

**RECENT TRANSFORMATIONS IN WEST-COAST
RENOSTERVELD: PATTERNS, PROCESSES AND
ECOLOGICAL SIGNIFICANCE**



**A thesis submitted in fulfilment of the requirements for the degree of Doctor
Philosophiae in the Faculty of Natural Sciences, University of the Western
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KEY WORDS

Coastal Renosterveld

Natural habitat transformation

Remote sensing

Satellite imagery

Aerial photography

Time series

Vegetation mapping

Pattern analysis

Classification techniques

Human threats



Frontispiece

Excerpt from Simon Van der Stel's journal of his expedition to Namaqualand, 1685-1686 (Valentyn 1726):

September 12 1685: "...en de valey zandig. Wy sloegen ons op half weg van de zelve neder ontrent een kloof in 't gebergte aan onze linkerhand. Deze plaats was maar tamelyk voorzien van gras, doch bevogtigt met 2 sprutjens waar van 't eene brak en 't ander maar passelyk zoet water was. De voorsz valey is bewassen met Rhinocer-bosch, alhier zoo genaamt, om dat de zelve daar gemeenelyk in legeren."

["...and the valley sandy. We camped half-way along it, near a pass in the mountains to the left. This place was only fairly well provided with grass, but was watered by two streams, one brackish and the other of only passably sweet water. The valley is overgrown with rhinoceros-bush, so called because these commonly lodge in it"].

ABSTRACT

RECENT TRANSFORMATIONS IN WEST-COAST RENOSTERVELD: PATTERNS, PROCESSES AND ECOLOGICAL SIGNIFICANCE

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Natural Sciences, University of the Western Cape.**

Modern humans and their ancestors have inhabited the western lowlands of the Western Cape Province, South Africa for hundreds of thousands of years. However, widespread human-induced transformation only began in earnest with the introduction of livestock about 2000 years ago. Although slow at first, pressures on the vegetation increased, culminating in the extensive tracts of wheat and vines that dominate the landscape today. West-Coast Renosterveld is now considered to be the most transformed vegetation type in South Africa, with less than 10% remaining in any sort of natural condition.

This thesis examines the changes that have occurred within West-Coast Renosterveld within the last 350 years, and assesses the viability of the remaining fragments.

The concept, and proposed original extents, of West-Coast Renosterveld are first examined. English translations of early descriptions of the region are reviewed and the development and impact of the intense agricultural practices of the last 120 years summarized. Finally current threats to the remaining fragments are considered. These all affirm that the area has been grossly transformed, and remains under threat.

A twenty-year set of monthly maximum NDVI (Normalized Difference Vegetation Index) satellite images of the Western Cape coastal lowlands showed patterns that could be related to rainfall and land-cover. Specific changes identified were predominantly housing developments around Cape Town, and vineyard

development in suitable areas. However, overall there was relatively little change over the twenty-year period.

A fine-scale study of three localities using a 60-year series of aerial photographs showed that, with the exception of the Elandsberg Private Nature Reserve, there had been a steady decline in the extent of natural vegetation as formal agriculture expanded into marginal lands.

In order to assess how much West-Coast Renosterveld remained, fragments of greater than three hectares were mapped using Landsat-7 ETM+ (Enhanced Thematic Mapper Plus) imagery. Using the different published original extents of Renosterveld led to estimates of the amount remaining to range between 5.4% and 9.4%. Problems encountered in the use of the imagery to identify these fragments were discussed.

Published extents of West-Coast Renosterveld were analysed in terms of their geological, pedological, altitudinal and rainfall characteristics. From these a predictive extent was developed. Analyses of the region confirmed that most of the remaining fragments occurred on land of marginal agricultural worth, while fractal analyses suggested that many of these fragments were unlikely to persist.

Literature relevant to the conservation of West-Coast Renosterveld suggested that fragments smaller than 25 hectares were probably unviable, but due to the persistence (longevity) of many Renosterveld plant species, this factor was being masked. Dispersal-cost analyses suggested that most of the region was hostile to typical Renosterveld organisms, both in terms of inter-fragment distances and matrix variability. Autocorrelation studies, combined with published information on the dispersal distances of typical local endemic plant species suggested that, in terms of dispersal distances, fragmentation of the landscape *per se*, was not a serious threat to the survival of these species. Fertilizer run-off, pesticides, invasion by alien species, reduced habitat heterogeneity and the loss of pollinators were probably more of a threat. The extermination of large herbivores has probably upset some of the ecological processes that shaped coastal Renosterveld, but these could be partly compensated for by the use of livestock. Applying cluster analyses to the

available plant species lists, suggested beta and gamma diversity levels of 40% to 50%.

In conclusion it was found that West-Coast Renosterveld has been subjected to gross transformation, and that many of the ecological processes that originally occurred have been highly modified. It appears unlikely that these changes can be reversed. Conservation needs to be directed towards the removal of alien species, a reduction in agricultural influences, and attempts at the re-introduction of pollinator and dispersal vectors.

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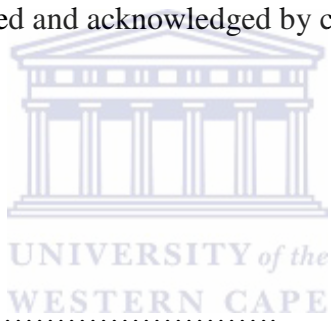


DECLARATION

I declare that “*RECENT TRANSFORMATIONS IN WEST-COAST RENOSTERVELD: PATTERNS, PROCESSES AND ECOLOGICAL SIGNIFICANCE*” is my own work, that it has not been submitted for any degree or examination in any other university, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

Ian Paul Newton

March 2008



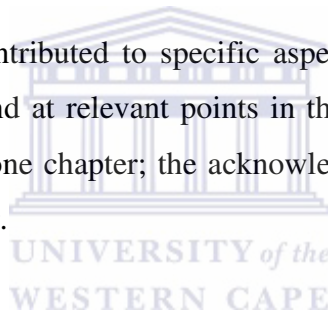
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A number of people contributed to specific aspects of the project, and these are acknowledged below (and at relevant points in the text). Some of the information was used in more than one chapter; the acknowledgements below are restricted to the most relevant chapter.



Chapter 1.

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Chapter 2.

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Chapter 4.

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Chapter 6.

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collected during the Lowlands Renosterveld Project, and the list of rare and endangered West-Coast Renosterveld plant species.

Appendix A.

I would like to thank Dr Graham Avery for giving me his list of archaeological references to the Western Cape.

Finally I would like to say that any mis-interpretation of the information supplied to me by the above people, is entirely my own fault.

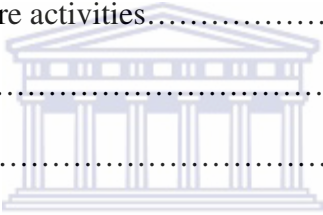


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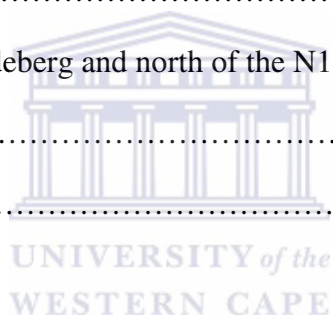
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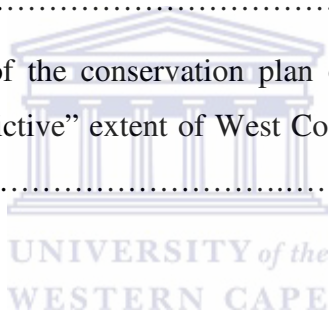
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INTRODUCTION.

Homo sapiens and his pre-sapient ancestors have inhabited the west coast lowlands of the Western Cape Province, South Africa for hundreds of thousands of years (Deacon 1992). Early-hominids began using fire over a million years ago (Brain and Sillen 1988), and Deacon (1983) suggested that a “fire-stick” technology had been used to manage the veld in this area for at least 125 000 years. The burning of Fynbos vegetation encourages the sprouting of geophytes, which can be dug up for their edible underground storage organs (Deacon 1992). It also stimulates the growth of grasses and forbs, which attracts grazing animals that can be hunted for meat (Deacon 1992). About two thousand years ago sheep, and later cattle, were introduced into the region (Schweitzer and Scott 1973). The herding lifestyle that developed introduced new pressures into the local ecology. The herders made widespread and frequent use of fire to maintain a high grass component in the vegetation, which was heavily grazed before the stock were moved on (Thom 1952).

These western lowlands were the first part of South Africa to be colonized by Europeans. It took about 70 years for the colonists to spread to the furthest reaches of the region now considered to encompass West-Coast Renosterveld (Theal 1922) (Figure 1). Their impact upon the natural vegetation was low at first, but by the mid-1700's the grasslands that had previously existed were being invaded by the Renosterbos (*Elytropappus rhinocerotis*) and other unpalatable shrubs (Sparrman 1786). In the southern regions of the west coast lowlands, vineyards were planted, while in the Mamre-Darling area cattle rearing became important. Areas more distant from the main market of Cape Town were usually managed for little more than subsistence farming and were mainly pastoral (Talbot 1947). The discovery of gold and diamonds in the interior of South Africa in the late 1800's stimulated the development of efficient transportation systems. These allowed the rapid and easy transport of farm produce to the interior and to the port of Cape Town, leading to a boom in agricultural activities in the region (Talbot 1947). During the First World War wheat imports dropped, leading to more intense farming practices (fewer fallow periods). By 1930 it was cheaper to import wheat than to produce it locally, due to the high input of fertilizer required. To protect local farmers, tariffs and

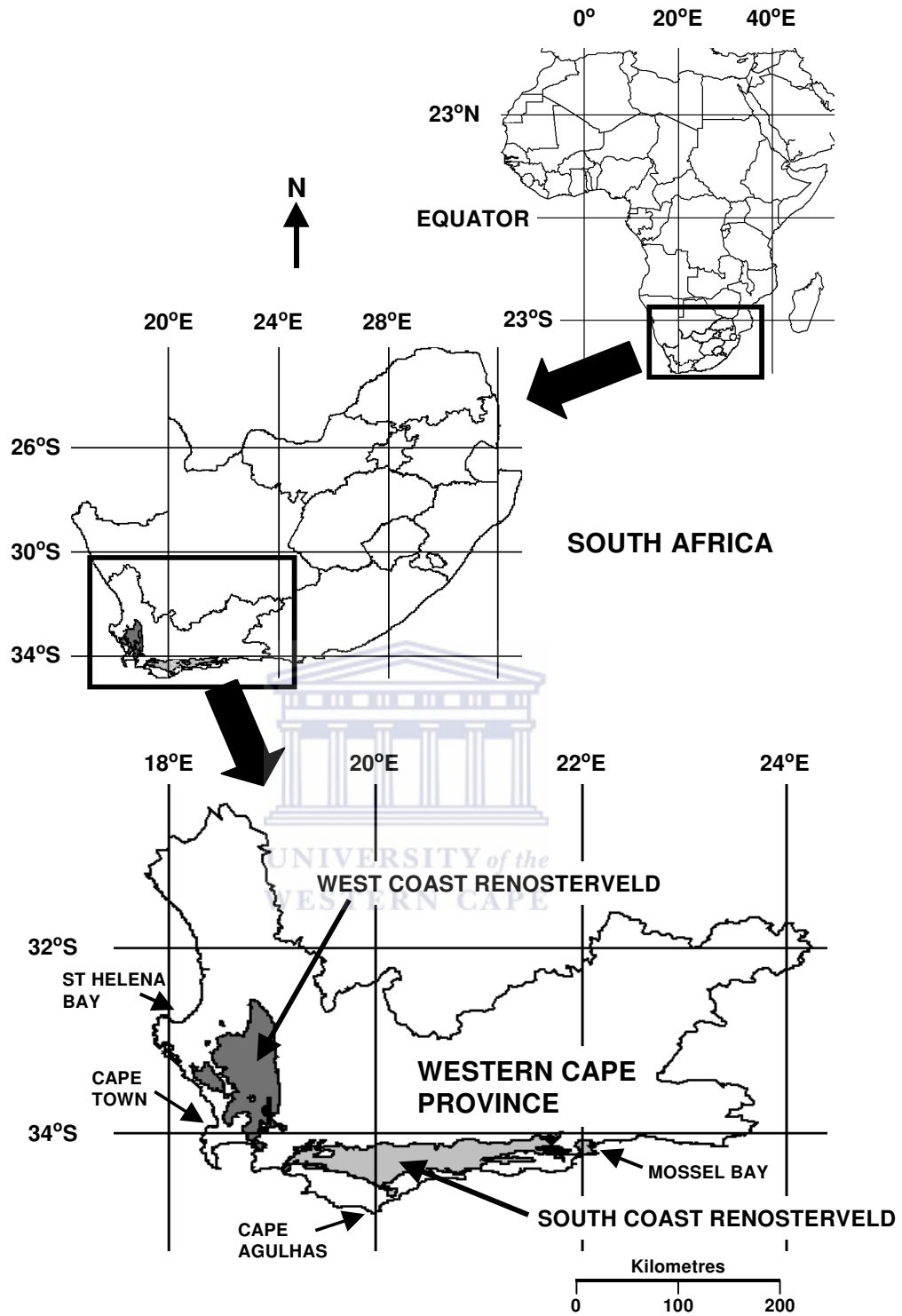


Figure 1. Map showing the two main blocks of coastal Renosterveld as used in this thesis. Variations in extent and nomenclature exist in the literature, and these are discussed in Chapter 1. Scale bar is valid for the bottom map only.

restrictions were placed on such imports, while local subsidies increased to such an extent that wheat became the most lucrative crop to grow (Talbot 1947). The result of this was that soil degradation increased and marginal lands were ploughed up, as profit became more important than sound land management. In 1992, McDowell and Moll compared the extent of the transformation of West-Coast Renosterveld to agriculture with that of the prairies of North America, the steppes of Russia and the Mallee scrub of Western Australia. Similar events took place along the south coast lowlands, although the topography becomes too steep in the east for the cultivation of cereals (Kemper *et al.* 2000). Land that was unsuitable for cereals was used for pasture, and exotic species were sometimes introduced to improve the forage value (Cowling *et al.* 1986). Nevertheless, a great-deal more “natural” (or near-natural) coastal Renosterveld remains on the south coast lowlands than it does on those of the west (*e.g.* Reyers *et al.* 2001, Rouget *et al.* 2003). By the time that enough pressure had been placed upon local and governmental institutions to pay more than lip-service to conservation, much of the land that was home to coastal Renosterveld had been transformed into fields of wheat and barley, or hillsides of vines.

The most recent estimates of the amount of natural vegetation remaining within the original extent of West-Coast Renosterveld are 9% (Reyers *et al.* 2001), 16.2% (Rouget *et al.* 2003) and 5% (von Hase *et al.* 2003). Although these are all improvements upon earlier estimates of 3% remaining (McDowell and Moll 1992, Low and Rebelo 1996), only that of Rouget *et al.* (2003) exceeds the 10% conservation level recommended by the IUCN (Rebelo 1995).

Along the south coast, the situation is somewhat better, although the use of significantly different extents by different authors makes a comparison of their figures more difficult. Kemper *et al.* (2000) estimated that 14.4% of South-Coast Renosterveld (as approximated by Figure 1) remained, with significantly more in the eastern sector (33.4%) than in the west (4.4%). The estimate of Reyers *et al.* (2001) for a combined South and South-West Coast Renosterveld (*sensu* Low and Rebelo 1996) was 39.4% (plus 1.9% degraded). Rouget *et al.* (2003) calculated that 11.8% of Overberg Renosterveld and 30.9% of Riversdale Renosterveld (19.9% combined; area as approximated by Figure 1) remained relatively untransformed, while Von Hase *et al.* (2003) suggested 10.85% of the Overberg Renosterveld

remained. Pressey *et al.* (2003) concluded that none of the coastal Renosterveld units had sufficient extant vegetation to adequately preserve biodiversity.

The actual definition of West-Coast Renosterveld varies slightly from author to author, but that of Low and Rebelo (1996) can be quoted as being typical:

“Characterized by mid-dense to closed cupressoid and small-leaved, mid-high evergreen shrubs, with regular clumps of broad-leaved, tall shrubs as emergents (especially on heuweltjies). The overstorey is dominated by Renosterbos *Elytropappus rhinocerotis*, with subdominants of Wild Rosemary *Eriocephalus africanus*, Dune Teabush *Leysera gnaphalodes*, Jakkalsstert *Anthospermum aethiopicum*, *Athanasia trifurcata*, *Felicia filifolia*, *Metalasia muricata* and *Stoebe spiralis*. The understorey is mainly annual and herbaceous with perennial grasses. The grass cover is sparser than in most other Renosterveld types, being dominated more by C3 grasses (e.g. the genera *Ehrharta*, *Pentaschistis*, *Merxmuellera*, *Tribolium*, *Cymbopogon* and *Eragrostis*). Redgrass *Themeda triandra* and Cape Turpentinegrass *Cymbopogon marginatus* are locally abundant. Geophytes, mainly Irises (Iridaceae), Lilies (Liliaceae) and Sorrels (Oxalidaceae), are characteristic and may be abundant. The Mediterranean annual grasses, Oats *Avena*, Quaking Grass *Briza* and Ryegrass *Lolium*, have become widespread and common, and their effect on the indigenous grasses and geophytes is unknown. Bush clumps are dominated by typical Thicket Biome species, such as Wild Olive *Olea europaea subsp. africana*, Dune Taaibos *Rhus laevigata* and Bush Guarri *Euclea racemosa*”.

The somewhat less detailed, but possibly more succinct description of “grey-bush community” was used by Duthie (1930).

Renosterveld has also been referred to as an ecotone and as a transitional shrubland (Taylor 1978, Day 1983), implying that it is not a distinctive veld type at all. There are also references to “Fynbos” and “Strandveld” vegetation occurring within areas that are spatially defined as Renosterveld (e.g. Boucher and Moll 1981, Boucher 1987). Although the vegetative definition of Renosterveld as proposed by Low and Rebelo (1996) has been given, it needs to be kept in mind that a physical definition of coastal Renosterveld may in fact be more appropriate than a community definition. Almost every author refers to the physical aspects, especially soil nutrient quality. In a region where nutrient-poor soils are the norm, Renosterveld is found on relatively nutrient rich soils that are suitable for agriculture (e.g. Kruger 1979, Joubert 1991). Rainfall is moderate, and the altitudinal spread is low (Acocks

1953). It is because of its high agricultural potential that coastal Renosterveld is endangered.

There have been a number of studies of West-Coast Renosterveld. Levyns (1922 [published under her maiden name of Michell], 1926, 1929, 1936, 1956) examined both the Renosterbos, and Renosterveld succession at Signal Hill, Stellenbosch and Riversdale (South-Coast Renosterveld). Duthie (1930) studied the plant communities of Stellenbosch. Tansley (1982) looked at some of the remaining fragments to determine their conservation-worth. De Jager (1985) speculated on what Renosterveld originally looked like. Boucher (1987) classified Renosterveld communities as part of his phytosociological study of west coast lowland vegetation. McDowell (1988) examined the conservation of West-Coast Renosterveld in terms of social and legal factors. Joubert (1991) looked at the history and vegetation of Signal Hill, while Randrianasolo (2003) looked at the effect of fragmentation on bird communities in West-Coast Renosterveld. The Botanical Society of South Africa (von Hase *et al.* 2003) has just completed its fine scale conservation plan for Cape lowlands Renosterveld. Three M.Sc. theses on seed dispersal within Renosterveld (Shiponeni 2003), on alien grass invasions into disturbed and undisturbed Renosterveld (van Rooyen 2003) and on vegetation community dynamics (Walton 2006) have recently been completed. These are in addition to many studies that have incorporated coastal Renosterveld within a wider framework.

In the south coast block, Muir (1929) did a detailed plant-community study in the Riversdale region. Kemper (1997) examined the effects of fragmentation upon plant communities, while Cameron (1999) examined the effect of fragmentation on bird communities. Donaldson *et al.* (2002) looked at how fragmentation affected the pollination and seed set of seven herbaceous perennials. Many of the fragments remaining within Overberg Coast and Elgin Renosterveld Broad Habitat Units (BHU; Cowling and Heijnis 2001) have been assessed for their conservation value as part of the Botanical Society's lowland Renosterveld plan, mentioned in the previous paragraph (von Hase *et al.* 2003).

The layout of this thesis

This thesis examines West-Coast Renosterveld from a temporal and spatial point of view. The temporal chapters look at the historical and archaeological records, at coarse scale changes over the west coast lowlands as a whole, and at fine scale changes at three selected localities. The spatial aspect is related to the distribution of the remaining fragments within the landscape, their relationship to each other and how these relationships may influence ecological processes within the system.

The objectives are:

- 1 To determine to what extent this vegetation type has been transformed in terms of the amount remaining and the vegetation components, and whether this transformation is still occurring.
2. To map the remaining fragments, to suggest which of them may contain genuine Renosterveld and which are likely to maintain a mosaic of Renosterveld with some other vegetation type.
3. To suggest conservation measures, based on spatial analyses of the fragment map developed in this thesis, in conjunction with the available literature.

Chapter 1 looks at Renosterveld from a historical context. Early references to the type of vegetation existing in West-Coast Renosterveld were reviewed. The impact of man's past activities, and those of current and future threats from human and non-human sources are examined. An appendix speculating on the recent evolution of coastal Renosterveld is included, in order to identify possible long-term processes acting upon the area.

Chapter 2 takes a broad scale look at the western coastal lowlands, using spatially coarse-, but temporally fine- scale NOAA (National Oceanic and Atmospheric Administration) AVHRR (Advanced Very-High-Resolution Radiometer) NDVI (Normalized Difference Vegetation Index) imagery. A Principal Components Analysis identified a number of patterns, which could often be related to geographic and land-cover parameters.

Chapter 3 looks at three West-Coast Renosterveld sites by means of spatially fine-, but temporally coarse- scale changes using a series of aerial photographs taken at approximately 10-year intervals from 1960. Photographs from 1938, 1942 or 1949 were also available for each site. The area covered by the natural vegetation at each time interval was measured and changes were discussed in terms of slope and aspect. Problems related to the use of aerial photographs in identifying natural vegetation and monitoring temporal changes were also examined in the light of field verification. Local information was obtained about the history and management regimes (if any), which had been applied to the sites.

Chapter 4 describes the production of a map of the remaining West-Coast Renosterveld fragments, using Landsat 7 ETM+ (Enhanced Thematic Mapper Plus) imagery. It deals with the techniques and the problems encountered, notes differences in the results obtained using different classification methods and looks at the difference between spectral classes and information classes. It compares the problems encountered and the results obtained with those of similar works by other groups and individuals. The ability of Landsat imagery to identify Renosterveld is discussed. An appendix describes the sites visited for field verification.

Chapter 5 has four sections. The first part looks at four published original extents of West-Coast Renosterveld and the physical parameters that each encompasses. From these, a predictive map based upon soil, geology, altitude and rainfall is developed, assigning probability ratings to the region as to whether the vegetation is Renosterveld or some other natural vegetation type. The second part describes the distribution of the natural vegetation, cereal fields and vineyards within the landscape, in terms of slope and aspect. The third looks at how physical parameters (geology, slope, aspect) may have affected the spectral classification processes, and discusses these spectrally defined classes in terms of landscape and ecological factors. The final section describes the distribution of the remaining fragments in terms of fractal mathematics, and discusses the findings in terms of similar fractal studies.

Using the products developed from the previous chapters, along with the available published species lists, the conservation of West-Coast Renosterveld is discussed in terms of fragmentation (island biogeography), dispersal corridors and levels of local

endemism. The available literature is critically reviewed, and integrated into a package identifying aspects that need to be considered in conservation planning.

Note on the different terms and spellings used for Renosterveld

The term “Renosterveld” is one of several that have been used to refer to certain parts of the Cape Floral Kingdom where the Renosterbos has become dominant. The proposed original extents of Renosterveld have undergone changes since 1835, when Drège first recognized Renosterveld as a separate entity (Meyer 1875), up to the most recent mapping by Mucina and Rutherford (2004).

Renosterveld consists of two major types, namely mountain and coastal Renosterveld. Within each of these, there are further sub-divisions that have been given different names by various authors. Within the context of this thesis, only coastal Renosterveld is considered. Although West-Coast Renosterveld is the primary focus, reference to South and South-West Coast Renosterveld will be made for comparative purposes. There is considerable ambiguity surrounding the term “South-Coast Renosterveld”, and so it will be stated here that, unless otherwise specified, only that Renosterveld occurring to the west of Mossel Bay and south of the southern Cape Fold Mountains is being discussed (see Figure 1).

While this thesis was being written, two new vegetation maps were published. The first was the BHU system of Cowling and Hejnis (2001), which was limited to the Cape Floristic Region. They divided West-Coast Renosterveld into two units (Boland and Swartland) and classified the upper regions of the Paarlberg and Perdeberg as a Fynbos/Renosterveld mosaic. On the south coast, two major blocks of Renosterveld were identified, namely Overberg and Riversdale Coast Renosterveld. Combined, these approximate the extent shown in Figure 1, with Overberg Coast Renosterveld being analogous to the South-West Coast Renosterveld block of Moll and Bossi (1984). More recently the SANBI (South African National Biodiversity Institute) vegetation map (Mucina and Rutherford 2004) has further subdivided these regions.

The term “Renosterveld” has been subjected to variations in its spelling. Thus we encounter Rhenosterveld, Rhenosterbosveld and Rhenoster shrub land. The term

“Renosterbos” itself has evolved through the past three hundred years from “Rhenosters bosch” (Waterhouse 1932) or “Rhinocer-bosch” (Valentyn 1726) (official and original versions respectively of the journal of Simon van der Stel’s 1685 expedition) through “Rhenoceros Bosjes” (used by Schrijver four years later [Mossop 1931]), “Rhinosceros-bush” (used by Brink in 1761-1762 [Mossop 1947]), “Rhinosterbosjes” (Lichtenstein 1812), “Rhinoster bosch” (Burchell 1822) “Rhenosterbush” (Adamson 1938) and finally to Renosterbos. Throughout this project, the spellings “Renosterbos” and “Renosterveld” will be used, except where a direct reference to an author’s text is being made. Finally, it needs to be kept in mind that the term Renosterbos, while currently referring to *Elytropappus rhinocerotis*, was for many years a generalized term for plants resembling this species. Burchell (1822) referred to it as “*Stoebe rhinocerotis*” and said that “Rhinoster bosch” was the common name for several *Stoebe* species. The level of this confusion can be understood when one finds references to the Renosterbos from southern Namibia (Mossop 1947) and even south-west Malawi (Waller 1880)!

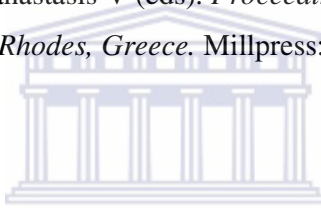
A note by the editor to the article by Newton and Knight (2004) noted that in 2002, M. Koekemoer revised the *Metalasia* group of the Relhaniinae for her doctorate at the Rand Afrikaans University. In this, the genus *Elytropappus* was changed to *Dicerotheramnus*. As this revision has not yet been published *Elytropappus* remains the current official name for this genus (M Koekemoer *pers comm.*).

CHAPTER 1.

A REVIEW OF WEST-COAST RENOSTERVELD: HISTORICAL REPORTS, VEGETATION CLASSIFICATIONS AND CHARACTERISTICS, THE IMPACT OF AGRICULTURE AND CURRENT CONSERVATION THREATS.

Extracts from this chapter were used in a presentation by Rainer Krug at the 10th MEDECOS conference at Rhodes in Greece:

Krug RM, Krug CB, Midoko Iponga D, Walton BA, Milton SJ, Newton IP, Farley N and Shiponeni NN 2004. Reconstructing West Coast Renosterveld: past and present ecological processes in a Mediterranean shrubland of South Africa. In: Arianoutsou M and Papanastasis V (eds). *Proceedings 10th MEDECOS Conference, April 25 – May 1, 2004, Rhodes, Greece*. Millpress: Rotterdam. CD file: “101.pdf”.



Abstract

This chapter reviews the existing historical information relevant to West-Coast Renosterveld. It examines the development of the term Renosterbos and the relevant vegetation maps from 1875 to 2004, noting how vegetation classification ideas have changed through time. It then looks at the characteristics of coastal Renosterveld, and its affinities to the surrounding vegetation types. Historical records are examined in order to recreate the Renosterveld encountered by the first European visitors to the Cape and its subsequent transformation under European farming practices. A detailed look is taken at wheat farming in the Swartland in the last century. Brief comparisons with events in South-Coast Renosterveld are made, but due to fewer records and the emphasis of this project on the west coast situation, these are cursory. The chapter concludes with a brief look at present day threats to the conservation of West-Coast Renosterveld.

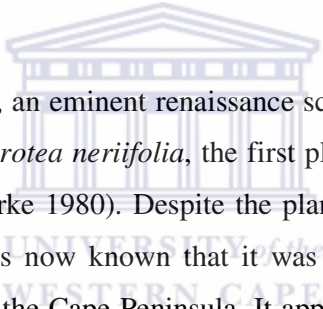
Introduction

The aim of this chapter is to provide:

1. A review of the definition and geographical extent of West-Coast Renosterveld.
2. A review of the transformation of West-Coast Renosterveld to European-style agriculture, and the effect that this has apparently had on plant community composition.
3. An assessment of the current threats to the remaining fragments of natural vegetation.

Figures one to three show the locations of most of the places mentioned in the text.

The Fynbos Biome



In 1605 Carolus Clusius, an eminent renaissance scientist, described and illustrated a dried flower head of *Protea neriifolia*, the first plant ever scientifically described from South Africa (Rourke 1980). Despite the plant being described as a “thistle” from “Madagascar”, it is now known that it was *P. neriifolia* and was probably collected somewhere on the Cape Peninsula. It appears however that, although this was the first South African species described, the first known horticultural export to Europe was *Moraea ciliata* in 1587 (Cowling and Richardson 1995). After the Dutch East India Company (DEIC) set up a victualing station at the Cape in April 1652, plants from this area began trickling back to Europe, to private and botanic gardens. The trickle became a flood, and eminent botanists and naturalists either personally visited the Cape, or sent underlings to collect species. Famous naturalists such as Masson (Bradlow 1994), Sparrman (Sparrman 1786), Thunberg (Thunberg 1795) and Burchell (Burchell 1822) visited, collected and wrote about the natural wonders of the Cape and surrounding areas.

