more earthworms and greater earthworm activity in the managed transformed renosterveld compared with renosterveld. To explain my findings, I also examined the soil properties, soil moisture and soil temperature in natural renosterveld and managed transformed renosterveld.

7.2 Study area

The study area was located on the farm Glenlyon, a 7000 ha property immediately south-east of the town of Nieuwoudtville. The study area is characterised by remnant patches of renosterveld located within a matrix of managed transformed renosterveld (see chapter 6 for a definition of these vegetation types). Lands for wheat production were created in the 1930s and 1940s. However, wheat production was terminated in 1961 as the farmer regarded this as an uneconomical activity due to the marginal nature of the area. The focus of this farm's production in the last forty years has been on producing Merino sheep for both the meat and wool markets. Medicago pastures were established on the managed transformed renosterveld in the late 1980s and early 1990s, and no further tillage has taken

place since then. These medicago pastures are top dressed with super-phosphate every second year between March and April.

7.3 Methods

7.3.1 Mesofaunal and microbiological activity

Soil activity was measured using the bait-lamina method as described by von Törne (1990). Bait-lamina measure the feeding activity of soil organisms, mesofauna (excluding earthworms) and micro-organisms (Kratz 1998; Larink & Sommer 2002). The bait-lamina strip holes were filled with a bait mixture that consisted of cellulose powder, agar-agar, and the milled and dried leaves from the dominant plant species, in a ratio of 6.5:1:2.5. Sets of 16 bait-lamina strips were placed in the ground, to a depth of 80 mm, at 50 sites along five transects. Transects were selected based on the researcher's view of what constituted typical vegetation types, ensuring that results could be extrapolated to the greater area. Sites were spaced out along transects at 10 m intervals progressing outwards from the renosterveld remnant and managed transformed renosterveld boundary for 50 m. Transects were 100 m apart. One of the transects became inundated by Kikuyu grass during the experiment, making it different to the other transformed areas, producing erratic results, justifying its exclusion from this analysis. Baits were left in the ground for 22 days between June and September 2002. Feeding activity was calculated by examining individual baits with a microscope and calculating the total number of baits that had been removed per lamina strip. This took place within 48 hours of baits being removed from the soil. Mann-Whitney U tests for non-parametric data were used to test for significant differences between the number of baits taken in renosterveld and managed transformed renosterveld. Regression analysis was used to examine the relationship between distance from the natural remnant-transformation boundary with number of baits taken to determine if feeding activity decreased with distance from the natural remnant. Wilcoxon paired tests were used to compare the depths at which baits were taken in the renosterveld and the managed transformed renosterveld.

7.3.2 Earthworm biomass and activity

Earthworm numbers and biomass were measured at a total of 36 sites divided evenly between renosterveld and managed transformed renosterveld in the month of October 2002. A soil pit of 0.125 m^3 was dug at each site and earthworms were hand sorted, counted and weighed. Soil turnover at these sites was measured by the volume of castings

or discrete egested pellets (Hendrix 2000). This was calculated by sweeping up casts from five, 50 cm^2 quadrats around each soil pit. The sweepings were then hand sorted to remove all stones and plant matter and then placed through a two-micron mesh sieve to remove all loose sand, whilst retaining earthworm castings. The calculated mean weights of castings per soil pit were then analysed against earthworm number and biomass.

One hundred randomly located 1 m^2 plots were used to measure soil turnover by earthworms during the wet winter months (May to September) when activity was greatest, with 50 plots located in renosterveld and 50 in managed transformed renosterveld. At the start of the winter 2002 all 100 sites were swept clear of earthworm casts. This process was repeated at the end of the growing season, when casts were collected, dried and weighed. Mann-Whitney U tests were used to assess the differences between sites in earthworm numbers, biomass, and casting activity.

7.3.3 Soil disturbance and infiltration

The effects of soil turnover and disturbance, by porcupines and earthworms, on water infiltration rates were assessed using a single-ring infiltrometer, of 75 mm diameter. A small diameter infiltrometer was necessary for assessing the direct influence of casting activity on infiltration rates, and a single ring was used as this was simple and quicker to use than a double-ringed infiltrometer. It was also felt to be sufficiently accurate for a comparative study. Variability between sites was also reduced by the use of an infiltrometer with a small diameter.

A total of 200 random infiltration measurements were obtained in both the managed transformed renosterveld and renosterveld. These were measured along four 50 m paired transects in renosterveld and managed transformed renosterveld, where infiltration was recorded every meter. The amount of time for 50 ml of water to infiltrate was recorded along with the observed presence or absence of earthworm casting activity within the area enclosed by the infiltrometer. Differences in infiltration rates where casting was present and casting absent were analysed using a Mann-Whitney U test for both renosterveld and managed transformed renosterveld. Infiltration rates using this technique were also assessed on and alongside porcupine diggings. Fifty paired sites were investigated in renosterveld and 25 paired sites in managed transformed renosterveld. Wilcoxon paired

tests were used to compare infiltration rates on diggings and off diggings in both renosterveld and managed transformed renosterveld.

7.3.4 Soil properties

In the previous chapter I investigated simulated rainfall infiltration, soil texture, soil nitrogen and carbon content. In this study soil moisture retention and soil temperature were investigated as these relate to soil as a habitat for soil organisms.

Soil moisture retention

A bulked soil sample which comprised three soil cores taken to a depth of 10 cm were taken directly beneath the canopy of the two most dominant shrubs, and the dominant grass species in renosterveld, *Dicerothamnus rhinocerotis, Eriocephalus purpureus,* and *Merxmuellera stricta*, in open areas in renosterveld, and from adjacent managed transformed renosterveld. These are referred to as micro-sites from here onwards. Samples were collected in spring 2002 and again in late summer 2003 so as to determine soil moisture patterns at the end of the rainfall season and following the hot dry summer. In the spring, a total of 85 samples (17 for each treatment) and in late summer a total of 100 samples (20 for each treatment) were taken. Soil moisture was calculated as the percentage difference in mass between wet and dry samples. Comparisons between micro-sites were made using a one-way ANOVA, and a post-hoc comparison using Tukey's honest significant difference. Seasonal differences in soil moisture for each micro-site were investigated using a t-test for independent variables.

Soil temperature

Soil temperature was measured using six data loggers with temperature probes. These were located at three sites on either side of a fence. Temperature probes were placed in the soil to a depth of 5 cm and recorded mean hourly soil temperature. Data loggers ran for four months from November 2002 to February 2003. Maximum daily temperatures for renosterveld and managed transformed renosterveld were compared using Student's t-test.

7.4 Results

7.4.1 Mesofaunal and microbiological activity

Managed transformed renosterveld showed a significantly lower level of feeding activity ($U = 71001.5$, $p < 0.01$, $n = 800$) as measured by the bait-lamina method, despite feeding

activity appearing to be more variable in the renosterveld. There was a significant decrease in feeding activity and microbial decomposition with distance from the natural renosterveld remnant (Fig. 7.1). Table 7.1 shows the variety of depths at which baits were taken in renosterveld compared with managed transformed renosterveld. Significant differences were found between 45 mm and 80 mm depths below the surface, with renosterveld having a greater number of baits taken between these depths.

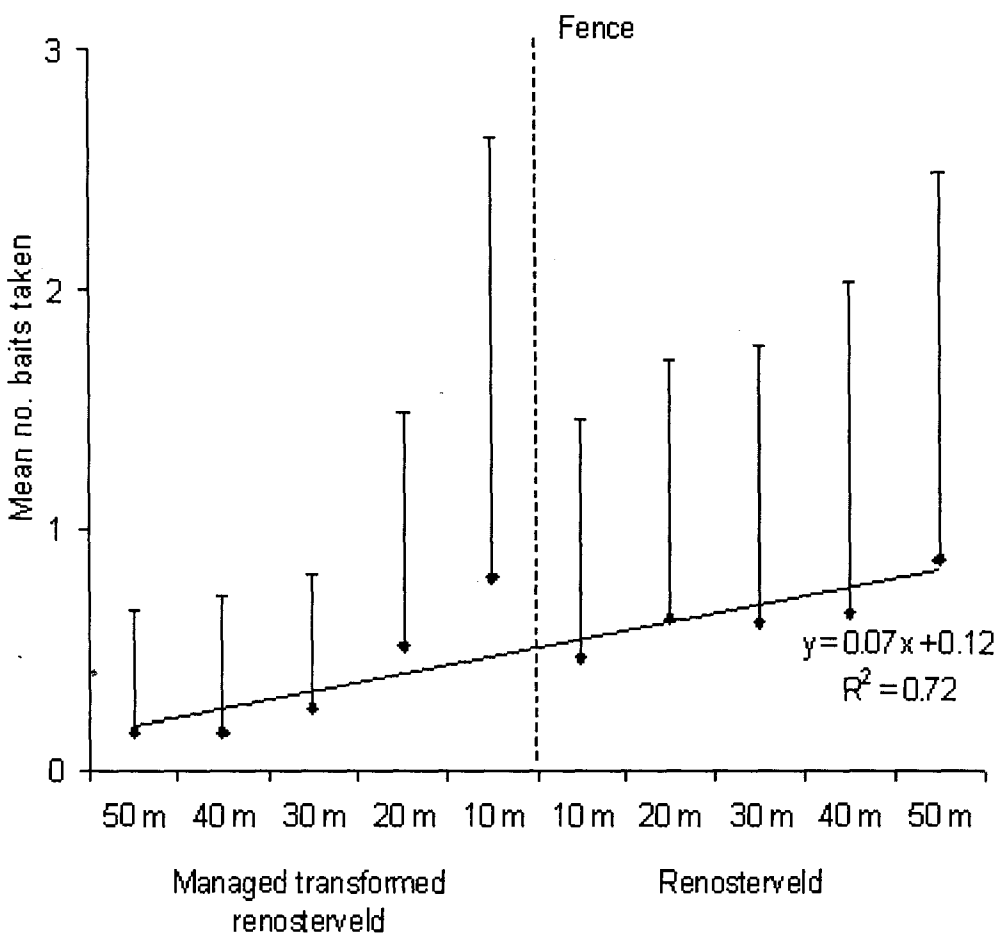

Figure 7.1 Mean (± SD) number of baits taken in a set at five sites 10 m apart over a distance of 50 m in managed transformed renosterveld to the fence and at five sites 10 m apart over a distance of 50 m from the fence into the renosterveld, ($F = 3.9$, $p < 0.05$, $n = 640$).

Table 7.1 The mean (± SD) values for baits taken at depths 5 mm–80 mm in renosterveld and managed transformed renosterveld. Significant differences tested using a Wilcoxon paired test, Z values and significance levels are given.

Depth (mm)	Renosterveld	Managed transformed renosterveld	Z	p (n = 20)
5	3.3 ±2.27	2.1 ±2.23	1.01	NS
10	2.9 ±2.25	2.5 ±2.12	1.78	NS
15	2.9 ±2.05	1.7 ±1.55	1.05	NS
20	3.1 ±2.14	1.4 ±1.66	0.63	NS
25	2.6 ±1.73	1.4 ±2.06	1.6	NS
30	1.8 ±1.70	1.7 ±1.82	1.35	NS
35	2.4 ±2.02	1.3 ±1.57	1.01	NS
40	1.8 ±1.92	0.8 ±0.82	1.01	NS
45	1.8 ±2.03	0.8 ±0.82	2.1	0.05
50	1.4 ±2.11	0.4 ±0.54	1.64	NS
55	1.2 ±2.30	0.4 ±0.66	0.36	NS
60	1.4 ±2.40	0.4 ±0.68	2.39	0.05
65	1.6 ±2.63	0.5 ±0.69	2.38	0.05
70	1.6 ±2.78	0.4 ±0.74	2.4	0.05
75	1.9 ±2.95	0.4 ±0.61	0.78	NS
80	1.9 ±3.23	0.4 ±0.60	2.24	0.05

7.4.2 Earthworm biomass and number

A total of 320 earthworms were found, all of an indigenous earthworm species, in the genus *Microchaetus*. No significant differences were found in the individual weight of worms found either in renosterveld or managed transformed renosterveld (Table 7.2). The average total earthworm biomass found in the soil pits was significantly greater in managed transformed renosterveld compared to renosterveld. This was also true for numbers of individuals, with a mean of four worms found per renosterveld soil pit compared with 14 in a soil pit in managed transformed renosterveld. Casting activity comparisons surrounding the soil pit showed that significantly greater casting activity occurred in managed transformed renosterveld compared with natural renosterveld. Soil turnover, measured by casting activity in the growing season between April and November 2002, was also found to be significantly greater in managed transformed renosterveld than in natural renosterveld (Fig. 7.2). Earthworm biomass and earthworm number were not found to correlate with earthworm cast sweepings around the soil pit ($F = 0.22$, $p = NS$, $n = 34$; $F = 2.21$, $p = NS$, $n = 34$).

Table 7.2 Mean (± SD) individual earthworm weights, the number of individual worms per sample, the total earthworm biomass per sample, and the mean weight of castings collected around soil pits for the renosterveld and managed transformed renosterveld vegetation types. The U test statistic, p-value and sample size are given.

	Renosterveld	**Managed transformed renosterveld**	**U**	**p (n)**
Individual worm weight	0.35 (±0.454)	0.34 (±0.506)	7809	NS (257)(63)
Number of individuals per 50 cm^3	4 (±2.9)	14 (±14.3)	77	0.01 (36)
Earthworm biomass per 50 cm^3	2.8 (±6.7)	4.8 (±4.5)	79	0.001 (36)
Casting volume around soil pit ($g.50\ cm^{-2}$)	158 (±79)	259 (±131)	80	0.01 (36)

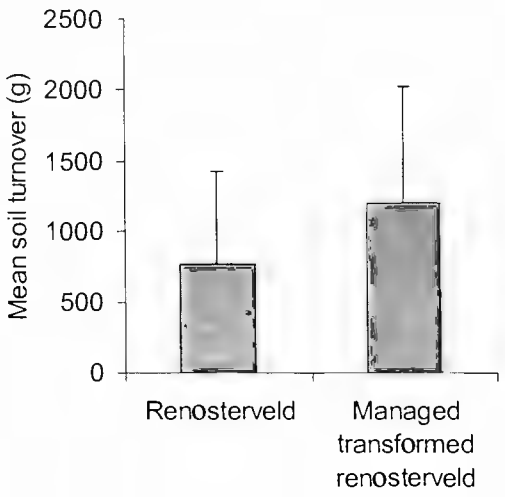

Figure 7.2 Mean cast accumulation (g) (± SD), of soil turnover for renosterveld and managed transformed renosterveld from 1 m^2 cleared plots in the growth season, from April to November 2002 ($U = 714.0$, $p < 0.001$, $n = 100$).

7.4.3 Soil disturbance and infiltration

Results from the single ring infiltrometer infiltration experiments show infiltration rates as significantly higher where there was evidence of earthworm casting for both renosterveld and managed renosterveld (Fig. 7.3). Similarly infiltration rates were found to be significantly higher on porcupine disturbances compared to those measured just next to the disturbance (Fig. 7.4). Differences in infiltration rate in both renosterveld and managed transformed renosterveld between the 'casting absent' treatment and the 'off diggings

treatment' are attributed to the fact that these experiments were carried out one month apart during which two major rainfall events took place.