In the twentieth century, the focus turned from individual species descriptions to community descriptions, broad habitat units, floristic regions and floral kingdoms. It is now generally agreed that the Cape Floral Kingdom is the smallest of the six floral kingdoms of the world (Good 1974, Takhtajan 1986), and it was identified

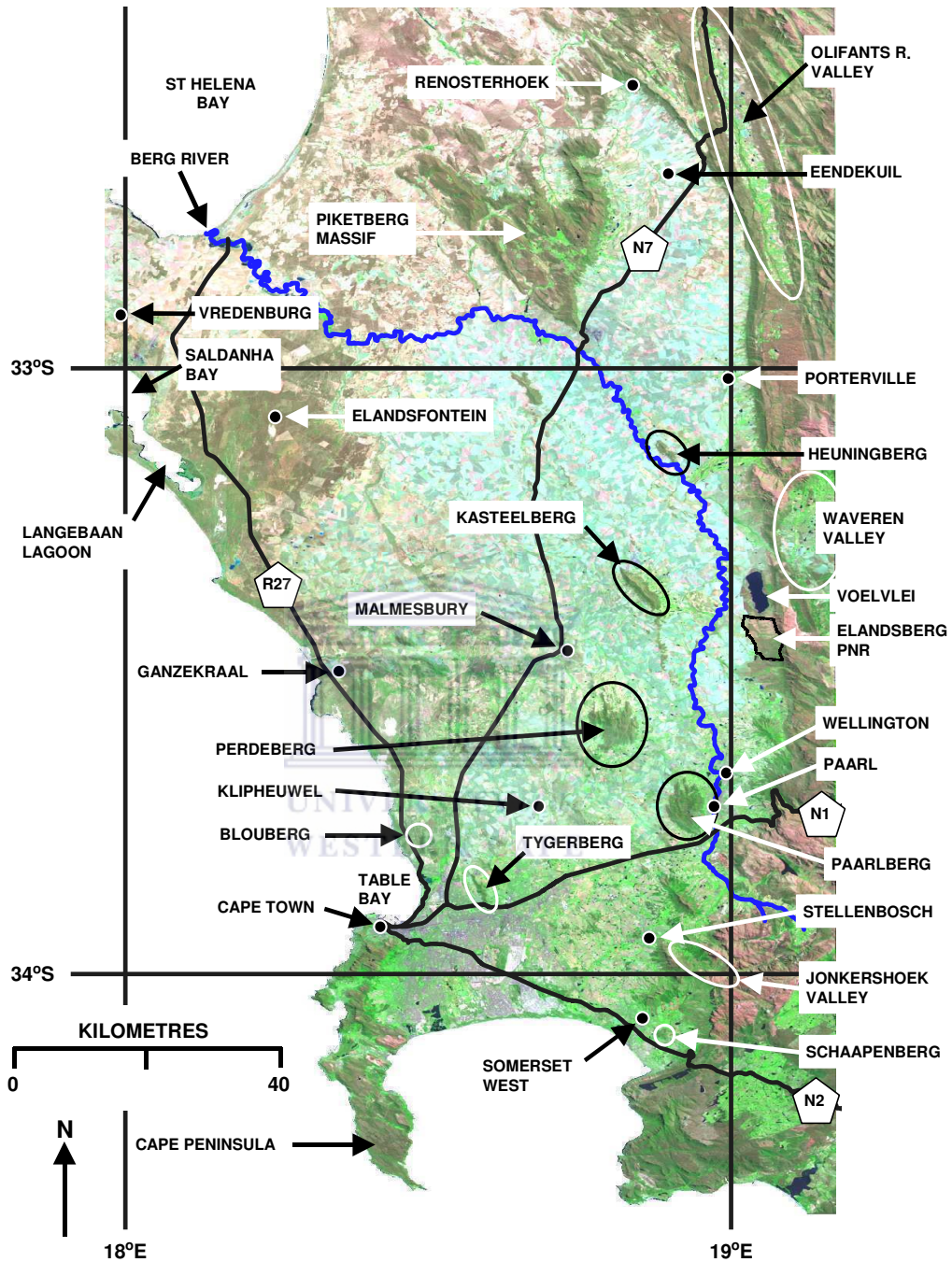


Figure 1. False colour composite Landsat image of the western Cape lowlands showing the national and west coast roads, the Berg River and some of the places cited in the text.

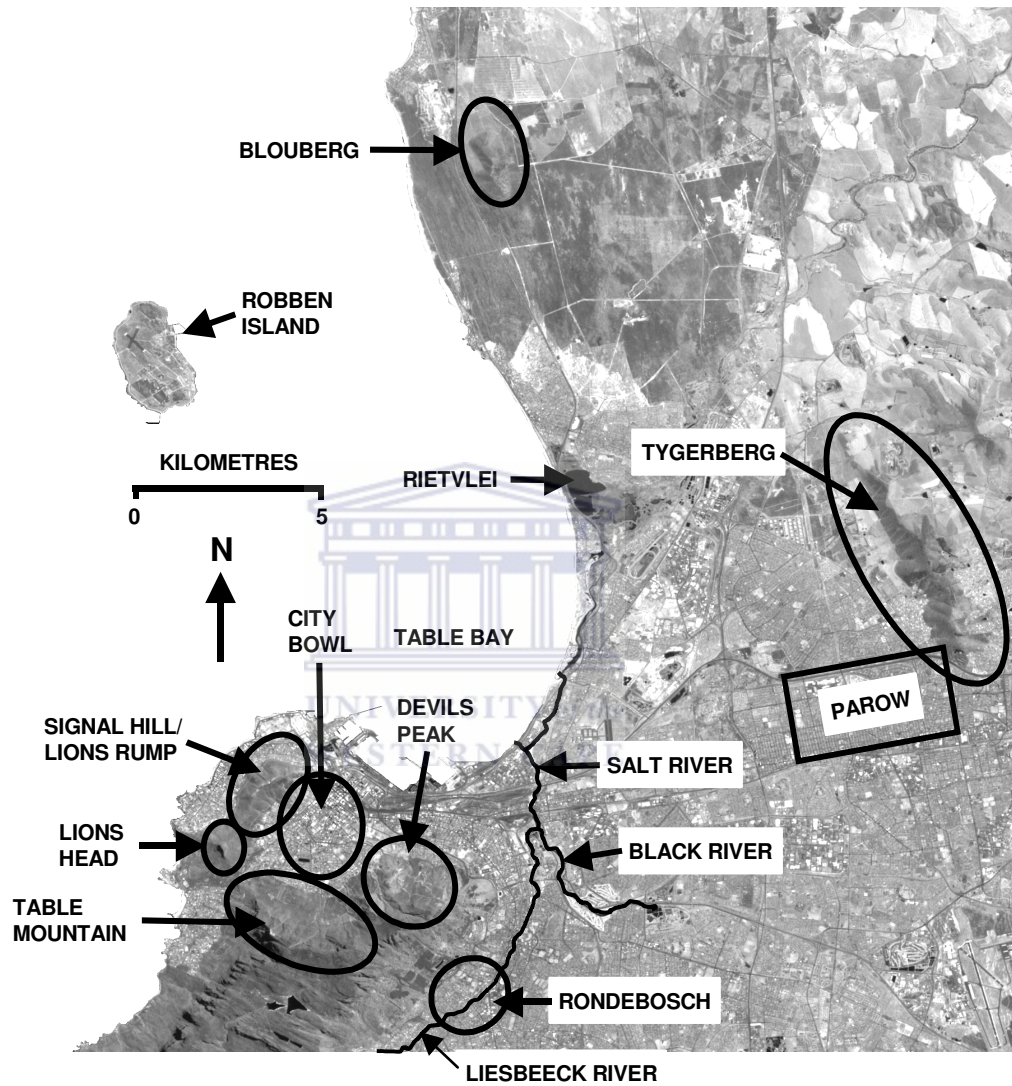


Figure 2. Landsat panchromatic image of the environs of Cape Town showing some of the places mentioned in the text.

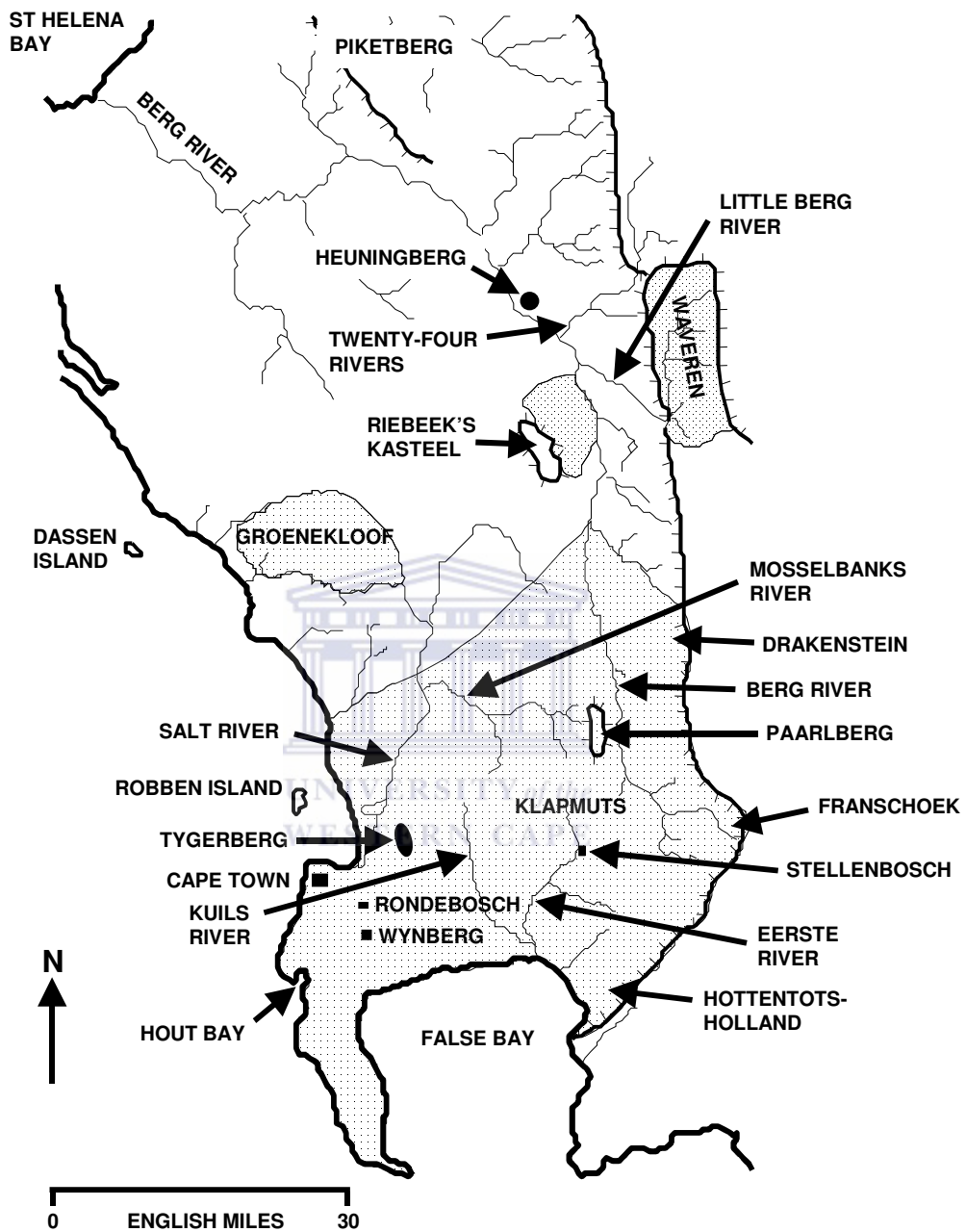


Figure 3. Map of the south-western Cape showing the areas occupied by Europeans in the year 1700 (stippled). Map modified from Theal (1922).

30 English miles \approx 50 km.

by Myers *et al.* (2000) as one of the world's 25 hotspots for biodiversity conservation action. It stretches from the vicinity of the Olifants River in the Western Cape to Port Elizabeth in the Eastern Cape, and inland from the coast into the Cape Fold Mountains. In the east, it merges into the coastal Thicket of the Eastern Cape, while to the north it merges with the various arid vegetation types of the Karoo. Its 90 000 km² is home to over 8500 species (Bond and Goldblatt 1984), of which about 6000 are endemic (Cowling and Hilton-Taylor 1994). In addition, 20.7% of its genera are endemic (Goldblatt 1978). The species : area ratio is the highest in the world (Bond and Goldblatt 1984). It also has the highest proportion of geophytes in the world, four to five times as high as any other Mediterranean area (Goldblatt and Manning 2000). One thousand five hundred and fifty species (> 17% of all species occurring in this area) have some sort of underground storage organ and are seasonally dormant (Goldblatt and Manning 2000).

Terms such as “Cape Floral Kingdom”, “Cape Floristic Region” and “Fynbos Biome” have been rather loosely defined in the past and were generally interchangeable. The term “Cape Floral Kingdom” appears to have been superseded by the term Cape Floristic Region. This latter term encompasses the Fynbos Biome communities (Fynbos, Grassy Fynbos and Renoster Shrublands), plus those forest, thicket and karroid communities that are mosaiced within it (Cowling and Holmes 1992). Rutherford and Westfall (1986) objectively defined the biomes of South Africa, suggesting that most biomes could be distinguished on summer aridity indices and rainfall parameters alone. They assigned 70 000 km² to the Fynbos Biome. A further point of confusion is often between Fynbos and Renosterveld. Fynbos is considered as a Mediterranean heathland, while Renosterveld (along with Acocks' [1953] “Strandveld”) is a Mediterranean shrubland (Boucher and Moll 1981). Heathlands occur upon leached nutrient-poor sands, while shrublands occur upon soils and sands that are generally more fertile (Boucher and Moll 1981). In sandy areas, mosaics of heathland and shrubland exist, making absolute distinctions between these two vegetation types difficult.

A history of Renosterveld classification

First references to the Renosterbos

The quote (frontispiece) from the journal of Simon van der Stel appears to be the first written reference to Renosterbos, *Elytropappus rhinocerotis* (Boucher 1980). Boucher was of the opinion that the reference was to the vegetation in general, rather than the plant species, and places it in the Olifants River Valley. Although mention is made of Olifants-jagt and Olifants-valey, these do not refer to what is now termed the Olifants River valley, but rather refers to a location in the Lange River valley, Mossop (1927, 1931) placing it in the vicinity of the Sandberg railway station (Figure 4). Although the description of the route taken makes the absolute location of this spot vague, the important point to note is that this area represents an interface between Sand Plain and Mountain Fynbos (Cowling and Heijnis 2001). The soils are generally sandy (*pers. obs.*), suggesting that the species observed was not *Elytropappus*, but some similar Fynbos species such as *Stoebe* or *Passerina*, which would be expected to occur on the sandy soils found there.

As to the origin of the term “Renosterveld”, Levyns (1972) suggested it came from the similarity of the vegetation, when viewed from a distance, to the wrinkles on rhinoceros hide. Earlier works (Valentyn 1726, Lichtenstein 1812) suggest the species name came from the fact that rhinoceros were fond of eating it. It is therefore just as likely that the term developed to describe the vegetation type in areas where this (or similar) species predominated. Newton and Knight (2004) have suggested that the term in fact originally referred to coastal Fynbos as found on the Cape Flats.

Early West-Coast Renosterveld classifications

Between 1826 and 1834, Drège collected about 200 000 specimens of almost 8000 plant species from the Cape Colony (Meyer 1875). Meyer undertook the task of cataloguing and identifying these and wrote “Commentaries on Drège’s Distributed Plants”, which was published in 1835 (in German). This publication described Drège’s travels and the floral regions he had identified, but the map to which he

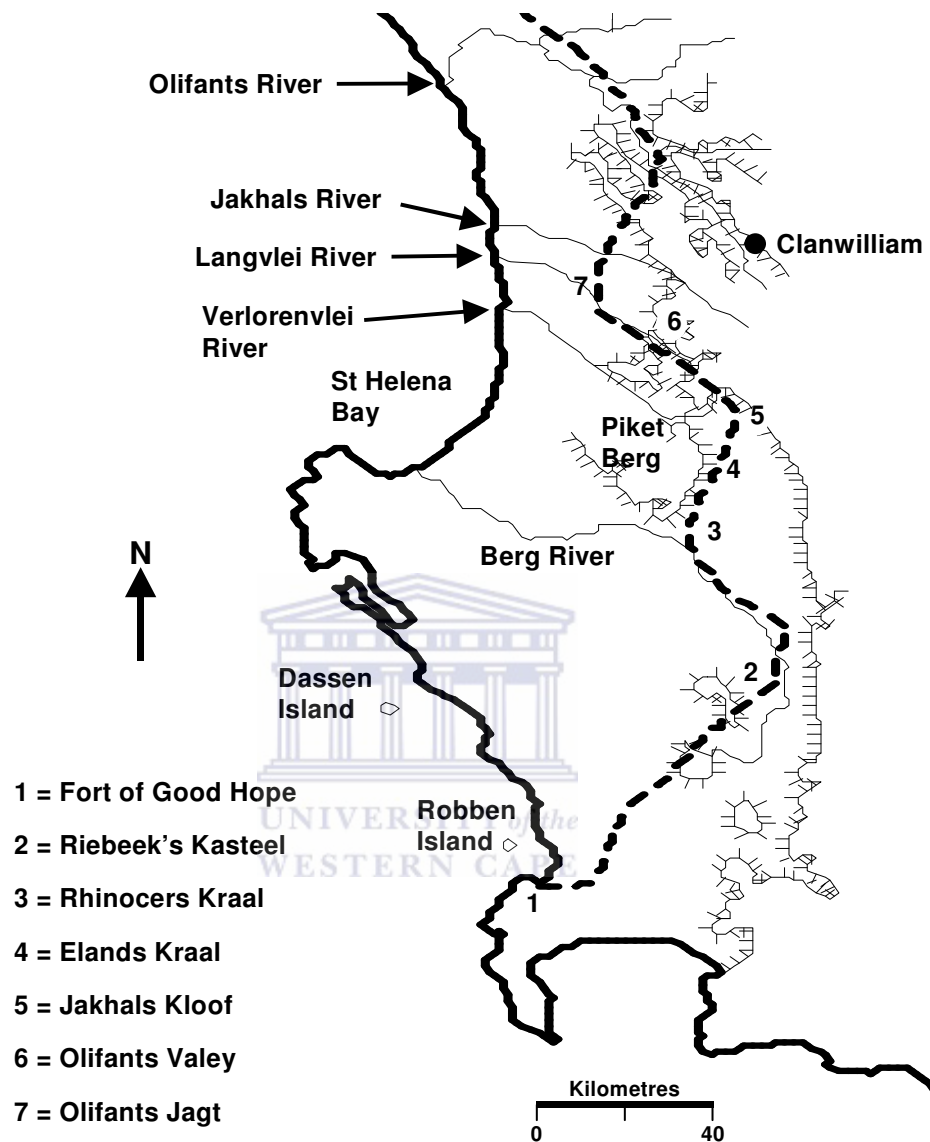


Figure 4. The southern part of the route taken by Simon van der Stel's 1685 expedition to Springbok, with some place names relevant to the first published use of the term Renosterbos. Map modified from Valentyn (1726).

Sandberg station is situated approximately where the number "7" appears on the map.

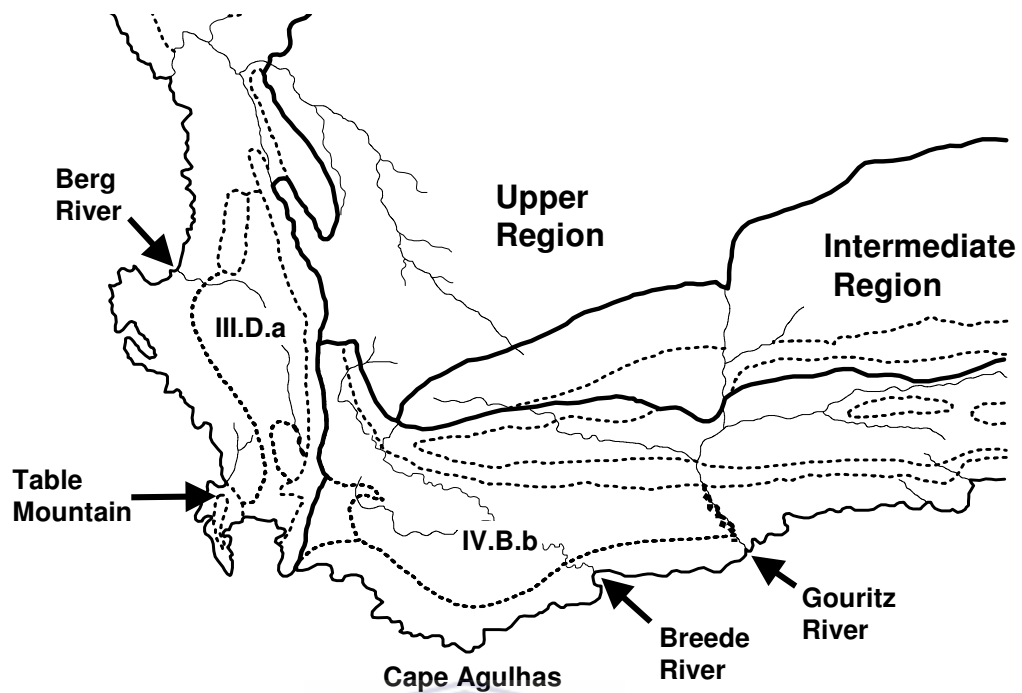


Figure 5. Drège's Regions, and the two sub-districts described as being home to substantial densities of "Rhenosterbosch" (Meyer 1875).

III.D.a = Lower Region; Western Section; Hilly part of Stellenbosch and Cape District; Piquetberg to False Bay Sub-district.

IV.B.b = Lower Region; Southern Section; Hilly District; Breede River Sub-district. This Sub-district extends as far east as the Gouritz River

referred (Figure 5) did not appear in print until 1843, when it was appended to "Zwei Pflanzen-Geographische Documente", published by Drège, in *Flora*, a German botanical magazine (Meyer 1875). It was only in Bolus' translation (Meyer 1875) of the 1835 commentaries, that the map and its regional descriptions were combined into a single publication. Drège defined 5 regions, 21 districts and 11 sub-districts of the Cape flora. Seven of these sub-districts had a substantial presence of "rhenosterbosch" growing in them. In terms of this study, the main region of interest is III.D.a. Although not shown on Drège's map, sub-district III.D.b: "Roots of Table Mountain", is also of importance as it notes that in

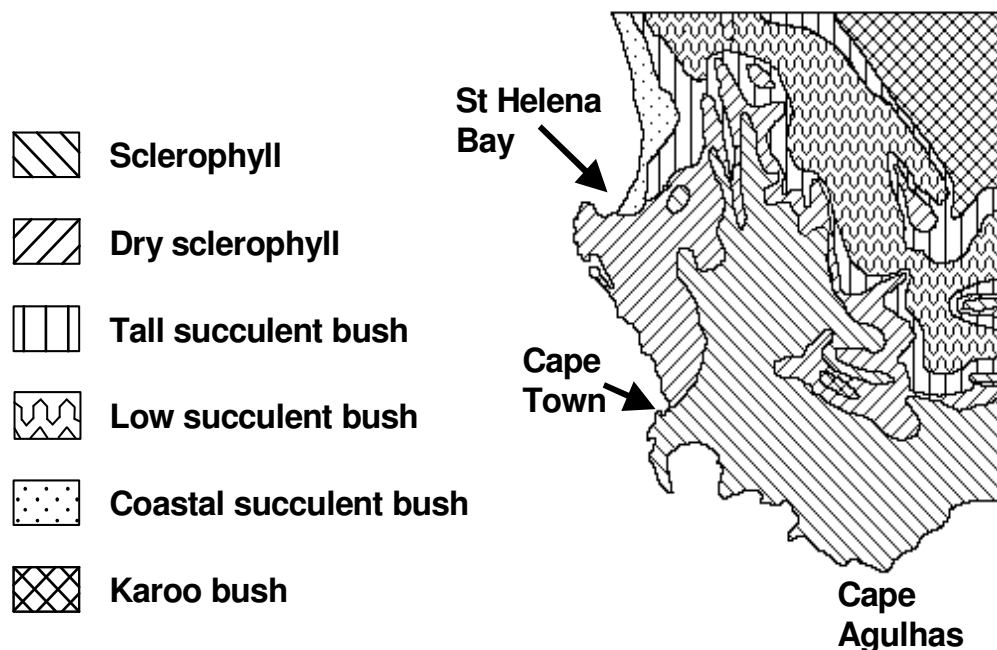


Figure 6. Vegetation classification map of Adamson (1938).

this area, the “...rhenosterbosch seems to have been put to flight by the plough, not to have been originally wanting.”

A number of other broad-scale vegetation maps of South Africa appeared between 1871 (or 1872) and 1936, some of which appear in Marloth (1908) and Werger (1978). Most identified a “South-Western” or “Cape Flora” Region, which usually approximated the current extent of the Fynbos Biome, but none identified Renosterveld as a separate entity.

Bolus (1905) referred to the predominance of “Rhenosterbosch” as being mainly in the valleys between the mountains of his “South-Western Region”.

Marloth (1908) only mapped the vegetation of South Africa into very broad units, but in the text he described a number of distinct sub-regions, one of which was “Rhenosterveld”, occurring on the Hills and Foothills.

Adamson’s (1938) vegetation map (Figure 6) appears to have developed from that of Pole Evans. Most Coastal Renosterveld, Mountain Fynbos and South Coastal

Fynbos communities have been combined into his “Sclerophyll” vegetation, while Western Coastal Fynbos, Coastal Thicket and Mountain Renosterveld have been roughly assigned to a “Dry Sclerophyll”. He referred to “renosterveld” as being found in the driest regions of the sclerophyll community, and being typically characterized by the dominance of a single species.

Acocks' Veld Types

In 1953 the Botanical Research Institute, in conjunction with the Department of Agricultural Technical Services published "The Veld Types of South Africa". This publication came to be colloquially referred to as "Acocks' veld types" or simply "Acocks", after the author JPH Acocks. It was primarily aimed at the agricultural sector, and indeed, the definition of the term "veld type" given in his introduction is: "...a unit of vegetation whose range of variation is small enough to permit the whole of it to have the same farming potentialities.". Local ecologists quickly latched onto the utility of his work, and few South African ecological publications failed to mention the veld type(s) in which their work was carried out. A work such as this obviously had its shortcomings, a fact freely admitted to by the author in his introduction (and spelled out in more detail by Cowling 1984 and McDonald 1997), but it did provide a framework upon which vegetation studies could be based.

Acocks' original Renosterveld

This project takes as its starting point veld type number 46 "Coastal Renosterbosveld", which comes under sub-heading "V - Temperate and Transitional forest and scrub types". Acocks recognized that coastal Renosterveld had two distinct blocks, one on the west coast, the other on the south coast, separated by the Hottentots-Holland Mountains. His west coast distribution extended from about Redelingshuis in the north to False Bay in the south (Figure 7). It was bounded on the east by the Cape Fold Mountains stretching from the Cederberg in the north to the Hottentots Holland in the south. Narrow bands of Strandveld (34) (numbers in brackets indicate Acocks' veld type number), and Coastal Fynbos (47), separated it from the Atlantic Ocean. To the east, it merges into Macchia (69) along the foot of the mountains. An isolated patch was identified

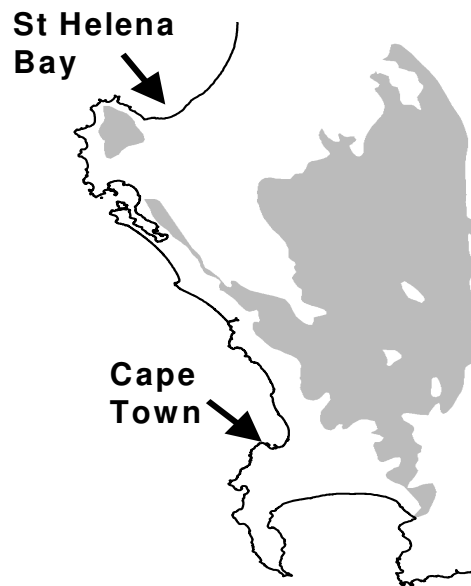


Figure 7. The West-Coast Renosterveld extent of Acocks (1953).

in the Ceres valley (warm Bokkeveld), although interestingly he excluded the Waveren valley (Tulbagh-Wolseley), an area that is “suitable” in terms of geology, rainfall and altitude but which he classified as Fynbos (69). He included rainfall and altitude within his definition, with ranges of 300 to 500 mm of rain per annum and an altitude of 0 to 300 metres.

Referring to his "Mountain Renosterbosveld" (43), which comes under the sub-heading "IVA - False Arid Karoo", he suggested that it was a relict of a southern type of grassland that had been ousted by the expansion of the boundaries of the Karoo. He also mentioned that Renosterbos had invaded much of the "Merxmullera Mountain Veld replaced by Karoo" (42) veld type. Under this heading he also pointed out that the Renosterbos had actually invaded False Fynbos (70) to such an extent that (at the time of his survey) it was almost indistinguishable from Renosterveld. However, under the heading of "False Macchia" (he used the terms “Macchia” and “Fynbos” interchangeably) he said most of this veld type (the False Macchia) was indistinguishable from true Macchia (69) and no reference was made to the Renosterbos invasion mentioned above. These observations about the invasiveness of Renosterbos into other vegetation types are mentioned in order to

compare them with the apparently similar situation in coastal Renosterveld, which will be discussed later.

Subsequent West-Coast Renosterveld classifications and descriptions

The first land-cover classification of the Western Cape, using satellite imagery, was by Taylor and Boucher (1973). No copies of this publication could be traced, but a copy of the classification was reproduced in Jarman *et al.* (1981). The classification was interpreted in terms of the maps of Acocks' (1953), combined with geological and soil data (Margie Jarman *pers. comm.*). They noted an apparent lack of differentiation in the vegetation occurring where Acocks (1953) had placed a tongue of Renosterveld to the east of the Langebaan lagoon. Boucher and Jarman (1977) made a vegetation survey of the Langebaan area and concluded that there was no Renosterveld vegetation there. Lichtenstein (1812) reported that farms occurring along the eastern shoreline of the Langebaan lagoon tended to have good grazing, or were growing corn. This apparent fertility probably accounts for Acocks classifying the area as Renosterveld.

Boucher (1981) mapped his view of the original extent of the different vegetation types occurring on the western coastal lowlands of the Western Cape south of the Berg River. He based this map upon orthophotos and personal field studies. He reclassified the granitic vegetation in the Vredenburg area, mapped as Renosterveld by Acocks (1953) to Strandveld. Boucher's (1981) Renosterveld boundaries were used, with minor variations, by a number of subsequent authors, such as Boucher and Moll (1981), Tansley (1982), Moll and Bossi (1984), McDowell (1988) and McDowell and Moll (1992). McDowell's (1988) map (Figure 8) acknowledges input from a geological map drawn up by Visser in 1984. It differs from that of Boucher (1981), in extending the coverage north of the Berg River, and it includes the geologically compatible formations occurring on the Cape Peninsula. Moll and Bossi (1984) added a strip of coastal Renosterveld along the west side of the Piketberg, in the Aurora district. They also reclassified the "coastal" Renosterveld in the Ceres and Waveren valleys as Central-Mountain Renosterveld.

Low and Rebelo (1996) largely accepted the boundaries set by Boucher (1981) for West-Coast Renosterveld (Figure 9), although they pointed out that in areas of

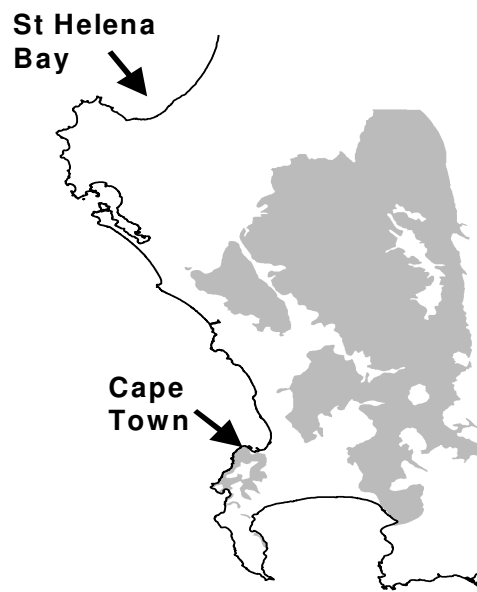


Figure 8. The extent of West-Coast Renosterveld, as used (with minor variations) by Boucher (1981), Tansley (1982), McDowell (1988) and McDowell and Moll (1992). The McDowell (1988) version is shown here.