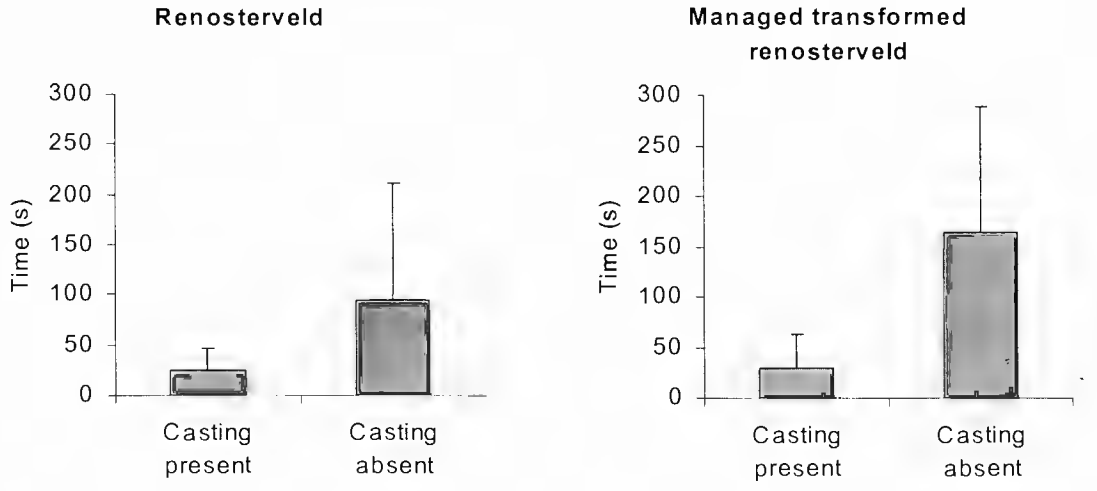

Figure 7.3 The influence of earthworms on rainfall infiltration rates in renosterveld ($U = 1888$, $p < 0.001$, $n = 200$), and in managed transformed renosterveld ($U = 553$, $p < 0.001$, $n = 200$) where earthworm activity, as indicated by casting, was present or absent, and infiltration rate was the mean time (± SD) taken for 50 ml of water to infiltrate the soil.

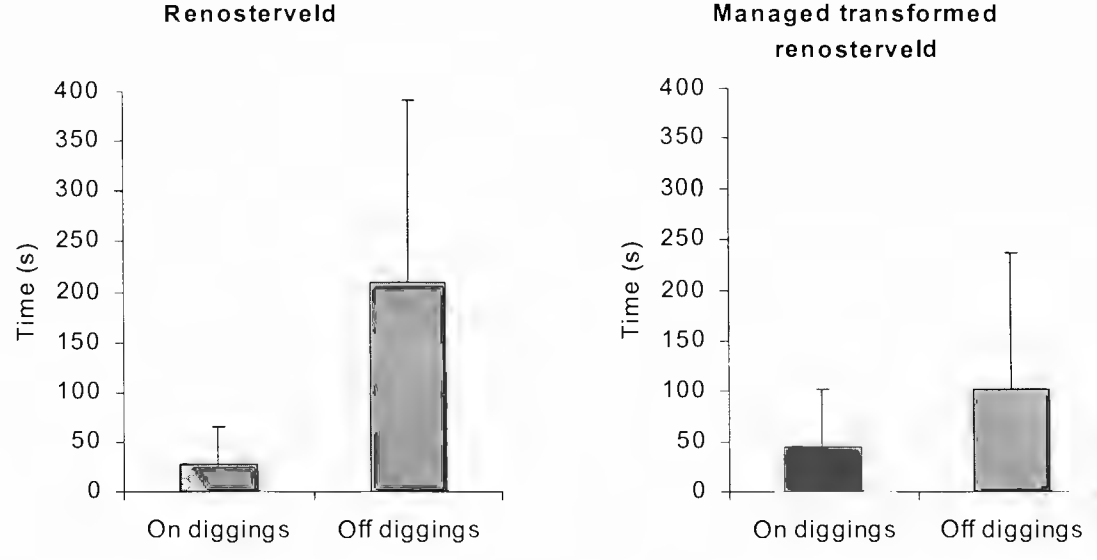

Figure 7.4 The influence of porcupine diggings on infiltration rates in renosterveld ($Z = 6.1$, $p < 0.001$, $n = 100$), and in managed transformed renosterveld ($Z = 3.9$, $p < 0.001$, $n = 50$) where mean (± SD) infiltration rate of 50 ml of water was recorded on porcupine diggings and alongside diggings.

treatment' are attributed to the fact that these experiments were carried out one month apart during which two major rainfall events took place.

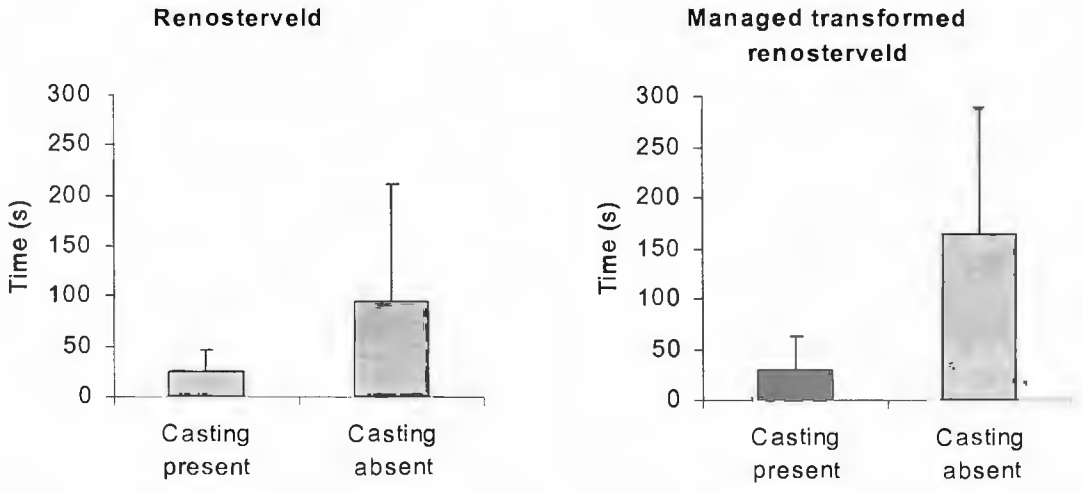

Figure 7.3 The influence of earthworms on rainfall infiltration rates in renosterveld (U = 1888, $p < 0.001$, n = 200), and in managed transformed renosterveld (U = 553, $p < 0.001$, n = 200) where earthworm activity, as indicated by casting, was present or absent, and infiltration rate was the mean time (± SD) taken for 50 ml of water to infiltrate the soil.

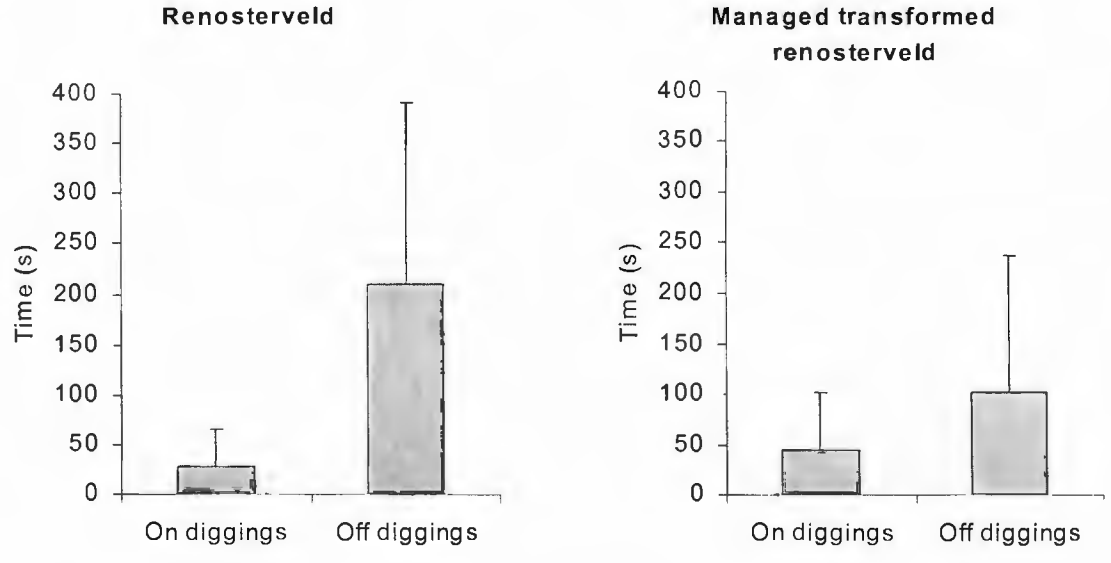

Figure 7.4 The influence of porcupine diggings on infiltration rates in renosterveld (Z = 6.1, $p < 0.001$, n = 100), and in managed transformed renosterveld (Z = 3.9, $p < 0.001$, n = 50) where mean (± SD) infiltration rate of 50 ml of water was recorded on porcupine diggings and alongside diggings.

7.4.4 Soil properties

Soil moisture

Soil samples taken from specific micro-sites in October 2002, indicate that soil moisture was significantly greater in managed transformed renosterveld (Fig. 7.5). The driest soil was found in open areas in renosterveld. Soil moisture recorded under shrubs in late spring indicated that the greatest moisture is retained under *D. rhinocerotis*. Soil samples taken during mid-summer indicate that certain micro-sites had dried out at faster rates than others. The highest moisture levels at the end of summer were found under *D. rhinocerotis* followed by *M. stricta*, these being significantly higher than the open renosterveld. Table 7.3 compares moisture differences at each of the micro-sites for spring and summer. It shows that the managed transformed renosterveld had experienced the greatest degree of change, drying out at the fastest rate.

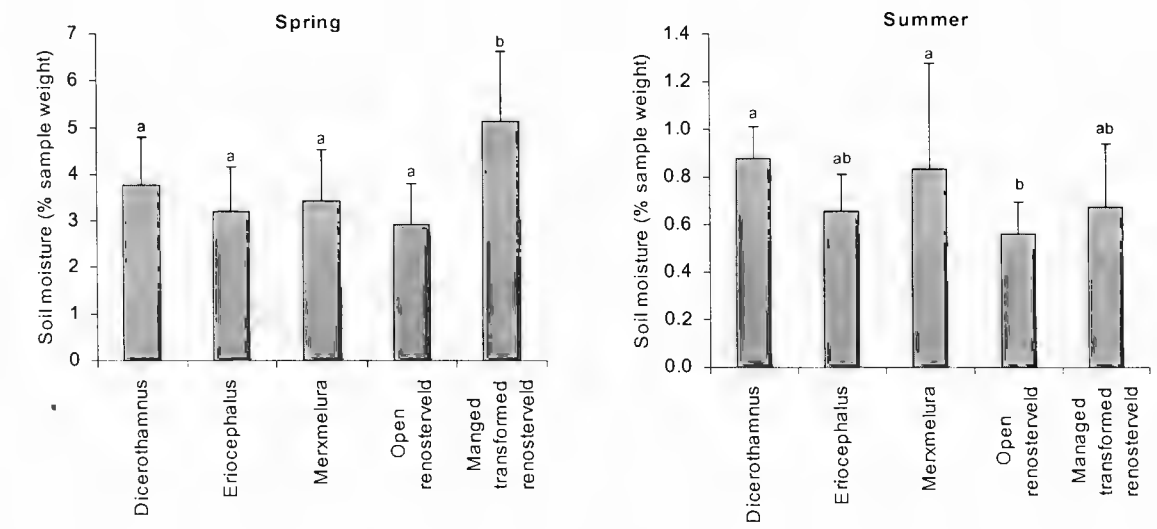

Figure 7.5 Soil moisture content expressed as a percentage (± SD) of a soil sample, for different micro-sites, spring 2002 ($F = 10.4$, $p < 0.001$, $n = 86$), and summer 2003 ($F = 4.7$, $p < 0.001$, $n = 100$). Significant differences at the $p < 0.05$ level are indicated by superscript.

Table 7.3 The mean (± SD) values for soil moisture measurements, calculated as a percentage of a sample, comparing soil moisture in spring with summer for the investigated micro-sites. The mean difference for each micro-site, the t-value, p-value and sample size are given.

	Spring	Summer	difference	t	p (n)
Dicerothamnus rhinocerotis	3.8	0.9	2.9	12.5	0.0001 (36)
Merxmuellera stricta	3.4	0.8	2.6	9.8	0.0001 (37)
Eriocephalus purpureus	3.2	0.6	2.6	11.8	0.0001 (38)
Open renosterveld	3.0	0.6	2.4	11.9	0.0001 (38)
Managed transformed renosterveld	5.1	0.7	4.4	12.9	0.0001 (38)

Soil temperature

Soil temperature was found to be consistently significantly higher in the managed transformed renosterveld compared with renosterveld for the period November to March (Fig. 7.6). A mean temperature of 33.4 (±3.5) and 39.7 (±3.9) were recorded in renosterveld and managed renosterveld respectively for this period.

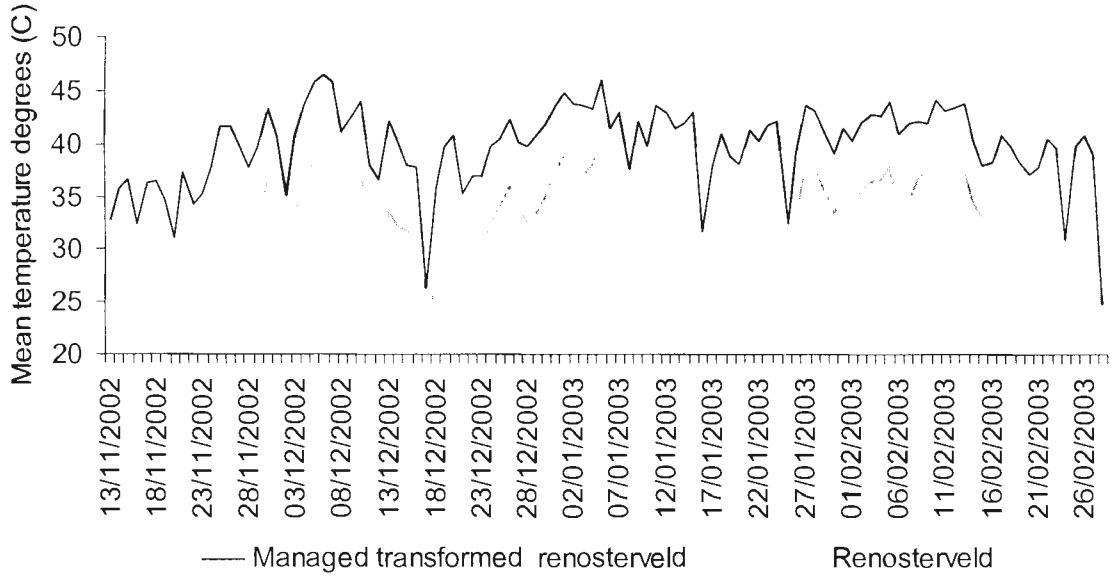

Figure 7.6 Soil temperatures recorded at a 5 cm depth between mid-November 2002 and March 2003 in managed transformed renosterveld and adjacent renosterveld remnants. Managed transformed renosterveld had significantly higher soil temperatures over this period ($t = 12.54$, $p < 0.001$, $n = 216$).