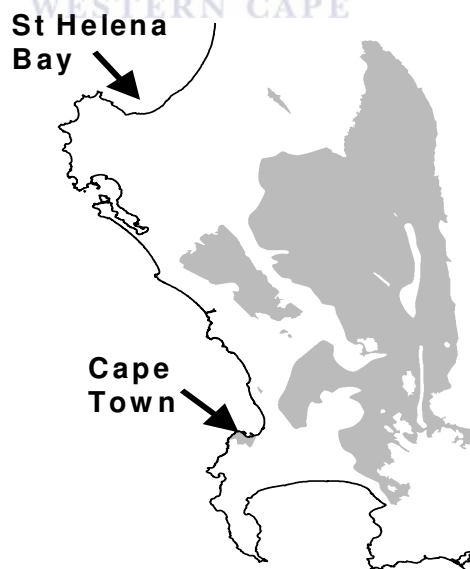
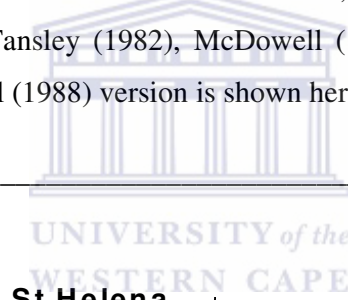


Figure 9. The extent of West-Coast Renosterveld, as defined by Low and Rebelo (1996).

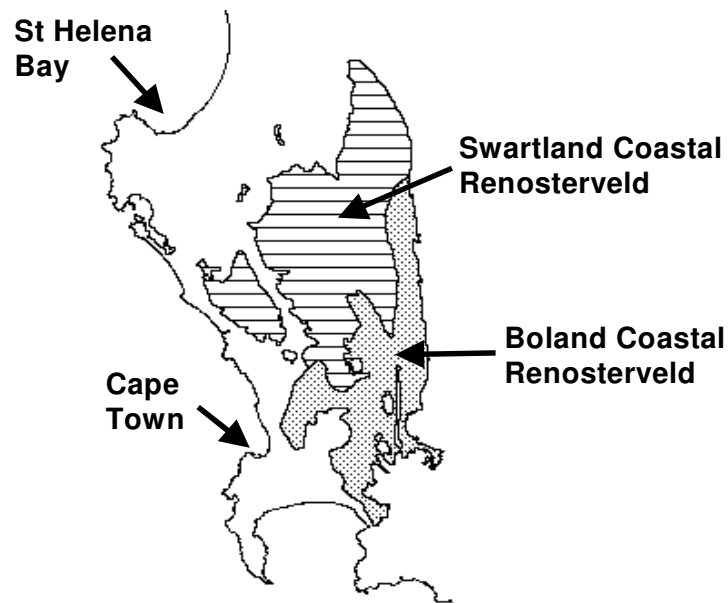
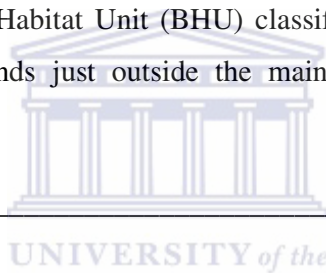


Figure 10. The Broad Habitat Unit (BHU) classification of Cowling and Heijnis (2001). The small islands just outside the main Swartland unit are Swartland Coastal Renosterveld.



higher rainfall Fynbos elements become prominent, and the boundary becomes diffuse. They rejected McDowell's (1988) geologically based expansion of Renosterveld onto the Cape Peninsula (possibly due to scale considerations), and reduced the coverage there to Signal Hill and the lower northern slopes of Table Mountain and Devils Peak. Britton and Jackelman (1995) in a fine scale study, identified four areas of Renosterveld on the Table Mountain complex. These were Signal Hill, the Groote Schuur Estate (on the lower east slopes of Devils Peak), and some small patches around the Tin mine and Lemoenskloof ravine (these are both on the lower north-west slopes of Devils Peak, above Vredehoek).

The Coastal Renosterveld boundaries of the Cowling and Heijnis (2001) Broad Habitat Unit (BHU) system were based upon the vegetation map of Low and Rebelo (1996), but also took into account geology, topography, climate and peer review, which resulted in some minor changes (Figure 10). The aim of their classification was to develop conservation planning units for preserving biodiversity, and as such, small isolated fragments (such as Signal Hill and

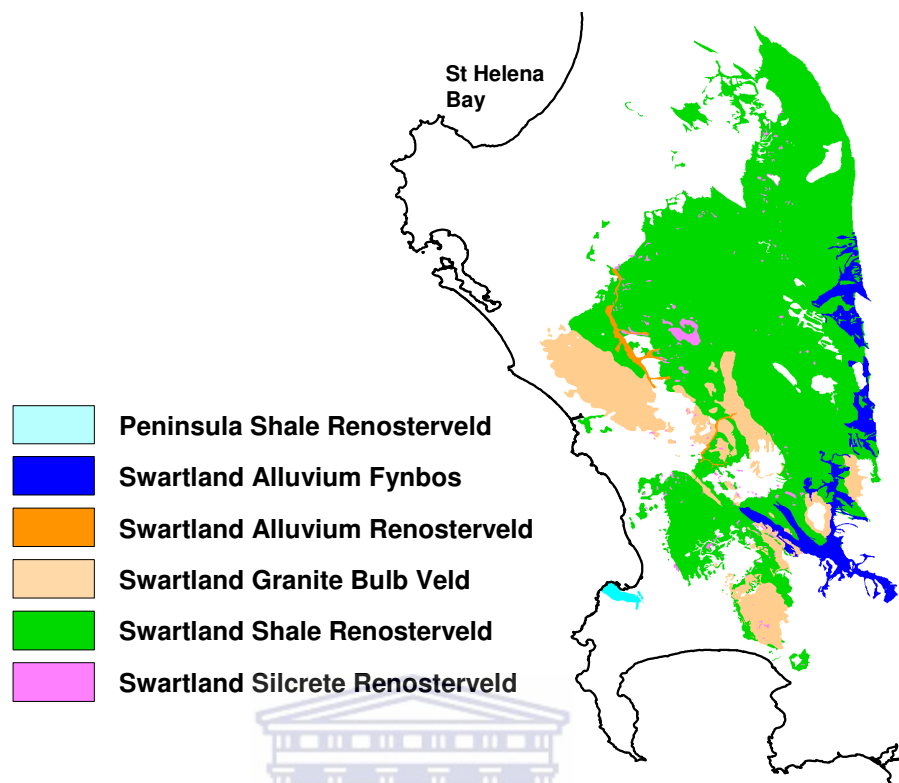


Figure 11. The SANBI vegetation map (Mucina and Rutherford 2004). The vegetation units relevant to this study are shown.

Blouberg) were incorporated into the Fynbos units that surrounded them. They divided West-Coast Renosterveld into three blocks: Swartland Coast Renosterveld, Boland Coast Renosterveld and Perdeberg Fynbos/Renosterveld mosaic. This last area was restricted to the upper regions of the Paarlberg and Perdeberg, which was defined as Mountain Fynbos in the coverage of Low and Rebelo (1996). They also extended their coverage of coastal Renosterveld to include those granite hills near Darling that were excluded by Low and Rebelo (1996).

The most recent vegetation map (Mucina and Rutherford 2004) is currently in its beta edition and may therefore undergo some changes before final publication. It has been produced by the South African National Biodiversity Institute (SANBI) and has divided the west coast lowlands (as defined in this study – see Chapter 5) into 29 vegetation units, of which four are classified as some form of Renosterveld,

and one as “Bulb Veld” (Figure 11). It appears to have relied heavily upon geological maps and the opinion of local ecologists. Of relevance to the conservation of Renosterveld is that Voelvlei and the Elandsberg Private Nature Reserve (PNR) have been allocated to an alluvial Fynbos classification, wherever the Terrace Gravel formation occurs.

South-Coast Renosterveld classifications

Drège was also the first person to identify what was essentially a south coast block of vegetation dominated by Renosterbos (Meyer 1875). It incorporated much of the current South-West Coast (Overberg) Renosterveld region, but also included the Breede River valley as far north as Tulbagh. Meyer (1875) noted that sub-district region III.D (see Figure 5), resembled that of the west coast (“Renosterveld”) described above, “...and the Rhenosterbosch here also predominates over other plants.”. He did note however, that east of Swellendam grassy plains became more frequent. Bolus (1905) also noted that between Caledon and Swellendam there were considerable grassy tracts with thinner bush, but that it could not be described as grassland proper.

Marloth (1908), after incorporating much of the Breede valley vegetation into his major West-Coast Renosterveld formation, noted that east of Swellendam, *Aloe ferox* became extremely common among the Renosterbos. As with West-Coast Renosterveld, there was then a fifty-year break before Acocks (1953) mapped his proposed South-Coast Renosterveld extent. This extended from Bot River in the west to a point just west of Knysna, in the east. The northern boundary was the Cape Fold Mountains stretching from the Riviersonderendeberge in the west to the Outeniquaberge in the east. To the south, it was separated from the sea by a strip of coastal Fynbos, stretching as far east as Mossel Bay. Between Mossel Bay and Knysna, the coastal Renosterveld reached the coast, except where intersected by strips of Valley Bushveld (23). His rainfall and altitude boundaries were the same as for the west coast.

Acocks’ map was modified by Moll *et al.* (1984), who divided the south coast block into two: South-West Coast Renosterveld lying west of a line drawn approximately between Swellendam and Bredasdorp, and South-Coast Renosterveld, extending

east to just beyond Mossel Bay. In addition they also mapped South-Coast Renosterveld patches close to Port Elizabeth, and in parts of the eastern Little Karoo. Low and Rebelo (1996) mapped South and South-West Coast Renosterveld as a single entity, largely following the classification of Moll and Bossi (1984). Cowling and Hejnis (2001) confined their southern coastal Renosterveld units to the coastal lowlands west of Mossel Bay. They identified two BHU: Overberg Coast Renosterveld and Riversdale Coast Renosterveld. They also added three Fynbos/Renosterveld mosaics (Elgin, Elim and Blanco). Mucina and Rutherford (2004) identified five coastal Renosterveld vegetation units within the south coast region as used in this thesis: Western-, Central- and Eastern- Ruens Shale Renosterveld, Mossel Bay Shale Renosterveld and Ruens Silcrete Renosterveld.

Characteristics of coastal Renosterveld communities

Meyer (1875) described the Piquetberg to False Bay sub-district of the Western region so: “Here at length the rhenosterbosch grows very copiously, yet not so crowded together but that various grasses, *Irideae*, *Orchideae*, *Oxalideae*, *Cyphiae*, *Microlomata*, and other smaller plants, are enabled to grow intermediately with it.”. The Breede River sub-district of the Southern region was similarly described, although it was noted that grassy plains became more frequent east of Swellendam. Marloth (1908) considered Renosterveld to be a product of disturbance by man and said it was a “kunstformation” He described two distinct, but geographically overlapping Renosterveld communities occurring in the western region. The most widespread one, having a grey-green appearance, was dominated by *E. rhinocerotis*, and occurred over much of the area currently accepted as being West-Coast Renosterveld, as well as around Tulbagh, Ceres and Caledon (effectively the upper reaches of the Breede River valley). The other community (between Porterville and the Piketberg) was described as having more of a grey appearance, and here the Renosterbos shared dominance with five other composites: *Eriocephalus umbellatus*, *Relhania genistifolia*, *R. ericoides*, *Pteronia incana* and *Euryops tenuissimus*.

Bews (1916) described Renosterveld as a community dominated by Renosterbos, associated with which were a number of grasses and other species. He said it

covered large areas of land in the south-western Cape. Adamson (1929) wrote about a very characteristic community, covering great stretches of the fertile tracts of the south-western Cape, which was dominated by a "...useless grey-green shrub..." (Renosterbos). It occurred in regions receiving 300-500 mm of rain and having mainly clay soils. He considered this community the most abundant of any at the lower altitudes of the region, and said its presence was a result of interference or destruction of the original vegetation, particularly by burning and overgrazing. He said it was more abundant then, than in the past (implying within living memory). Muir (1929) described the Renosterveld in the Riversdale region (South-Coast Renosterveld). At the time of his study, it was overgrown with Renosterbos of one to two metres in height. Nevertheless, he mentioned that the inhabitants of the Klein Karoo continued to refer to his study area as "Gras veld", which Muir perceived as being applicable to a state that had long since passed away. Duthie (1930) carried out a community study on the Stellenbosch Flats, which is now mostly covered by the University of Stellenbosch. She identified five communities in an area of about four square miles, one of which was based upon clay soils and was referred to as the "grey-bush" community. This was the Renosterveld community. In undisturbed areas, Renosterbos was absent, while in mildly disturbed areas it was present but not dominant. Where severe disturbance had occurred, Renosterbos became dominant. Of interest was the very high percentage of geophytes occurring in this community, with 45% of the 127 species recorded being of this life form.

Levyns (1929, 1936, 1956) said that Renosterbos achieved the closest approach to single species dominance in the Cape floral area. She felt that the Renosterbos communities in the Riversdale region (South-Coast Renosterveld) were climax communities, because of the presence of young Renosterbos seedlings growing up under the mature adults. However, in West-Coast Renosterveld she indicated that Renosterveld was not a stable community and was probably just a (protracted) stage in succession. This view was held due to the absence of any Renosterbos seedlings occurring under mature adults. She recorded 66 species in an area of 1455 m² in Idas Valley near Stellenbosch. She found that by clearing the natural vegetation, grasses were favoured, whereas burning encouraged the spread of Renosterbos and other shrubby plants. She also made an important observation that communities

growing on the granite soils of Lions Head inclined towards true Macchia, while the shale soils were “singularly deficient” in a number of these families (Michell 1922).

Pole Evans (1936) described Renosterbos as occurring in the valleys and on the mountain slopes “...where man has upset the balance of nature”.

In 1938, Adamson again referred to Renosterveld as a simple open community, often characterized by the dominance of a single species, developing in areas where moisture becomes a limiting factor for the development of sclerophyll vegetation. In particular, he mentioned *E. rhinocerotis* and *Pteronia* spp. He placed the *Pteronia* spp. as occurring along the borders between sclerophyll and semi-desert vegetation, while he considered the *Elytropappus* communities to be more extensive and usually found on deeper fine-grained soils. Like Levyns (above), he also believed that the Renosterbos communities, which developed because of disturbance, were temporary, because they formed closed cover communities from which the development of Renosterbos seedlings was impossible. They were therefore gradually replaced by other species, which could withstand seedling shading.

Wicht (1945) thought that the dominance of Renosterbos was due entirely to the combined effects of burning and pasturing. He felt that if these practices were removed, Renosterbos would be replaced by other species whose seedlings develop below the Renosterbos.

Hutchinson's (1946) only reference to Renosterbos was that it only occurred in any density inland, between ranges of mountains, but no specific localities were given.

Acocks reportedly recorded 938 species from the western, and 1320 species from the southern blocks of Renosterveld (Taylor 1978). Taylor himself recorded 39 species in a 64 m² quadrat in the Riversdale nature reserve (South-Coast Renosterveld).

In 1974, Van Wilgen did a community-analysis of the vegetation of Paarl Mountain, and identified 31 physiognomic communities. Five of these, which occurred predominantly on the southern side of the mountain, had *E. rhinocerotis* as one of the dominant species.

In 1976, Linder carried out a community study on the Piketberg Mountain. He found that there was a clear distinction between Renosterveld, which occurred only on shale soils, and the Fynbos, which occurred only on the sandstone soils. The change from Renosterveld to Fynbos was abrupt and followed the boundaries between the two soil types. Most of the Renosterveld had an 80% to 90% cover of Renosterbos, but in some areas Renosterbos was absent and *Euryops thunbergianus* and *Merxmuellera* sp. shared dominance. In all he listed 15 species occurring in the Renosterveld areas.

Jones (1986), Savory (1986) and Scott (1986) all carried out community studies of the vegetation of the Eensaamheid (Jan Brier Louw) reserve and the adjoining pasture (Eensaamheid extension), which was used for grazing by merino sheep (McDowell 1995). This study was carried out in more detail by McDowell (1988, 1995). He recorded 51 families and 207 species, of which 199 were indigenous (reserve and extension). Six species were in the red data category. There was no significant difference in total species numbers, nor in projected canopy cover between the reserve and the extension. There was however, a community shift. Asteraceae and Iridaceae were unaffected, although in some cases they benefited from the grazing. Poaceae and Rutaceae were mainly negatively affected by grazing, while no Proteaceae survived outside of the reserve. This change in species composition, while retaining the basic community structure, was noted in the Humansdorp area by Cowling (1984). In contrast to Cowling's conclusion that Renosterveld conservation and the grazing of stock were compatible, McDowell suggested that this was not always the case, indicating the loss of Proteaceous species from the grazed area. It should be added that Tansley (1982) did not consider Eensaamheid to be Renosterveld, but thought it would be better classified as coastal Fynbos. Savory (1986) also classified the reserve as seasonally flooded coastal Fynbos. It should also be mentioned that a number of Proteaceous species grow within the Elandsberg PNR, where indigenous herbivores have been reintroduced (see below).

Boucher (1987) recorded 564 species occurring within his West-Coast Renosterveld communities. He felt that half of these communities could be phytosociologically classified as Fynbos, and the rest as pseudo-Fynbos. He said that this indicated the

intermediate nature of Renosterveld (*i.e.* that it is not a genuine veld-type). However, he omitted many annual species and deciduous geophytes from his list.

Fish (1988) and Stander (1988) both looked at community structure in the Elandsberg PNR. Fish looked at the difference between areas that had been ploughed and unploughed, prior to 1982, when both were burnt, and which had been grazed by game since then. Total species richness (22 in ploughed, 23 in unploughed, 31 in total), and canopy cover in the two areas was similar, but the ploughed site had a greater species richness per unit area. *Athanasia trifurcata* was more dominant in the ploughed area, while *E. rhinocerotis* was more common in the unploughed areas. Stander (1988) concluded that the area grazed by indigenous herbivores showed no difference in terms of species richness (*c.f.* Eensaamheid, above), although the species composition was different. In grazed areas, average shrub heights were less, but canopy cover was greater, due to an increase in procumbency.

Low and Rebelo (1996) have provided the most recent floristic definition of Renosterveld, which does not differ significantly from those offered by Moll *et al.* (1984), Boucher (1987) or McDowell (1988). This was quoted on page 4 in the general introduction to this thesis. Differences between West-Coast and South-Coast Renosterveld exist. West-Coast Renosterveld generally has a mid-dense to closed canopy cover (50-90%), while a more open to mid-dense (25%-75% cover) structure is found on the south coast. This would be in line with Levyns' (1956) opinion that the south coast's more open canopy allows the growth of Renosterbos seedlings, while the west coast's denser canopy suppresses this. A question that could be asked is why does South-Coast Renosterveld develop a more open canopy than that of West-Coast Renosterveld? Grasses are particularly abundant on the south coast, particularly towards the east (Low and Rebelo 1996). While grasses in West-Coast Renosterveld are mostly C3 species, C4 grasses such as *Themeda triandra* predominate on the south coast, particularly in the eastern areas (Cowling 1984, Low and Rebelo 1996).

Clumps of emergent broad-leaved shrubs are more common in the west coast region, in particular on the heuweltjies (Acocks 1979). Geophytes are well represented in Renosterveld (Ruiters 2001), particularly on the west coast (Acocks

1979), although Taylor (1978) disagreed, saying there were more in the south coast block. Goldblatt and Manning (2000) said that geophytes make up 23.3% of the Fynbos Biome. Published geophyte abundance figures within West-Coast Renosterveld vary from 22% (Boucher 1983) to 45% (Duthie 1930). Only Mountain Fynbos has more geophyte species than Renosterveld (1418 and 1288 species in the winter rainfall areas, respectively [Ruiters, 2001]).

Hall and Veldhuis (1985) listed 181 red data species/sub-species as occurring in West-Coast Renosterveld. However, all but 74 also occurred in adjoining vegetation types. Rebelo (1995) pointed out that the use of a grid square system, such as used by Hall and Veldhuis (1985) might have resulted in species being allocated to a particular vegetation type where it never occurred. A similar criticism could be made of the study of Ruiters (2001), although in many cases the authors are victims of the format in which the data they use has been archived.

Renosterveld affinities

In the preamble to a workshop on Renosterveld conservation, Rebelo (1995) attempted to point out the “enigma” of Renosterveld. Was it is a true vegetation type, or simply an extended transition between Strandveld or Karoo and Fynbos?

Due to the very sparse nature of the remnants, and the fact that most of these remnants have been greatly influenced by human activities, it is difficult to determine what affinities West-Coast Renosterveld really has with the surrounding vegetation types. Acocks (1953) felt that it was probably originally some form of shrubland. He described the west coast area as an admixture of Fynbos, with less grass than the south coast, and suggested that in the drier areas it became more succulent and merged into Strandveld. Taylor (1978) stated: “The Coastal Renosterbosveld and Strandveld are transitional types containing elements of the Cape, the Karoo-Namib and the Afromontane floras.”. Later in the paper, he says that typical Cape plants (Restioid and Proteoid) are absent or rare. Tansley (1982) indicated that her most northerly site (the Koringberg) had a strong succulent element, suggesting karroid affinities. Heydenrych and Littlewort (1995) made a similar assertion about the most northerly of the Darling Hills (the Klipberg) that they sampled.

Day (1983), in her introduction, defined Renosterveld as an ecotonal, often degraded Mediterranean shrubland dominated by Renosterbos, on soils moderately rich in nutrients. In the same publication, Westman *et al.* (1983) described it as a “putative disclimax” largely dominated by Renosterbos, and probably derived from an essentially tropical shrub and grass complex, marginal to succulent dwarf shrubland. They suggested this because of the presence of essentially tropical shrubs such as *Olea*, *Rhus* and *Euclea*, and thought that in the past those shrubs may have been more abundant. Their supposition was based upon the hypothesis of Moll *et al.* (1980) that the present lack of a tree element in the Cape flora was possibly due to too frequent fire periods, initially by the Khoekhoen herders, and later by the European settlers. Regarding this, Linder *et al.* (1992) hypothesized that the mid-Pliocene contraction of the tropical forests that previously occurred in the Western Cape, due to the development of a Mediterranean-type climate, led to niches that needed to be filled. In the case of the nutrient-poor soils, there were few pre-adapted species, and this led to the explosive speciation of typical Fynbos species. Renosterveld soils, which had higher nutrient levels, were able to support many of the extant species of that time, thereby limiting the niches available for the development of new species. Cowling (1984) noted that in the Eastern Cape Renosterveld areas, Thicket species (with the exception of a few shallow-rooted species) were confined to areas of deeper soil, and would typically be found along streams and on termitaria. Similar physiographic factors, along with the summer drought regime of the Western Cape, would presumably also limit the distribution of trees in the western and southern coastal areas.

Boucher (1987) noted that many of the species occurring on the heavier granite soils of Jonkershoek (Mountain Fynbos) were also present in West-Coast Renosterveld. As mentioned above, Boucher (1987) felt that half of the West Coast Renosterveld communities could be phytosociologically classified as Fynbos, and the rest as pseudo-Fynbos.

Joubert (1991) investigated the relationships between five different Renosterveld sites, two on the west coast (Signal Hill [454 species] and Tygerberg [444 species]), one on the south coast (Bontebok Park [433 species]) and two Mountain Renosterveld areas (Worcester [405 species] and Robertson [340 species]). Signal

Hill and Tygerberg were the most closely related, sharing 234 species. The Bontebok Park shared 108 and 117 species with the Tygerberg and Signal Hills respectively. Using published species lists, she did a similar comparison between Coastal Renosterveld, Mountain Renosterveld, Strandveld (*sensu* Acocks 1953), Mountain Fynbos and forest. Coastal Renosterveld (70 families, 179 genera) shared 31 families and 37 genera with Mountain Renosterveld (33 families, 62 genera) and 51 families and 88 genera with Strandveld (56 families 167 genera). With Mountain Fynbos (60 families, 156 genera) and forest (60 families, 112 genera), Coastal Renosterveld shared 46 and 37 families, and 69 and 37 genera respectively. These figures suggest that Coastal Renosterveld is most closely allied to Strandveld and has the least affinity with Mountain Renosterveld. This suggests that these two Renosterveld communities have been so-called, because of the invasiveness of one or two species, rather than on the general community composition as a whole.

Heydenrych and Littlewort (1995) looked at seven granite hills around Darling, and found that each was floristically distinct in some way. One (Klipberg), which had a high cover of rock, had karroid features, while the one nearest the coast (Rondeberg) had many typical Strandveld species. A third (Contreberg) had Fynbos elements present, particularly on its wetter south slopes.

Low and Rebelo (1996) estimated that one third of typical Renosterveld species were Cape endemics, but that few of these endemics were confined exclusively to Renosterveld. Goldblatt and Manning (2000) declared that Renosterveld shared few species with Fynbos. Ruiters (2001) reported that 284 (47.33%) of the 600 threatened geophyte species occurring in the winter rainfall region of the Cape floral kingdom occurred in Renosterveld, and said that most of them were localized endemics. This conflicts with Rebelo's (1992) statement, that there are very few localized endemics in Renosterveld (although Rebelo was specifically referring to the West-Coast region).

Three author's speculations about the original vegetation of West-Coast Renosterveld

In 1979, Acocks published an article in which he speculated upon the original (*i.e.* pre-European) vegetation occurring in South Africa. He believed that the coastal

Renosterveld area (*sensu* Acocks 1953) would have been comprised of a fairly dense *Themeda* dominated grassveld for a few years after a fire. A “thick sprinkling” of shrubs would grow up between the grass, but there would be continued grassiness between them, and Renosterbos would never become dominant. Tansley (1982) recorded a stand of pure *T. triandra* at Voelvlei, in an area that had been undisturbed since a fire seven years previously. De Jager (1985) was unable to find this three years later, although Sue Milton (*pers. comm.*) has indicated that such a patch existed upon the Voelvlei-Elandsberg boundary in 2006.

Boucher (1983, 1987) postulated that, at the time of arrival of Europeans, the west coast lowlands probably comprised a grassy Fynbos, with scattered Thickets that were associated with rock outcrops, heuweltjies and watercourse verges. Patch burning by the indigenous and peripatetic Khoekhoen, as well as natural fires, had resulted in complex successional patterns developing. With European farming practices, stock movements were restricted, resulting in heavy localized grazing pressure. To encourage the growth of grass, veld burning was temporally intensified (despite strict laws against it enacted in 1687 and again in 1741 [Sparrman 1786]) resulting in unpalatable pioneer species becoming dominant. Kruger and Bigalke (1984) quote Louw’s description of how the practice of local burns on a fairly short rotational basis (4-8 years) keeps some areas of the Fynbos in a mosaic pattern. Louw said that the burns usually occurred towards the end of the wet season, so they didn’t spread far, and were usually associated with some form of transhumance such as between Fynbos and Karoo.

An unpublished project attempted to reconstruct what West-Coast Renosterveld would have looked like in pre-historic times, that is, before the arrival of the European (De Jager 1985). His basic conclusion (from both literature studies and field work) was that “pristine” Renosterveld was distinctly grassy with bush clumps, composed of tropical shrub taxa such as *Olea* and *Rhus*. Where the microclimate and soil conditions were suitable, trees such as *Rapanea*, *Kiggelaria* and *Acacia karoo* were also likely to develop.

Environmental factors delimiting coastal Renosterveld

There are only minor published disagreements about the environmental factors delimiting the extent of West-Coast Renosterveld. It is generally considered to occur on undulating lowlands from near sea level to an altitude of about 300 m (Acocks 1953, Taylor 1978) or 400 m (Kruger 1979). Linder (1976) reported West-Coast Renosterveld occurring on shale soils at 500 m on the Piketberg. He said its presence was entirely edaphically determined, and the vegetation underwent abrupt changes to Fynbos as one crossed onto sandy soils.

Rainfall limits have been defined as ranging from 250 mm to 500 mm (Taylor 1978) to 300 mm to 600 mm (Acocks 1953, Low and Rebelo 1996) per year, with local variations. For instance, rainfall at McDowell's (1988) sites ranged between 338 mm (Heuningberg) and 875 mm (Paarlberg, west slopes) for the sites he examined. Tansley (1982) noted that her study sites (a sub-set of McDowell's' 1988 sites) lay between the 250 mm and 800 mm per annum isohyets. A personal examination of the maps supplied in her report failed to find any of her study sites occurring below the 300 mm isohyet. On the other hand, it would also appear that areas considered to be Renosterveld (*e.g.* around Franschoek) can receive up to 1000 mm of rain per year. An analysis of the rainfall image from the South African atlas of agrohydrology and climatology (Schulze 1997) with current published extents of West-Coast Renosterveld indicated a maximum rainfall of over 2500 mm, but this is probably due to scale and interpolation errors.

The soils are generally some sort of base saturated clay or clay loam, derived from the weathering of Malmesbury, Klipheuwel, Bokkeveld or Cape Granite rocks (Kruger 1979, Deacon *et al.* 1992). On the west coast, the Malmesbury group is the predominant formation, although Cape Granite and (to a lesser extent) Klipheuwel intrusions are present (Deacon *et al.* 1992). It may also occur on Cenozoic (colluvial, alluvial and/or coastal) deposits (Deacon *et al.* 1992). These are the limestones and eutrophic sandy soils referred to by Boucher and Moll (1981), who quote Marloth as saying that under these conditions a Fynbos-Renosterveld mosaic tends to develop. On granitic soils, an increasing moisture gradient creates a transition from Strandveld, through Coastal Renosterveld to Fynbos (Boucher and

Moll 1981). South-Coast Renosterveld tends to occur on soils derived from the Bokkeveld group (Deacon *et al.* 1992), which has a higher availability of nutrients than that of Malmesbury shales (Wicht 1945, Deacon *et al.* 1992, Schulze 1997).

Geology and palaeoenvironment

Most of the Renosterveld on the west coast lowlands occurs on soils derived from the Malmesbury Group of rocks. These are predominantly marine sedimentary assemblages (Theron 1983) laid down in the Precambrian period (600+ million years before present [mybp]) (Deacon 1983). Through this layer, rocks of the Cape Granite suite intruded during the Cambrian (510-570 mybp) period (Deacon 1983), with some small outcrops of the Klipheuwel formation appearing slightly more recently (450-500 mybp). At that time, an extensive, featureless peneplain covered the south-western Cape, with only a few rolling hills in the Piketberg and Worcester areas (Theron 1983). At the end of the Jurassic period (150 mybp), continental break-up began, which left the southern continental margin of Africa almost in its present day form by 100 mybp (Deacon 1983, Deacon *et al.* 1992).

Soils developing from the Precambrian and Granite rocks in this area are shales, phyllites and schists. These soils are rich in bases such as calcium, magnesium, potassium, and sodium (Deacon *et al.* 1992). Two erosion surfaces are distinguishable. The first, lying between 80 m and 140 m above sea level has two groups of soils: The first of these, occurring on convex slopes where most of the pre-weathered substrate has been removed, is composed of shallow mispahs and Glenrosa soil forms. The second group, which are found on remnants of plains where some thickness of pre-weathered substrate is preserved, is composed of the duplex soils of the Swartland and Sterkspruit forms. Silcretes and deflection pans are common and the soils are moderately to highly sodic or magnesian. The second erosion surface, lying between 150 m and 200 m above sea level has similar soil forms to the above, but because of the underlying shales and phyllites they have a higher degree of pre-weathering and the soils are less sodic. No pans occur here, but true laterites with mottled saprolites and maghemitic grit lines are common (Information in this paragraph condensed from Schloms *et al.* 1983).

The present day Sandveld (Quaternary Sands) area is mainly composed of sediments laid down in the late Tertiary and the Quaternary ages. It occurs below an altitude of 200 m, and can be broadly divided into two (Hendey 1983a). The first type is the older acid sands, which are largely leached and generally support coastal (Sand Plain) Fynbos. The second type is the younger calcareous dunes which are rich in calcium (lime) and have reasonable amounts of nitrogen, potassium and phosphate (Talbot 1947). These soils generally support Strandveld (Coastal Thicket) (Hendey 1983a).