7.5 Discussion

The negative relationship between land transformation and loss of soil biological activity is evident in this study. Bait-lamina studies demonstrated a gradient of soil biological feeding activity decreasing with distance from the natural remnant, supporting theories and previous studies suggesting that reduced natural plant cover results in the loss of, or reduction in, soil biological activity (Garcia *et al.* 2002). Similarly, the service provided by the remnant patches of renosterveld in the refuge they provide for soil organisms, and possible source of soil organisms to adjacent transformed areas, is evident in the gradient of biological activity with proximity to the remnant patches. The decline in invertebrate activity with distance from the renosterveld boundary could also be as a result of increasing mortality with greater distance from the habitat and conditions that these organisms can tolerate.

The shrub *D. rhinocerotis* and the grass *M. stricta* are key species in terms of their role in holding moisture in the landscape over the long dry summer period, retaining the function of ecological processes, and possibly sustaining populations of soil organisms. The structure of renosterveld also provides shade and keeps soil temperatures cooler than those experienced on the managed transformed renosterveld. The physical stresses on soil as identified by Van Bruggen and Semenov (2000) of extreme temperatures, extreme drying and wetting cycles, and osmotic potentials, would be less extreme in this study under natural vegetation conditions. Soil faunal activity is generally reduced by higher temperatures and drying in summer months (Zelles *et al.* 1991; Harte *et al.* 1996; Schloter *et al.* 2003). Renosterveld remnants could therefore play a vital role in sheltering these soil organism communities from extreme temperatures and associated effects over the dry summer months.

An examination of the vertical stratification of biological activity showed that it is limited to the surface (0–35 mm) in the managed transformed renosterveld, possibly as a result of the shallow rooting of the medicago pastures. The very shallow nature of the measured feeding activity on the managed transformed renosterveld would mean these soil faunal communities would be even more vulnerable to further soil compaction or changes in microclimate, suggesting that the communities which do exist here are possibly more ephemeral than those of the adjacent renosterveld.

One of the proposed links between the various communities of soil organisms is that the invertebrates that contribute to bioturbation and soil structuring, such as the earthworms in this study, should be correlated with increased mesofaunal and microbiological activity (de Bruyn 1997). No such relationship was evident in this study. While the general relationship between mesofaunal and microbiological activity, and land transformation was anticipated and readily explained, the increase in earthworm biomass and numbers in managed transformed renosterveld was unexpected. This supports the view that some macro-organisms are common in cultivated soils and may have greater biomass in fields that have been fertilised (Hendrix 2000). This may to some extent explain the higher biomass of earthworms in the managed transformed renosterveld, where management practices consist of top dressing with phosphate every second year and the termination of ploughing activities. In an ecosystem with low levels of phosphorus the addition of this major nutrient, plus leguminous nitrogen fixation, is likely to improve many aspects of biological activity. However microbial facilitation of access to phosphorus is likely to be much better in intact vegetation and would constitute an important ecosystem service. Previous studies have noted that earthworm species showed different preferences for available food types (Darwin 1881; Neilson & Boag 2003). Therefore an alternative hypothesis is that the *Microchaetus sp.* in this study prefers food types available in the *Medicago sp.* pasture environment compared with the renosterveld.

The presence of earthworms in the managed transformed renosterveld, where other invertebrates are less dominant, could also be attributed to the ability of earthworms to aestivate and rapidly burrow deeper in the soil during unfavourable conditions (Jiménez *et al.* 2000), allowing them to persist in the soil at times when other soil organisms are eliminated. Almost all earthworm species have this response to seasonal changes in soil temperature and moisture (Jiménez *et al.* 2000). Earthworms have the ability to cope with the increased soil temperature and the rapid moisture evaporation from the soil in managed transformed renosterveld over the summer period. Earthworms, with their hermaphroditic reproductive abilities are also described as good colonisers, potentially allowing population numbers to build up rapidly in the managed transformed renosterveld under favourable conditions (Hendrix 2000).

Primary productivity in semi-arid regions is related to, and limited by moisture availability to plants after rainfall events (Breman & De Wet 1983). The local distribution of plants in these ecosystems is affected by infiltration and the water holding capacity of the soil. The

previous chapter 6 show significantly faster infiltration in managed transformed renosterveld. This probably results from higher levels of earthworm activity and a greater plant cover attributable to the proliferation of annuals following the wet season on managed transformed renosterveld. The positive relationship between earthworm biomass and infiltration rates has been well demonstrated (Bouche & Al-Addan 1997).

Of the various macrofauna contributing to soil structure and function, earthworms are described as having a great impact (Hendrix 2000). Casts, which are egested discrete pellets of mineral and organic matter, are described as stable aggregates in the soil. They contain enriched plant available nutrients and contribute to improved productivity. Henrot and Brussaard (1997) demonstrated how earthworm activity and casting return important nutrients to the surface of the soil, making them once again available to plants. Tomati *et al.* (1990) demonstrated how earthworm casts significantly increased protein synthesis of radish and lettuce. The creation of macro-pores, through burrowing, aerates the soil and aids water infiltration, which is of vital importance in this arid and groundwater-dependent landscape (Hendrix 2000). The presence of both porcupine activity and earthworms was positively associated with faster infiltration rates on both renosterveld and managed transformed renosterveld. Porcupines are significantly less active in managed transformed renosterveld compared with the renosterveld (Bragg *et al.* 2005) The significantly greater earthworm numbers, biomass and, more importantly, soil turnover in the managed transformed renosterveld, is believed to explain the significantly faster water absorption in managed transformed renosterveld. The associated presence of earthworms and the rapid infiltration rates experienced on managed transformed renosterveld points to an essential ecosystem service offered by the earthworms in further aiding infiltration and reducing the potential for erosion during winter.

Van Bruggen and Semenov (2000) argue that long-term stress will result in long-term succession leading to a new dynamic equilibrium among ecosystem components. Frost *et al.* (1995), working at Little Rock Lake in the USA, found that the zooplankton community in the lake showed a high level of functional compensation to acidification of the water. Here the decline in some taxa was matched by an increase in other species. Creed and Sheldon (1995) and Creed (2000) also working in North American aquatic systems found that a herbivorous aquatic weevil, *Euhrychiopsis lecontei* regarded as a minor grazer became a keystone herbivore controlling the spread of an alien watermilfoil species *Myriophyllum spicatum.* Rosenfeld (2002) cautions that the outright conversion of

an ecosystem will alter the functioning of that ecosystem more severely that the loss of diversity within an ecosystem. This chapter has not attempted to assess the functioning of the transformed renosterveld ecosystem, but has focused on a few ecosystem services that are essential components of soil health. My findings indicate that in a natural state renosterveld soil health processes are dependent on porcupines and earthworms for soil turnover and infiltration and earthworms and a range of other soil organisms for nutrient cycling. However renosterveld in its transformed state, with some management intervention, continues to provide there services as earthworms have become more dominant and continue to provide these services to farmers after transformation. Klein *et al.* (2002), working on the edge of the Lore-Lindu National Park in Central Sulawesi, Indonesia, found that some insect species beneficial to human production activities also benefit from tropical forest transformation and conversion to agriculture. Thus, transformation activities or vegetation clearance does not necessarily result in the collapse of ecosystem services, but these are dependent on the possibility of functional compensation amongst species with overlapping functional niches, the nature of transformation activities and management actions thereafter, and the ability of species to survive or re-colonise a transformed area.

The loss of genetic and species diversity that occurs amongst below-ground organisms as a result of human impacts is largely undocumented (Madong & Nkolbisson 1999). Biodiversity which incorporates a number of species in a functional group is viewed as providing a form of biological insurance against changing environmental conditions and the loss or poor performance of selected species (Naeem & Li 1997; Aarts & Nienhuis 1999). The role of renosterveld remnants in preserving below ground diversity is still largely unknown. However, the conservation of the array of soil organisms that provides ecosystem services, such as improved water infiltration and retention, the decomposition of organic matter, the structuring of soil and nutrient cycling, on the basis of the provision of these services alone, should constitute a conservation priority.

7.6 Conclusion

This study demonstrates the multiple ecosystem services rendered by renosterveld fragments. They retain soil moisture during the dry summer months in this arid environment which potentially contributes to the productivity of renosterveld and the maintenance of microbial communities. Remnant patches may act as refugia for soil organisms from which surrounding managed transformed renosterveld can be re-colonised

when conditions are favourable. The importance of vegetation cover is emphasised, and it is speculated that the loss of cover in managed transformed renosterveld in summer and the associated increase in soil temperature has implications for soil faunal communities, decomposition processes and nutrient cycling. While the importance of renosterveld is not demonstrated with regards to the maintenance of earthworm communities, the important ecosystem service provided by earthworms in the agricultural landscape is evident from the rapid infiltration experienced on managed transformed renosterveld during winter rainfall events. This may reduce the potential for erosion in winter and play a greater role in the recharging of ground water sources than natural areas. I argue that earthworms may functionally compensated for the reduced activity of other soil organisms important for nutrient cycling. In addition they have also compensated for soil turnover processes usually carried out by porcupines, and are important for rainfall infiltration. This study highlights the fact that transformation does not necessarily result in the loss of an ecosystem service and demonstrates how influential the level or degree of transformation is on ecological functioning and the provision of ecosystem services. The managed transformed renosterveld is clearly not as heavily impacted by transformation practices below ground as would be the case if these included annual ploughing and the continual application of pesticides. The continued provision of ecosystem services is however dependent on functional compensation amongst species, the nature of transformation activities and management actions thereafter, and the ability of species to survive or re-colonise a transformed area. Given this, the retention of natural vegetation remnants could play a vital role in the provision of specific services in transformed areas, as well as providing an array of key services based on their continued ecological functioning.

Chapter 8

The development potential of a perceived ecosystem good: the viability of and issues involved with indigenous plant production

8.1 Introduction

Ecosystem goods are important components of local and national economies and sustain livelihoods of millions of people living within these ecosystems (Bawa & Gadgil 1997). Global plant diversity contains fundamentally important ecosystem goods that contribute to agriculture, medicine and industry, however, only a small percentage of the available 250 000 species benefits have been explored (Myers 1997a). The horticultural application of plant diversity has been significant and this diversity has proved to be a very valuable ecosystem good, with the global horticultural market worth billions of dollars (Kaiser Associates 2000).

The Bokkeveld plateau is situated on the edge of two highly diverse biomes, Succulent karoo and Cape Floristic kingdom (van Wyk & Smith 2001). Furthermore, the Bokkeveld plateau is regarded as a local biodiversity hotspot having a great diversity of geophytes in the renosterveld and dolerite vegetation types, and succulent species in the karoo veld. Interviews conducted with farmers in the study area revealed that they also perceived the natural vegetation as providing ecosystem goods with future development potential (chapter 3). Currently, 60% of these farms are actively involved in tourism. They described tourists' desire to purchase plant species that they have seen in the study area. Farmers perceive this to be an economic opportunity that they could pursue in the future, as well as one that could be exploited to improve the lives of the broader rural population in the study area. Farmers described the area as having a high level of unemployment which negatively impacts on all rural society. A number of short-term, once-off employment opportunities offered by government through schemes such as Working for Water and Landcare, do little to reduce poverty after completion of the project. There is a need for projects that offer a sustainable livelihood.

If local communities are acknowledged, empowered and benefit from ecosystem goods and services and conservation they are arguably the most effective, efficient and economic conservers of local biological diversity (The Crucible Group 1996; Bawa & Gadgil 1997).

International experience indicates that sustainable livelihoods can be achieved through the establishment of indigenous plant nurseries which have the dual aim of conservation and development. Tree nurseries are the most common community nursery projects. Over-exploitation of indigenous trees in countries such a Nepal, Sudan and Tanzania have prompted the establishment of community nurseries to protect natural resources whilst allowing for community development (Arens *et al.* 1994; Ndulu *et al.* 1994; Vogt *et al.* 1994). Cycads have long been traded in almost all countries where they naturally occur. There are examples from both South Africa and Mexico where nurseries have been successfully established allowing local communities to benefit from this ecosystem good whilst simultaneously achieving greater *in situ* conservation with conserved wild populations used as a seed source (Donaldson *et al.* 2003).

At present a number of plant species found in the study area are on the World Conservation Union's (IUCN's) Red Data List, and illegal plant collection is believed to be an important contributor to this loss and endangerment of species (Victor 2002). Current calls for action to curb the loss of species in South Africa include, 'integrating the protection and management of biodiversity resources and abiotic processes with human development' (Reyers 2002). The development of nurseries and the proliferation of these species would be a major species level conservation initiative.

This study explores the perception that there are potential opportunities offered by natural vegetation as an ecosystem good for community use and development within the study area. This ecosystem good is, however, fundamentally tied to the ecosystem service that functioning natural fragments provide in that they contain and store biodiversity with future use options. I focus on the potential of nurseries to produce succulents and bulbs found in this study area, thereby simultaneously providing sustainable livelihoods for the rural community, and facilitating the conservation of the local flora by providing demanded plant species for sale to public. In doing so I answer the following seven questions:

1. What are the trends in international floriculture markets?
2. What is South Africa's contribution to these markets, and how important are bulbs and succulents on local and international markets?
3. What are the trends in the nursery industry in South Africa?
4. What are the species under pressure and what causes this pressure?

5. What legislation is in place to protect ecosystem goods of this nature?
6. What are the lessons and key issues to be learnt from nurseries and community projects already established in the study area?
7. Is a project with the joint aims of assisting in conservation and in improving the quality of life of those living in this biodiversity hotspot feasible?

8.2 Approach

A qualitative approach was adopted in this study given both the breadth of the topic and the lack accessible scientific and economic data. The approach included an extensive literature search of electronic databases for papers and information on all aspects pertaining to nurseries, plant propagation and development. Semi-structured interviews were conducted with 45 individuals using questionnaires to guide the process (see Appendix 3). Questions were developed for the following target groups: international horticulturalists, national horticulturalists, nursery owners and workers in the surrounding area, community development initiatives, tourism groups, conservation organisations, agricultural workers, scientists and plant interest groups (Table 8.1). Interviews were conducted either in personal meetings, telephonically, or via email. Information was then assimilated to answer the key questions outlined above. A cross interview analysis method (Patton 1990) was used where data was coded and categorised to identify the primary patterns and key issues.

Table 8.1 Target group identified, and the number of people interviewed in each of these groups.

Area of expertise	**No. interviewed**
International horticulturalists	2
National horticulturalists	7
Nursery owners and workers in the surrounding area	8
Interest groups	6
Community development initiatives	7
Tourism groups	2
Scientists	5
Conservation organisations	6
Agricultural workers	2
Total	45

8.3 Floriculture markets

8.3.1 Trends in international markets

The economic importance of the ornamental horticulture market has increased in recent years and international production has expanded rapidly to meet this demand. Cut flower production occupies the largest segment of the industry, followed by flowering pot plants, trees, nursery crops and flower bulbs (Lawson 1996). The total value of worldwide imports of floriculture products in 1998 was $6.85 billion, with Germany as the largest importer, accounting for $1.7 billion of this total (Kaiser Associates 2000). The main suppliers are the Netherlands, which contributes nearly 60% of the world's cut flowers, followed by Colombia and Israel (Lawson 1996). World production centres are changing with Ecuador, India and several African countries (for example Kenya) emerging as centres of cut flower production (Lawson 1996). Floriculture is growing in east and southern Africa at a rate of 10–15% per year (Petitjean 2002).

There is increasing emphasis in the global market on flower quality and longevity. Growing concern over the presence of pathogens and viruses means plants must be certified disease-free (Lawson 1996). It is predicted that within the next five years all products sold in Europe will require an eco-label, which records all chemicals and fertilisers use and prescribes working conditions and contracts for staff (Kaiser Associates 2000). While there is still a growing demand for a wider assortment of new and different cut flowers, there is a worldwide market trend towards flowering pot plants. Pot plants have become an important branch of the ornamental horticulture industry, with demand increasing at the expense of traditional cut flowers. Potted and bedding plants accounted for 30% of sales at Dutch auctions in 2001 (Kras 2001).

8.3.2 South Africa contribution to international markets

South African indigenous plants have a long history in the global market. Shortly after the establishment of the first European settlement in the Cape, South African plants started entering Europe via the Netherlands. Succulents above all caught the attention of botanists and gardeners (Musgrave 2003). This was partly because of their potential medicinal value, as anything resembling an aloe was felt to be worth investigation, and partly because of their novelty value (Musgrave 2003). In the late 18th century succulents began to be rivalled by Cape bulbs such as species of *Amaryllis*, *Crinum*, *Brunsvigia* and *Gladiolus* (Musgrave 2003). The first flowers from South Africa to reach Europe were the

blooms of the bulbous plant *Ornithogalum thyrsoides*, which due to its long storage life could be transported by ship (Littlejohn 1994). Over time, South Africa has made significant contributions to the world's floriculture industry with more recent contributions from among the pelargoniums, freesias, gladioli and plumbago (Littlejohn 1994). International specialist nurseries outside South Africa meet much of the demand for South African bulbs and succulents.

There is a recognised demand, both nationally and internationally, for both horticultural, ornamental and medicinal plants from a wide range of South Africa's plant taxa (Donaldson & Raimondo 2000). This demand is such that Donaldson and Raimondo (2000) cite South Africa's succulent and bulbous taxa as threatened by this trade and in need of protection. It is estimated that of all plant material traded in South Africa, succulents make up about 10% and bulbs about 20% of the total (Oliver pers comm.). Furthermore the demand for both South African bulbs and succulents is believed to be growing (Retief pers comm.).

Despite these contributions, it is felt that South African products are not well perceived on the international market. Reasons for this are cited as the apparent lack of an industry-wide production plan, production not linked to demand, poor product quality, a lack of eco-labelling, and insufficient production to meet demand. South Africa needs to improve the international perceptions of its floriculture industry, improve its marketing and initiate compliance with an eco-labelling strategy if it is to expand its global market. It would be in the country's interest to take this one step further and have a fair-trade label, in addition to the aim of promoting community development.

8.3.3 Bulbs

It is said that more than half the bulb species grown in gardens around the world, though not produced here, have their origins in South Africa (Hadeco 2003). However South Africa's own bulb producing industry has been described as fairly static in recent years (Barnhoorn pers comm.). Bulbs are grown over as little as 370 ha and generate an annual turnover of R85 million (Amsterdam Cape Town Group Management Consultants 2001). The industry is described as small, but with good prospects (Barnhoorn pers comm.). Lilies, gladioli, irises and narcissus dominate the industry, accounting for 64% of the total bulb production.

There is a perception that indigenous bulbs are very difficult to grow, which has resulted in a lack of interest in their cultivation. Some small scale growers argue that this is not the case and more than half of South Africa's indigenous bulbs can be grown in the open with relative ease (Summerfield pers comm.). It is believed that people prefer to buy flowering items that require less work such as pot plants or cut flowers, over bulbs which need to be planted, tended, dug up at the end of the season and stored. It is felt there is insufficient local demand to sustain nurseries only producing indigenous bulbs and succulents (Craib pers comm.). However, currently there is growing interest as bulb growers recognise the demand for a broader range of products in the global market.

In addition to the formal trade in bulbs, members of the Indigenous Bulb Growers Association also grow and distribute seed, bulbs and corms amongst themselves at meetings and through personal exchanges. This is believed to be small and highly specialised and the value of this trade is unknown (Summerfield 1996).

8.3.4 Succulents

While the volumes of succulents traded are small, at present South Africa's succulent market is described as doing very well (Aslander pers comm.). There is demand for South African succulents on both the international and domestic markets. Estimates of international sales are between R2–3 million a year (Retief pers comm.). International succulent buyers on the whole are mostly collectors, with only a few species having mass appeal. There is some demand for succulents by the Succulent Society, which has a membership of some 1200 people, of which 600 are foreigners. Succulents are frequently traded among members. Demand among collectors is typically for aloes, lithops, and haworthias (Fick pers comm.).

The demand for succulents is in the region of half that of bulbs (Oliver pers comm.). For example one grower reported that there is demand for only about 400–500 specimens of haworthia per year on the international market (Aslander pers comm.). The overseas market is highly specific and collectors generally want only the rare species or unusual varieties. Evidence of a potentially expanding market is given in that the Select a Succulent nursery in Cape Town has been approached by a Dutch company and asked to

supply 500 000 lithops specimens annually. This nursery has also had interest from Asian companies for succulents (Aslander pers comm.).

A recent growth in domestic demand for succulents, in particular aloes, is believed to be due to the increased water tariffs and a movement towards more water-wise gardening. The value of these markets is virtually impossible to capture, and no figures could be obtained on what income this generates for South Africa.

Succulent nurseries are limited to less than a dozen in the country. Their plants sales are mostly to South Africans, with limited sales overseas. One of the main reasons for this is that most of South Africa's succulents in demand are already being produced and sold overseas. On the whole the commercial development of plant resources in South Africa has been slow, and the bulk of development has taken place outside the country (Cunningham & Davis 1997). People have been collecting plant material here for centuries. In the 1920s there was a flush of illegal succulent exports to Germany from South Africa, and they have been propagating the material since then (Wiese pers comm.). The main overseas markets for South Africa's succulents are Europe, the United States of America and the Far East (Newton & Chan 1998), (Retief pers comm.). In all these regions it is not uncommon to come across extensive advertisements in plant catalogues and journals for South African succulents, on the whole being produced in these countries (Newton & Chan 1998). There are a distressingly high number of examples of species indigenous to the region that are being successfully exploited abroad, and one can only guess at the value of the lost opportunities for employment and income generation (Cunningham & Davis 1997).

The establishment of succulents requires specific conditions depending on their origin and only species with similar requirements could be grown in bulk. Succulent export material in demand is for both potted plants and seed. The market for succulents is to a large degree dictated by fashion. For example, Bruce Bayer's book on the haworthia (Bayer 1999) saw an increase in demand for haworthias. Similarly, a new book released recently on stapeliads (Bruyns 2005) is predicted to have the same effect (Fick pers comm.). Those producers who pay attention to the packaging and presentation of succulents, ensuring they are attractively potted, are said to do better than those who do not (Aslander pers comm.).

8.4 Trends in nurseries in South Africa

Nurseries today are split into growers and retailers (Kirsten 1997). Retail nurseries have to compete with other entertainment centres, which they do by providing coffee shops, craft centres, children's playgrounds and butterfly houses. Commercial retail nurseries in Cape Town argue that to be profitable, 70% of their sales must be comprised of goods other than plants for example equipment, books or revenue from the coffee shops (Mckenzie pers comm.). It is felt that the nursery industry in South Africa and small private nurseries will soon be engulfed by larger public companies and chain operations (Kirsten 1997). Three types of growers are likely to emerge: large-scale specialist growers, large-scale generalist growers, and small-scale growers specialising in niche markets (Kirsten 1997). Connection through the Internet could see more plants being sold through mail order companies. Branding is predicted to become increasingly important, as more and more people associate with the colour, style and logo of a product (Kirsten 1997). It is felt that local demand and purchase by both local and foreign tourists is insufficient to sustain a nursery in this region and that there is a need to specialise, find new markets and create other products (Wiese and Rosch pers comm.).

8.5 Species under pressure and the causes of pressure

8.5.1 Species in the study area recognised as under pressure

Red Data Lists are intended to be comprehensive and authoritative accounts of the global, regional and national conservation status of plants and animals. In doing so they aid in guiding conservation priorities (Hilton-Taylor 2002). In line with global IUCN Red Data Lists of Threatened Species, Sabonet and the South African National Biodiversity Institute have recently compiled the Southern African Plant Red Data List, which provides a catalogue of species whose future survival in nature is at risk (Golding 2002). Species covered in the Southern African Plant Red Data List include the following:

- Socially and economically important species such as those used for medicinal purposes
- Species known or suspected to be utilised unsustainably
- Indigenous commercial timber
- Taxonomically poorly known taxa
- Species of special botanical interest such as endemics or range-restricted species

- Species that are subject to poaching

8.5.2 Causes of pressure

Historically the most damaging impact on South Africa's flora has been through agricultural practices and the associated clearing of land and loss of indigenous flora (Victor 2002). Aside from this more obvious pressure, the collection of indigenous plants for horticultural purposes, harvesting for local domestic and medicinal use, and over-grazing all place South Africa's indigenous flora in peril. Greater accessibility, population growth and an increase in economic potential, mean these are growing pressures and are recognised as posing a conservation problem (Goldberg 1998).

8.5.3 Collectors

The illegal collection for commercial trade targets specific sought-after taxonomic groups (Victor 2002). In particular, a number of succulent species that occur in the study area are considered collector's items (Golding 2002). While by no means the norm, a few of these specialist collectors pose a potential danger to plant conservation in their willingness to deal illegally in plants taken from the wild. This creates a market for wild-collected plants and opens opportunities for participation by organised crime (Donaldson *et al.* 2003). Where possible, species under pressure due to over-harvesting, poaching, and in general those in need of conservation should be targeted for propagation and sale. Despite improved propagation techniques, plants continue to be harvested from the wild, and those that are not exported illegally are often declared as propagated to by-pass CITES controls (Newton & Chan 1998). While collectors are willing to pay enough for these, there will always be the threat of their removal from the wild. Propagation in a nursery could reduce the price to such a degree as to make collection from the wild less appealing to local dealers selling illegally to collectors. It is argued that the magnitude of illegal trade in plant species in South Africa is grossly underestimated (Newton & Chan 1998; Donaldson & Raimondo 2000). Illegal trade in plants within the country's boundaries largely goes unaccounted for, and much of the international trade takes place via the postal system, by-passing the authorities (Newton & Chan 1998).

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8.5.4 Domestic use

During 2002 a total of 24 permits were issued for plant collection in the Northern Cape (Koen pers comm.). No figure is available, however, for any harvesting and collection undertaken by those communities living in the province. One of the criticisms of the existing legislation is that it makes no provision for the harvesting of indigenous plants by economically disadvantaged communities. As a result the harvesting of indigenous plants from the wild is not regulated and cannot be monitored, and this practice poses a considerable and largely unmeasured risk to plant conservation (Glavovic 1993). Wild plants are widely used across South Africa, largely as a buffer against poverty (Archer 1990). Fuel wood, fencing and building materials account for the highest volume of plant material harvested from the wild annually (Cunningham & Davis 1997). Some indigenous species are harvested as food. While this is in small quantities, these species are often an important aspect of rural people's diets. In Namaqualand children are said to greatly benefit from the fruit of *Rhus viminalis* and *Rhus undulata*. The gum of *Acacia karoo* is a good source of calcium, and oxalis species prepared as porridge are a source of Vitamin C (Archer 1990).

8.5.5 Medicinal use

In a study investigating the sustainability of medicinal plant harvesting in a rural communal area of Namaqualand, it was established that 70% of the community used medicinal plants harvested from the wild (Goldberg 1998). While on the whole the resource was found to be resilient, certain species, for instance *Sceletium emarcidum* and *Mentha longifolia*, were being negatively impacted by the harvesting pressure (Goldberg 1998). The study area has a long history of plant use and inhabitants of the Richtersveld, to the north of the study site, regularly use 70 plant species as foodstuff, 40 species medicinally and 54 species for a variety of other purposes (Cowling & Pierce 1999).

Trade in medicine derived from plants is described as a multi-million rand 'hidden economy' in South Africa (Cunningham & Davis 1997). Over the past 100 years medicinal plant collection has changed from a specialist activity carried out by trained herbalists, to a thriving trade involving unskilled hawkers and gatherers (Cunningham 1990). Reduced available areas for collection, increased demand, and unskilled and unsustainable harvesting techniques, pose a significant danger to the continued survival of many indigenous plant species.

8.5.6 Grazing

The arrival of European farmers on the subcontinent and their diffusion into the arid zones during the seventeenth to nineteenth centuries saw the creation of a settled pastoralist economy for the first time in the region (Hoffman 1997). Over the last three hundred years the Bokkeveld plateau has been used extensively for small livestock farming and recently the impact of this on the diversity, productivity and sustainability of the broader Succulent Karoo biome has been raised (Milton & Dean 1995; Allsopp 1999; Todd & Hoffman 1999). While increased population numbers alone cannot simply be cited as the cause of degradation, land tenure systems in South Africa have seen the restriction of large numbers of people to limited areas, with resultant high grazing pressures (Hoffman 1997). High grazing pressure has been shown to promote certain, frequently unpalatable species, over other, more palatable species, with a negative impact on productivity (Cunningham & Davis 1997; Goldberg 1998). Livestock grazing places considerable pressure on the indigenous flora of the region.

8.5.7 Addressing pressures

If the role of wild plants as a buffer against poverty and in providing a range of basic needs is to be maintained, then the issue of over-exploitation, on all fronts, must be addressed with some urgency (Cunningham & Davis 1997). One of the recommendations arising out of an evaluation of South African plant species listed on the CITES appendices, is that there should be a promotion of the development of community-based projects relating to CITES species (Donaldson & Raimondo 2000). This report goes on to say that listed species could be grown or harvested by local people in a fashion that would allow for effective monitoring and could therefore be sustainable and simultaneously create an opportunity for community upliftment. The propagation of CITES species would certainly contribute to improving their conservation status, albeit through *ex situ* conservation. Some concern has been raised that nurseries might popularise plants, which in turn could be illegally collected from the wild to generate income (Geldenhuis pers comm.) (Cunningham 1990). It is important to note that for the cultivation of useful plants to succeed as a means of reducing collection from the wild, the prices must undermine the prices of those specimens collected in the wild, making collection from the wild an unrewarding option (Cunningham 1990).