Sea level changes over the last 55 million years have sometimes been extreme. In the Tertiary period (40-55 mybp), they ranged up to 200 m above the current level, inundating most of the west coast lowlands (Vogel and Marais, quoted by Deacon and Lancaster 1988). During the mid-Oligocene (30 mybp) they dropped to 120 m below the current levels. This resulted in a wide coastal plain extending out from the present coastline, making it up to three times its current width in places. In the past half million years, sea levels have see-sawed dramatically with the glacial-interglacial sequences. During the last glacial maximum (about 20 000 ybp) sea levels were again probably 130 m below their current level (Vogel and Marais, quoted by Deacon and Lancaster 1988). However, they have probably never risen more than about six metres above the current level in the last two million years (Hendey 1983a).

Climatically it is believed that the inception of Mediterranean type climate conditions in this area began about five million years ago (Axelrod and Raven 1978, Deacon *et al.* 1992). Since then, there have been variations in average seasonal temperatures, and in the amount of rainfall received (Tyson 1986). For example, evidence suggests that average annual temperatures were five to six degrees centigrade lower during the Last Glacial Maximum (Deacon and Lancaster 1988). Rainfall patterns have likewise varied, with heavier than current rainfall being experienced over the west coast during the same period (*e.g.* Cowling *et al.* 1999, Parkington *et al.* 2000). The past 10 000 years have seen general climate conditions similar to the present, although extreme, short-term fluctuations have been noted ((Tyson *et al.* 2000, Tyson *et al.* 2001). Appendix A gives a more detailed description of the climatic events of the past 130 000 years.

Historical mammal presence as a possible indicator of vegetation in the past

Two problems arise when trying to determine the presence of a particular species of mammal in this area when Europeans first arrived. The first is that few, if any of the visitors were actually versed in natural history. The second is that many of the species had never been encountered before, so they were referred to in terms of similar European species. Thus, there are records of "Harts", "Elks" and "Roes" being present at the Cape. However, by the time the Renosterveld areas were being colonized, the major herbivores had been identified and named. The south-western Cape appears to have had only five common large herbivore species. These were (list from Skead 1980, food preference from Smithers 1983) the Black Rhinoceros *Diceros bicornis* (obligate browser), Eland *Taurotragus oryx* (predominantly browser), Elephant *Loxodonta africana* (mixed feeder) Rhebok *Pelea capreolus* (browser [Skinner and Smithers 1990; note that Smithers 1983 records this species as being an obligate grazer]) and Red Hartebeest *Alcelaphus buselaphus*. Red Hartebeest are predominantly grazers, although up to 44.4% of their diet consisted of browsed products in the S.A. Lombard Nature Reserve (Van Zyl quoted in Smithers 1983). Zebra (both Quaggas *Equus quagga* and Cape Mountain Zebra *E. zebra*) appeared to be present, although not in great numbers in the western lowlands (Skead 1980). They are predominantly grazers (Smithers 1983), and so their presence implies sufficient quantities of grass. The Hippopotamus *Hippopotamus amphibius* was confined to rivers and estuaries and their immediate surrounds, and cannot be considered helpful in determining widespread vegetation patterns.

We could surmise from the species of mammal present that the vegetation was predominantly shrubby, although there must have been a substantial amount of grass, either between the shrubs, or as fields developing after fire, in order to support the numerous cattle of the Khoekhoen. However, we also need to take into account the actual density of each species, which from the records available we are generally unable to do. There were often reports of large herds of mixed hartebeest and eland, but rarely were proportions specified. One exception was that "thousands" of hartebeest were reported in March 1661 in the Twenty-four Rivers region (Thom 1958).

Human presence in the south-western Cape lowlands

In this section, the general historical facts (uncited) are from Theal (1922). Other authors are cited where relevant.

Pre 1652

Evidence suggests that of all the Mediterranean regions, that of the Western Cape has been inhabited by humans and their predecessors the longest (Deacon 1983). The remains of *Homo erectus*, a hunter-gatherer have been found from 600 000 ybp (Deacon 1983) and there is direct evidence that either *Homo* or *Australopithecus*, or both, were able to make fire more than a million years ago (Brain and Sillen 1988). We must therefore assume that, to a greater or lesser extent, the vegetation of the Western Cape has been shaped by hominid made fires, in addition to natural fires, for many tens (if not hundreds) of thousands of years. Despite this, Groves *et al.* (1983) suggested that man's impact on the environment would not have been as great as it was in the Mediterranean basin (inhabited for 400 000 years), due to their lower density in South Africa. Modern humans (*H. sapiens*) have been present in the Western Cape since their first appearance as a distinct species approximately 125 000 years ago (Deacon 1983). Towards the end of the Pleistocene period (~ 10 000 ybp) they became more "patch bound", that is their movements became restricted to particular areas (Deacon 1983). It is believed they would "cultivate" geophytes by means of burning practices ("fire-stick farming"). The burns would also encourage new growth, which would attract antelope that could be snared for meat (Deacon 1992).

Despite the above practices, it seems likely that it was only with the introduction of domestic stock about 2000 years ago that any substantial transformation of the landscape began. There are records of sheep remains being found at De Kelders between 1500 and 2000 ybp (Schweitzer and Scott 1973, Schweitzer 1979). The presence of cattle is more difficult to determine, due to the similarity of their bones to those of certain indigenous ungulates (Klein 1986). In the south-western Cape, there is circumstantial evidence from pottery shards that cattle were present at Boomplaas by 300.AD, and hard evidence of their presence at Kasteelberg by

800.AD (Klein and Cruz-Uribe, quoted by Deacon 1992). It would be at this stage that frequent widespread burns would have become common.

With the development of a herding lifestyle, the Khoekhoen herders were forced to become more nomadic, in order to provide pasture for their cattle. The circuitous routes proposed in Smith (1992) would appear to be rather simplified, as it is clear from reports in Thom (1952), that movements over the Hottentots-Holland Mountains into the Overberg were frequently made. The movement of the herders into the Cape Town region was also not regular (Thom 1952). Nevertheless, some Khoekhoen apparently remained sedentary. Van der Stel's journal of his expedition to Namaqualand in 1685-1686 (Waterhouse 1932) notes that in the locality of the "Tiger Mountains" (Tygerberg) they met Khoekhoen that remained there the whole year, as there was sufficient grass and water to do so. The equivalent report in Valentyn (1726) makes no mention of these herders remaining resident the whole year, simply that they were present at the time of the expedition.

European expansion onto the western lowlands

Once again, uncited facts in this section are from Theal (1922).

Based on figures quoted in Thom (1952, 1954, 1958) it appears likely that no more than 50 000 indigenous people were living on the west coast lowlands (south of the Olifants River) prior to 1652. The establishment of a refreshment station at Cape Town marked the beginning of an exploitative impact on the land. When van Riebeeck left the Cape in 1662, the station was well developed, and bartering with the Khoekhoen provided meat for visiting ships, as well as for the colonists had been firmly established. A hedge of *Brabejum stellatifolium* had been planted to define the boundaries of the settlement, which was about 6000 acres in extent. Even during this short period, the exploitation of natural resources had been such that supplies of firewood and timber had become a problem, and washaways (apparently caused by the removal of trees) on Table Mountain occurred in the winter of 1656 (Thom 1954).

With the expanding population of the settlement (by growth and immigration) expeditions were sent out to identify other fertile areas for settlements. In 1672

development began at the foot of the Hottentots Holland Mountains, and by 1678 corn was being cultivated there. By 1679, cattle were being grazed along the Eerste River, while two farms had been leased to the east of Tygerberg. By the end of 1680, at least nine families had moved to what is now known as Stellenbosch.. By 1682 there was a company farm at “Cuylen” (= Kuils River – Mossop 1931) and in 1683 a pasturing farm was set up at Klapmuts as alternative pasturing for the Hottentots Holland cattle. In 1687 the first farmer arrived at Drakenstein, and a census (not accurate) estimated that over 900 Europeans and slaves were present in the Cape, along with more than 33 000 stock and more than 400 000 vines. In 1688 the first of the Huguenots arrived, followed in 1691 by more Dutch and French colonists. By then, the European farmers had spread beyond Wellington and by 1700 cattle were being grazed around Riebeeck Kasteel and at Groenkloof (Mamre). Figure 3 (modified from Theal 1922) shows the approximate extent of European settlement in 1700. By 1712 there were graziers and other farmers at the Piketberg and by 1771 expansion had occurred to well beyond the Olifants River. We can therefore surmise that, by the mid-1700's, the western coastal lowland area would have been subjected, to a greater or lesser extent, to European farming practices.

From about 1670, the Khoekhoen clans started weakening and breaking up, and many began drifting off inland to get away from European expansion. Others simply fell into an indigent lifestyle, selling their cattle to Europeans for brandy and tobacco, or losing them to internecine feuds and depredations by the San. The final axe fell with the outbreak of the smallpox plague around 1712. Lacking any sort of inherited resistance to smallpox, most of the Khoekhoen remaining in the Cape succumbed to the disease. The European population was also badly affected and the censuses in 1712 and 1716 recorded 1939 and 1697 persons respectively. Bradlow (1994) reported that the population of Cape Town in 1772 was approximately 7000 (including 1700 sailors and 4000 whites). In addition, there were approximately 2000 free blacks and slaves. By 1786, the population had probably doubled, as there were then more than 7000 whites (Bradlow 1994).

Changes to West-Coast Renosterveld since the mid-1600's

In the face of the human-induced land transformations that have occurred, it is easy to forget that humans are part of the natural fauna of the world. Although diseases, wars and famines have helped to control the population, humans have been responsible for severe land degradation at least as far back as Plato's (427-347.BC) time (Forman, quoted by Saunders *et al.* 1991). There is also speculation that humans may have been, at least partly responsible for the extinction of a significant number of species during the Late Pleistocene (Klein 1984, Miller *et al.* 1999), and even some of the more recent extinctions of major species cannot be blamed solely upon the industrial revolution and European colonization (*e.g.* Falla *et al.* 1982). It might be reasonable however, to consider the state of affairs that existed in South Africa at the time of arrival of Europeans as reasonably natural, although the recent introduction of sheep and cattle into the area and the resulting changes in land-management these caused, would suggest that new pressures were being placed upon the indigenous flora and fauna.

What was the vegetation of the Renosterveld areas of the south-western Cape at the time of arrival of van Riebeeck? Reports of visitors to the Cape between 1600 and 1702 gave widely differing pictures of the Cape, ranging from "lush meadows" (*e.g.* Aldworth in 1611), to de Graaf's 1640 opinion of the Cape as "...a wild land, waste and uninhabited – nothing but bare rocks, heaven high hills, dangerous clefts, wide valleys overgrown here and there with trees, scrub, marram and grass..." (Raven-Hart 1967). Many of these early reports are unreliable, being biased by the expectations and experience of the writers, most of whom were unversed in natural history and would have given a Eurocentric point of view.

Regional observations

This section will look at different regions of the west coast lowlands, in order to monitor changes in the landscape, as described by early visitors to the Cape.

Cape Town

The most reliable and factual reports of the south-western Cape from the mid-1600's, are those in the Journals of the DEIC (referred to as van Riebeeck's Journal for the period 1652 to 1662 [Thom 1952, 1954, 1958]). It is clear that there was a considerable amount of grassland present in the immediate vicinity of Cape Town, and the Journal records Table Valley as having the finest clay soil in the world (Thom 1952). Many references are made to the pastures used by the Khoekhoen (and later the Dutch) around the castle, on the lower slopes of Table Mountain and Devils Peak, and out to the Liesbeeck and Salt rivers. There were also pastures near Hout Bay, as well as on, and south of, the Lions rump/Signal Hill (all of which could be termed Renosterveld, from an edaphic perspective). Michell (1922) mentioned that Signal Hill was still being used for the grazing of cattle and collection of firewood as recently as 1920.

There are reports of the Khoekhoen grazing approximately 20 000 cattle and sheep in Table Valley, both in December 1652, and again in December 1655. At this latter date, there was an estimated five to six thousand Khoekhoen travelling with their stock. There are also many references to the grass being burnt by the locals, in order to encourage the growth of new grass for their next visit. There are two enigmas here. The first is that it is hard to understand how grass that has been heavily grazed manages to burn. The second is that, if the herders had been burning the area for a thousand years or more, why did the biodiversity of the area not suffer? While it is accepted that Fynbos is a fire-driven ecosystem (Bond *et al.* 2003), frequent fires (in summer) should have led to the local extinction of shrubs and trees that could not produce seeds within the short burning periods. Granger (1984), for example, noted that burning in mid-summer reduces the regeneration of heaths from seed.

It is interesting to note that management advice to stock farmers in coastal Renosterveld areas is that burning should take place shortly after the first rains of the year (autumn) have begun. The veld should then be rested for at least nine months before introducing stock to the area (du Toit and du Toit 1938). It would appear that, while the burnt area was rested (except for indigenous grazers) until the Khoekhoen returned a year or more later, the actual burn date simply depended

upon where they happened to be at the time. Burns around Cape Town were usually in early to mid-summer (December-January), so maybe it is the rest, rather than the time of burn, which is the important factor.

Tygerberg district

Aldworth was probably describing an area close to the Tygerberg in 1611 when he wrote that, despite it being mid winter, the grass still came up to his knees (in view of the winter-rainfall regime of the south-western Cape, this is not altogether surprising). He also mentioned there were “much deer” and that “...the abundance of cows and ewes is astonishing” (Raven-Hart 1967). By 1670, thirty to forty wagonloads of hay were being collected annually from the Tygerberg for the horses belonging to the company (Theal 1922). In 1685, Simon van der Stel reported it as well grown with ample grass and water, and that one group of Khoekhoen remained in the region permanently (Waterhouse 1932 – this is not mentioned in Valentyn’s 1726 version). Kolben (1731) described the Tygerberg hill as the most fertile of all the hills in the region, with ample water, although somewhat brackish in the dry season. He said the hillsides had cornfields, vineyards and gardens, and meadows stocked with cattle. He also noted that there were great numbers of Renosterbos on the “Tiger hills” and the “Mushel-bank”. The map that appears in Valentyn (1726) shows a hill with this name (Mushel-bank) between the Mosselbank and Stink rivers, to the east of the Rondeboschieberg. The gross misplacement of places on the map makes it impossible to give a precise location, but from its general relative location to other named landmarks, the Klipheuwel is the most likely candidate. In 1772, Francis Masson wrote that there were many fine plantations, cornfields and vineyards at the foot of the Tygerberg (Bradlow 1994). Sparrman (1786) said the area had extensive cornfields, and that the only wheat (for human) and barley (for fodder) in the Cape was grown here (but see later sub-sections). Mentzel (1787) observed that the quality of the vegetation in the Cape region was very variable, and that as one moved away from the Tygerberg, the soils became sandy and the vegetation low and woody. These regions were mostly uninhabited, with no cereals grown or viticulture practiced. Barrow (1801) said that, going east from Tygerberg,

the soil consisted of yellowy clay and sand, with many thousands of termite mounds.

Somerset West and Schaapenberg

Expeditions to the region of Somerset West in 1657 reported lush pastures, with nearby forests. By the end of 1673, stock were being sent to this area for fattening, cereals were being harvested and hay was being cut and transported to Cape Town (Leibbrandt 1902). In the early 1700's, Schaapenberg was described as having grass suitable for grazing sheep, the whole year round (Valentyn 1726¹, Kolben 1731). In 1772, Masson reported fine vineyards and cornfields in this region (Bradlow 1994). Burchell (1822) describes this area as having fine fertile soil, and added that the Schaapenberg was a large grassy mountain.

Stellenbosch area

In 1679, Simon van der Stel described this area as a beautiful valley with rich soil and abundant water, and by the end of the following year, fine crops of wheat were being produced (Theal 1922). Bogaert, in the late 1600's reported that Stellenbosch had valleys grown with healthful grass and herbs (Raven-Hart 1971). Valentyn (1726) reported that there were many Khoekhoen there when first visited, but that they were forced to leave by the "...courage and industry of the Dutch...after which we cleared the country of its bush, scrub and useless trees.". Mentzel (1787) also mentioned that though fertile, "...the land had first to be cleared of a great deal of shrub and undergrowth.". Masson described the area as having plantations, orchards and vineyards when he was there in 1772 (Bradlow 1994). Bottelary was described by Valentyn (1726) as having "...in all of Africa no lovelier grass fields than here",

¹ According to the editors of the 1971 reprint and translation of the copy of Valentyn consulted, Valentyn would "plagiarize" other writer's works. The editors refer to him as a "... tireless compiler of facts, not distinguishing between data obtained by his own observation...and that found in existing publications or painstakingly delved from manuscripts". At the time he was writing, this was accepted, and was not considered as "theft" of intellectual property. His version of Simon van der Stel's expedition would probably have been copied from the original, and was the only version in existence for over 200 years, until the "official" version was rediscovered by Waterhouse (1932). Most of the descriptions relevant to this project are direct copies, or paraphrasings of the journals of Kolben, the truthfulness of whom was often highly questionable (see introduction to the 1975 reprint and translation of Sparrmann's 1786 travel journal). To explain the apparent anachronism, it should

and noted that most of the hay used for the horses kept in Cape Town was reaped here. Kolben (1731) explained that this was because in most other places the dry grass was eaten *in situ*, rather than being mown. Mentzel (1787) said the farms there tended to have very mixed soils. Part of a farm would be good for agriculture, while the other part was a dry land, full of small stones on which only “Rhenoster shrubs” grew, and which offered poor grazing. Barrow (1801) wrote that the lands along the foot of the mountains between Paarl and False Bay mainly produced wines and fruit for the Cape market.

Central Swartland (Perdeberg - Riebeeck Kasteel - Mamre)

In 1657 the area along the Berg River (probably around Wellington), was described as having fine lands and good pasture. It was also reported that, in the region of the Perdeberg there was fine grass, suitable for making hay (Thom 1954). In 1658 there were reports of Khoekhoen with herds of cattle and sheep “... as numerous as the grass on the veld...” (Thom 1954). Although no definite location was given, this was in an area about three days march from Cape Town. However, the vegetation was clearly not fertile and grassy everywhere, as there were numerous reports of areas with little or no grass and a lack of water. One of these was from November 1657, where, three and a half Dutch miles east-north-east of Tygerberg the soil was reported to be poor and barren with insufficient grass for oxen to fill their stomachs (Thom 1954). One Dutch mile is reported in Waterhouse (1932) and Thom (1954) as being equivalent to about four English miles (~ 6.4 km).

In March 1659 an expedition that apparently reached the Berg River, found the country everywhere so barren, parched and ill supplied with pasture and water that they had to turn back (Thom 1958). An expedition along a similar route in March of 1661 (Thom 1958) considered the area around Riebeeck Kasteel to be suitable for agricultural purposes, although somewhat sandy in places. It also noted that between there and the confluence of the Berg and Little Berg rivers, there were “horses” (zebra), rhinoceros, ostrich and thousands of hartebeest. On the eastern side of the Berg River, a similar condition prevailed. This would suggest a

be noted that Valentyn had access to Kolben’s original 1719 “*Caput Bonae Spei hodiernum*”, rather than the 1731 translation that was used here.

substantial grass component. Simon van der Stel's 1685 expedition reported Riebeeck Kasteel as a hill clothed in "...wild and desolate forest" with good timber (Waterhouse 1932). Valentyn's (1726) translation of the same expedition described it as "...thickly grown with trees suitable for timber". It also noted a fair supply of grass between Riebeeck Kasteel and the Heuningberg. Mentzel (1787) was in the same area in the 1730's and reported that, while the area around Riebeeck Kasteel was fertile, with much grass, and bush suitable for firewood, there was no timber on the mountain. Barrow (1801) travelling between Wellington and Voelvllei noted that the soil changed from a fine hard clay to a sandy soil as he went north. He noted that the road wandered over an uninterrupted forest of verdure, arising from a variety of frutescent plants such as Proteas and heaths, but which was dominated by two species of *Seriphium*, "...called here rhinosceros-bush.". Lichtenstein (1812) reported that in the Twenty-four Rivers district, there were farms with orchards, corn-fields and vineyards. Their major disadvantage was that the cost of transporting the produce to Cape Town was too great, except in years when there was a shortage of crops around Cape Town.

The Mamre area (also called "Groenekloof" "Groene Kloof" or "Groote Post") became an important grazing area for the DEIC. The farm "Groenekloof" lies on the south-western slopes of the Dassenberg. In 1772, Thunberg described Mamre as having a considerable number of grazing farms, and the area was much inhabited and cultivated (Thunberg 1795). He also commented that between Groenekloof and the sea were low, level sandy plains, but these were not well populated as the fertility of the soil was very variable and water was scarce. Mentzel, (1787) said that the Groenekloof was a valley rich in grass between the Kapokberg and the Langeberg and this was the only good pasture between Cape Town and St Helena Bay, the rest being sandy and uninhabitable. The map of de la Caille, drawn up in the 1750's (Evans 1992) shows the Langeberg (or Langberg) as a range of hills just south of the Langebaan lagoon, and a little to the north of the hills in the Darling region. Groene Kloof is shown between the Langberg and the "Capoeborg", thus placing it to the north-west of the Kapokberg, whereas it lies to the south-east. The author believes that the Langeberg and the Darling hills are in fact one and the same, and their division is due to maps at that time being produced from hearsay, rather than detailed surveys.

Barrow (1801) visited Groene Kloof in April (before the winter rains), and commented that there was little verdure on the hillsides, except around the springs. In 1803, van Reenen (Blommaert and Wiid 1937) said that the Groene Kloof district had extensive fields covered with grass, but only for six to seven months of the year. At other times the grass withered, the fountains dried up and one was obliged to use the moors and downs, which were better supplied with water. In the report of his trip to Saldanha in May 1804, Paravicini Di Capelli wrote that the farm Ganzekraal, which lies near the sea, to the west of Mamre, was producing wheat, barley and rye (de Kock 1965). Ganzekraal occurs in a region consisting of a mixture of clays and Quaternary sands (Anon. 1990). Lichtenstein (1812) also agreed that Ganzekraal was very fertile, and mentioned a number of other farms growing corn, or with good grazing close to the coast.

Northern Area (Piketberg – Renosterhoek – Porterville)

The DEIC expedition inland in March 1661 reported that, between the Piketberg and the Olifantsrivierberge, there were valleys with waist high grass and the soil was suitable for agriculture, and (Thom 1958). A few years later Simon van der Stel's September 1685 expedition noted that the clay and sandy-clay soils along the eastern foot of the Piketberg were abundantly grown with grass and "wild oats". There was ample water and good firewood and timber everywhere (Valentyn 1726). In 1705, Starrenberg reported beautiful grassy hills between the Twenty-four Rivers district and the Piketberg (Valentyn 1726). He also reported pleasant valleys and grassy ridges along the eastern foot of the Piketberg. Theal (1922) reported that graziers and farmers had reached the Piketberg by 1712. Sixty years later, Thunberg (1795) noted that on the eastern slopes and along the foot of the Piketberg were vineyards and cornfields. In 1774, Masson reported the area between the Perdeberg and the Piketberg as being barren uninhabited country (Bradlow 1994). Oddly, Lichtenstein (1812), who travelled a similar route 28 years later (Piketberg to the Twenty-four Rivers region), noted the area as being fertile and having ample water. He also commented on the cornfields along the eastern foot of the Piketberg, but noted that the ravines were overgrown with bushes. Mentzel (1787) reported that

the Piketberg had few farms, and cattle-rearing was the predominant activity, as most of the soil was sandy and not fertile.

Past perceptions and recent research

It is clear from the above reports that perceptions varied. This could be ascribed to the time of year an area was visited, the changes that occurred over time, and to the personal experience of the people making the reports. There appears to have been a considerable presence of grassland (probably a grass/shrub mixture) in the south-western Cape at the time of arrival of the Dutch. In South-Coast Renosterveld regions, there are a number of recent reports of extensive grasslands (Muir 1929, Smit 1943, Cowling *et al.* 1997), in which *Themeda triandra* is mentioned as the dominant grass species. In West Coast Renosterveld, both Acocks (1953) and Tansley (1982) refer to dense patches of *Themeda triandra*, although it appears to be less common here than on the south coast. *Themeda*, along with some other grasses (*e.g.* *Hyparrhenia hirta*) are C4 grasses (although C3 morphs do exist [de Jager 1985]). C4 species have a different isotopic signature of carbon ($\delta^{13}\text{C}$) to those of C3 shrubs and grasses. If an extensive C4 grassland existed over the west coast lowlands for a substantial period of time, this should be discernible in the isotopic signature of the upper soil layers. Stock *et al.* (1993) measured the isotopic signatures of soils at different depths in three localities in the west coast area, two typical Renosterveld areas (Signal Hill and Tygerberg), and one Renosterveld-Fynbos transitional area (Bain's Kloof). The results from all three areas showed clear C3 signatures. While the results of this study do not disprove an extensive grassland theory, (there are many C3 grasses indigenous to the area [*e.g.* *Merxmuellera disticha*, *Ehrharta* spp., *Pentaschistis* spp.]), it has unfortunately not provided firm evidence for it either (see Appendix A for more details).

The short section on the major herbivores present suggested that the area was predominantly shrubby. There are two comments to be made here. The first is that the non-Renosterveld vegetation would have been Fynbos or a form of dune scrub thicket (Acock's 1953 Strandveld), which are predominantly shrubby. The second is that the animals present would be the species that were indigenous to Renosterveld *prior* to the transformation brought about by the change to a herding lifestyle by the

Khoekhoen. Appendix A suggests that the natural (*i.e.* pre-herder) condition of West-Coast Renosterveld during the Holocene was a shrubland, with grasses being present between the bushes, and more widespread after natural or man-made fires.

Recent reports

Land-cover changes

In this section, we specifically look at comments relating to land degradation in the area.

By the mid-1700s, the fertile areas of the south-western lowlands had largely been taken over for grazing, or for some other form of cultivation, such as cereals, vineyards or citrus (Thunberg 1795). European wild oats had become a problem in the wheat fields (and presumably also in the wild), having escaped in the previous century (Kolben 1731, Thunberg 1795). Before the arrival of the Europeans, it was of little consequence how far a fire started by the Khoekhoen spread. By 1700, this had changed, as a runaway fire could devastate crops and property.

Whereas the Khoekhoen herders were peripatetic, most European farmers were sedentary. Old pasture was still burnt, but in contrast to the Khoekhoen, the new shoots were immediately grazed, without a rest period. This led to the degradation of the grasslands and its invasion by shrubs, particularly Renosterbos (Sparrman 1786). Nevertheless, until the late 1800's farming was generally carried out at a level that would maintain the local community, mainly due to the difficulties and cost of transporting the produce to Cape Town (Talbot 1947). A typical land use scenario would be to clear some natural vegetation, leave the area fallow for a year, produce one crop of wheat the next year, followed by a crop of oats the next, after which it would be rested for several years. During this rest period, annual grasses and edible shrubs would grow, and the veld was generally described as being "...much better than the original veld, especially for sheep" (Neethling quoted in Talbot 1947). With the discovery of gold and diamonds in the interior of South Africa, and the development of efficient transport systems, this all changed.

Wheat and the degradation of the Swartland (1880-1945)

A summary of the rapid expansion of cereal farming in the Swartland area (as described by Talbot, 1947) between 1880 and the Second World War is given here. With the construction of railways to the interior, new markets for wheat became available. This resulted in more land being cultivated, and rest periods being shortened. The First World War led to reduced wheat importations, and so more had to be produced locally. Within the Malmesbury magisterial district (as it was then), just under 125 000 ha of cereals (of which about 55 600 ha was wheat) were being grown in 1919. Crop rotation was typically a four-year cycle of wheat, oats, old lands and fallow. Between 1919 and 1929, the area cultivated remained constant, but the amount of oats grown declined because machinery was replacing draught animals. By 1930, it had become cheaper to import wheat than to grow it locally. The Government thus proclaimed the Wheat Importation Restrictions Act, prohibiting the importation of wheat, flour or meal, except under permit from government, and then a minimum “landing cost” was prescribed. Prior to this, 25-30% of South Africa’s wheat was imported and the high quality imported wheat was mixed with local “weak” (low quality) wheat. These restrictions led to wheat becoming a lucrative farming option. Production in the western Cape lowlands was 45.5% higher in 1934-38 than in 1924-28, with approximately 141 471 ha of land under cereals (of which about 85 700 ha was wheat) in the Malmesbury district. Increased wheat yields were achieved by ploughing marginal lands (steeper slopes, poorer soils), by reducing the area of other crops, and by reducing the rotational frequency to a year of wheat and a year of fallow. The “old lands” that had been used for stock were thus reduced in area, but the number of stock remained the same, resulting in the overgrazing of the remaining natural vegetation fragments, and the associated erosion and reduced nutritive quality problems. The increased frequency of wheat growing led to an increased prevalence of weeds, diseases and pests. Disease resistant varieties of wheat were introduced, but by that stage, Swartland farmers were spending more on fertilizer per hectare, than any other farmer in the Union. Soil preparation became more involved as it often had to be ploughed three times before sowing and often harrowed as well afterwards. This was due to the soil degradation having become so bad that the soil structure was

breaking down, resulting in it becoming so compacted that the seeds were unable to emerge. The outbreak of the Second World War led to an even more urgent need for wheat, but by then returns were very poor, with little more than five bags (~ 90.5 kg/bag) per morgen (~ 0.85 ha) being produced.

The result of all this was that when Talbot did his survey in 1938, erosion was rife in the Swartland. Gullies and dongas littered the countryside. Ploughing was being done up and down the slope, and slopes of 30% (16.7°) and more were being cultivated. This was done despite gullies developing on slopes of 10% (5.7°) or less (the Heuningberg slopes had serious soil losses on slopes as low as 5% [2.9°]). Contour ploughing was unknown, with only 100 of approximately 400 000 morgen (~ 85 of ~ 339 200 ha) surveyed exhibiting this.

The Swartland – the last fifty years

Morel (1998) reviewed the situation in the Swartland and Sandveld, fifty years after the publication of Talbot's (1947) work. She confined her detailed studies to two 55 km² sites, one in the Swartland, and the other in the Sandveld. Her overall conclusion was that, at the Swartland study site, there had been an 85% decrease in gully density between 1938 (Talbot's study) and 1989 (the dates of the aerial photographs used by both parties). Only gullies of longer than 50 m were looked at, due to scale considerations on the aerial photographs. The Sandveld situation was more complicated, in that the total area of her study site affected by wind erosion had decreased by 17% between 1938 and 1986. However, the *frequency* of wind erosion was higher. This was mainly due to large continuous areas that had been subjected to wind erosion in 1938 being now only fragmentally affected by erosion. This land rehabilitation was ascribed to governmental legislation, education and subsidies (Morel 1998, Meadows 2003). Meadows (2003) discussed these in terms of political vote-gaining manoeuvres. Whatever the motives, the overall result has been an (apparent) improvement in land quality, at least within the study sites. Indeed, statistics from the Department of Agriculture (Anon. 1994) showed that wheat yields per hectare in the Swartland more than doubled between 1955 and 1992.