8.6 Legislation

The maintenance and sustainable use of biological resources in South Africa is not the sole responsibility of nature conservation or natural resources agencies. It is also the function of an extensive body of law which exists to regulate or manage activities which have effects on biological resources arising from a number of sectors including agriculture, forestry, energy, trade, health and land-use planning (Department of Environmental Affairs 1996).

The South African government is a signatory to a number of international conventions that relate to conservation. Of relevance are the Convention of International Trade in Endangered Species (CITES), to which South Africa became a signatory in 1975 (Donaldson & Raimondo 2000) and the 1993 Convention of Biological Diversity (Glavovic 1993). Species threatened by trade are controlled by CITES whereby listed species may only be traded if they have been propagated *ex situ* and subject to a trade license, or from both *ex situ* cultivation and from the wild, and also subject to a trade license (McGough 1997). The establishment of indigenous plant nurseries, with the dual aim of promoting conservation and development, is wholly in keeping with the Convention on Biological Diversity. In order to export plant material, South Africa needs to adhere to the import legislation of other countries.

There is general concern that South Africa is failing to effectively conserve its indigenous flora from over-harvesting and illegal trade. Legislative shortfalls in this regard include: non-uniform and fragmented legislation between provinces, inadequate law enforcement, inconsistent laws and penalties, extremely large areas for monitoring, insufficient personnel and the lack of any law to accommodate the use of indigenous species by local communities (Glavovic 1993; Department of Environmental Affairs 1996; Newton & Chan 1998; Donaldson & Raimondo 2000). In light of these criticisms there is a proposal to develop a National Endangered Taxa Protection Act (Department of Environmental Affairs 1996; Newton & Chan 1998). Current legislation that relates plant protection and use includes the National Environmental Management Act (No. 107 of 1998) and more recently, the National Environmental Management: Biodiversity Act (No. 10 of 2004). However, until some specific national legislation and associated authority is in place, the day-to-day practicalities of plant propagation, collection, sales, export and the permitting for these activities, remain under the jurisdiction of the different provinces in accordance with the provincial ordinances.

While new ordinances for each of the new provinces are in various stages of preparation, the old ordinances are still the relevant legislation with regards to permitting. In the case of this study, the Nature and Environmental Conservation Ordinance No. 19 of 1974 is the relevant ordinance for the Northern Cape Province (Newton & Chan 1998). Aspects of this ordinance deal with the establishment of nurseries, plant propagation, sale and movement of plants. Indigenous, unprotected, protected and endangered flora may only be sold or bought on the premises of a registered flora grower or flora seller or at a place designated by the local authority.

The Skills Development Act (No 97 of 1998) provides an institutional framework to devise and implement national, sector and workplace strategies to develop and improve the skills of the South African workforce (Republic of South Africa 1998). While the central focus is on the development of public assets, the programme also aims to support community-building initiatives and capacity building, and includes among the aspects funded, environmental protection projects (Republic of South Africa 1997).

As party to the General Agreement on Tariffs and Trade (GATT), South Africa is automatically a signatory of the Trade Related Agreement on Intellectual Property Rights TRIPs agreement (Botha 1994). This agreement ensures that all signatories adhere to one intellectual property rights system, which has been recently extended to include biodiversity. History has seen considerable exploitation of plant material from developing countries by more developed nations. For example, the Netherlands obtains an income from bulbs of South African origin which is larger than the annual South African income from gold mining (Littlejohn 1994). Increasingly human genius and innovation are revolutionising the potential use of biodiversity (The Crucible Group 1996). There is growing concern over the ownership of biological material, in particular as much of the expertise in processing biomaterial lies in the developed world, while two-thirds of the world's plant material originates in less developed nations (The Crucible Group 1996).

South Africa's new Biodiversity Act (No. 10 of 2004), does make provision for bio-prospecting and subsequent benefit sharing, and it is to be hoped that these regulations will be potent enough to protect South Africa's indigenous flora and knowledge from unfair exploitation. The act does make mention of indigenous knowledge and reference to the inclusion of any material that contains indigenous gene strains which should go

towards ensuring the protection of these two aspects which are felt to be overlooked by the patenting system imposed by the TRIPs agreement.

8.7 Nurseries and community projects in the study area and lessons learnt

There are a number of nurseries in operation within the vicinity of the study area (Fig. 8.1). These are discussed in some detail below so as to highlight their views on nurseries in this semi-arid environment (see Table 8.2 for a summary of these findings).

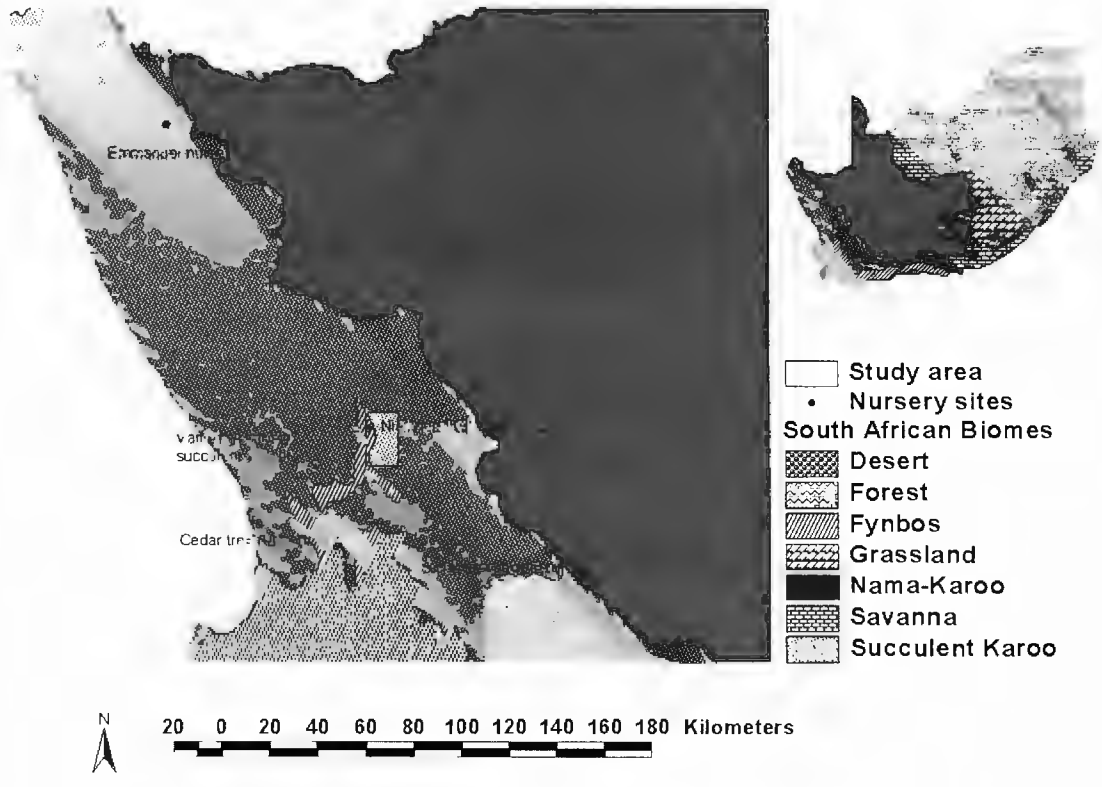

Figure 8.1 Map showing the study area, and the location of nurseries within the vicinity of the study area, and the biomes of South Africa.

8.7.1 The Nieuwoudtville bulb nursery

The Agricultural Research Council (ARC) started the Nieuwoudtville bulb nursery in 1996 with funds from the Reconstruction and Development Programme (RDP) (Steenkamp 2002). The aim of the project was to develop a number of bulb species for domestic and international sale. The focus has not been on the production of indigenous bulbs, but on cultivars developed by the ARC.

Infrastructure development and training took place in the first years. The project struggled in the early years with funding and changes in management. Infrastructure costs were

higher than expected, and the first major profits, of R80 000, were only made in 2001. The nursery is under the management of the Department of Agriculture and at present employs five permanent staff and 30 temporary workers who are employed for six months of the year.

The nursery is largely a commercial, supply nursery not aimed at the tourist, retail market. Of the R490 000 generated in sales in 2002, only R4000 was from sales to tourists, largely in the form of pot plants. However, during the 2002 flower season there were about 700 visitors to the nursery, and an entrance fee has been charged since 2003. The main commercial buyers are Vosbol, who buy all the lachenalias, and Showers for Flowers, who buy the remaining bulbs. Currently the demand from these two buyers is not being met and there is a desire to expand production. Marketing was initially a stumbling block and the relationships with retailers took a while to establish and have had to be carefully fostered.

Nieuwoudtville is an excellent place for the growing of bulbs as the climate and substrate are ideal. Plants grown here include cultivars of lachenalias, tritonias, ixias, sparaxis, freesias, watsonias, *Babiana ditichyn* and *Ixia viridiflora*. Other plants which are being trial-grown at present are zantedeschia and tulips.

The lachenalias are grown from bulblets purchased from a private supplier. Seed to establish the other species was purchased from Kirstenbosch Botanical Gardens in Cape Town. It is believed that it is too expensive to collect seed from the wild. Developed cultivars are largely used due to their more uniform and frequently enhanced appearance and have a more mass appeal. It is felt that the market for the actual original species is highly limited. However, in 2002, collection permits were obtained for the collection of species of *Babiana, Bulbinella, Gladiolus, Lapeirousia, Romulea, Spiloxene, Oxalis* and *Zantedeschia odorata* to satisfy the limited tourist market that do buy from the nursery. The recently discovered clivia, *C. mirabilis*, to be grown from material from the South African National Biodiversity Institute, will be available in the nursery by the end of 2005. The Department of Economic Affairs has provided funding for the shed extensions and the development of the greenhouse specifically for the growing of this clivia.

Difficulties experienced include the expense of the necessary chemicals used in the process and the presence of viruses limit the species combinations that can be grown

together and what can be grown on the same land in subsequent years. Water may become a limiting factor, possibly restricting expansion in the future. The ownership of the project has been a complex issue. While the intention was to hand the project over to the community, in the form of a Section 21 company, this has yet to take place. Currently the project is still managed by the Department of Agriculture, with limited consultation with community members working in the nursery. Those working in the nursery feel it is time to expand the operation, to diversify their product, and to start collecting and growing Nieuwoudtville species from seed. One of the workers felt strongly that this would save the cost of buying bulblets and would also create more employment and subsequently community upliftment. It was felt the community at large should be more involved in the project, especially as there is a wealth of knowledge around indigenous plants and their propagation that is currently unused.

8.7.2 The Emmanuel nursery

The Emmanuel nursery, established in 1996 with funds from the Namaqualand Diamond Trust, forms part of the Emmanuel Home for the Disabled in Steinkopf. While this nursery falls just north of the area included in this study, it was felt the venture warranted investigation, in particular given its focus on endemic succulent species. The home is fairly large and run by the Dutch Reformed Church, with about 60 residents and is the only institution for people with disabilities in the region.

The aim of the nursery was to grow rare and endemic succulents of the Namaqualand region, with the intention of generating revenue for the home and skills for the residents. The nursery is functioning and plants are sold to locals and tourists. The nursery receives on average two busloads of tourists a month (Oppel pers comm.). Marketing has been through the Steinkopf tourism organisation and to a lesser degree by groups like Succulent Safaris. Sales however are limited because the nursery is still establishing a stock of plants. At present the nursery employs two people. Major sellers are the aloes, in particular *A. dichotoma* and *A. pillansii*. The establishment of the nursery has been slow, largely because of the slow establishment and growth rate of succulent species. The centre around the nursery is diverse and offers arts and crafts for sale and there is also a tea garden.

8.7.3 The Cedar Tree nursery project

The cedar restoration project, started by Cape Nature Conservation, closed down because of a lack of resources. The nursery has recently been re-established in a more efficient location. This project is not a commercial venture, but has the sole purpose of re-populating the Cederberg with *Widdringtonia cedarbergensis*. While there has been some dispute over ownership and management between the conservation authorities involved, it is currently under the direction of the Western Cape Nature Conservation authority. To date there has been no community involvement, but plans are underway to get members of local communities to collect seed for the establishment of seedlings. In addition to this there are plans to establish a number of satellite nurseries in schools to promote awareness around the conservation issue of the declining *W. cedarbergensis* populations. This scheme will include a reward system for these nursery participants for replanting saplings, as well as the option for private sales to tourists in the season.

8.7.4 Tulip farming in Sutherland

Recognising that Sutherland in the Karoo was an ideal site for tulip production, a commercial farmer in the area set up a tulip bulb production process in 1996. The extreme winter temperatures, water quality, rainfall volumes and soil type in this area are all good for tulip production (Naude-Moseley 2003). The cold snaps in winter have the added benefit of killing pests (Naude-Moseley 2003).

Tulip production is capital intensive; the bulbs must be purchased, irrigation installed, fencing erected to deter porcupines and rabbits, and considerable volumes of fertiliser, pesticides, fungicides and mulch applied (Naude-Moseley 2003). It is also fairly labour intensive with half a hectare requiring between 10 and 12 labourers. The work, however, is not permanent but limited to intensive periods during various stages of production. This farmer only produces bulbs, which are then sold on to a flower grower in Cape Town who produces flowers for export.

8.7.5 Succulent nursery in Van Rhynsdorp

The Kokerboom nursery in Van Rhynsdorp, one of the most well known succulent nurseries in the country, was established in 1963 by Mr Buys Wiese. The nursery produces over 1000 different species of succulents, and provides employment for about 10 people.

It took the nursery approximately 10 years to become successfully established. Initial problems with cultivation techniques and start-up cost for infrastructure and production were considerable stumbling blocks. Pesticides are a major expense to the nursery, at a cost of R5000 per month.

Sales to the public are seasonally dependent, with the most lucrative months between May and October during the flower season. Succulent markets are described as limited as the plants are difficult to grow; the seedlings are extremely sensitive and require pure rainwater. Once established, succulents are difficult to keep alive in other areas. There is a perception that South Africans are reluctant to pay for something they see as freely available to them in the veld, and that on the whole city people prefer exotic plants.

Difficulties in starting the nursery included a working knowledge of plant production and on what the markets demand. Effective training of workers, which is done on the job, takes about three to four years. Developing the products also takes a long time. First, a seed source must be established and then there is the slow growth rate of most succulents, in particular the larger species such as the aloes, to be taken into account.

Over 90% of the nursery's material is sold to South Africans. Exporting is not an option largely because most of South Africa's succulents are already available overseas. In addition, the legislation and permitting required for export are complex and the added cost of airfreight excessive. Permits are not available at the nursery for foreigners wanting to export plants they have purchased. Should the permitting process be improved and different transport options explored (for example preventing plants from freezing, thereby being able to survive the longer, but cheaper, shipping process) there may be an opportunity to branch into the overseas market.

Table 8.2 Summary of information derived from an investigation of five local nurseries operating in the study area.