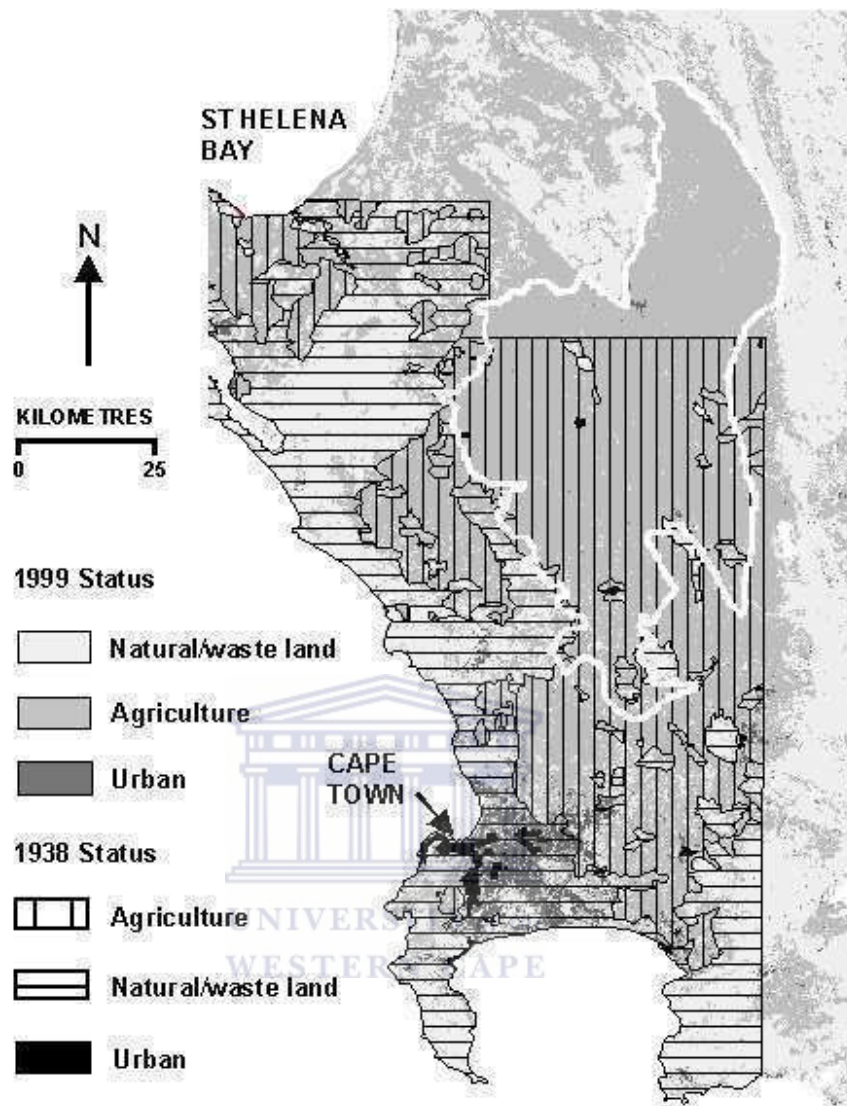


Figure 12. Generalized land-cover map of part of the Western Cape lowlands. Grey layer represents the current status. Lined overlay is from Talbot (1947) and represents the situation in 1938. White line represents the relevant section of the Swartland BHU of Cowling and Heijnis (2001).

Figure 12 shows a generalized version of the land-use map of Talbot (1947), laid over a simplified land-cover classification produced from a 1999 Landsat image (see Chapter 4). Talbot's map was produced from aerial photographs taken in 1938 and analysed at a scale of 1:50 000. Over the Boland and Swartland (West-Coast

Renosterveld areas), there is little noticeable difference in land use between the two maps. Hoffman (1997) plotted the change in the area of land under cereals between 1918 and 1981 showing that, in four magisterial districts on the west coast lowlands, the extent of land under cereals rose from 205 000 ha to 268 000 ha between 1940 and 1981. Due to changes in magisterial districts between 1935 and 1993, a better idea of the change can be obtained from Anon. (1998), who gives figures for 1993 for the four magisterial districts (Malmesbury, Moorreesburg, Hopefield, Vredenburg) that together made up the Malmesbury district of 1935. These show that in 1993, 151 758 ha was under wheat, 186 735 ha was under cereals (including wheat), 340 231 ha was under all crops combined, while all crops plus grazing land covered 513 947 ha. Talbot (1947) recorded 254 647 ha of land being cultivated (including fallow) in 1936/37. This suggests a doubling of the amount of land transformed to agriculture in this district over 60 years. However, it should be noted that less than a third of the Malmesbury district, as defined, could be considered to support West-Coast Renosterveld (see Figure 12), and it is likely that most of the transformation recorded over those years occurred on the Sandveld. The area of marginal land available around the hills in the Swartland would be insignificant compared to the total area (532 146 ha) that makes up this district (Anon. 1998). Talbot (1947) reported a Departmental Wheat Committee recording that almost the entire area of arable land in the Swartland was being cultivated in 1919. Wheat is still the major crop in the area, with the Swartland producing approximately 60% of the annual production of the Western Cape (*sensu* 2000 provincial boundaries) (Van Rooyen 2000). Although the amount produced varies from year to year, figures quoted by Van Rooyen (2000) suggests that there was no decline in production between 1985 and 1996.

Personal enquiries into west coast farming practices showed that there was a great deal of local variation in farming practices. In some cases, a monoculture of wheat would be grown for 5 years, after which the land was left fallow for a year. In other cases wheat may be alternated on an annual basis with *Medicago* or Lupins, or it may be left fallow (ploughed or unploughed) (Sakkie Slabbert *pers. comm.*). In the Darling area, wheat may only be grown in a field once every five years, the other years being used for Lupins or Lucerne, or it may be left fallow (Simon Steward *pers. comm.*). Around Elandsberg a typical cycle would be wheat followed by

barley, and in the third year the field is either planted with clover, or left fallow (Bernard Wooding *pers. comm.*). Near the Koringberg, wheat is the major crop, but is alternated annually with Lupins, Australian clovers or Canola. This alternation of dicotyledonous and monocotyledonous crops allows land to be sprayed against weed species of the opposite cotyledonous type to that which has been planted (Pagel Dippenaar *pers. comm.*). Canola also appears to produce an exudate that inhibits the growth of root pathogens, such as *Phytophthora* (Sakkie Slabbert *pers. comm.*). Annual fertilizer application levels are generally 60 kg/ha to 100 kg/ha for nitrogen, 10 kg/ha to 30 kg/ha for phosphate, and zero to 30 kg/ha for potassium (*c.f.* an average of 4.8 kg/ha for nitrogen and 4.1 kg/ha phosphorous applied in Western Australia [Hobbs 1993, quoting the Australian Bureau of Statistics]). In most cases there is sufficient potassium in the soils of the Swartland (Dr Agenbag, Sakkie Slabbert, Simon Steward *pers. comms.*).

Wheat subsidies have now been phased out (Donaldson 2002) and the price of wheat is based solely upon market pressures (Van Rooyen 2000). This should reduce the planting of crops on marginal soils. However, an import duty of R196 per ton was still payable on certain wheat types in 2003 (Anon. 2003a), and local markets have to compete against the subsidies paid to European and North American farmers.

Legislation quoted in the Conservation of Agricultural Resources Act 43, of 1983 (Anon. 1983a, 1984), allows slopes of up to 11.3° to be cultivated in this area. Kemper (1997) and Kemper *et al.* (2000), working in South-Coast Renosterveld quote legislation set by an “Agricultural Resources Act” (unreferenced) allowing slopes of less than 1.8° to be worked without any measures to counteract erosion, slopes between 1.8° and 8.1° to be worked with anti-erosion measures (*e.g.* contouring), while slopes greater than 8.1° cannot be worked. It is assumed that these figures were guidelines set by the local soil conservation committee.

What the implications of these will be upon Renosterveld conservation remains to be seen. Improved soil management of the cultivated areas should lead to less fertilizer runoff and less erosion of adjoining natural areas. On the other hand,

improved soil conservation techniques might encourage further expansion of agricultural practices into marginal areas.

Implications for conservation

The implication of all this, as far as the conservation of Renosterveld is concerned, is far reaching. Much of the topsoil in this region has been lost. Even worse is that the *soil structure* itself has been changed in many areas (Talbot 1947). McDowell (1988) reported that at Kalbaskraal (near Malmesbury), a field that had been left fallow for 15 years had only twelve indigenous species growing on it, despite being adjacent to a well-stocked nature reserve. High levels of fertilizer are being added, some of which no doubt runs off into natural areas. Donaldson *et al.* (2002) noted that the owner of the farm where they were working, treated fragments less than 10 ha in extent as part of the adjoining wheat fields, being burnt and sprayed as and when the surrounding wheat fields were. Although they were working in South-Coast Renosterveld, it is not unreasonable to expect west coast farmers to do the same. John Duckitt (*pers. comm.*) mentioned that about 25 years ago, his father planted clover as extra feed for his stock in the Darling area. The recommended dosage of phosphate for clover was added and the clover grew well for a couple of years. However two unwanted events occurred. The first was that an *Eragrostis* grass species took over after a couple of years (which most stock refused to eat), and the second was that the wild flowers completely disappeared. The flowers only began re-appearing in 2001 after a wet winter, but the dry winter of 2002 led to them being scarce again.

South coast

There is no work equivalent to that of Talbot (1947), relating to the situation along the south coast. The soils of South-Coast Renosterveld have a higher nutrient status than those of the west coast (Schulze 1997). Although European stock farmers have used this area for almost as long as the west coast area, it was only after the First World War that extensive clearing for cereal production began (Hoffman 1997). In the Bredasdorp, Caledon, Heidelberg, Hermanus and Mossel Bay districts, an estimated 90 000 ha of land was being used for cereal production in 1918. This rose

to an about 325 000 ha in 1965, but had dropped to about 260 000 ha by 1981 (Hoffman 1997) and to 217 000 ha by 1993 (Anon. 1998). The western parts of the south coast lowlands are flat to rolling and suitable for extensive agriculture; towards the east, the landscape becomes steeper, and the reliability of the winter-rainfall required for successful cereal production drops (Kemper *et al.* 2000). In the east, there is a greater tendency to use the land for grazing purposes (Low and Rebelo 1996).

Land that is used for the growth of cereals usually requires 20 to 25 kg of nitrogen/ha and 15 to 20 kg/ha of phosphate (*c.f.* figures for west coast region above). The natural levels of potassium are usually sufficient. Cereals are usually rotated on an annual basis, alternating with *Medicago* or Lucerne (Dr Agenbag *pers. comm.*). Wheat and barley are grown in approximately equal amounts in the south-western region, although the proportion of barley has been declining over the past 10 years (figures from Sentraal Suid Kooperasie, Swellendam and the Nasionale Kooperasie Landbou, Bredasdorp).

Current knowledge of conservation status

Due to disagreements about original extents, and to the lumping of Renosterveld from the western and southern blocks together by some authors, estimates of the amount of coastal Renosterveld remaining vary. Edwards (1974) estimated that 12 556 ha (of an original 1 459 100 ha = 0.9%) of coastal Renosterveld was conserved in provincial and forestry reserves. Boucher (1981) estimated that there were 29 502 ha of West-Coast Renosterveld left, but he did not consider patches north of the Great Berg River. In 1987, he estimated that 6% of its original extent remained. Considering all (West and South) Coastal Renosterveld (*sensu* Acocks 1953), Boucher and Moll (1981) estimated that less than 9% of its original extent remained untransformed. Parker (1982) noted that of the 29 502 ha of West-Coast Renosterveld remaining, only 2063 ha (7%) were in reserves. Tansley (1982) claims to have surveyed the 20 100 ha of West-Coast Renosterveld that were present in 21 study sites. A further 9400 ha was considered to exist as road verges, winter grazing and patches too small for conserving. This claim is a little confusing, as the Elandsberg PNR and many of the Darling Hills were not listed within her 21 sites.

They were however assessed remotely (aerial photographs) and comments made. Moll and Bossi (1984) estimated that 225 600 ha (14.75%) remained, but that included West, South-West and South-Coast (*sensu* Moll and Bossi 1984) Renosterveld. Jarman (1986) suggested that of the 13 619 ha of West-Coast Renosterveld remaining, only 2484 ha (18.2%) were conserved. Of this, 1000 ha were in a single private reserve (Elandsberg), 922 ha in local authority reserves and only 8 ha in a provincial reserve. McDowell (1988) estimated that 22 400 ha was being conserved in the 55 sites he looked at (he didn't consider patches north Eendekuil). Low and Rebelo (1996) estimated that less than 3% of the original 614 100 ha of West-Coast Renosterveld remained untransformed, with 1.76% (of the original area) being conserved, but less than 1% remaining in proclaimed nature reserves (private or public). The estimate of Reyers *et al.* (2001) was that 9.01% of the original extent, (*sensu* Low and Rebelo 1996) remained in a reasonable condition and a further 1.1% was badly degraded. Rouget *et al.* (2003), using the BHU system of Cowling and Heijnis (2001), suggested that 15.4% remained untransformed, and a further 0.8% existed, but had a greater than 75% woody alien cover. The most recent estimate is that of von Hase *et al.* (2003), who, using a geologically modified version of the west coast extent of Cowling and Heijnis (2001), estimated that 5% remained largely untransformed with 0.28% (189 327 ha) being in protected areas.

Tansley (1982) looked at 21 West-Coast Renosterveld sites in terms of area, species composition and threats. She then ranked them in terms of their "quality", based upon 15 factors that she considered relevant to their survival as conservation entities. Jarman (1986) condensed these factors to three main attributes (habitat diversity, plant species richness and number of threatened species) and four secondary attributes (size, shape, extent to which it had been invaded by alien woody species, and abuse [overgrazing, mining *etc.*]). Although Voelvllei and Dassenberg were in the top three in both lists, Tansley's number two (Klapmuts Kop) was rated as 13th by Jarman. When the two lists were compared, there was an obvious difference of opinion between the two authors (Table 1).

Moving to South-Coast Renosterveld, Low and Rebelo (1996) estimated that of the original 1 407 400 ha of South and South-West Coast Renosterveld (*sensu* Low and

Table 1. A comparison of the rankings given to the main remaining West-Coast Renosterveld sites by Tansley (1982) and Jarman (1986).

Sites assessed by Tansley	Tansley's rank	Jarman's rank	Sites assessed by Jarman, but not by Tansley	Rank
Voelvllei	1	2	Eensaamheid extension	4
Klapmuts Kop	2	25	Porseleinberg	6
Dassenberg	3	1	Heuningberg	8
Klein Dassenberg	4	10	Piketberg E foothills	9
Paarl Mountain	5	3	Harmony Flats	11
Schaapenberg	6	27	Groenrivier	14
Klipheuwel Radio Mast	7	7	Kuilenberg koppie	15
Contreberg	8	29	Groenberg	16
Helderfontein	9	12	Mamreweg	18
Tygerberg	10	5	Darling Hills	20
Saronberg	11	17	Malmesbury common SE**	21
Klipheuwel Kop	12	28*	Malmesbury common NE**	24
Joostenberg	13	22	Klipfontein	26
Koringberg	14	19	Kraaifontein Forest Reserve	31
Blouberg	15	30		
Neulfontein se Berg	16	N/A		
Riebeeck Kasteel	17	23		
Bottelary Hills	18	13		
Signal Hill	19	N/A		
Malmesbury Commonage	20	21/24**		
Kahlenberg	21	N/A		

* This is Jarman's Klipheuwel quarry site.

** Tansley assessed the two sections of Malmesbury Common as one unit.

N/A = Not assessed by Jarman

Rebello 1996), approximately 32% was transformed and 1.42% conserved. Kemper *et al.* (2000) estimated that of the 816 796 ha that they looked at (extent approximating that defined for this thesis), about 117 967 ha (14.4%) was natural Renosterveld. They divided the area they looked at into three sections, east, central and west, and related natural vegetation cover to various aspects of rainfall and

slope. The western sector, which had conditions conducive to agriculture (flat lands, seasonal rainfall) had only 4.4% of its original extent remaining untransformed, while the eastern sector, which was more rugged and had less seasonal rainfall had 33.4% remaining. Fragment size was also larger in the hillier east. The estimate of Reyers *et al.* (2001) was that 39.87% remained, with a further 1.9% degraded (extent *sensu* Low and Rebelo 1996). Rouget *et al.* (2003) estimated that 19.24% of the natural vegetation remained in the combined Overberg and Riversdale Renosterveld BHU; an additional 0.66% was natural but had an alien vegetation component of greater than 75%. Von Hase *et al.* (2003) estimated that 12.6% of the Overberg and 5.71% of the Elgin BHU remained untransformed. The amount conserved in these two areas was given as 282 264 ha (0.51%) and 23 281 ha (1.36%) respectively.

Current threats to West-Coast Renosterveld remnants

Among the threats noted by Tansley (1982) at the 21 sites she visited were alien invasion, grazing, trampling, fertilizer drift, firewood collection, dumping, and quarrying. This section takes a brief look at some of the major threats to the survival of West-Coast Renosterveld.

Aliens

Boucher (1981, 1987) reported that in 1972 approximately 30% of all remaining West-Coast Renosterveld had been invaded by woody alien species to some extent. He also estimated that a 100% alien cover would be achieved within 110 years of the first appearance of the aliens on the site. He later (1995) revised that figure to 150 years, and suggested it was more rapidly invaded by large woody species than any of the other coastal vegetation types in the Western Cape. The figures of Rouget *et al.* (2003) suggested that about 2.96% of the Swartland, and 6.86% of the Boland BHU fragments had been invaded to a level of 75% or more by woody alien species. Heydenrych and Littlewort (1995) on the other hand, felt that the main invasive problem with Renosterveld lay with the alien herbaceous flora and grasses, which tended to be overlooked and unstudied. Milton (2004) listed 32 alien grass species as occurring in Fynbos, half of which were annuals. Control of alien grasses

occurring within Renosterveld have been examined by Musil *et al.* (2005) who found that the subsequent increase in density of indigenous forbs and geophytes following initial control measures also helped reduce the abundance of alien perennial grasses. Vlok (1988) looked at five lowland “Fynbos” sites, three of which were Renosterveld, and one a limestone Renosterveld-Fynbos mosaic. He examined the effect that the density of alien annual species had on the alpha diversity of the natural flora. A high density of exotic herbaceous species led to a decline in the diversity of the natural flora of both annuals and geophytes. Alien annuals tended to occur only at sites where the shrub cover was very sparse, or absent. Although no hard data were given, most of his sites had been recently, or were regularly, disturbed (mowing, burning, heavy grazing, fertilizers added). Three of the four alien invasive plant groups listed as a problem on Signal Hill by Britton and Jackelman (1995) were herbaceous.

Agricultural activities

Agriculture is the major reason that so little Renosterveld remains. The physiographic definition of coastal Renosterveld (nutrient rich soils), and the fact that the area is mostly flat, has determined its fate. Most of the original extent of West-Coast Renosterveld has gone under the plough and many of the remnants are used for grazing. What is the future for the remaining fragments?

McDowell and Moll 1992 did a detailed study of 55 major fragments of West-Coast Renosterveld. They ranked them in terms of their agricultural potential, and commented upon their known threat status at the time of writing (1988). This status was determined by rankings they had given to the soil quality (suitability for agriculture), slope and rainfall; the higher the product of these values, the greater the threat (or to put it another way, the greater the agricultural potential). The remnant with the highest score was an area conserved by a family for five generations, the current owner also intending to conserve it. Conservation status of the fragments ranged from private/provincial nature reserves with high conservation probabilities, to fragments that the farmer was planning to cultivate in the (then) near future. McDowell and Moll (1992) pointed out that just because a fragment of vegetation appeared natural, or was occurring on land that was not agriculturally

viable, it did not mean it was safe, as developments in machinery or crops could change this. Several of the farmers interviewed acknowledged they had planted dry-land legume species amongst the natural vegetation and were applying fertilizers to encourage the growth of these to improve the forage value of the fragment.

The brief summary of wheat growing in the Swartland between 1880 and 1945 (Talbot 1947) showed how subsidies made wheat farming highly lucrative, and led to the degradation of both good and marginal lands. With the ongoing reduction, or total withdrawal of subsidies to farmers (Donaldson 2002), increased social responsibilities (*e.g.* minimum wages for farm workers), harsher economic conditions (*e.g.* fuel price increases due to the falling rand-dollar exchange rate, and increased crude oil prices) and the introduction of rates on all land (Botha 1999, Anon. 2000), profit margins on farms are being reduced. For this reason, farmers are looking to diversify to other crops, so that a failure of the wheat crop can be buffered by alternative income. The results from questionnaires sent to various agricultural co-operatives showed little or no change to the preferred cereal crop in the Swartland, which is wheat (> 90%). On the south coast around Swellendam, the proportion of wheat had dropped from around 42% in 1993 to 31% in 2001, and barley production had dropped from 38% to 23% in the same period (although a barley fodder had been produced from 1998). Oat production had risen slightly, while Korog (a wheat/rye hybrid) had risen from 2% to 15%, and Canola from zero to 9%. On the other hand, around Bredasdorp Barley and Wheat each represented 45% of cereal production in 2002, contrasting with the situation 10 years earlier, when Barley made up 80%.

McDowell (1988) questioned farmers in the Swartland as to what use they might put their land, as an alternative to cereals. Among the responses were vines, dry legume pastures, Eucalypt and pine plantations, olives and a number of more exotic uses. Olives (*Olea europaea* var. *europaea*) may at first glance be considered an “environmentally friendly” choice, as they can be grown in the natural veld in much the same way that the indigenous *O. europaea* subsp. *africana* does. However, Heydenrych and Littlewort (1995) pointed out that for an optimal yield, domestic olives need deep ploughed soils and irrigation. In addition, the trees may gradually shade out indigenous shrubs, and spraying and fertilizing would affect indigenous

plants and invertebrates. There may also be problems with hybridization between indigenous and cultivated olives. Dry legume pastures can likewise unbalance the natural vegetation, due to the accompanying spraying and fertilizing (*c.f.* pers. comm. from John Duckitt on page 57). An “advantage” of some of these alternative crops is that they can be grown on slopes unsuitable for ploughing. As McDowell and Moll (1992) put it “It is doubtful whether natural diversity could be retained in the face of both competition with introduced pasture species and altered nutrient regimes”.

Fairbanks *et al.* (2004) examined the potential impact of viticulture expansion on the various habitat types in the Cape Floristic Region (CFR). They found that, while the total area of land under vines had increased by about 15%, a substantial amount of this was on land that had previously been used for wheat and other crops (Troskie quoted by Fairbanks *et al.* 2004). They felt that the wine industry did not pose an immediate threat to biodiversity within the CFR, but suggested that pressure should be put on farmers to expand into previously ploughed land, rather than into fragments of natural vegetation. Initiatives, such as the Biodiversity and Wine Initiative of the Botanical Society, which gives recognition to wine farmers who set aside land for conservation (Winter 2006), encourages farmers to conserve land, in exchange for an environmentally friendly label for their product, which can help with marketing.

Climate change

In the 1980’s, the discussion about climate change due to anthropogenic factors was in its “is it or isn’t it?” stage. The current consensus is that climate change is occurring (even if the human influence is being questioned [*e.g.* Hulme *et al.* 1999]), and the discussion now is along the lines of “how much?” and “what effect will it have?”.

Rainfall data from the South African Weather Service showed that there was an overall increase in annual average rainfall between 1982 and 1999 on both the south and west coast lowlands of the Western Cape. Data from the Darling district indicated that this trend had continued for over 100 years on the west coast. Walther *et al.* (2002) confirmed that, west of the Overberg, not only did rainfall increase

between 1976 and 1990, but annual average temperatures dropped by 0.7°C to 1.0°C per decade during the same period. Nevertheless, all the current general circulation models (GCM) of the southern African sub-region predict an overall increase in temperature in the near future, although there is a significant amount of variability between the different models (Joubert and Tyson 1996). Predicted changes in rainfall are even more variable, with increases in some areas, and decreases in others. For the west coast lowlands, most models predict a decrease of up to 10% with a doubling of CO₂ levels in the atmosphere (Joubert and Tyson 1996). However, the palaeoecological evidence suggests that the south-western lowlands shows an anomalous response to general climatic trends. For example, during the Last Glacial Maximum, while conditions were generally drier throughout southern Africa (Tyson *et al.* 2001), the west coast apparently received unchanged (or increased) levels of rainfall (Cowling *et al.* 1999).

The effect of climate change on species distribution and persistence has become a hot topic for ecologists. The major problem is that not enough is known about the current ecological factors determining a species distribution, nor is enough cognizance taken of the fact that current distributions may not yet have reached an equilibrium after the lows of the Last Glacial or highs of the mid-Holocene. In the past 16 000 years, average annual temperatures have varied from about 7°C below (Talma and Vogel 1992) to about 4°C above current (Tyson *et al.* 2000, Tyson *et al.* 2001). Changes have sometimes been extreme and have occurred much faster than are presently being experienced. For example, average temperatures during the mediaeval warm period (AD 900 to AD 1300) may have been 4°C above that of today, while the Little Ice Age around 1700 had mean annual daily maximum temperatures depressed by a degree or so, compared with the present (Tyson *et al.* 2000, Tyson *et al.* 2001). While these extremes were of short duration, and included considerable fluctuations in terms of decadal changes, plant species with short life-spans, or very restricted ecological ranges must have been seriously affected by a few decades of higher temperatures, possibly with lower rainfall. Partridge (quoted by Tyson *et al.* 2001) has estimated that temperatures around 7000 ybp, were on average 2°C above those experienced today. The period of time involved in the

rising and falling of average temperatures in that case was two or three thousand years, surely long enough to affect species persistence and distributions.

In the case of many Renosterveld endemics, there is not only the problem (also common in many Fynbos species) of short range dispersal distances, but an additional problem in that the clay and granite soils on which they exist are surrounded by low nutrient sandstones. The large herbivores responsible for the dispersal of a number of Renosterveld endemic species no longer roam the landscape. In addition, should rainfall decrease (particularly the small amount that falls in summer) drought-stresses are going to be far greater than would be the case on sandy soils, due to the lower water-potential of clay soils (Bidwell 1974). Will West-Coast Renosterveld develop into a succulent type of vegetation, such as seen on the northern slopes of the Koringberg? Many of the dominant species (*Elytropappus*, *Eriocephalus*, indigenous grass species *etc.*) are found in other regions where climatic (and often edaphic) conditions are very different. *Elytropappus* can certainly survive under drier conditions than are experienced on the coastal lowlands, as shown by its presence along the boundary of the karoo. Analyses of the CREW (Custodians of Rare and Endangered Wildflowers) data (see Chapter 6) showed that even the rare species were widespread within the West-Coast Renosterveld area, suggesting that they are tolerant of a range of macro-climatic conditions. The truth is that we do not know. This suggests that a lot more effort should be put into developing distribution inventories (which must include *detailed* micro-habitat data), as well as experiments to assess to what extent climate is playing a role in the current distribution of species.

Grazing and trampling

This subject is examined in Chapter 6. Evidence is amassing that, rather than being a threat to the conservation of coastal Renosterveld, these are actually important processes in maintaining the biodiversity (Hendey 1983, McDowell 1995, Krug *et al.* 2004; comments by John Duckitt and John Donaldson at the 4th Renosterveld Information Sharing Session, Darling, 2003).

Mining


The soils and base-rocks found in West-Coast Renosterveld are used for making bricks (clay), as well as supplying granite chips for roads and concrete. Hillsides make access to these raw materials easier than pit-mining (although pit-mining does occur just south of the town of Piketberg). Where sandy soils occur, these are also mined for building activities (*e.g.* the Contreberg and to the south-west of the Perdeberg).

Residential and leisure activities

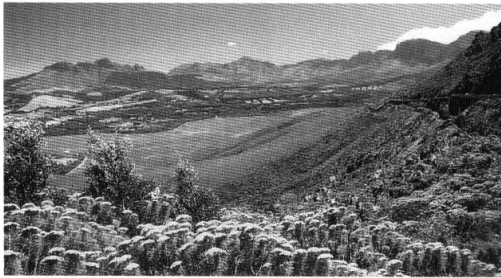
Urban populations are increasing and crime rates are high, which has led to a demand for “security complexes”. Land that is of marginal agricultural worth, but which is situated not too far from a major centre can be developed as housing estates. The indigenous flora and “eco-friendly” developments are used as excuses to inflate prices for land that may be otherwise economically worthless. Figure 13 shows one such development, while Kirkwood (2000) questions the “greenness” of a country estate in South-West Coast Renosterveld.

High disposable incomes in some sectors of the economy, have led to the growth of the leisure market. One such aspect is the sale of 4 x 4 vehicles. Market figures from the National Association of Automobile Manufacturers (NAAMSA) showed that between 30 060 and 31 470 units (8.5% to 9.4% of the South African passenger and light commercial vehicle market) were sold each year between 2000 and 2003. Irresponsible use of these has led to the degradation of many natural areas, such as on Blouberg Hill (Figure 14). Most of the remaining West-Coast Renosterveld is on private land and the landowner has very few constraints upon what he may do with it. He can open up a 4 x 4 trail, allowing the users of the trail to claim that they are supporting nature conservation by not driving over (state-owned) coastal dunes, or similar. They do not (or do not want to) understand that endangered species do not recognize human-defined borders, and so they will happily drive over endangered plants on private land despite being “very aware of the environment”.


ARCHITECTURAL GUIDELINES



he form and nature of the building work at Boskloof will directly determine to what extent the inherent characteristics of the terrain will be affected. It is desirable to restrict the scale, height, materials and finishes of all proposed structures and to encourage extensive use of natural materials to minimise visual impact and ecological damage. Guidelines and controls have been formulated to guide and inform the future development of housing within the scheme.



LANDSCAPE GUIDELINES



he greater landscape conservation, rehabilitation, design and construction of the nature reserve will preserve and protect the unique qualities of the Renosterveld landscape. It is characterised by its openness, rolling landforms, the dense indigenous vegetation of extraordinary variety and the occasional forest filled kloofs. The nature reserve layout preserves and rehabilitates substantial areas of Renosterveld, a vegetation type indigenous to this area. The private gardens within the development continue and consolidate this theme, integrating the estate with the surrounding nature reserve. In order to maintain continuity in the overall landscape character, owners of erven are required to design and implement landscape rehabilitation around their houses in accordance with certain conditions, specifications and restrictions to preserve the collective natural landscape of the eco-estate for the appreciation and benefit of all.

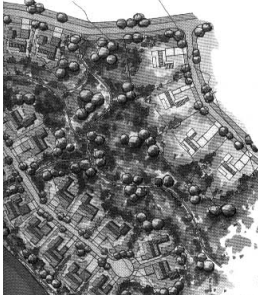


Figure 13. Part of an advertisement for an “eco-friendly” housing development close to Somerset West. (From *Earthyear* 1999–2000, edition 20, page 135).

Outrage as 4x4 cowboys wreck plants and gouge dongas into Blaauwberg Hill

MELANIE GOSLING
Environment Writer

OFF-ROAD vehicles have ripped into the rare vegetation in the Blaauwberg Conservancy, creating deep dongas on the steep inclines of Blaauwberg Hill.

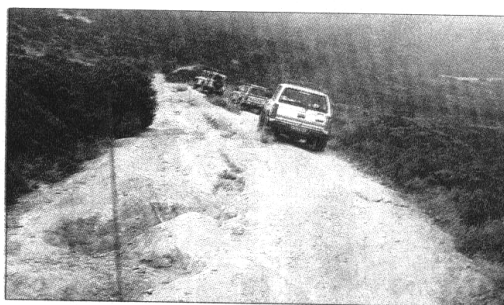
Yesterday members of the Blaauwberg Conservancy Area Implementation Committee and three 4x4 clubs met to try to thrash out a way to stop vehicles degrading the site further.

They have appealed to members of the three clubs not to drive through the conservancy, but say there is no law preventing them from doing so.

Andy Gubb of the Wildlife and Environment Society of SA described the vehicle damage as “horrendous”.

“There are some dongas that are so deep you can step into them and not be able to see out. Even from Cape Town if you look across you can see the brown scars on the hill.

“Everyone wants to get to the top of the hill, all part of putting man and machine to the test and all that rubbish. Some evenings there are up to 30 vehicles on the hill,” Gubb said.