Case Study	Species cultivated	Funding body	Ownership	Tourist sales	Exports	Training	Numbers employed
Nieuwoudtville bulb nursery	Hybrid bulbs	The RDP and the Department of Economic Affairs	Department of Agricultural Affairs, but to become a Section 21 company	Yes, limited	Sell to local exporters	On site	5 permanent staff, 30 seasonal staff
Emmanuel nursery	Namaqualand endemic succulents	Namaqualand Diamond Trust	Emmanuel home and the Dutch Reformed Church	Only	None, but have had requests	None, but one is trained.	2 permanent staff
Cedar nursery	Widdringtonia cedarbergensis	The Botanical Society	The Western Cape Nature Conservation Board	No, potential	No	None	2, with possible expansion with proposed community involvement
Small scale tulip farmer	Tulip hybrids	Private	Private	No	No	Unknown	10–12 people on a seasonal basis
Van Rhynsdorp commercial succulent nursery	Succulents	Private	Private	Yes	Yes	On site training of 3–4 years	8

8.8 Issues and constraints

8.8.1 Emerging key issues

There are a number of lessons that can be learnt from the nursery and community development projects already established in the vicinity of the study area and those raised in interviews with relevant parties who were either directly or indirectly involved in horticulture or horticultural related community development projects.

Start-up funding and continued longer-term support for marketing are described as essential. Ownership is an important foundation for a sustainable enterprise and can be enhanced through sound participatory involvement at the start-up of a development project. Having reputable and recognised partners helps in obtaining funding. Project monitoring needs to take place to identify shortcomings, formulate corrective and innovative action and is the basis for improving future development.

An understanding of, and sensitivity to, the social context and dynamics is vital to the sustainability of any community project. A preference for employing women was noted by a number of nursery owners. A study on entrepreneurship in South Africa placed South Africa below the international average, thus indicating the need to foster entrepreneurial activity. Statistics indicate that this is most lacking among rural, previously disadvantaged communities. Education is identified as vital in addressing this issue (Driver *et al.* 2001). Projects are most effective when built upon existing skills in the community, and this should be pursued whenever possible. Communities should develop skills and thus become empowered to succeed in the enterprise, and develop confidence to cope with new challenges. Management skills and financial administration are vital to the success of any enterprise and these need to be developed within the communities involved. Technical skills need to be developed with regard to horticulture and associated activities.

Organisational development is a core activity of any business, and is critically important when the majority of owners and participants lack business and organisational experience. The development of a constitution, with the active participation of all parties involved, goes a long way in ensuring that everyone has common goals and approaches to achieving these goals.

Crucial to the success of any business venture is developing a detailed business plan, identifying target markets and establishing trading partners at the outset. There is a need for general market research to identify opportunities. Trade, and in particular overseas trade, requires certain infrastructure investments, and phytosanitory certification is needed for export to certain countries. All legislation pertaining to the enterprise needs to be understood and effectively followed by all parties. Direct plant sales aimed at tourists will fluctuate with the tourist season.

Deciding which species, of those demanded by the public, to propagate, needs to be considered carefully. Common or easily propagated species would mean community nurseries would be at a disadvantage in trying to compete with bigger, established commercial nurseries. Rare and threatened species might only appeal to a limited market but could have greater conservation consequences. The selection of the species for propagation and the markets to be targeted are vital to the success of a nursery scheme. Commercial retail nurseries in Cape Town argue that to be profitable 70% of their sales must be goods other than plants for example equipment, books or revenue from the coffee shops (note this relates to retail nurseries, not growers or supply nurseries). Propagation and cultivation require certain infrastructure costs and investments, such as warehouses, shade cloth, possible pesticides, etc. Climate, substrate and a good water supply are essential and potentially limiting in an arid environment. The condition of plants, quality of production, and consistency in the product are all felt to be very important in ensuring sales and developing a market. Location is important, where distance from markets and accessibility will affect the viability of an enterprise.

8.8.2 Feasibility and constraints

The development of nurseries in the Bokkeveld plateau is unlikely to provide a great number of employment opportunities nor generate vast amounts of revenue. Nurseries do, however, offer the opportunity for secure employment for a few people, and a number of opportunities for involvement of members of local communities, and the potential for expansion into other enterprises.

The size of the succulent market is presently unknown, and the financial returns on succulents are not great. Succulents are slow growers, people generally demand larger plants which can take up to ten years to reach a saleable size, therefore profits will not be

realised for a few years. Export of succulents has been argued as difficult, and for successful transportation consignments must be stored at ambient temperature.

The market for bulbs is greater that that of succulents. The general view is that there is considerable potential for expansion and development in this sector. Not all bulbs are worthy of investigation as many South African bulbs produce small blooms and flowering can be erratic. There is a difference of opinion between the major commercial growers and smaller bulb nurseries on the feasibility of bulb production as part of a community development project. Cultivating indigenous bulbs in their area of origin is problematic as the same area is home to their specific pathogens. This both increases the risk of the operation and presents problems in certifying them disease free. It is argued that this is why South African bulbs are grown more successfully elsewhere in the world. Extensive use of Methyle Bromide can solve this problem, but presents other environmental concerns.

To maximise profits, products need to be targeted at the export market. The most successful approach is believed to be bulk propagation of a few carefully selected species. Start-up costs for large-scale wholesale production tend to be high at about R1 000 000 per ha including all support facilities. If glasshouses are required then this figure can triple. Others argue that start-up costs need not be exorbitant. Smaller growers argue that more than half the indigenous bulbs can be grown out in the open with no need for cover. Predation by porcupines, rabbits and other animals must be considered and may require some infrastructural intervention.

To establish successfully in the market place, and in particular the overseas market, products must be of high and consistent quality. To gain access to international markets the development of cultivars and hybrids is the most appropriate strategy as these are more consistent. However, this would not meet the dual conservation aim. If propagation is to take place at a species level then clonal material needs to be used for consistency. The cut flower markets are extensive and frequently in search of new and innovative species, and many of South Africa's bulb species may make excellent cut flowers.

Some respondents stated that water is as a considerable constraint as bulbs require more water than any other crop. This suggestion would appear to apply to exotic bulb production, as indigenous bulb producers have stated that it is important not to water

excessively. Seed availability is a further constraint and obtaining from other nurseries is both crucial and essential for the start-up of any project.

There is a difference of opinion as to the degree of technical knowledge required to cultivate bulbs. Once again it is argued that for large-scale wholesale production detailed technical knowledge is required. Smaller-scale producers do not agree with this.

The existing tourist industry in Nieuwoudtville is well supported during the flower season when the town is visited by relatively large numbers of tourists. The town has a well-established tourism committee and tourist information services, which have effectively promoted Nieuwoudtville as the 'Bulb Capital of the World'.

The bulb nursery in Nieuwoudtville had not, in the past, focused attention on the tourist trade. Being a commercial supplier nursery it doen not advertise or encourage tourist, have any tourist facilities nor on site outlet for plants produced here. Nonetheless, it was visited by over 700 tourists in 2002, who purchased R4000 worth of bulbs from the nursery. These tourists expressed considerable interest in purchasing the indigenous bulbs of plants they had seen while on tour or in the field guides. While the nursery is primarily a supplier nursery, in light of the evedent visitor interest, it is suggested that the nursery expands their production beyond that of predominantly a supply nursery by placing more emphasis on retail. This should be by diversifying into the indigenous bulb flora of the Bokkeveld escarpment, aimed at taking advantage of this tourist market. The Nieuwoudtville nursery is currently a successful supply nursery, and this proposed expansion would take advantage of the emerging demand for retail material from tourism.

It would be worthwhile to start production on five or six of the most popular indigenous species. Seed to initiate production should be collected from the surrounding natural areas, with the necessary permits. It generally takes about three years for a seedling to reach flowering age. Establishment of local indigenous species is viewed as straight forward. It is argued that there is a clear potential here which should be explored and developed, especially given that the Nieuwoudtville nursery is currently sustainable and generates profits. There are a number of difficulties foreseen with the possible expansion of the Nieuwoudtville bulb nursery. These include resolving ownership issues, developing management skills within the community and securing a water supply, all of which need to be resolved before pursuing this development option.

8.9 Discussion and conclusion

8.9.1 Development potential of a perceived ecosystem good

Plants species and diversity are integrally linked to the supply of ecosystem services, and humans are dependent on them for a range of identified ecosystem goods including forage, timber, biomass fuels, natural fibre, pharmaceuticals and industrial products (Daily 1997b). There is also considerable human interest in plants from both their aesthetic and curiosity value, and more recently, from a conservation perspective (Glavovic 1993). Farmers in the study have perceived this and the development potential of indigenous plant species in their landscapes. My analysis validates these perceptions and indicates that plant species within the study area are ecosystem goods with future development potential, although there are a number of constraints that need to be overcome if this opportunity is to be realised.

There is a great deal of interest in the vegetation of the study area, visible in overseas markets and as expresses by tourists to the study area. At present bulb species production is not meeting this demand and it has been suggested that expansion into indigenous bulbs should be attempted. This would have both the desired effects of generating long-term income possibilities for the community and conservation of the bulb flora in this area.

The horticultural potential of South African plant species generally, has long been recognised, with particular interest shown in bulb and succulent species (Musgrave 2003). The Cape Floristic Region and the Succulent Karoo Biome are both exceptionally rich in plant species with many endemics (Cowling *et al.* 1992; Cowling *et al.* 1999; van Wyk & Smith 2001). The horticultural potential of the Cape Floristic Region has been explored and species of *Cyrtanthus, Nerina, Ixia, Watsonia, Gladiolus, Pelegonium, Protea Leucospermum, Restios* among numerous other species are already important horticultural crops (Donaldson & Scott 1994; Cowling & Richardson 1995). This is a strong indicator that the same could be achieved in the neighbouring Succulent Karoo biome, and more importantly within the study area on the Bokkeveld plateau.

Rural livelihoods are often inextricably linked to the supply and availability of ecosystem goods. In South Africa plant species provide important ecosystem goods for both cultural purposes and as important informal sector products, providing small but necessary

incomes for harvesters. The trade in medicinal plants is one such example, providing vital income for harvesters and a desired product that is often harvested at unsustainable levels (Botha *et al.* 2004a; Botha *et al.* 2004b). The harvesting of mangroves for charcoal production is a further example of community use and reliance on an important plant species and one where sustainable livelihoods are being achieved in South Africa (Geoghegan & Smith 2002). Ecosystems goods have the potential to provide local communities within the study area with opportunities to develop sustainable livelihoods. Nurseries and the production of indigenous plant species are one such opportunity. However, only a limited number of people could be employed in such a venture and there are numerous obstacles that would need to be overcome in order to ensure success. These include establishing ownership, developing management and horticultural skills, having partners in the process, developing detailed business plans which include complying with legislation, and developing infrastructure to ensure good water supply and growing conditions.

This study has shown that farmers correctly perceive the opportunities for horticultural development provided by plant species within the study area. However, it is limited in that it will not provide sustainable livelihoods for a large number of people, and there are a number of constraints that need to be overcome if this opportunity is to be realised. Nonetheless it still represents a development opportunity and demonstrates that future use options within the plant species diversity of the study area exists.

8.9.2 Remnants, biodiversity storage and future use options

Daily (1999) in her development of an ecosystem services framework describes the preservation of options as one of five ecosystem service categories. She characterises this ecosystem service as requiring the maintenance of the ecological components and systems needed for future supply of goods and services and others awaiting discovery. This study has shown that farmers see value and future potential in their natural vegetation and that this has been verified. Fragments of natural biodiversity on farms provide a repository for this biodiversity, which can be developed in the future. This study demonstrates that there is value for farmers in retaining natural vegetation fragments for the future use options they provide, not just to themselves but for the broader rural community as well. Higgins *et al.* (1997) examined this storage value of biodiversity in fynbos. They argued that given the high option value of this diverse vegetation type, reflected in the cultivation potential

of many species, the future economic potential of this genetic diversity can be equated with the establishment of a gene bank. From this they demonstrated the economic value in investing in effective management of fynbos systems which are a store of this valuable diversity for future use. While remnants provide future use options, once produces are identified and established there is less motivation for remnant conservation, and the conservation initiative becomes a more species-specific one.

Natural vegetation fragments on the Bokkeveld plateau contain a diversity of plant species many of which has not yet been explored and exploited, and careful management of these biodiversity storage areas is required if farmers and the broader community are to gain the maximum benefit from the ecosystem goods held here in the future as demonstrated by this study.

Chapter 9

The relationship between ecological processes, land-use strategies and biodiversity conservation

9.1 Motivation for the study

Just as biodiversity loss and ecosystem degradation is recognised as a global problem, there is growing awareness that it is not politically, socially, or economically possible to create enough conservation areas to protect all biodiversity. Conservationists must now look to private land to meet conservation needs (Bond 1999; Wessels *et al.* 2003) and in South Africa the majority of this land is held by commercial farmers. Agricultural production inherently relies on natural processes or on expensive substitutes for these natural processes. Conservation could be achieved in commercial agricultural landscapes through the promotion of biodiversity-friendly agricultural practices if farmers see the value in adopting this type of approach.

Ecosystem service research is conceptually a relatively new field of enquiry. While the realisation that benefits flow to humans from the functioning of natural systems has long been recognised (Mooney & Ehrlich 1997), there is little understanding of the links between ecological processes, biodiversity and the delivery of ecosystem goods and services (Kremen 2005). Previous research in the area of ecosystem services has generally been focused at regional-scale studies aimed at influencing policy. This study, however, explored the opportunities for promoting biodiversity-friendly land-use practices, through the identification and examination of ecosystem services at a local level that farmers valued. In discussing risk analysis, Wynne (1992) states that the inclusion of local perspectives allows for, 'placing scientific knowledge on a more legitimate, properly conditional and ultimately more effective footing'. My study deliberately incorporated local perspectives on ecosystem goods and services thereby increasing the possibility of affecting land-use change in the study area. In this chapter I return to the four key research questions posed in the first chapter dealing with each of these in detail below.

Farmers identified a number of ecosystem processes that are vital to the functioning of their farming operations and the maintenance of their resource base that would be costly to replace. In particular, soil, the very land on which these people farm, was possibly the most important element, given that it is the basis of all farming activities. All activities that maintain this resource were particularly highly valued. These included soil turnover activities of porcupines and soil organisms, and vegetation cover both generally and those fragments that acted as windbreaks. Farmers also perceived a number of ecosystem disservices, one of which was suggested that the loss or decrease in abundance of small mammals results in greater predation on sheep by medium-sized predators.

Farmers on the Bokkeveld plateau are aware of the natural functioning of their environments and have clear perceptions of how their farming practices interact with a number of ecological processes. They are conscious of the ecosystem goods and services and disservices they derive from their environments, and in turn are aware to some degree of the impacts their practices have on ecosystem functions. They perceive agricultural resources and their use to be synonymous with ecosystem goods and services. This awareness is entrenched, and it was apparent that farmers manage their land within an ecosystem-service framework, which can be divided into the categories of structural services, information services, production and regeneration services, provisioning services, and cultural services.

9.3 What are the effects of land-use practices on the identified ecosystem goods and services, and is their delivery dependent on the incorporation of natural vegetation and the maintenance of key ecological processes?