LEAVING THEIR MARK: An example of the damage inflicted on the Blaauwberg Conservancy by 4x4 drivers. *Picture: DENZIL MAREGELE*

The conservancy was created because of the historic, archaeological and biological importance of the site, where fynbos, strandveld and the rare renosterveld are found. Much of the renosterveld has been wiped out by

agriculture and urban development. Brian Woodborne, of the Fourwheel Drive Club, said the club was conservation-minded and had told members to stay away from Blaauwberg Hill. “The degradation is horrendous,” he said.

Figure 14. Front-page article appearing in the Cape Times on the 12th December 2002.

Taxation

Changes to legislation (Anon. 2000) allowed municipalities to impose a land tax (equivalent to urban rates) on farms and other rural land. The primary aim of these was to help finance rural service delivery and social upliftment. Monies raised could also be used to assist in conservation projects (clearing of aliens *etc.*) thus helping with nature conservation. The disadvantage of this system is that private landowners might be “penalized” for conserving their fragments of natural vegetation. Worse still, they might be encouraged to leave these fragments to be over-run by aliens or to become badly eroded, as this would reduce the “market-value” (and hence rateable value) of the land (Maze and Botha 2000). Fortunately new legislation, the Property Rates Act of 2004 (Anon. 2004) has been enacted which allows for formally proclaimed protected areas (Anon. 2003) to be exempted from rates on that portion of the property that has been so proclaimed (Winter 2004).

Conclusion

This chapter has shown that the west coast lowlands of the Western Cape Province have been subjected to anthropogenic pressures for tens of thousands of years. In the past two thousand years this impact has become heavier, culminating in a hundred and fifty years of rapid transformation. Regular burning by the Khoekhoen for their cattle and sheep placed negative pressures upon species that needed several years to grow before producing seeds. It may also partly explain the lack of trees in the area. The arrival of Europeans with their sedentary farming practices, and their extermination of the larger indigenous herbivores, forced an unnatural disturbance regime on the veld, resulting in an invasion of indigenous (and alien) species (weeds), many of which were unpalatable to domestic stock. The opening up of distant markets, mechanization, two World Wars and a short-sighted wheat subsidy policy led to an almost total denudation of natural vegetation in the area.

The various floristic definitions of coastal Renosterveld have largely been defined in terms of their shrub component. Many of these dominant shrubs are pioneer species, benefiting from large-scale disturbance regimes. Renosterbos, far from

being an aggressive invasive is in fact poorly adapted to invade established vegetation. The relatively high nutrient levels of the soils has also meant that species from adjoining vegetation types can also grow there, thus making the vegetation difficult to define.

Recent mapping exercises of the original extents of coastal Renosterveld, on the other hand, has predominantly been determined by the soil component, modified secondarily by rainfall and altitude. To this must be added the particular goals of the people doing the mapping, leading to relatively minor changes in boundaries since Boucher's (1981) map.

Estimates of the amount of natural vegetation remaining have varied, due to differing viewpoints about the boundaries delimiting the original extent of West-Coast Renosterveld. However, with one exception, all published estimates have been below 10%. Although the remaining fragments are still under threat, awareness campaigns, particularly by the Botanical Society of South Africa, are informing the owners of these fragments about the ecological importance of maintaining them in a good condition. Enlightened legislation recently passed will also encourage the conservation of these fragments, by offering the owners tax relief on parcels of formally conserved land. The question now remains whether enough West-Coast Renosterveld remains to maintain the biodiversity of the region, or if it has been a case of "too little, too late". This question is explored in more detail in Chapter 6.

CHAPTER 2.

A 20-YEAR COARSE-RESOLUTION TIME-SERIES ANALYSIS OF THE WESTERN LOWLANDS OF THE WESTERN CAPE, USING NOAA-AVHRR NDVI IMAGERY.

Abstract

Vegetation patterns over the western coastal lowland areas of the Western Cape Province were examined using monthly-maximum value composite Integer-NDVI images at a spatial resolution of 1 km. The first component of a Principal Components Analysis identified five regions of different annual \sum NDVI levels. While four of these were related to increasing levels of rainfall, the fifth was identified by its lack of seasonal synchronicity with the other regions, which was caused by its high proportion of irrigated agriculture. The second component identified five zones, largely based upon the amplitude their annual cycles of NDVI, which in turn was largely dependant upon their level and type of agricultural transformation. Correlations between rainfall and NDVI in those areas where irrigation was minimal was good, although not significant. Correlations were better when restricted to the growing season. There were also good correlations between estimated annual plant productivity and \sum NDVI when background values were subtracted, but in areas where irrigation was practised, this did not hold true. No correlation was found between NDVI and cereal production. A change analysis suggested that in the central and southern regions there was an overall increase in annual maximum NDVI over the period examined, while the north-west regions had an overall decrease. These general changes could not be explained, except possibly in terms of image processing, but some local changes were explainable in terms of housing developments, fires or plantation felling (negative) or vineyard developments (positive). It was concluded that imagery at this resolution was too coarse for monitoring changes in Renosterveld fragments.

Introduction

Time-series analyses using satellite imagery provides a useful means of monitoring land-cover changes at scales ranging from regional to global. They are of particular use in third world areas where access is either physically difficult (lack of infrastructure) or in which conflict is happening. Africa is a continent plagued by civil and cross-border conflicts, serious food shortages, burgeoning population growth, infrastructure decline and land degradation. To help counter these problems, and to provide advance warning of potential famine areas, USAID (United States Agency for International Development) set up its Famine Early Warning System (FEWS) project. For this, dekadal (10-day) maximum-composite NDVI (Normalized Difference Vegetation Index) images are produced from NOAA's (National Oceanic and Atmospheric Administration) AVHRR (Advanced Very-High-Resolution Radiometer) satellite system. They are processed to an approximately 8 km resolution and are available to the public (at no cost). They have been used in numerous time-series studies of Africa, ranging from continental overviews (*e.g.* Tucker *et al.* 1985; Eastman and Fulk 1993; Eastman *et al.* 1994; Lambin and Ehrlich 1995, 1996, 1997) through regional studies (*e.g.* Tucker *et al.* 1983, 1984, 1985a; Nicholson *et al.* 1990; Farrar *et al.* 1994; Nicholson and Farrar 1994; Milich and Weiss 1997, 2000; Eklundh 1998; Fuller 1998; Richard and Pocard 1998; Sannier *et al.* 1998; Pelkey *et al.* 2000; Sobrino and Raissouni 2000) to local biomass production studies (*e.g.* Prince 1991).

Although useful for over-views of extensive areas, the 8 km resolution imagery is too coarse for smaller areas, or regions with compact, diverse land-cover components. For this, imagery at the platform sensor resolution of 1.1 km is necessary. These can be downloaded directly from the satellite using relatively simple equipment, and institutes throughout the world collect the data relevant to their area of interest. One such institute is the Satellite Applications Centre (SAC) at Hartebeeshoek in South Africa. Data collected by the SAC between February 1985 and December 2004 has been processed into ten-day maximum value composites (MVC) by the Agricultural Research Council, Institute for Soil, Climate and Water (ARC-ISCW). These were the data used in this study.

Satellite Information

NOAA-1 was launched in 1970 (Rees 1999), but only carried the VHRR (Very-High-Resolution Radiometer). It developed from the TIROS (Television Infrared Observation Satellite) series of satellites (ten in total), the first of which was launched in April 1960 and the last in April 1966 (Rees 1999). NOAA-2 to NOAA-5, launched between 1972 and 1976 also carried VHRR units, each recording radiation in four non-overlapping wavebands (Rees 1999). The AVHRR series of satellites began with the launch in October 1978 of the TIROS-N satellite (now usually referred to as NOAA-6) (Lillesand and Kiefer 2000). NOAA-7 was launched in June 1981, and was followed in March 1983 by NOAA-A (later renamed NOAA-8) (Jensen 2000). The satellites relevant to this study are NOAA-9 (launched December 1984), NOAA-11 (launched September 1988), NOAA-14 (launched January 1995) and NOAA-16 (launched September 2000) (Jensen 2000, Anon 2000a). NOAA-13 (launched August 1993) failed to deploy correctly, and no data were collected (Rees 1999). NOAA-9 to NOAA-14 carried the AVHRR/2 instrument, which has five channels (Rees 1999, Jensen 2000). From NOAA-16, the satellites have carried the AVHRR/3 instrument, which has a sixth channel collecting data in the 1.58 to 1.64 μm wavelength range (Rees 1999).

The satellites orbit approximately 833 km (even numbered satellites) and 870 km (odd numbered satellites) above the earth at an inclination of 98.7° and 98.9° (even and odd numbers respectively). They record data over a swath 2400 km wide with a 1.1 km pixel resolution at nadir (Lillesand and Kiefer 2000). Two satellites are usually operational at any one time, collecting data from the whole earth on a daily basis. Up to NOAA-13, the odd numbered satellites crossed the equator at 02:30 and 14:30 local time, while even numbered satellites crossed at 07:30 and 19:30 local time. With the failure of NOAA-13, NOAA-14 took on the orbital characteristics of the earlier odd-numbered satellites (Anon. 2003b). Sub-orbital tracks do not repeat on a daily basis, as the number of orbits per day is not an integer divisor of their orbital track length. Each satellite returns to the same geographic position approximately every nine days, and this variation leads to cyclic differences in the illumination of any particular area on different days (Jensen 2000). However there is a gradual degradation of about three hours (20 minutes per

year - Roderick *et al.* 1996) in the orbit of the satellites over the period of their lifetime (*i.e.* the satellite crosses the equator at a later local time).

NOAA-NDVI Imagery

NOAA-NDVI imagery is described in terms of three scales. The finest resolution, which is that “seen” by the satellite, is the 1 km (actually 1.1 km at the point directly below the satellite – the nadir point) local area coverage (LAC). Due to the huge amount of data amassed at this resolution, the imagery is usually transmitted to Earth in the form of 4 km GAC (global area coverage) images (Tucker *et al.* 1985). One should be aware that each pixel of the GAC image is the average of only four of the fifteen 1.1 km pixels occurring within the GAC field of view. Each GAC pixel is 5 x 3 LAC pixels in extent. On board the satellite, the first four pixels of a scan line are averaged. The next pixel is ignored. This “four-averaged, one-missed” sequence continues to the end of the scan line. The next two scan lines are skipped, and the process begins with the line after that (Townshend and Justice 1986, Jensen 2000). GAC images are available for the whole world on a daily basis, whereas LAC images are more temporally and regionally restricted (Tucker *et al.* 1985). Finally, there is the “degraded” (Holben 1986) imagery with cell boundary lengths of 8 km or more.

A number of vegetation data sets have been produced from the AVHRR imagery (Smith *et al.* 1997), and one should be aware that different processing methods have been used on different sets. For coarse resolution analyses over large areas, the Pathfinder set, produced by NOAA/NASA is freely available (for details see Smith *et al.* 1997), although other sets are also available (*e.g.* the Global Vegetation Index [Kidwell 1997, Kogan *et al.* 2003] and the Global Change Series produced by Clark Labs). Data at the 1.1 km level are generally more spatially restricted. A project to produce dekadal images at a resolution of 1 km over the Earth’s entire land surface was begun by International Geosphere-Biosphere Programme (IGBP) in May 1991. The aim was to develop inventories, such as determining the extent of tropical forests for the United Nations Food and Agriculture Organization’s 1990 Forest Resources Assessment project (Eidenshink and Faundeen 1994). These data are downloadable from the USGS EDC DAAC (Eros Data Center’s Distributed Active

Archive Centre) web page at <http://edcdaac.usgs.gov/1-km/comp10d.html>, but are only available for limited time periods.

The following quote (Anon. undated) summarizes the intrinsic shortcomings of the NOAA satellites for vegetation monitoring:

“The NOAA-AVHRR sensor was designed to collect meteorological data around the globe. The potential of the AVHRR for vegetation monitoring was realized after the satellite became operational (NOAA-7 was launched in 1981). However, the designing of the sensor for meteorological applications has resulted in shortcomings for vegetation monitoring, such as limitations in accurately determining satellite orbit (Emery et al. 1989), the method of onboard data resampling (Kidwell 1988), a lack of onboard calibration to correct for decreasing sensitivity of the AVHRR over time (Price 1987, Kaufman and Holben 1993), and the selection of an early afternoon crossing time, which generally coincides with the time of maximum cloud development around the globe (Sellers and Schimel 1993).”¹

These and other problems inherent in the imagery have been discussed at length by a number of authors (*e.g.* Holben 1986, Gutman 1991, Roderick *et al.* 1996). Each geographic area has its own particular set of problems (*e.g.* Zhu and Yang, undated), and it is impossible to completely determine all the atmospheric and sensor-related perturbations present and correct for them. Within the published literature, one finds a range of approaches towards these problems, usually based upon the objectives of the study. The general opinion is that monthly-maximum composite data are good enough for most studies, and largely ameliorate many of

¹ The references cited in this quote are:

Emery WJ, Brown J & Nowak ZP 1989. AVHRR image navigation: Summary and review. *Photogramm. Eng. Remote Sens.* 55: 1175-1183.

Kaufman YJ & Holben BN 1993. Calibration of the AVHRR visible and near-IR bands by atmospheric scattering, ocean glint and desert reflection. *Int. J. Remote Sensing* 14: 21-52.

Kidwell KB 1988. *NOAA polar orbiter data (TIROS-N, NOAA-6, NOAA-7, NOAA-8, NOAA-9, NOAA-10 and NOAA 11) users guide*. National Oceanic and Atmospheric Administration, Washington, DC 20233.

Price JC 1991. Timing of NOAA afternoon passes. *Int. J. Remote Sensing* 12: 193-198. [Although the dates do not agree, this was the reference given on the website].

Sellers PJ & Schimel D 1993. Remote sensing of the land biosphere and biochemistry in the EOS era: science priorities, methods and implementation - EOS land biosphere and biogeochemical panels. *Global and Planetary Change* 7: 279-297.

the errors inherent in the imagery (*e.g.* Eastman and Fulk 1993). However, where crop or biomass production studies are being undertaken, extensive correction and calibration procedures must often be undertaken (*e.g.* Tucker *et al.* 1983, 1985a, Ferencz *et al.* 2004).

Normalized Difference Vegetation Index

The normalized difference vegetation index (NDVI) is calculated using the reflectance values of the red and the near-infrared (NIR) channels ($[\text{NIR} - \text{Red}] / [\text{NIR} + \text{Red}]$) (Jensen 2000). It ranges from a theoretical +1, through zero (generally considered as no plant productivity) to -1. Values between 0 and -1 are usually indicative of clouds, water or snow (Kidwell 1990). In practice, the minimum value for indicating photosynthetic activity is generally considered to be around 0.05 (Malo and Nicholson 1990), although values between 0.025 and 0.05 were found to represent vegetation in the Sudan (Kogan 1990). Maximum valid NDVI values from the NOAA satellites are invariably below 0.6 (Uganai and Kogan 1998).

This ratio is used to estimate plant productivity and leaf-area coverage. It is based on the fact that photosynthesizing plants absorb light (particularly red and blue) in the visible spectrum (400 nm to 700 nm), while strongly reflecting radiation in the near-infrared portion of the spectrum (700 nm to 1200 nm) (Jensen 2000). Although chlorophyll absorbs light more strongly in the blue (400 nm to 500 nm) than the red (600 nm to 700 nm) spectrum, red is less affected by the atmosphere (Jensen 2000). There are currently more than 20 forms of the vegetation index in use (Eastman 1999). These have developed from the first form (the simple ratio of NIR/Red), into forms that can estimate not only “greenness”, but also leaf-water content and/or moisture stress. Some take into account the effect of soil brightness and colour, which is particularly useful in areas of low vegetation cover (Eastman 1999, Jensen 2000). However, for global coverage the NDVI ratio appears to be the most generally used (*pers. obs.*). In the case of the AVHRR data, the “red” value actually includes the upper half of the green band as well, ranging from about 580 nm to 680 nm, while the NIR band is 725 nm to 1100 nm (Jensen 2000).

One should keep in mind that NDVI and other ratios developed from satellite imagery are platform specific, and therefore not directly comparable. For instance,

in the other satellite imagery used in this project, namely the Landsat-7 ETM+ (Enhanced Thematic Mapper Plus) imagery, the bandwidths are finer. The Landsat-7 red channel (band 3) is sensitive to a range of 630 nm to 690 nm. It has two NIR bands – a reflective infrared (band 4) sensitive to wavelengths between 760 nm and 900 nm, and a mid-infrared band (band 5) of 1550 nm to 1750 nm. Tucker *et al.* (1984) quote Dave as saying that narrower bandwidths (*e.g.* as in Landsat imagery) give improved vegetation monitoring abilities, largely due to reduced atmospheric effects.

The aim of this chapter was:

- 1 To determine whether the western lowlands of the Western Cape Province and the surrounding mountains could be partitioned in terms of NDVI response.
2. To monitor the annual vegetation cycles occurring within the study area.
3. To determine whether there were any correlations between NDVI, rainfall, estimated annual biomass production and crop production in this area.
4. To determine whether there had been any gross land-cover changes over the western coastal lowlands between 1985 and 2004.

Methods

All image analyses were carried out in Idrisi32 (©Clarklabs, Clark University, MA, USA.), using the standard integrated modules.

Sources of data

A. Ten-day (more correctly, three are produced per month, but they will be referred to as dekadal for conciseness) maximum value composite (MVC) Integer NDVI (I-NDVI) images at a resolution of 1 km were donated by ARC-ISCW. These covered the period from February 1985 to December 2004, with 1994 and January 1995 missing due to the failure of NOAA-13 to deploy. These had been processed to correct for sensor degradation and satellite changes following the guidelines set out by Rao and Chen (Wessels *et al.* 2004). The images were geometrically corrected

and projected to Plate Carrée. After compositing, the dekadal images were checked for cloud or other atmospheric perturbations that had not been excluded by the compositing procedure (Wessels *et al.* 2004). The original real number NDVI images were converted to integer (byte) format by the formula:

$$I\text{-NDVI} = (\text{NDVI} * 400) + 0.5$$

with zero reserved for flagged data (cloud cover, water bodies). This means that the range of the data is restricted to the original values of zero (which goes to one) and 0.6375, which converts to 255. This has been found to be adequate to cover the NDVI conditions recorded (Dawie de Villiers, *pers. comm.*), and encompasses the range typically displayed by vegetation (Unganai and Kogan 1998). Some local perturbations were noted during the analyses performed here, and 22 monthly images were removed from the series before the final analyses.

B. Monthly rainfall data for the years 1985 to 2004, from all weather stations south of 30°.30'S and west of 23°.00'E were supplied by the South African Weather Bureau (www.sawb.gov.za) (now called Weathersa [www.weathersa.co.za]). Questionable data, which were indicated by an asterisk, were omitted. Unmarked values that were obvious errors, *e.g.* a figure of more than 600 mm in a month, when all other stations in the area were reporting 20 mm or less, were also removed.

C. Crop production data were requested from five co-operatives in the study area. The annual cereal tonnage delivered to the silos under the management of the co-operatives concerned was supplied from three co-operatives, for nine silos, although data was not available for the entire twenty-year period. Relative proportions of the different cereal types and any changes occurring over the time period were also requested.

D. Median monthly rainfall images were obtained from the CD accompanying the South African atlas of agrohydrology and climatology (Schulze 1997). These images were computer generated from rainfall stations that had data records of twenty years or more (Dent *et al.* 1989).

Data pre-processing

All 10-day MVC's were cropped to the co-ordinates of 32°18'S to 34°24'S and 17°48'E to 19°12'E. This encompasses the entire West-Coast Renosterveld area and the surrounding mountains. The three dekadal images for each month were then combined into monthly-maximum I-NDVI images and further processing was based upon these monthly images.

Previous experience with NOAA NDVI time series imagery had suggested that in some images there were regions with missing or apparently faulty data. In order to identify these, a preliminary Principal Components Analysis (PCA) was performed on the data set. Examining the component one trace showed some deep troughs. When the month(s) occurring at the bottom of these troughs were examined, it was noted that substantial areas of the image had very low (or flagged) values, which may have significantly affected regional averages had they been retained. Seventeen such months of data were removed from the series. A further five containing abnormal data that may have affected analyses were later identified and removed.

Image analysis

Two methods were used to analyse the monthly NDVI images. The first was a standardized PCA, and the second a time-profile system. The Idrisi32 "PCA" module can produce as many component images as there are original images, but for reasons which will be discussed later, this is rarely done, and in these analyses only ten were requested. The PCA was used to identify patterns occurring within the landscape. Monthly loading values for each of the first ten principal components were plotted. These identify seasonal (or at least regular) cycles and long-term trends, and are also useful for identifying faulty data, as mentioned above. The graphs were examined alongside their component images to assess what seasonal changes were occurring, and where in the landscape these changes were most pronounced. Based upon this information, the first two components were divided into areas having similar loading values (characteristics). Regional identification of these zones was done visually – the component being divided into regions based upon ranges of the integer component values that appeared to identify definite

zones. This was done liberally, so that there were initially more zones identified than were used in the analyses presented here. Profiles of the monthly average NDVI in each of the zones were then plotted and examined, and by means of combining zones that were obviously similar, and shifting zone boundaries where necessary, each of the first two principal component images were reduced to five classes.

Rainfall

For each of the classes developed from the PCA, the average monthly rainfall for each year was calculated from data from all stations occurring within that class. There was some subjectivity in this exercise. If the station occurred within the class, it was included. Because certain classes (*e.g.* the Mixed Zone) had few stations in them, stations occurring within about 10 km of the class were included. This was not done if it was considered that there was a topographic reason why there should be a big difference in precipitation between the station and the zone. For example, rainfall stations occurring on mountains within 10 km of a lowland area would be omitted, while a station in the Cereal Zone could be included in a Mixed Zone.

The interpolated monthly-median rainfall images (Schulze 1997) were cropped to cover the same area as the 1 km NDVI images. These images were used for illustrative purposes only.

Rainfall – NDVI Correlations

When the rainfall versus NDVI correlations were assessed, the rainfall was always lagged by some time-period. The reason is that, within any one month the rainfall is the total for that month, while the NDVI value is the maximum for that same month. As neither the time of the maximum NDVI, nor the monthly distribution of rainfall is known, the correlation of same month values is unwise. An example would be a month in which the maximum NDVI value was at its greatest on the first day (due to the harvesting of some widespread cereal crop later in the month) while the rain fell only at the end of that month.

Land-cover changes

In order to detect any major land-cover changes over the period examined, annual-maximum I-NDVI composite images were created. To lessen the likelihood of anomalous start and end images, the first three year's (1985 to 1987) images were composited into a three-year MVC I-NDVI image. The same was done with the last three years of the series (2002-2004). Two methods were used to identify areas of change. In the first case the early image was simply subtracted from the later image to produce a difference image. In the second, a PCA was performed on the two three-year MVC images. The changes identified were then divided into appropriate classes, and an annual-maximum NDVI plot of these classes was produced, using the complete series of annual-maximum composites.

Land cover and Productivity

Correlations between NDVI and rainfall at different lag periods were compared with cereal production figures as obtained from those co-operatives that responded to the questionnaire. These were performed at the landscape level, and also at a local scale. For the latter, the location of the silo (town) from which the production data were received was determined, and an annual-maximum NDVI image profile run on the 16 pixels surrounding that point. In cases where the silo abutted a non-agricultural zone, only those pixels falling within the agricultural sector of the zone were used. In addition wheat production figures from Van Rooyen (2000) were used. These figures were for the Western Cape as a whole, and were therefore only compared at the landscape level.

In order to correlate the analyses performed on the NDVI time series with events on the ground, subsidiary data were used. For this the National Land-cover Classification of the CSIR-ARC (Council for Scientific and Industrial Research-Agricultural Research Council) was used (Thompson 1996). Each class derived from the first two components was analyzed to determine the area of each major land-cover type incorporated.

An examination of component one suggested that the pattern shown might have been reflecting annual biomass production. An estimate of annual plant productivity

within each of the classes derived from components one and two was therefore made. This was not easy due to the relatively coarse information available about local annual biomass production, the (surprising) dearth of annual biomass production of perennial crops and the actual area covered by particular vegetation types. In addition, many fruit-tree studies are done upon young trees, thus underestimating commercial biomass production levels. Serrano *et al.* (2000) report cereals as typically having an above-ground biomass of more than 20 tonnes/ha⁻¹ (dry weight) at harvest time, the actual value being a function of the amount of fertilizer applied. Estimates based upon the data of Kroodsma and Field (2006) gave an estimated net primary productivity (NPP) of wheat in California as 17.5 tonnes/ha⁻¹/yr⁻¹. Table two of Kroodsma and Field (2006) suggested that the annual biomass production for peach trees in California averaged a little over 36 tonnes/ha⁻¹/yr⁻¹ (no data were given for apples). Forshey *et al.* (1983) had estimates of 36 to 40 tonnes/ha⁻¹/yr⁻¹ for apple trees, of which 11 to 15 tonnes were “green” (fruit, leaves).

The data on the NPP of vineyards was similarly deficient and again age-related, but those which were found gave reasonably similar biomass production estimates. The data of Kroodsma and Field (2006) gave a Californian average of 17.7 tonnes/ha⁻¹/yr⁻¹, while they quote Williams as measuring the carbon sequestration of three vines as ranging between 550 g and 1100 g of carbon/m⁻²/yr⁻¹. This translates into an average annual dry biomass production of 20.6 tonnes/ha⁻¹/yr⁻¹. The data of Treeby and Wheatley (2006) converted to an average of 2861 vines/ha⁻¹ (average planting density in the Tygerberg district; SAWIS, *pers. comm.*) gave a figure of just over 16 tonnes/ha⁻¹/yr⁻¹ for above ground annual productivity.

The above figures will exclude the growth of grass and other weeds of cultivation below the trees and vines, particularly during their dormant season, which being mid winter, coincides with the period of rapid growth of natural (and weedy) vegetation. As far as the natural vegetation is concerned, Kruger (1977) has estimated that the annual productivity of Fynbos is between one and four tonnes per hectare per year, with the higher rates occurring one to two years after a fire, and dropping off as the vegetation matures.

The final values used (per hectare) were two tonnes for natural vegetation, 17.5 tonnes for cereals, and 25 tonnes for perennial crops (apples, vines, forest).

Results

Figures 1 and 2 show the location of places mentioned in the text.

Visual Inspection

Figure 3 shows a typical (2001) seasonal (March, May, August and November) pattern of NDVI occurring in the region. The non-autoscaled Idrisi32 NDVI256 palette has been used making the images directly comparable. The most striking feature is the mid-winter (August) development of an extensive central region of green, representing the cereals that are grown here. In contrast, the late summer (March) image has large extents of brown, representing the bare fields after the summer drought.

Adjacent to each is a rainfall image for the same areas. These have been created by summing the median monthly rainfall for each of the three months preceding the month for which the NDVI image is shown. As mentioned above, this imagery is an interpolated view of median rainfall over twenty or more years (Dent *et al.* 1989), and is thus not a reflection of the actual conditions for 2001. It does however show the general rainfall patterns better than could have been produced with the point data available to the author. The palette used was produced by the author. The scale was set from 0 to 1000 mm. This means that areas receiving greater than 1000 mm of rainfall in that period have the same colour as areas receiving only 1000 mm. The maximum three-month interpolated rainfall falling within this imagery was 1400 mm. These images show the higher rainfall experienced over the Cape Fold Mountains, as well as on the taller hills spread over the lowlands.

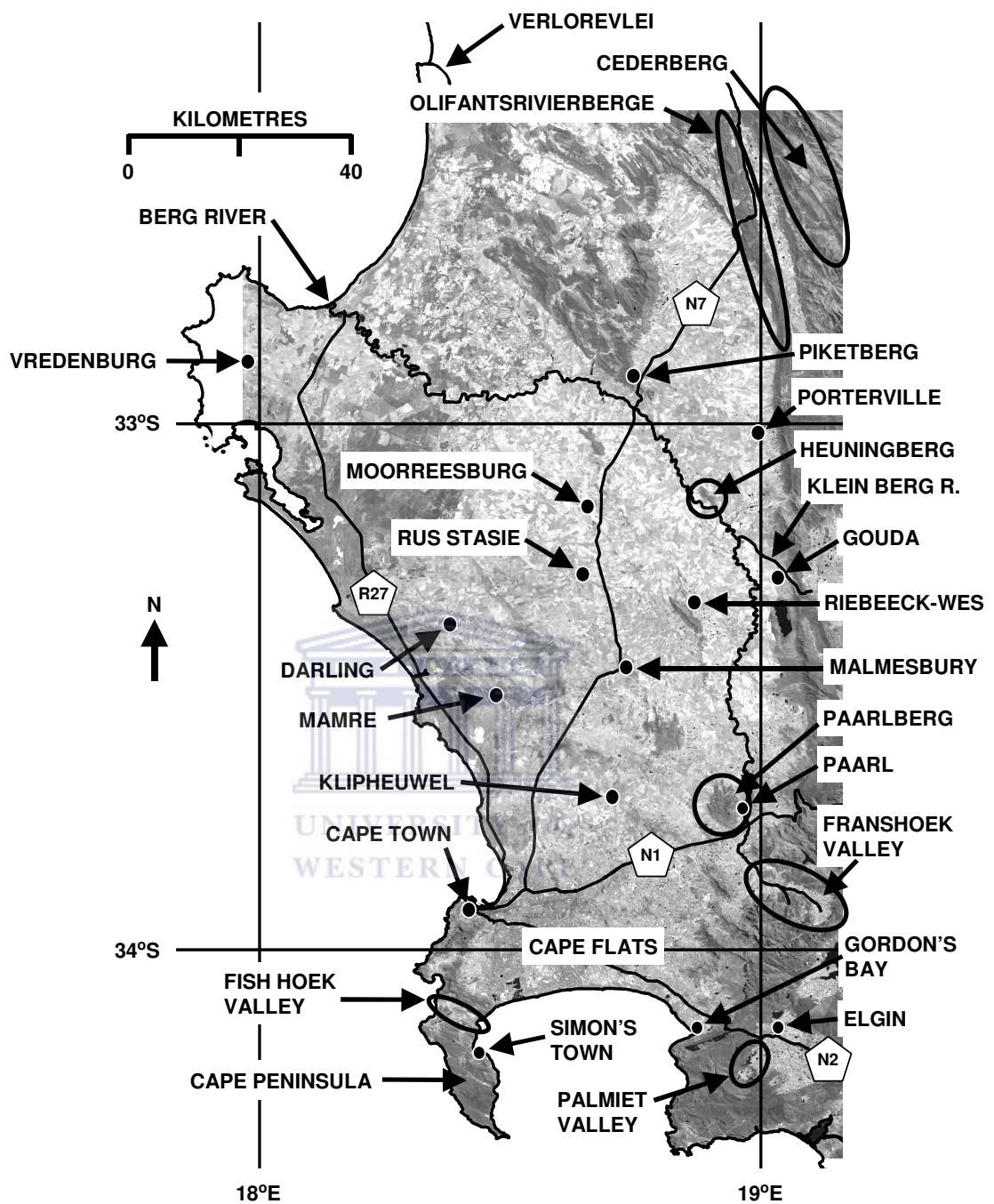


Figure 1. Landsat image of the western lowlands of the Western Cape Province, showing the Berg River, the west coast and national roads and places mentioned in the text. Landsat imagery was not available for the area west of Vredenburg.

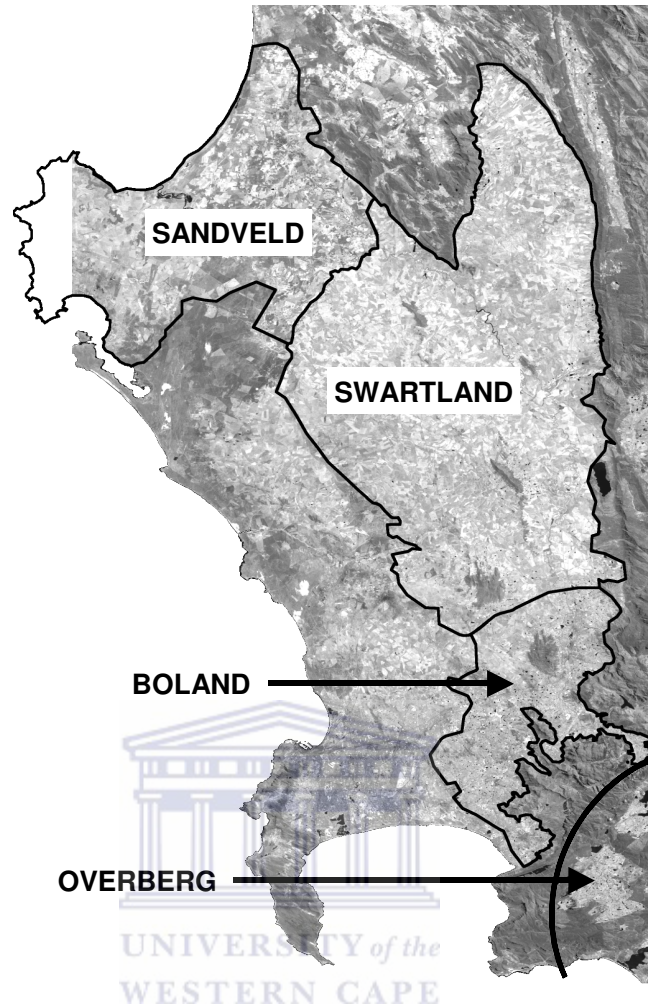


Figure 2. General view of the study area showing the major regional areas referred to in the text. Note that these regions are very loosely defined and this figure depicts the regions as discussed in this chapter.

For comparison, Figure 4 shows the August NDVI imagery for 2001, a year of good rainfall (451.1 mm over the central wheat growing area), with that of August 1999, a year of very low rainfall (253.0 mm over the same area). It must also be kept in mind that the 1999 image was taken towards the end of the life of the NOAA-14 platform, while that of 2001 was taken with the newly launched NOAA-16 platform.

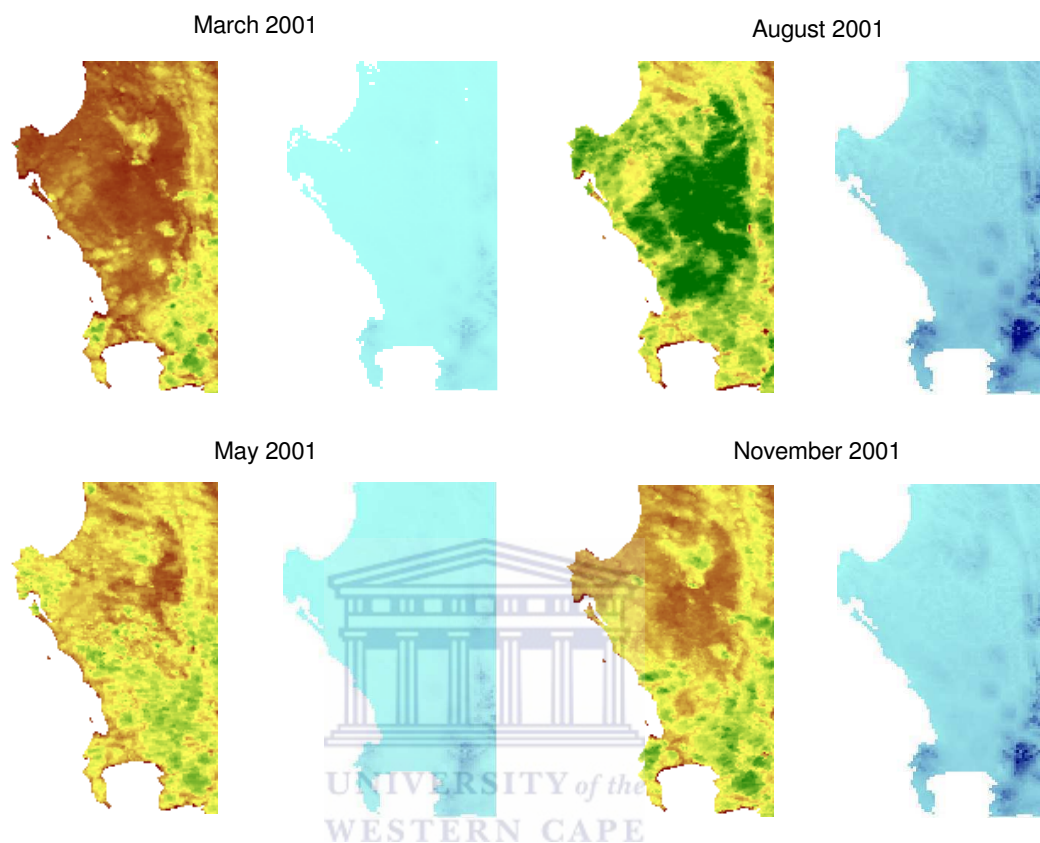


Figure 3. Typical seasonal pattern of NDVI and rainfall over the western coastal region of the Western Cape Province. For each month the left image shows a 1 km resolution monthly MVC NDVI image, while the right (blue) image shows the accumulative median rainfall for the three months preceding the month for which the NDVI image is displayed. See text for palette details.

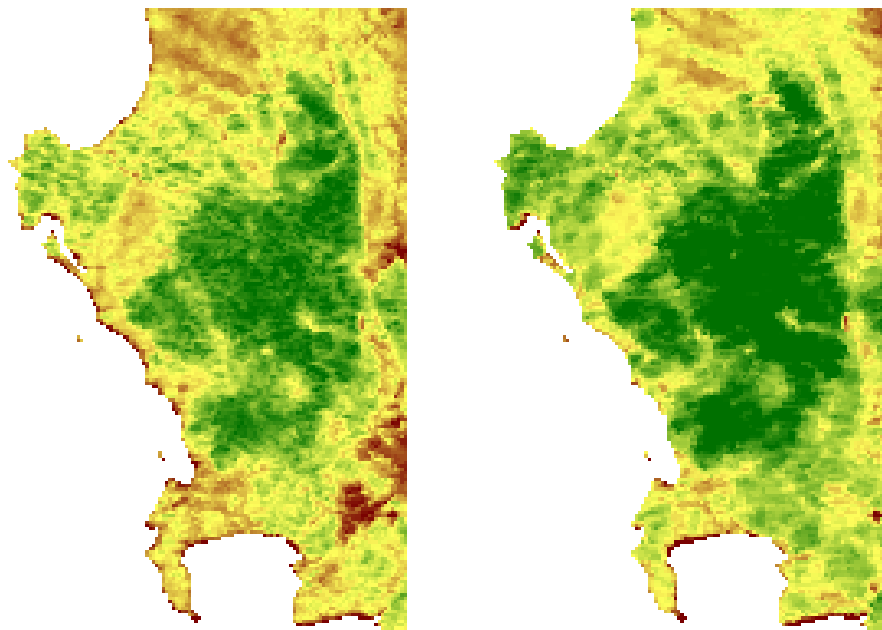
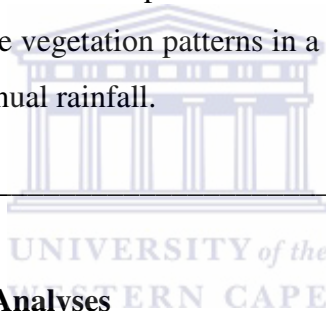


Figure 4. Monthly-maximum composite NDVI image of August 1999 (left) and August 2001, showing the vegetation patterns in a year of poor (1999: 253 mm) and good (2001: 451 mm) annual rainfall.

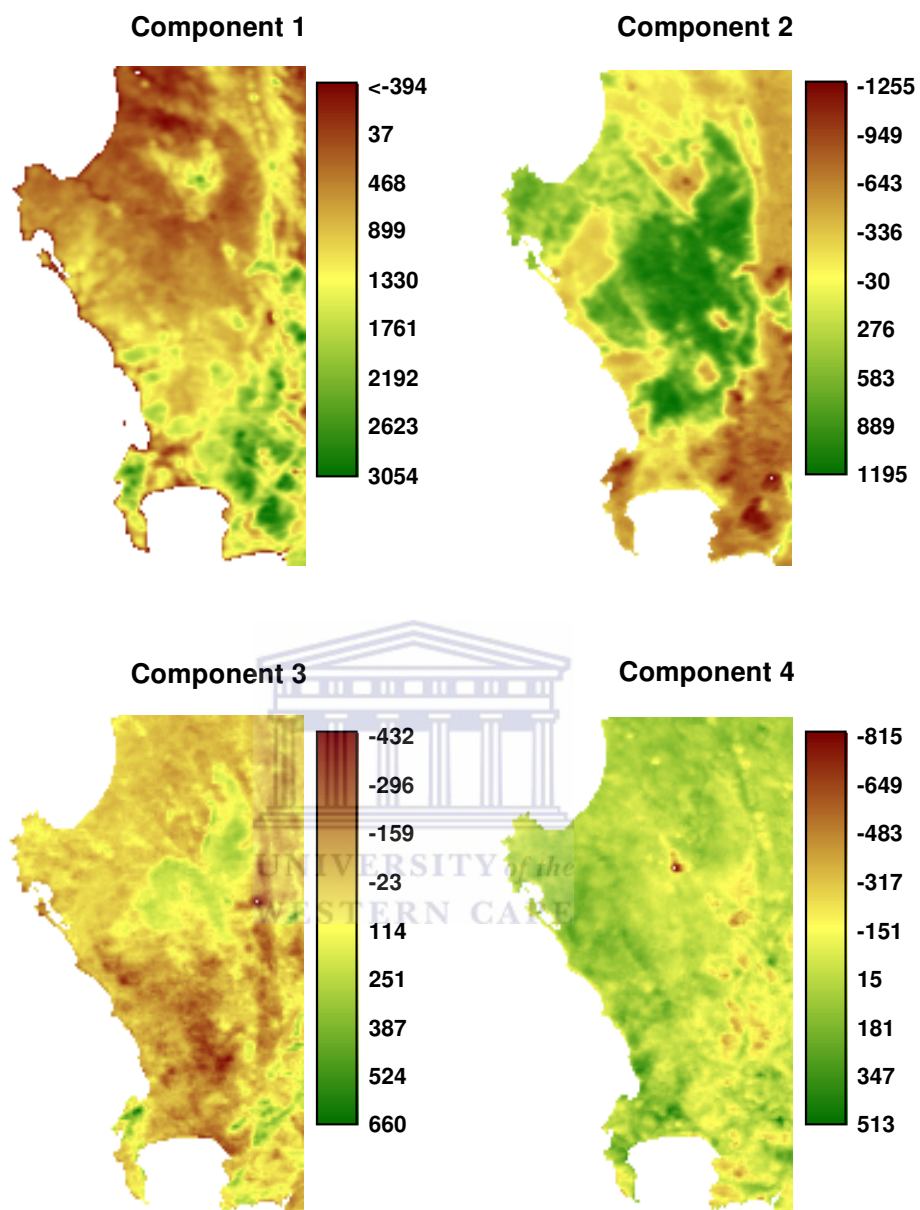


Principal Components Analyses

The first eight component images are shown in Figure 5. These should be viewed with their appropriate graphs (Figure 6).

Component one accounted for 85.02% of the variability occurring within the time-series. Loadings varied from 0.9808 (November 1996) to 0.7924 (August 1999), with distinct, and substantial, annual cycles – the loadings typically being at their lowest in August, and highest in November. Note the general gradation from brown in the north-west to green in the south-east, and the brown denoting the denser urban areas around Cape Town.

Component two accounted for 10.06% of the variability. There were very strong annual cycles, with the monthly loadings ranging between 0.5759 (August 1999) and -0.3771 (January 2001). In this component, maximum values generally occurred in August, while the minimum was usually a two-month low occurring between February and April. In this component image, note the central dark green



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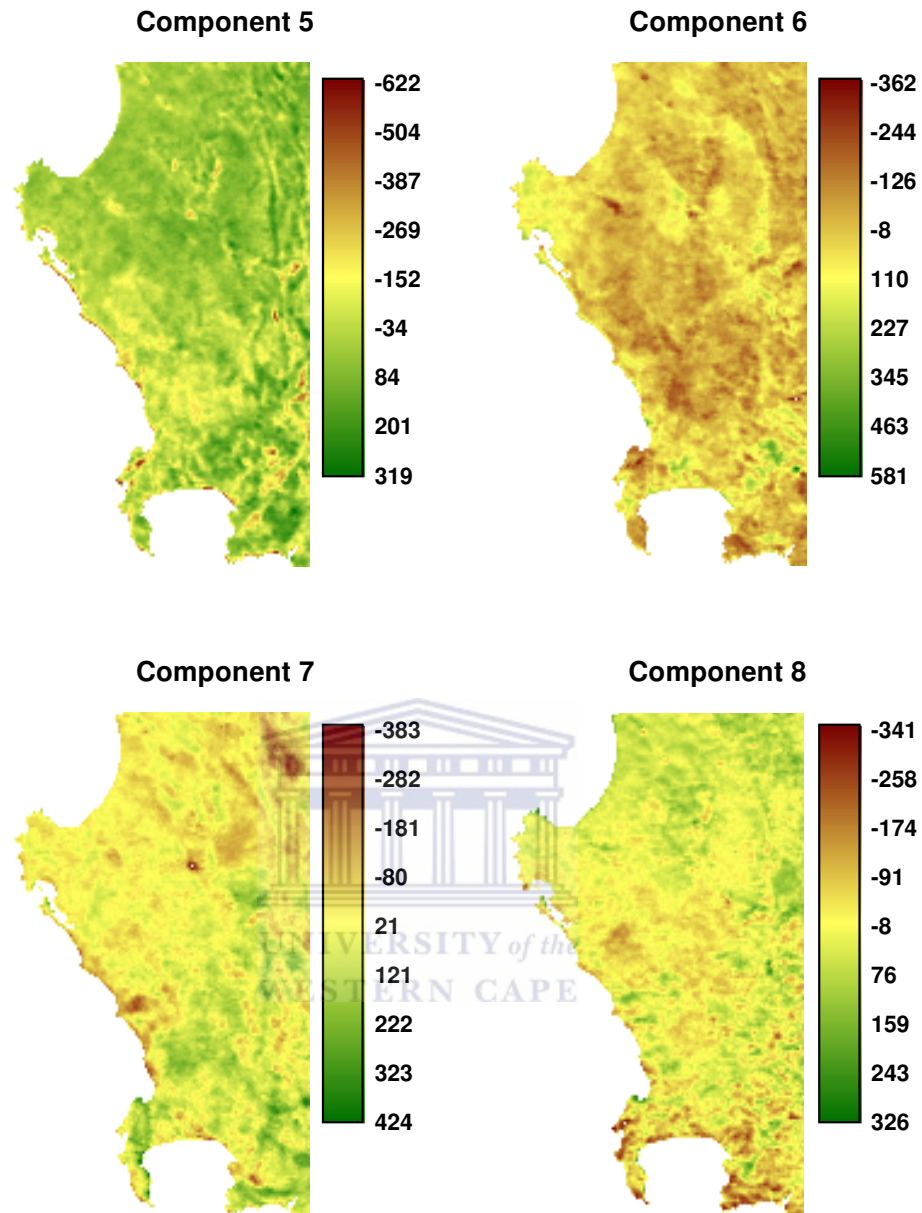
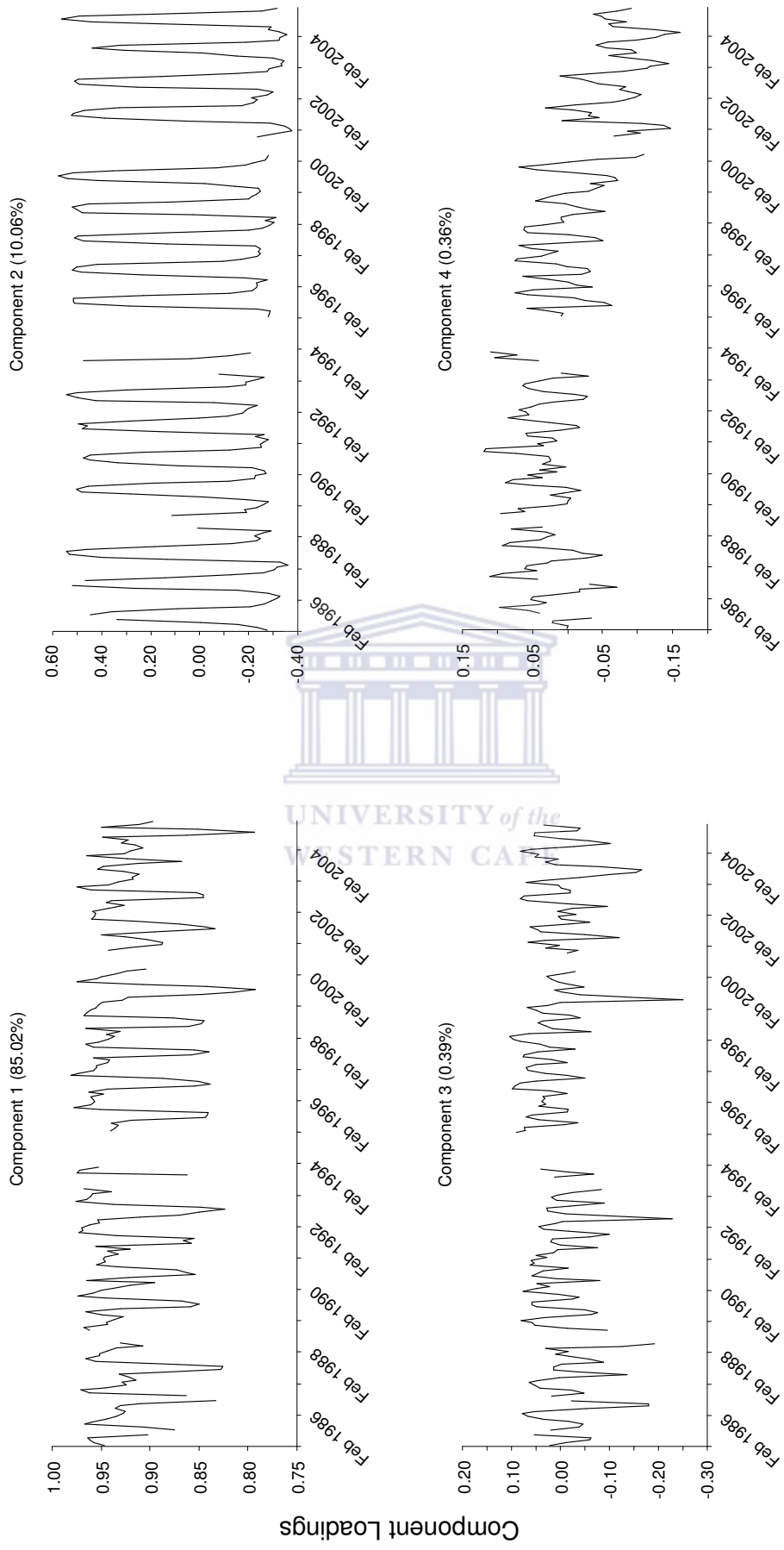


Figure 5. Components images one to eight from the PCA. Legend values are integer component loadings, produced by multiplying the loadings by 100 and rounding to the nearest integer value (Eastman 1999). Values of less than -394 in component one were allocated to the ocean (-1673), which has been masked out.



Continued on next page...

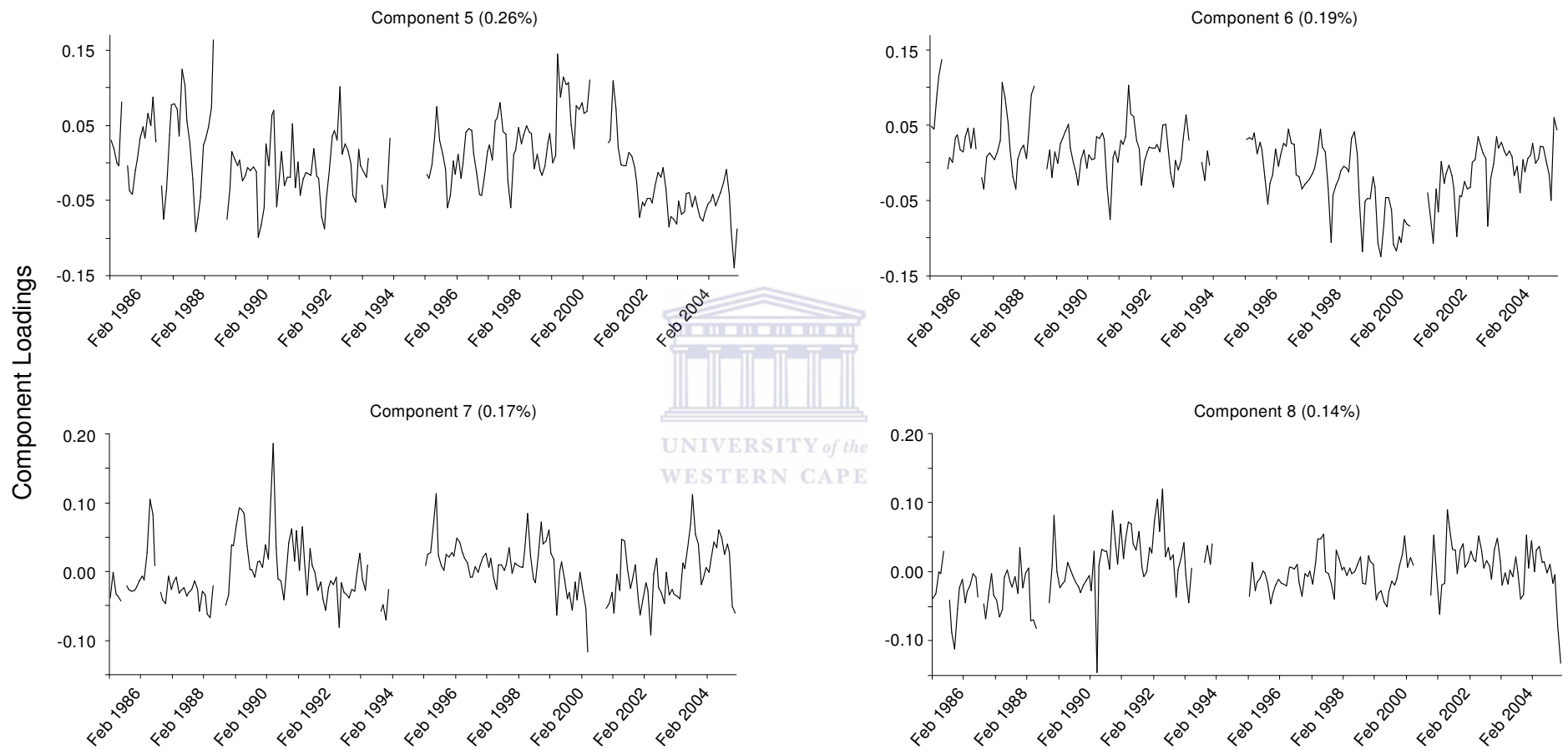


Figure 6. Plots of component loadings over the time series for components one to eight. Breaks in the graph indicate missing or faulty data. Percent variance of each component is shown in parentheses.

area where intense dryland agriculture is practised, the yellow to yellow-green over the rest of the lowlands and the darker brown representing natural vegetation at higher altitudes.

Component three accounted for 0.39% of the variability. In this component there were approximately two cycles per year. The complete time-series displayed nine major dips, eight of which occurred in the month of May. The most distinctive feature of this component image is the green area over the northern Swartland.

Component four accounted for 0.36% of the variability. Once again there were annual cycles with the month of June tending to be at the bottom of each cycle. The most obvious characteristic of the graph is the overall decline in the average value of each cycle from mid 1995. A small patch of dark brown to the south-west of the Piketberg, and the dark green areas around Cape Town are the important items to note in this image.

Component five (0.26%) showed annual cycles, with April or May being at the highest and October at the lowest points on the plot. The most obvious feature in this case was a steep decline in the average value of each cycle from 1999. Note the dark green lines running north to south in the eastern parts of this image.

Component six (0.19%) also showed annual cycles with peaks in June/July and troughs occurring in October. The deep trough in 2000 – 2001 is the most obvious feature of the graph. There were no obvious items of note to be seen in the component image.

Components seven (0.17%) and eight (0.14%), while having peaks and troughs, showed irregular cycles. Possibly the most significant factor was the extreme positive peak for component seven and the extreme negative trough for component eight, both occurring in April 1990, suggesting a significant but probably localized event. In component seven, note the small patch of brown to the south-west of the Piketberg, also seen in component four. The other two items to note are the western coastal cells, and the brown area over the Cederberg in the north-east. Component eight had no obvious features.

Time-series profiles

Classification into classes

In order to differentiate between the classes identified from components one and two (Figures 7 and 8), those derived from component one will be referred to as Regions (Region one to Region five), while those derived from component two will be referred to as Zones (Cereal Zone, Mixed Zone, Natural Dry Zone, Natural Wet Zone, Orchard Zone). Capitals will be used to differentiate between specific and general references.

Note that each Region and Zone encompasses a mixture of ecological and land-cover types. This is best exemplified by the suburbs of Cape Town and the arid north-western region of the study area both being incorporated into Regions two and three, while in the second component Cape Town is predominantly represented by the Natural Dry Zone.

Figure 9 shows the annual cycle of NDVI for each of the component one Regions. Note that while Regions one to four have distinct annual cycles that are effectively synchronous, the cycles of Region five lags the other four Regions by about three months, its cycles extend over a smaller range, and its average annual NDVI is much higher.

Component 2 was initially divided into seven zones. However, from previous unpublished work, it had been noted that it was better to use a coarser system, rather than break down areas of similar land-use (or cover) into sub-units of different intensity. The three intensities of dryland agriculture initially identified were therefore combined into one (and called the Cereal Zone). Two natural zones were identified. Although superficially similar in terms of land-cover components, they displayed substantially different annual NDVI responses, and were therefore analysed separately. They were referred to as the Natural Dry and Natural Wet Zones, as based on their annual average rainfall. There remained a distinct Mixed Zone, with characteristics intermediate between the Cereal and Natural Dry Zones (and usually separating the two), as well as an Orchard Zone having the characteristics of component one's Region five.

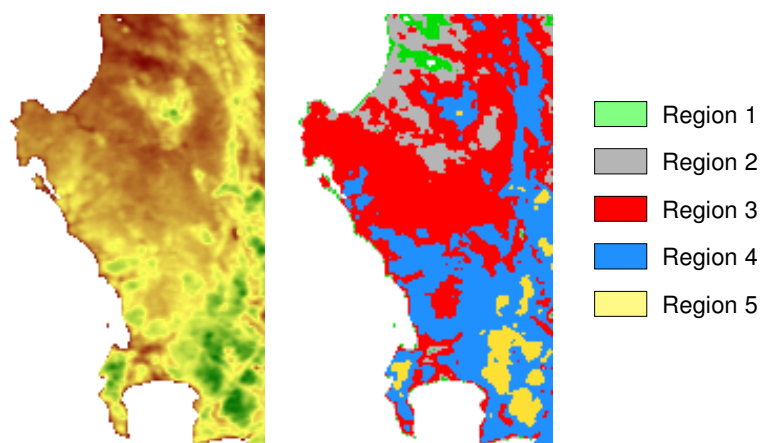


Figure 7. Component one image (left) and the five Regions derived from this.

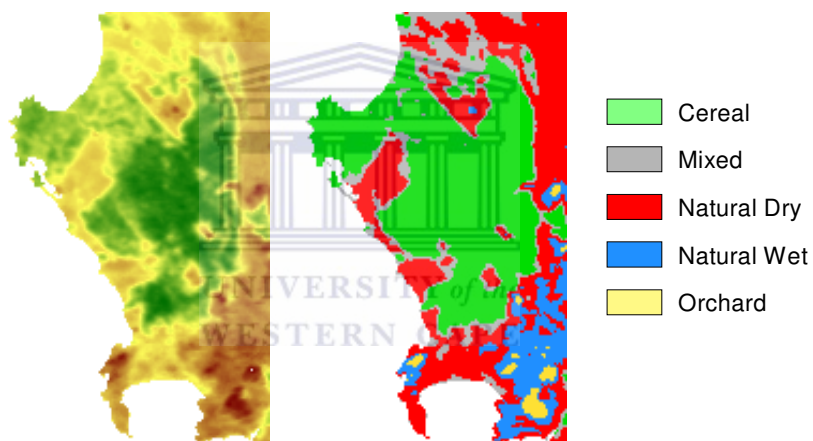


Figure 8. Component two image (left) and the five Zones derived from this.

Figure 10 shows the annual cycles of NDVI for each of the Zones derived from component two. In this case, three patterns emerge. Evident were the strong seasonal cycles of the Cereal and Mixed Zones. A lesser cycle, largely synchronous with the agricultural zones, but with a longer trailing slope, characterized the Natural Dry Zone, while the Orchard zone was largely analogous to Region five of component one. The temporal pattern displayed by the Natural Wet Zone was similar to that of the Orchard Zone, but with NDVI values intermediate between the Orchard and Natural Dry Zones.

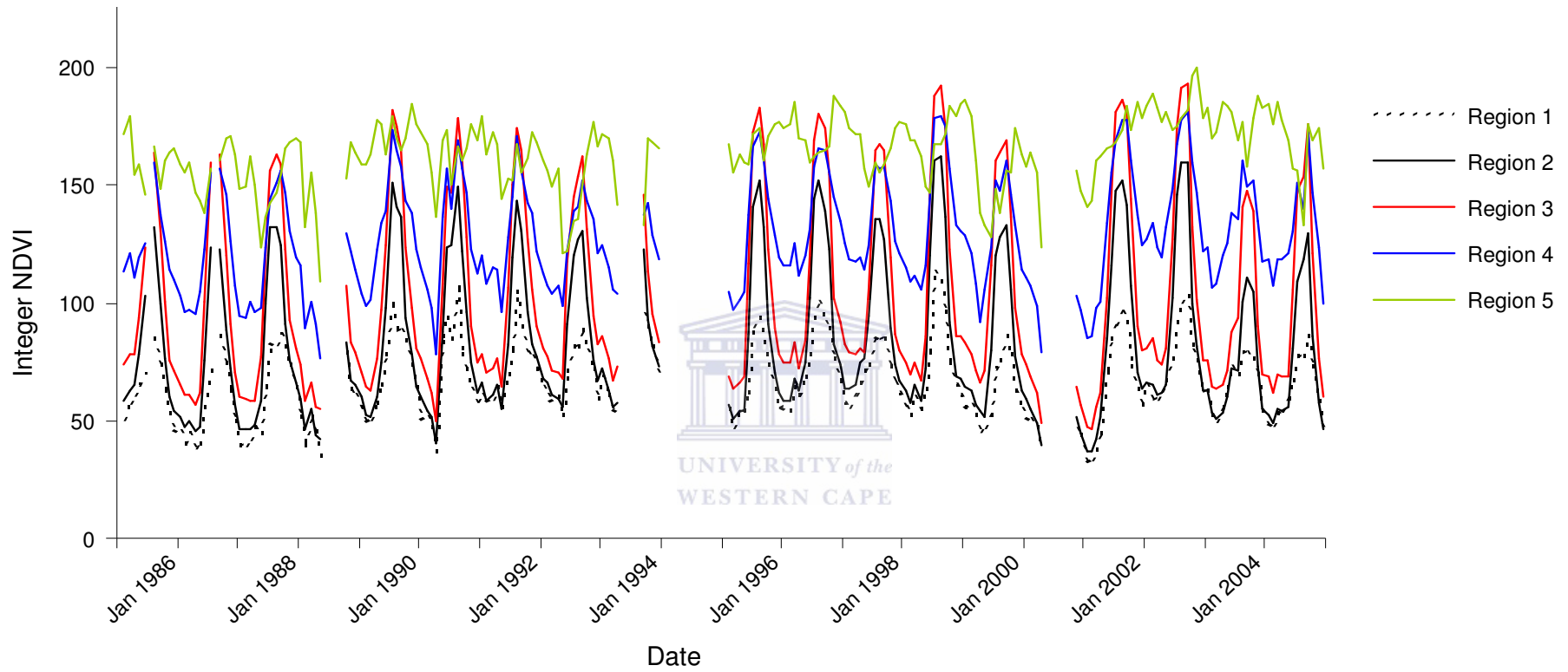


Figure 9. Plot of the monthly-maximum I-NDVI values for each of the Regions derived from component one. Breaks in the graph indicate missing data.