My investigations of identified services clearly indicate that the delivery of ecosystem goods and services depend on land-use practices that incorporate natural vegetation and maintain key ecological processes. The Bokkeveld plateau's land-use practices are dominated by livestock production, and there are a number of vegetation types utilised for grazing here. Vegetation types varied in their supply of ecosystem goods and services required for grazing. Vegetation structure and composition, nutrition, productivity and biomass were found to differ amongst vegetation types. Vegetation types provide different grazing goods and services, and access to these depends on access to different vegetation types.

Transformation and grazing can also have unexpected consequences for the farmer, where a previously unperceived ecological process may be altered, resulting in the loss of an ecosystem service. In this landscape, management practices were found to have an impact on small mammal abundance, which may skew predator-prey relationships, and in turn negatively affect livestock production. In investigating small mammal density and diversity I determined that these were strongly correlated with landscape and vegetation structure. My findings show that 82% of all small mammals trapped were trapped in the dolerite ridges. Transformation also has a major effect with seven times more small mammals trapped in renosterveld compared with transformed renosterveld areas. This investigation demonstrates the value of retaining landscape diversity because of the novel services offered by different vegetation types. This study stresses the importance of careful management in the dolerite ridges, and the importance of vegetation structure in the provision of this service. In this instance consideration for the loss of habitat diversity would have prevented the collapse or reduction in this ecological process and service.

My investigations clearly demonstrated that some ecosystem goods and services are lost through the transformation of natural vegetation. Results show that soil is rendered vulnerable to loss with soil retention services having been compromised. Eight times the volume of sediment was trapped in transformed areas compared with natural vegetation. Organisms that perform vital services involving soil turbation that influence infiltration, soil moisture and aeration, are also disrupted through transformation and the loss of above ground habitat diversity and vegetation cover. It appears that transformation of natural vegetation creates a landscape with greater variability in its provision of ecosystem services while natural areas provides a steady stream of benefits and are not as strongly affected by factors such as rainfall.

The retention of key components of biodiversity, functional diversity and functional compensation are necessary for providing and maintaining ecosystem goods and services in both transformed and natural states. Natural areas contain a diversity of organisms that are responsible for soil health. An examination of a number of these organisms and processes in this study, and reported elsewhere (Bragg *et al.* 2005), showed animals that typically turbate soil are negatively affected by transformation. Remnant vegetation islands are areas from which surrounding, transformed lands may be successfully re-colonised, and certain services thereby maintained. Possible evidence for this was in the gradient of soil invertebrate activity, an important component to soil health, radiating from

these remnant patches of vegetation and dissipating with increased distance from them. Alternatively these results indicate that the value of remnants extends beyond the vegetation boundary and includes possible edge effects within the proximity to the natural remnant. Interestingly, in this study there was a measured increase in earthworm activity in managed transformed renosterveld. This points to a possible functional compensation in managed transformed renosterveld, where previously a number of species contributed to the delivery of an ecosystem service. With their loss, this role is adopted by one remaining species, which has either survived transformation activities or has successfully re-colonised transformed areas. Not all ecological processes that are beneficial to humans are lost through vegetation transformation activities, and as demonstrated here transformed areas still provide ecosystems goods and services. While management inputs such as the application of fertiliser and sowing of pasture, could to some degree compensate for the loss of some services, this is widely recognised as an expensive intervention (Daily *et al.* 1997b).

Biodiversity remnants are important reservoirs and repositories for species including those that could have future potential use and application. A study examining the creation of nurseries producing indigenous plants found within the study area, demonstrated one such potential future use option of the areas' plant diversity. Land-use practices need to ensure that processes maintaining biodiversity in natural vegetation fragments continue to operate for these future use values to be appreciated. While grazing practices may degrade these ecosystem goods, the details of which would need to be explored, the transformation of further fragmentation would most certainly result in their loss. The same would be true for the aesthetic value placed on natural vegetation.

9.4 Are farmers' perceptions about ecosystem goods and services accurate?

Farmers perceived that there were important spatial and temporal differences in grazing goods and services amongst different vegetation types. My findings indicated there were differences in vegetation structure and composition, biomass, productivity and nutrient content in vegetation types used for grazing. Unlike these perceived spatial differences in vegetation, no temporal differences in vegetation growth and reproduction could be verified. However grazing strategies appeared to take advantage of the differences in vegetation nutrient content at key times, and avoided areas where disservices would be incurred.

Farmers seemed to be aware of the consequences of their management practices on ecosystem goods and services. They correctly concluded that rainfall infiltration was better on managed transformed lands, which was shown to be true. In addition, their perception of the importance of functional groups of species in maintaining infiltration processes was also accurate, with both earthworm activity and porcupine diggings having a significant influence on rainfall infiltration rates. In interviews, farmers noted that soil was more likely to be lost from transformed area than from natural vegetation and this perception was shown to be correct. Despite their recognition of this service, the structural properties of natural vegetation are not extensively incorporated into farm planning, with only a couple of farmers having retained natural vegetation along boundaries as a windbreak. This indicates that while their perceptions are correct, the value that farmers place on a particular service may not be sufficient to influence farming practice.

The analysis of small mammal abundance also corroborated farmers' perceptions that prey density would vary in different parts of the landscape and was influenced by land-use. I was unable to test whether small mammals provide an alternative food source for predators, but small mammal densities were found to be high enough to sustain medium-size predators given normal range conditions.

Farmers perceived the future economic development potential of indigenous plant species for horticultural production. My assessments concurred with these perceptions, and there is future developmental potential for the establishment of nurseries in the study area supplying indigenous plants. Farmers did not make the link between the future use of plant species and the retention of natural remnants as repositories holding biodiversity with future use value. This indicates that farmers substantially underestimate the future potential value of natural remnants, given scenarios of climate change, and market demand for novel and new plant species for applications such as horticultural plants.

Whilst able to identify a broad range of ecosystem goods and services, farmers found it easier to identify goods than they did services or ecological processes. Gray and Morant (2003) compared scientific investigations with farmer perceptions of soil classification and fertility in Burkina Faso and had similar results. They found that farmers' perceptions of soil classification matched up well with scientific investigations, however this was not the case for the complex processes relating to soil fertility and its degradation over an eight-year period.

Despite an appreciation of the goods and services, comparisons suggest that farmers are unaware of the magnitude of effects that land-use practices, such as vegetation transformation, have on ecosystem goods and services.

9.5 How can conservation of biodiversity on farmland benefit from increasing our understanding of ecosystem goods and services at a farm level?

The broader aim of this thesis has been to facilitate and affect future land-use change and promote biodiversity conservation through a better understanding of the links between ecosystem goods and services and land-use strategies in a commercial farming landscape. The concept of ecosystem goods anPd services developed as a means of demonstrating the value of ecological processes to human society. While scientists are grappling with the conceptual issue of how diversity links to ecosystem processes and whether all species are important (Naeem 2002a; Lyons *et al.* 2005), farmers are working at a more intuitive level based on their experiences and perceptions. The approach that scientists take is to study biodiversity and then to look at ecological processes, and finally at possible human benefits. Farmers are working the other way round, trying to manage their farms to achieve benefits for themselves. In so doing, they may consciously or unconsciously be identifying ecosystem goods and services that benefit their farming practices. These perceptions influence land-use and farming practices. As a result, understanding farmers perceptions and testing some of their assumptions can provide a basis for illustrating the links between biodiversity and goods and services at a farm level and in this way offer opportunities for conservation on private land.

To date ecosystem goods and services studies have been carried out primarily at regional and global levels primarily aimed at influencing policy and legislation at these levels and valuing ecosystem services. The South African Millennium Ecosystem Assessment (SafMA) evaluated relationships between human welfare and specific ecosystem services (fresh water, food, fuel wood, cultural resources and biodiversity), across multiple scales noting trends in these services (Scholes & Biggs 2004; van Jaarsveld *et al.* 2005). As a component of this assessment, Bohensky *et al.* (2004) focused on the trends and conditions of ecosystem services in the Gariep basin between 1993-2003. They demonstrated links between human well being and ecosystem services and emphasised the need for the incorporation of ecosystem services into decision-making regarding development issues in this basin. Cowling *et al.* (1997) examined the value ecosystem

goods and services supplied by Fynbos ecosystems at a regional level. They highlighted the diverse array of ecosystem services this biodiversity hotspot supplies particularly the delivery of water in mountain catchments which has resulted in the initiation of alien vegetation clearing projects from these areas. The Ecosystem Service Project carried out by Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) is a prime example, examining ecosystem services across multiple scales (Binning *et al.* 2001; Abel *et al.* 2003). The primary aims of this project being to: engage policy developers and decision makers, assess services provided by a range of ecosystems and explore these under changing scenarios from an ecological, economic and social perspective, investigate structure for accounting and investing in natural assets and processes (Cork *et al.* 2001; Abel *et al.* 2003; Cork 2003).

The approach I adopted of examining ecosystem goods and services at a fine scale is novel in that only a limited number of studies have focused on ecological processes and their links to goods and services at this scale. Other studies that have been carried out at a local level, and adopted an ecological approach over an evaluation approach, have demonstrated the benefits of retaining biodiversity on private lands to ensure the continued delivery of a single ecosystem service. For example Kremen *et al.* (2002) working in California, demonstrated that native bees on organic farms near natural habitat, were able to provide crop pollination services for water melon (*Citrullus lanatus*) in place of managed honey bees. Ricketts (2004) working in Costa Rica also demonstrate the pollination benefits to coffee production of indigenous forest fragments close to plantations. These are both important studies providing much needed evidence of local level benefits of the value of retaining biodiversity for production. My study has attempted to build on this fundamental research, adopting a more holistic approach to examine as broad a range as possible of ecosystem goods and services beneficial to farmers at a local level combined with ecological process links. The conceptual model developed in chapter 3 shows the numbers of services farmers perceived to be important in their production processes which they benefit from. It further demonstrates how the delivery of goods and services are ultimately all interconnected, and a change in one service can have knock on effects, with the reduction or even loss of other services. I believe there is considerable value in demonstrating a range of ecosystem services, as it reduces the risk element of hinging conservation on a single service, as product prices drop and tastes change, and farmers switch their production focus accordingly.

There are difficulties attached a holistic fine scale examination of goods and service. No two farms are the same in terms of the resources they encompass, and management goals and strategies differ according to the goods and services farmers have access to. As landscape and farm heterogeneity increase, the breadth of knowledge of a variety of ecological processes and necessary experimentation increases making holistic studies difficult and time consuming.

It has been argued that the lack of awareness regarding ecosystems goods and services is one of the main factors contributing to their degradation (Cork 2003). This study has shown that farmers have an awareness of the ecosystem goods and services in their landscapes. Adopting a qualitative approach, whereby farmers identified the goods and services they perceived to be operating in their landscapes, I was able to narrow the focus of the research to investigate some of those ecosystem goods and services farmers regard to be most important in this heterogeneous environment.

Ecosystem goods and services studies at both the regional and local scale also have noted the benefits of involving the communities within the research area and the value of incorporating qualitative research methodologies. Cork (2003) stressed the importance of public participation and community involvement in identifying ecosystem goods and services, developing management plans and negating conflict between scientists and community members within the Goulburn Broken catchment, which formed part of the larger Ecosystem Service Project in Australia. In this same project, Shelton *et al.* (2001) developed an inventory approach to involve stakeholders to identify ecosystem service within the catchment. They used a workshop approach involving scientists, economists, representatives from industry, and the broader community within the catchment to define important products produced in the catchment, and then the ecological services central to their production. They then carried out a valuation of these goods and service, using a novel approach of capturing stakeholder values by combining a Deliberative Multi-criteria Evaluation with a Citizens' Jury process (Proctor 2001). This allowed for prioritisation, through the identification of both problems and trade-offs over this large catchment area (Abel *et al.* 2003). Kaplowits (2001) assessed community perceptions to ecosystem goods and services of mangroves in Mexico, and demonstrated that the most important ecosystems services are not necessarily the obvious ones. If an ecosystem goods and services approach to conservation and awareness raising is to be adopted, with the aim of

winning people over at a local level, it is essential to know what they perceive to be important.

My findings indicate that ecological processes are integrally linked into production activities and this provides fundamental evidence to farmers that they derive benefits from retaining biodiversity on their farms. I have shown that biodiversity-destructive practices erode ecosystem goods and services. Farmers may be able to technologically compensate for these, but this involves costs and risk in a product environment where set prices are no longer assured. Economic valuation, while fraught with complexities and frequently criticised, may be a useful area of future exploration at a local level, assessing economic value to individual farmers of the identified services. However, the approach adopted in this study, where research was guided by farmers' own perceived value of services, may negate the need for economic evaluation at this level, where one then operates within an individual's value system.

Economic studies do provide one side of a very important picture, in that they highlight the financial and economic conditions that favour conservation, conversion, or some state or combination of states between these. Valuation studies have made the very important point that conservation on private land is not necessarily economically optimal for the private landholder. Turpie *et al.* (2003) in their examination of the value of terrestrial and marine biodiversity in the Cape Floristic Region, South Africa, found that the private benefits of conserving fynbos areas do not provide sufficient incentives compared with transformation and more lucrative production including monocultures of indigenous species. Balmford *et al.* (2002) examined case studies at a biome level which compared the value of goods and services from intact areas with those converted to typical forms of human use. They found that the loss of non-market services outweighed the marginal benefits of conversion and did not make sense from a global sustainability perspective. A number of the studies they analysed indicated that conversion and destructive practices yielded higher short-term private benefits, some of these attributable to subsidies. Given the suggested lack of financial incentive for private land holders to conserve, a number of fiscal and monetary policy options and incentives have been suggested. These include the use of tax incentives, legislation, subsidies, the removal of harmful subsidies, grants and payments (Balmford *et al.* 2002; Tilman *et al.* 2002; Pence *et al.* 2003). Frazee *et al.* (2003) demonstrated that adopting this approach may also provide a cheaper way of ensuring conservation over establishing formal reserves.

Incentives and policies are important for promoting conservation. However these need to be introduced and coupled with a detailed knowledge of ecological processes and goods and services contributions to agricultural production. If farmers are going to meet future food demands whilst adopting sustainable agricultural practices, then current ecological knowledge needs to be placed in an agricultural context (Jackson & Jackson 1999), and the current biological and agronomic knowledge base needs to be rapidly expanded (Tilman *et al.* 2002). Farmers need to be given information on the range of ecosystem goods and services at their disposal, as a variety of production options enable them to best manage changing environmental and political conditions. It is particularly important to make clear to them the extent to which land-use decisions may be irreversible and result in the loss of goods and services, affecting current production and future use options. Encouraging agricultural practices that rely heavily on ecological processes compared with technological processes is the most direct way towards sustainable agricultural practices (Jackson & Jackson 1999; Jackson & Jackson 2002). Scientists need to lead the way in demonstrating the links between ecological process and farming production as businesses which supply most of the technological inputs will certainly not be leading this push (Jackson & Jackson 1999).

Conservation interventions are more likely to succeed if they meet the needs of the farmer and the rural communities (Donaldson 2002). If individuals perceive benefits from the maintenance of biodiversity and these out-weigh the benefits of transformation and the loss of biodiversity, then the conservation of this biodiversity is ensured (Jackson & Jackson 2002). By undertaking studies which demonstrate the effects of land-use activities on ecological processes, farmers are able to make better-informed decisions on how to adapt management practices to retain ecosystem goods and services if so desired. These studies and the concept of ecosystem services and biodiversity conservation, turn conservation from what is frequently perceived as a conflict of interests in a farming landscape, to a potentially beneficial farming tool.

The realisation of the value of ecosystems goods and services forms a bridge between land-use strategies and conserving biodiversity. In order to meet conservation targets we will need to use this bridge to save biodiversity in privately owned agricultural landscapes. The findings of this study show there is a great opportunity to promote biodiversity conservation through demonstrating the value of ecosystem goods and services at a local

scale, and thereby influencing land-use practices. In particular this study shows the potential to work within farmers' understanding of their landscape and to explore their land-use strategies as a means of highlighting the value of the natural ecosystem to their continued farming success. On the Bokkeveld plateau, farmers already work within an ecosystem goods and services framework, demonstrating a mindset that is open to the discourse of conservation. While the long-term value of this approach still needs to be tested, this study demonstrates that it is crucial for future conservation initiatives, particularly those focused on private land, to incorporate ecosystem goods and service studies into their arsenal of conservation tools.

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Appendices

Appendix 1

The aim of this series of questions was to open a channel of communication between myself and the farmers within my study area, and to develop an understanding of their perceptions with regards to ecosystem services relative to their farm history and land-use strategies. This series of questions was followed as a guideline and issues that farmers raised were pursued in detail. Answers regarded as ambiguous or insufficient were reworded and repeated at a later stage in the interview.

Questions for Nieuwoudtville farmers
Name:

Name of farm:

Farming details (To develop a picture of previous and current farming practice for the full extent of each farm included in the study area.)

Farm history
How long have you been farming on this farm?
Who farmed here before you?
How far back can the farm's history be traced?
Do you have farm records from before you started farming here (rainfall records, stock numbers, photographs)?

Farmed areas
How large is your farm?
What do you farm?

Schematic diagram of the farm (used to talk to in conjunction with 1:50 000)
Could you briefly sketch for me your farm, indicating where your paddocks and fenced-off areas are (confirm number of camps)?
Could you please indicate what activities take place in each area, at different times of the year?

Livestock
What livestock (and breeds) do you keep?
What is your stocking rate for each of these?
How many of each type do you have on your farm?
What are the sex ratios?
Do you keep records of fertility and mortality rates?
What is the greatest cause of premature mortality?
What proportion constitutes your off-take?
How many do you sell per annum?
Have you tried to keep other types of animals?

Do you know if anyone who farmed this land before you kept other types of animals?

Grazing strategy
Tell me about your grazing strategy.
How are the paddocks used on a seasonal basis?
Have the paddocks always been used on this basis?
How long have the paddocks been in this layout?
If changed, why was the layout changed and when?
Which of these paddocks are your favourites? Why?
Do you supply additional feed?

Wool (if applicable)
When do you shear your sheep?
How often do you shear your sheep?
What strand/quality do you aim to produce?
How would the a change in the wool price affect you

Cultivation
What do you cultivate?
How long have you been cultivating this crop?
Is this crop commercial or do you use it yourself?
Have you tried to cultivate any other crop in the past?
If so what and when?
If yes, why are you no longer cultivating this crop?
Do you have any other previously ploughed lands on your farm?
What was planted on these lands and when where they last planted?
What do you use these lands for now?
What grows there?
If you could turn these old lands into any other type of land on your farm what would you choose?
How would a change in the price of a previously or currently grown crop change your farming practice?

2. Farm management (What management techniques and strategies have developed in this environment.)

Land management
Do you remove any plants?
If so, by what means?
Do you ever burn land on your farm? If so, why and when?
Do you irrigate any lands?
What other land management strategies do you use?
Do have erosion on your farm?
If so, where?
Do you take any anti-erosion measures?
If so, what?

How do you manage water on your farm?
Have you built/altered water courses, built dams, pump groundwater, number of windmills?
Where are the water points on your farm?

3. Ecological Perceptions (Farmers' views/perceptions on the natural environment.)

Perceived ecological benefits
What does the natural environment on your farm offer you / assist you in your farming? (Ask farmer to expand on any suggestions made.)
What are the most important natural resources to you?
What areas of your farm have the most potential?
What are the most palatable plants?
Could you list the most palatable plants in order of preference?
What else do you use amongst the natural plants on your farm i.e. shelter, fuel, medicinal plants, eco-tourism?
In your opinion, are there any other potential future uses for the natural vegetation?
Do you engage in any form of eco-tourism or conservation?
Do you therefore practice any land management in relation to this?

Perceived ecological costs
What aspects of this natural environment make farming harder for you?
What is the most toxic plant on your farm?
Could you list the most toxic plants in order of preference?
Do you kill any wild animals on your farm?
If so, why and how (does this include hunting for the pot?)?
Do any of your land management practices relate to wild animals on your farm (i.e. fencing)?

Appendix 2

Species list of the dominant plant species which account for 80% of the vegetation cover, and the poisonous plant species as identified by farmers on the renosterveld, renosterveld transformed, dolerite plains, dolerite ridges, dolerite transformed and karoo veld vegetation types. Taxonomy follows Germishuizen and Meyer (2003).

Dominant plant species

Arctotis acaulis L.
Asparagus capensis L.
Avena fatua L.
Brachypodium distachyon (L.) P.Beauv
Bromus pectinatus Thunb.
Brunsvigia bosmaniae F.M.Leight.
Bulbinella nutans (Thunb.) T.Durand & Schinz subsp. Nutans
Cephalophyllum sp.
Chaetobromus dregeanus Nees
Chrysochoma ciliata L.
Cotula microglossa (DC.) O.Hoffm. & Kuntze ex Kuntza
Cotula nudicaulis Thunb.
Crosyne flava (W.F.Barker ex Snijman) D.Mull.-Doblies & U.Mull.-Doblies
Cyanella lutea L.f.
Dicerothamnus rhinocerotis (L. f.) Koekemoer
Dimorphotheca sp.
Ehrharta calycina Sm.
Emelia sp.
Empodium namaquensis (Baker)
Eriocephalus microphyllus DC. var microphylla
Eriocephalus namaquensis M.A.N. Muller
Eriocephalus purpureus Burch.
Erodium botrys (Cav.) Bertol.
Erodium cicutarium (L.) L'Her
Galenia affinis Sond.
Galenia africana L.
Galenia sp.
Geissorhiza subrigida L. Bolus
Gorteria diffusa Thunb. Subsp uncertain
Gorteria personata L. subsp. Personata
Hesperatha cucullata Klatt
Hexaglottis lewisiae Goldblatt

Moraea miniata Andrews
Hordium murinum L.
Karoochloa schismoides (Stapf ex Conert) Conert & Turpe
Lolium rigidum Gaudin
Lotononis hirsuta (Thunb.) D.Dietr.
Medicago polymorpha L.
Merxmuellera stricta (Schrad) Conert
Montinia caryophyllaceae Thunb.
Moraea tripetala (L.f.) Ker Gawl.
Ornithogalum conicum Jacq.
Oxalis grammophylla T.M. Salter
Oxalis obtusa Jacq.
Oxalis pes-caprae L. var. pes-caprae
Oxalis suteroides T.M. Salter
Pentzia incana (Thunb.) Kuntze
Plantago caffra Decne.
Poa bulbosa L.
Pteronia incana (Burm.) DC.
Pteronia sp.
Rhus undulata Jacq.
Rhynchopsidium pumilum (L.f.) DC.
Romulea tortuosa (Licht. Ex Roem. & Schult.)
Ruschia spinosa (L.) Dehn
Rushia sp.
Tetragonia sp.
Vulpia myuros
Wiborgia monoptera E.Mey.
Wiborgia tetraptera E.Mey.
Zygophyllum foetidum Schrad. & J.C.Wendl.

Poisonous plant species

Cotyledon orbiculata L. var. orbiculata
Dimorphotheca tragus (Aiton) B. Nord.
Galenia africana L.
Gomphocarpus fruticosus (L.) Aiton f.
Grielum grandiflorum (L.) Druce
Moraea miniata Andrews
Ornithogalum conicum Jacq.
Oxalis pres-caprae L. var. pres-caprae
Pteronia pallens L.f.
Tylecodon wallichii (Harv.) Tolken (var. uncertain)

Appendix 3

Questionnaire for target groups on the establishment of nurseries in the Succulent Karoo

International horticulturalists

- What are the current trends in the international horticulture markets?
- What components of South African flora are in demand in the international horticulture markets?
- What percentage contributions do South African bulbs and succulents make to these markets?
- Are these contributions increasing?
- Who are the main suppliers of South African bulbs and succulents to global and national markets?
- What are the sought-after South African succulent and bulb species?
- Who are the principal buyers of these?
- Are there opportunities for expanding in this market?
- How are South African indigenous succulents and bulbs marketed internationally?
- What is this industry worth?
- Do you think there is scope for the further development of nurseries focused on Succulent Karoo flora in South Africa?
- Could such a development be used to benefit previously disadvantaged communities?
- What are the major technical constraints involved in developing such a nursery?
- Are there legislative constraints?

National horticulturalists

- What are the trends in the international horticultural markets?
- What are the current trends in the national horticulture market?
- What components of indigenous South Africa flora are in demand?
- What are the proportional contributions do South African bulbs and succulents make in these markets?
- Is the demand for South Africa bulbs and succulents growing?
- Who are the main suppliers of South Africa succulents to global and national markets?
- What are the most sought-after South Africa succulent and bulb species?
- Who are the buyers of South African succulent and bulb species?
- Is there potential for market expansion in South African bulbs and succulents, nationally, and internationally?
- How are South African indigenous succulents marketed nationally, and internationally?
- Do you have any idea what this industry worth?
- Do you think there is scope for the further development of nurseries focused on Succulent Karoo flora in South Africa?

- Do you think such a development could be used to benefit previously disadvantaged communities?
- What would the major technical constraints be in developing such a nursery?
- Are there legislative constraints?
- Is there a demand or scope for plants supplied for practical purposes (e.g. erosion control, increasing productivity)?
- Do you see collections from the natural vegetation being a major issue?

Nurseries owners and workers in the Succulent Karoo

- What is the number of people employed at your nursery?
- What is the size/of the nursery?
- Where is your water supplied from and how much do you use?
- What are the start-up costs and running costs of a typical nursery?
- What are the main risks involved in setting up and running a nursery?
- How long has your nursery been running?
- What percentage of you stock is comprised of local indigenous plants?
- What percentage of your total income do indigenous plants contribute?
- Where do you get your start-up plant material from when growing a new indigenous species?
- What determines what plant you grow here?
- Which species are your top sellers?
- Is these demand or scope for plants supplies for practically possible (e.g. erosion control, increasing productivity)?
- How much technical knowledge is required to grow indigenous plants here?
- Who provides the horticultural information/know how to your nursery?
- What are the technical constraints in producing indigenous species?
- Are there legislative constraints in producing indigenous species?
- Is there potential for expanding the indigenous component of your nursery?
- Do you supply plants to other nurseries, are you a supplier nursery?
- Could nurseries be developed to facilitate community upliftment and job creation?
- Do your sales fluctuate seasonally?
- Who are your main buyers (local, national, international)?
- Do you market your plants locally, nationally, and/or internationally?
- What are the trends in the national horticultural markets?
- What components of South Africa flora area in demand?
- Where do South African bulbs and succulents fit into these markets i.e. what percentage contributions do they make?
- Are these contributions growing?
- Who are the main suppliers of South Africa bulbs and succulents to national and international markets?
- What are the sought-after South Africa succulent and bulb species?
- Who are the principal buyers of these products?
- Are there opportunities for expansion (bulbs and succulents) in this sector of the market?

- How are South African indigenous succulents marketed nationally/internationally?
- Do you have any idea what this industry worth?
- Do you think there is scope for the further development of nurseries focused on Succulent Karoo flora in South Africa?
- Do you think such a development could be used to benefit previously disadvantaged communities?
- What would the major technical constraints be in developing such a nursery?
- Are there legislative constraints?
- Is there a demand or scope for plants supplied for practical purposes (e.g. erosion control, increasing productivity)?
- Do you see collections from the natural vegetation being a major issue?
- Are there any other pressures on plants in their natural habitats?

Community development initiatives

- How do you ensure successful community involvement in development projects?
- What are the difficulties perceived in the establishment of nurseries in the Succulent Karoo aimed at community development?
- Where do community strengths lie?
- What would be the best role played by a community nursery, education, job creation, or conservation?

Tourist operators

- What are the routes and stops in Namaqualand and the Northern Cape?
- What are the main tourist draw-cards in these areas?
- Do you include nurseries in any of your stops and part of your tours?
- If not why not?
- If there were a community based development nursery en route would you include it in your itinerary?
- Do tourists buy plants and seeds, or express an interest in buying plants and seeds?
- If so what species or plant types do they go for?
- Do they collect plants from the natural vegetation on stops?
- Do they request any information, scientific, traditional, on plant use and plant diversity in the area?

Conservation organisations

- Do you perceive there to be community upliftment potential in the development of community based nurseries?
- Which species are affected by illegal collection pressures?
- Can you quantify the extent of these illegal collection pressures, officially and unofficially?
- Who are main culprits, people illegally collecting these species?
- What controls are in place to prevent the illegal collection of plants form the wild?
- Do you have special controls for international collectors?
- How are plant collection permits administrated?
- Could nurseries be set up to relieve this illegal collection pressure?

- Would your organisation use an indigenous nursery, for local planting possibly rehabilitation work?
- What is your relationship with the nurseries in your area?
- Where would be the best location for such a nursery?
- What are the technical difficulties, constraints in the establishment of an indigenous nursery in this area?
- What species would be the most important to propagate?

Local agriculture

- Do you think there is a potential for the development of indigenous nurseries?
- Would they make successful community upliftment projects?
- What types of plants would be most useful if indigenous nurseries were to be established in this area?
- Do you think commercial and small-scale farmers would make use of a nursery that was developed to supply indigenous plant and seed for restoration work in agricultural landscapes?
- Are there any organisations or nurseries in this area that are currently undertaking these activities?
- What would be the most useful species?

Scientists

- Do you think the development of nurseries for the propagation and sale of Succulent Karoo flora is a good idea? Why?
- Could the development of nurseries contribute to rehabilitation efforts?
- What groups of plants or species would be most suitable for these activities?
- Potential of nurseries for increasing productivity?
- What groups of plants or species would be most suitable for these activities?
- Potential of nurseries for community upliftment?
- What groups of plants or species would be most suitable for these activities?
- Potential of nurseries to satisfy the horticulture market?
- What groups of plants or species would be most suitable for these activities?
- Potential of nurseries for reducing collection pressure?
- What contribution could they make to conservation?
- What are the technical difficulties for seen in the establishment of nurseries for community development in the study area?

Interest groups

- Where do your members collect/ get most of their plant material?
- What are the main species, genus, of interest to your members?
- Would they make use of nurseries in the Succulent Karoo?
- Would they make use of nurseries selling Succulent Karoo flora?
- What would interest your members the most plant, seeds, or cuttings?