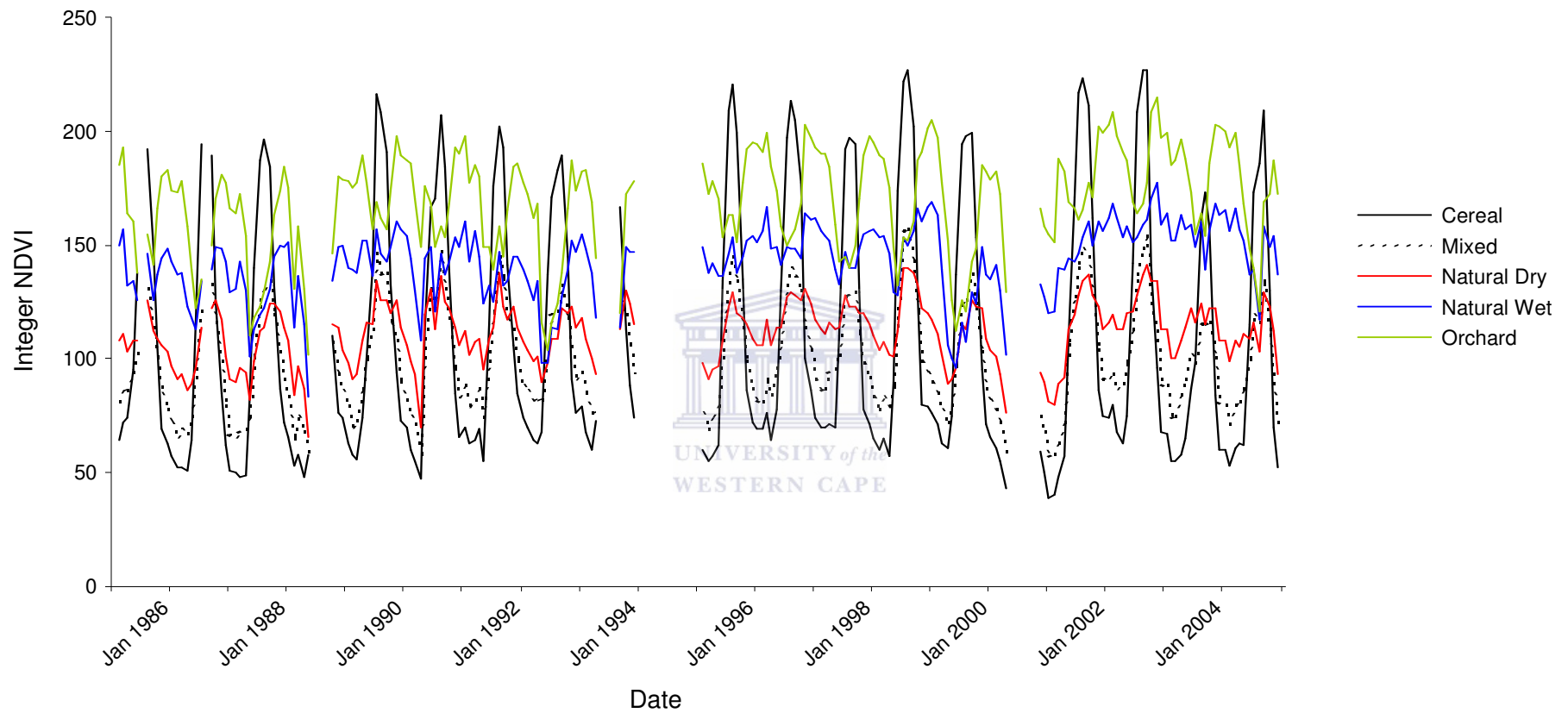


Figure 10. Plot of monthly maximum I-NDVI for each of the Zones derived from component two, over the time series. Breaks in the graph indicate missing data.

Table 1. The maximum and minimum correlations (r^2) between monthly NDVI values and accumulative monthly rainfall at different lag periods, for each Region (top) and Zone (bottom), derived from components one and two respectively.

	Max r^2	Lag period	Min r^2	Lag period
Region 1^a				
Region 2	0.6850	2	0.1591	6
Region 3	0.7283 ^b	2	0.1636	6
Region 4	0.7166	3	0.2440	6
Region 5	0.0660	6	0.0015	3
Cereal Zone	0.6967	2	0.1400	6
Mixed Zone	0.6700 ^c	3	0.2277	6
Natural Dry Zone	0.5226	4	0.2509	1
Natural Wet Zone	0.0566	6	0.0005	3
Orchard Zone	0.2244	1	0.0031	5

^a Region 1 was not assessed – only one rainfall station.

^b Significant correlation between rainfall and NDVI ($p = 0.013$).

^c Significant correlation between rainfall and NDVI ($p = 0.199$).

Rainfall – NDVI correlations

Rainfall-NDVI correlations within the west coast area as a whole, showed the best correlation ($r^2 = 0.7395$; $p = 0.45$) when related to the sum of the previous two months rainfall. Within the various component one Regions and component two Zones, there was a great deal of variation (Table 1), and only in two cases (Region three and the Mixed Zone) was there any significant correlation between rainfall and average NDVI. Nevertheless some near significant correlations were observed in Regions two and four, and in the Cereal and Natural Dry Zones. Region five and the Natural Wet and Orchard Zones showed almost no correlation between rainfall and NDVI.

Table 2. The maximum correlation (r^2) between monthly NDVI values and accumulative monthly rainfall at different lag periods, for each Region (top) and Zone (bottom) derived from components one and two respectively. Correlations have been restricted to the period February to August.

	Max r^2	Lag period
Region 1^a		
Region 2	0.7276 ^b	3
Region 3	0.7703 ^b	2
Region 4	0.7259 ^b	2
Region 5	0.0244	4 ^c
Cereal Zone	0.7134	2
Mixed Zone	0.6720	2
Natural Dry Zone	0.4698	3
Natural Wet Zone	0.0339	4 ^c
Orchard Zone	0.1976	1

^a Region 1 was not assessed – only one rainfall station.

^b Significant correlation between rainfall and NDVI ($p > 0.05$).

^c Due to the shorter time period used, 4 months was the maximum lag period used.

Restricting the correlations to the primary growth period (February to August), gave a small improvement in the strongly seasonal Regions and Zones (Table 2), but in those areas with smaller seasonal differences, the correlations were lower. Some of the improvements may have been due to the smaller data set.

Land-cover changes

The image produced by the simple subtraction method to identify regions of change was almost identical to the component two image of the PCA change analysis. Reclassing the image clarified the changes that had occurred between 1985 and 2004 (Figure 11). Just under 61% of the land area showed a positive NDVI trend, while 21.3% remained unchanged (less than five NDVI units difference).

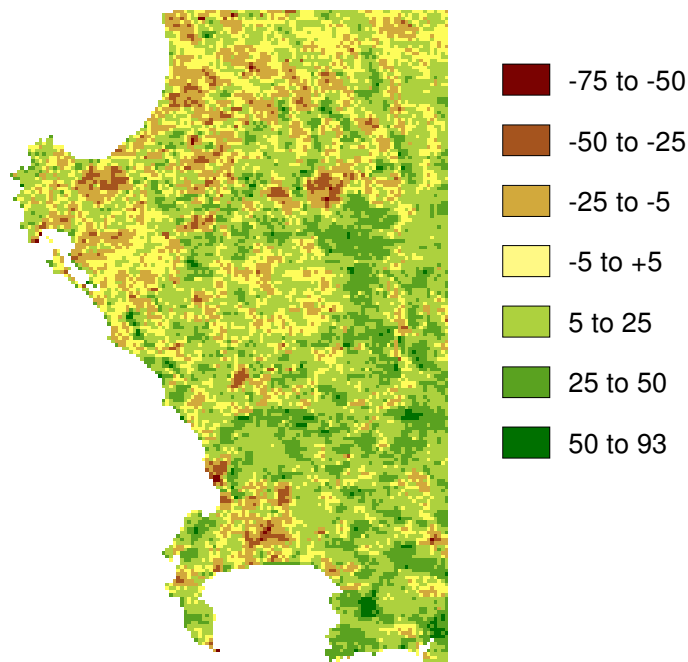


Figure 11. A seven-class change image of the study area. Values show I-NDVI units of change between a 1985-1987 annual MVC and a 2002-2004 annual MVC.

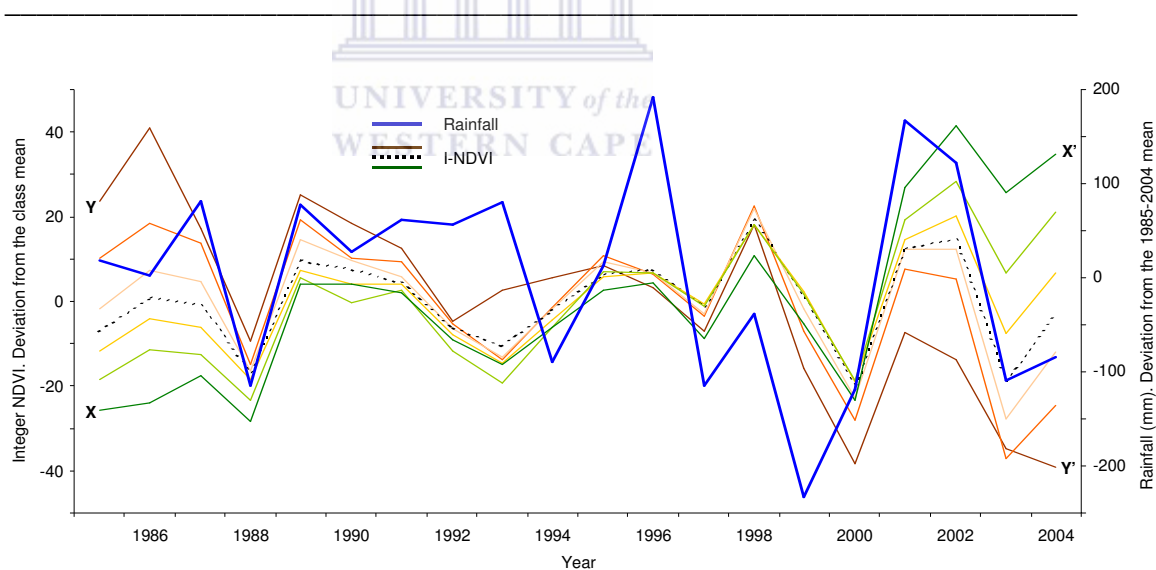


Figure 12. Change in I-NDVI (deviation from the class mean) of each of seven change classes between 1985 and 2004. Lines X-X' and Y-Y' underwent the most positive and negative changes respectively. The dotted line indicates the no change class. I-NDVI data for 1994 is interpolated for ease of interpretation. Annual deviation of the rainfall from the 1985-2004 mean is shown in blue.

Although changes were widespread, the central wheat-growing regions showed an overall positive trend, while the north-western parts showed an overall negative trend, particularly along the coast and in the northern Swartland. Urbanization on the Cape Flats and in other suburbs where informal and low-cost housing settlements had been developed was also evident. There was a similar darkening to the north of Mamre, possibly attributable to a fire towards the end of the series.

Figure 12 plots changes in the annual maximum NDVI for the seven classes over the twenty-year period. The two items to note are within any year, all will go up or down in synchrony and that the class differences are most pronounced at the start and end of the series.

Land-cover and Productivity

A breakdown of the basic land-cover classes of the component one Regions, and the component two Zones is shown in Table 3. As might be expected, land-cover has played a role in determining the patterns identified, especially with the component two Zones. Note the similarity of the land cover constituents of Region five and the Orchard Zone.

There were no significant correlations between crop production figures and annual maximum NDVI, either overall, or at a local scale (Table 4). Restricting the analyses to the two months prior to grain ripening, or by subtracting the background levels were similarly unsuccessful in predicting crop production, as was the use of the data of Van Rooyen (2000). The highest correlation measured was 0.6097 for the locality of Gouda using the \sum NDVI for August and September only.

Table 3. Land-cover representation (%) within each of the Regions (top) and Zones (bottom) derived from components one and two respectively. Land-cover categories are from the NLC classification (Thompson 1996).

	Region 1	Region 2	Region 3	Region 4	Region 5
Natural	67.1	44.4	41.3	53.3	35.0
Water Bodies	4.9	2.8	1.0	2.0	1.7
Dryland agriculture	10.7	40.7	50.9	25.3	20.5
Irrigated agriculture	13.3	8.6	3.3	15.1	39.9
Urban	4.0	3.5	3.6	4.3	2.9
	Cereal	Mixed	Natural Dry	Natural Wet	Orchard
Natural	19.0	55.2	73.1	64.8	34.9
Water Bodies	0.8	2.3	2.1	1.2	3.9
Dryland agriculture	75.9	18.2	4.6	13.1	14.4
Irrigated agriculture	3.4	19.4	12.3	18.3	43.2
Urban	1.0	4.9	7.9	2.5	3.5

Table 4. Correlations (r^2) between cereal production and maximum annual NDVI values.

Locality	r^2 correlation
All wheat (silo data)	0.0445
All wheat (van Rooyen 2000)	0.0017
Darling	0.0248
Gouda	0.3594
Klipheuwel	0.0244
Malmesbury	0.0737
Moorreesburg	0.0312
Porterville	0.1338
Riebeeck Wes	0.1895
Rus Stasie	0.0047
Vredenburg	0.0515

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Tables 5 and 6 show the average annual and growing season sums of NDVI for each of the Regions and Zones of components one and two respectively, both with and without background (annual minimum) values being subtracted. Also shown is the annual biomass production for each category, as estimated from the data specified in the methods section. The correlations (r^2) between the various categories of \sum NDVI and estimated productivity are shown both including and excluding the predominantly irrigated Region five and Orchard Zone. Excluding Region five and the Orchard Zone improves the correlations substantially when the background values are subtracted. Where the background values are ignored, correlations are improved if Region five and the Orchard Zone are included.

Table 5. Patterns of I-NDVI for each of the Regions derived from component one, as assessed from the Σ annual and growing season I-NDVI in each Region, excluding and including the average annual background I-NDVI levels. Estimated annual plant productivity and the correlation between this productivity and each of the I-NDVI categories are also shown.

Region	Average Σ annual I-NDVI	Average Σ I-NDVI during growth season ^a	Back-ground I-NDVI ^b	Average Σ annual I-NDVI – 12*Background I-NDVI	Average Σ I-NDVI during growth season – 5*Background I-NDVI	Estimated productivity (tonnes/ha ⁻¹ /yr ⁻¹) ^d
1	825.7	402.3	48.3	245.6	160.6	6.5
2	1031.5	564.9	51.9	408.2	305.2	10.2
3	1284.2	701.3	63.8	518.1	382.1	10.5
4	1579.3	734.4	99.9	380.3	234.8	9.3
5 ^c	1990.7	867.4	144.9	251.5	142.7	14.3
R² excl Reg 5	0.3053	0.6063	0.0705	0.8746	0.8310	
R² incl Reg 5	0.7111	0.7754	0.6242	0.0000	0.0026	

^a This is calculated as I-NDVI_{May} + I-NDVI_{June} +... I-NDVI_{September}

^b This is the average minimum I-NDVI per year over the study period.

^c Growth season for Region 5 = November to March.

^d Estimated from the relative proportion of dry and irrigated agriculture, and natural vegetation within each Region and their relative annual productivities. Natural: 2 tonnes/ha⁻¹/yr⁻¹; Dryland: 17.5 tonnes/ha⁻¹/yr⁻¹; Irrigated: 25 tonnes/ha⁻¹/yr⁻¹.

Table 6. Patterns of I-NDVI for each of the Zones derived from component two, as assessed from the Σ annual and growing season I-NDVI in each Zone, excluding and including the average annual background I-NDVI levels. Estimated annual plant productivity and the correlation between this productivity and each of the I-NDVI categories are also shown.

Zone	Average Σ annual I-NDVI	Average Σ I-NDVI during growth season ^a	Back-ground I-NDVI ^b	Average Σ annual I-NDVI – 12*Background I-NDVI	Average Σ I-NDVI during growth season – 5*Background I-NDVI	Estimated productivity (tonnes/ha ⁻¹ /yr ⁻¹) ^e
Cereal	1354.8	803.1	56.2	680.8	522.3	14.5
Mixed	1228.8	599.4	73.3	349.1	232.9	9.1
Natural Dry	1362.4	591.3	93.7	237.8	122.7	5.4
Natural Wet^c	1731.9	870.6	123.4	250.8	253.4	8.2
Orchard^d	2039.0	942.4	138.2	380.3	251.3	14.0
R² excl Orchard	0.0286	0.2381	0.4587	0.9205	0.9734	
R² incl Orchard	0.1330	0.4345	0.0031	0.6561	0.6035	

^a This is calculated as I-NDVI_{May} + I-NDVI_{June} + ... I-NDVI_{September}

^b This is the average minimum I-NDVI per year over the study period.

^c Growth season = October to March.

^d Growth season = November to March.

^e Estimated from the relative proportion of dry and irrigated agriculture, and natural vegetation within each Zone and their relative annual productivities. Natural: 2 tonnes/ha⁻¹/yr⁻¹; Dryland: 17.5 tonnes/ha⁻¹/yr⁻¹; Irrigated: 25 tonnes/ha⁻¹/yr⁻¹.

Discussion

Principal Components Analysis, Regional and Zonal classifications

Eklundh and Singh (1993) did a comparison of standardized and unstandardized Principal Components Analyses, and came to the conclusion that the standardized method consistently yielded significant improvements in the signal to noise ratio, compared with the unstandardized method. They felt that standardized PCA was the better method of analyzing remote sensing imagery. The standardized option was the only one available in the Idrisi32 package for processing more than 12 images.

PCA has been used by a number of workers to analyse satellite time-series (*e.g.* Byrne *et al.* 1980, Eastman and Fulk 1993, Hirosawa *et al.* 1996, Gurgel and Ferreira 2003, Nonomura *et al.* 2003). It produces a series of new images (components) that are related to the original images, but are uncorrelated with each other. This de-correlation results in tonal reversal in successive components (Lillesand and Kiefer 2000), a factor which should be kept in mind when interpreting the results.

The first component has the greatest correlation with all of the original images *i.e.* it explains the highest percentage variance of each image in the series (Eastman 1999). In time-series analyses it therefore tends to describe the geographic (*i.e.* permanent or landscape) pattern (Eastman and Fulk 1993). The second component is produced using the residual values from the analysis after the first component values have been subtracted (Johnston 1978, Eastman 1999a), and usually displays regions with similar patterns of seasonal change (Eastman and Fulk 1993, Hirosawa *et al.* 1996). Further components generally identify regions of lesser extent and change, until a point is reached where they show little more than noise (Eastman and Fulk 1993, Lillesand and Kiefer 2000).

Manual division of an area into Regions and Zones, similar to that carried out in this study has precedence in the literature. Sobrino and Raissouni (2000) used a 12-month composite image to define seven zones, each encompassing successive 0.05 NDVI units. Other workers have analysed their data upon bio-climatic zones (*e.g.* Schmidt and Gitelson 2000, Al-Bakri and Suleiman 2004). Within the area covered

by this study, there are no formal bioclimatic zones, and the area is one of transition. Thus, the actual data produced by components one and two were used as the basis for the division into Regions and Zones.

The question, therefore is, what do the Regions and Zones of components one and two actually depict? The plot of the loadings of the first component over the time series, showed relatively strong annual cycles. The range of these was far greater (~0.18) than that found by workers such as Eastman and Fulk (1993), Hirosawa *et al.* (1996) or Gurgel and Ferreira (2003). This suggests that seasonal events in this area are strong enough to impose themselves on the overall pattern of NDVI. In the papers just referred to, seasonal effects have only become obvious in the second component. In this study, the range of the second component cycle loadings was also higher (0.9), compared to *circa* 0.6, 0.4 and 0.1 respectively, in the three works just referred to.

The pattern shown by component one was not immediately assignable to vegetation communities or to land-use. However, it did show a strong resemblance to the annual rainfall pattern (Figure 13). Similar phenomena have been observed by Al Bakri and Suleiman (2004) in Jordan, Wang *et al.* (2001) on the Great Plains of the U.S.A and Malo and Nicholson (1990) in the Sahel. Although there were some statistical similarities between certain aspects of each Region, it was clear that they represented classes where rainfall, altitude and NDVI characteristics were distinct, although one must be aware that rainfall and altitude are strongly linked in this area. There is a general gradation of rainfall, increasing from NW to SE. Rainfall also increases by a factor of two to three as one moves from the bottom to the top of the Western Fold Mountains, a horizontal distance of only a few kilometres (Schulze 1997).

Region one represents areas where the annual rainfall is low (an average of 278 mm over the 1985-2004 study period. All further average rainfall data will be expressed in terms of the 1985-2004 mean). Agriculture is largely confined to areas close to the Verlorevlei River, with a little over half (13.3% of 24% total cultivated area) being designated as irrigated on the NLC classification (Thompson 1996). Although the annual range of NDVI was statistically similar to that of

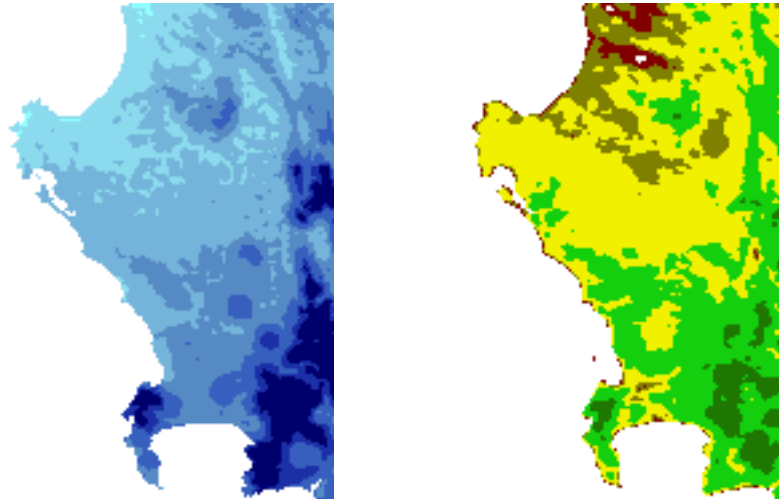


Figure 13. Similarity of pattern displayed by a reclassified median rainfall image (Schulze 1997) and the component one Regions of this study.

Region five, the average was much lower, which would be expected considering the big difference in rainfall.

Region two, while receiving sufficient rainfall for dryland agriculture in most years (408 mm), is more likely to suffer in very dry years, and parts of it can be seen to fall outside of the typical dryland Cereal Zone derived from component two (Figures 7 and 8). Removing the rainfall data from the southern parts of this Region, as well as those rainfall stations occurring above 500 m, reduced the average rainfall received over the 1985-2004 period to 267 mm, the same as that of Region one. Soil types (Quaternary sands, Anon. 1973) are the same in both Regions. The major difference is that Region one has a greater amount of topography. Region two varies by less than 100 m over its whole extent, except in the extreme north-west. Region one, while having a lower average altitude and smaller altitudinal range than that of Region two, covers a much smaller area, leading to generally steeper slopes. Combined with the Verlorevlei estuarine system, it means that a smaller proportion of Region one is available for intensive agriculture. Region two therefore supports almost twice as much agriculture as Region one (per unit area), leading to the higher average \sum NDVI of Region two.

The cultivated proportions of Regions two and three are similar (49.3% and 54.2% respectively). However, Region three has a higher average annual rainfall (542 mm) than that of Region two (408 mm). This translates into Region three having an average annual Σ NDVI around 25% higher than that of Region two. Restricting the rainfall analyses to the predominantly cereal growing lowlands, the respective average rainfall figures were 368 mm and 267 mm over the 1985-2004 period, which is still a substantial difference.

The two biggest Regions (three and four) both incorporate extensive dryland agriculture, as well as natural vegetation. They show statistically significant differences in their average rainfall (542 mm and 775 mm respectively), average altitude and minimum NDVI levels. Only the average NDVI values recorded for the two months in which these are at a maximum (August and September) showed no significant difference at the 5% level. Region three, although receiving sufficient rainfall for the practice of dryland agriculture, experiences very dry summers (111 mm, Dec-Apr) resulting in little or no vegetative growth during this period. Region four however, receives sufficient rainfall in the summer (160 mm, Dec-Apr) to allow the growth of annuals on harvested fields, and is also sufficient for the land to be used for pasture and other less seasonal agricultural activities. This presence of less-seasonal vegetation, leads to an overall higher (23%) annual Σ NDVI than that of Region three. The higher rainfall of Region four is enhanced by a 15.1% component of irrigated agriculture (compared with 3.3% for Region three). In terms of rainfall timing, Region four leads Region three by about a month, thus helping to explain component three (see later). Region four also incorporates most of the natural (mainly Fynbos) vegetation in the area, much of which occurs on the mountains which receive substantially more rain than do the lowlands (Lowlands [< 500 m]: Region four: 537 mm [North] to 726 mm [S]; Highlands Region four: 686 mm [N] to 1559 mm [S]; Region three lowlands: 368 mm [NW] to 542 mm [SW]). This further helps to maintain an overall level of greenness throughout the year. Where Region three represents natural vegetation it is mainly on the drier eastern sides of the higher mountains in the Cederberg, which also receive snow in winter, or on the deep, well drained sands in the west, which receive a low annual rainfall. Region three also represents most of Cape Town's more densely populated areas.

Region five showed the highest annual average NDVI, rainfall (810 mm) and altitude (333 m) of all the Regions. As mentioned in the results, this Region generally represents areas where deciduous, usually irrigated, crops are grown. It is a subset of the Natural Wet and Orchard Zones derived from component two. Annual NDVI cycles are small (~ 50 integer units) and its annual average NDVI is second only to the Orchard Zone. In most cases this pattern can be attributed to the presence of orchards and vineyards, which are irrigated in summer and dormant in winter, when the growth of the natural and other un-irrigated vegetation is at its peak. Of interest is the patch occurring on the Cape Peninsula. Although vineyards are present, much of it represents broad-leaf forest. There are two possible reasons for its incorporation into this Region/Zone. The first is that there is adequate ground water available to the forest throughout most of the summer, as the winter rainfall percolates through the rocks, thus giving the area a high level of photosynthetic activity at that time. The frequent presence of orographic cloud in summer (*pers. obs.*) will also contribute, possibly significantly (Schulze and McGee 1978) to the effective precipitation levels, as well as reducing transpiration. The second is that these forests occur on the steep east and south-east facing slopes of the mountain chain. In winter, some of these become shaded as early as 14h00 (*pers. obs.*). The result of this would be reduced photosynthetic activity at the time the NOAA platform is passing over the area. The annual cycles of photosynthetic activity in this area would therefore be similar to that of the deciduous fruit plantations on the Overberg, and the vineyards along the Western Fold Mountains.

It is therefore suggested that component one is showing a geographic pattern based upon rainfall, or more correctly, on the overall (year-round sum) of NDVI (or “greenness”), as perceived by the satellite sensors (Table 5). One might secondarily attribute the pattern to plant productivity (see later).

The Zones of component two were more easily described in terms of actual land-cover. About 35.6% of the land-cover (42.3% of that less than 500 m) in the imagery is used for the cultivation of cereals. In the central parts of the Cereal Zone, dryland agriculture takes up 75.9% of the land area. This results in high NDVI values during winter, followed by very low values during summer. Surrounding it is a narrow Zone of mixed land-use. This Mixed Zone mostly represents the interface

between the nutrient-rich clay soils of the Swartland and Boland, and the nutrient-poor Table Mountain sandstones of the surrounding mountains, or with the leached nutrient-poor acid sands of the southern and western coastal regions (Anon 1973, 1990, 1997). The soils of the Sandveld in the north-west are geologically more recent and contain sufficient levels of nutrients for crops to be grown with the addition of fertilizers (Talbot 1947, Hendey 1983a). Both the Cereal and Mixed Zones show strong seasonal cycles, although the range of the Mixed Zone is only half that of the Cereal Zone, which is understandable in the light of its lesser cereal component. The Mixed Zone has also manifested itself in the extreme north-west of the region, probably as a result of the combination of irrigated and natural vegetation occurring there.

The Natural Dry Zone mainly represents those areas where natural vegetation is predominant. It had low \sum NDVI values, which would be expected from the low primary productivity figures reported for Fynbos (Kruger 1977). It also represents minimally vegetated areas with relatively low average NDVI values. Thus the City and suburbs of Cape Town are depicted as part of this Zone. It mostly occurs on the infertile soils of the region, and has the least agriculture of any of the Regions or Zones.

The Natural Wet Zone also has a substantial component of natural vegetation, but rainfall in this Zone is higher than in the Dry Zone (1074 mm Wet; 715 mm Dry). It had growing season (\sum NDVI - Background) and productivity figures similar to that of the Mixed Zone. However, the primary growth period for this Zone was over summer, thereby reflecting the fact that it incorporates both vineyards and broad-leaf forest in the wetter southern parts of the study area. Like Region five, these help to maintain a high background NDVI level throughout summer.

Although the proportions of natural and agricultural land-cover are similar, the Orchard Zone has a smaller proportion of dryland agriculture than Region five (14.4% against 20.5%). As with Region five, its NDVI profile can be explained by a high level of irrigated agriculture with productivity peaking in summer, combined with the natural vegetation which peaks in late winter-spring.

Component three was distinguished by semi-annual cycles. This was also observed by Eastman and Fulk (1993) and Gurgel and Ferreira (2003). These workers were examining regions that stretched across the equator, and they suggested that this component was depicting the opposing spring and autumn events in the two hemispheres. In this study, the semi-annual cycles may be identifying the effect of rainfall on the relative sowing and harvesting times in the northern and southern parts of the region. Compare the November image (Figure 3) with this component (Figure 5) and note how the northern Swartland depicts very low NDVI in November, and how it shows a similar area of green in component three. As mentioned above, the southern parts of the predominantly agricultural region are about a month ahead of the northern parts in terms of spring rainfall.

Component four appears to identify localities where there has been a substantial change in the NDVI characteristics during the series. Figure 14 shows the unclassed change image and a reversed palette version of component four together. The reversed palette has been used so that vegetation degradation shows up as brown, rather than green. Aerial photographs taken as close as possible to 1985 and 2004 were used to identify the changes. While the simple change image has shown up differences between the start and end of the time-series, component four has also identified changes of a transient nature that the change analysis has missed. Localities A to E identify areas where (mainly informal or high density) housing developments have been established and these have been identified in both images. Component four has additionally identified land affected by the fires of the year 2000, adjoining the Fish Hoek-Kommetjie valley (A). Location F, just north of Mamre has been identified in both images, and apparently records a fire on the Dassenberg close to the end of the time series. Localities G and H identify areas where plantations were harvested towards the end of the time-series. In both cases fires occurred in the general area and may have also helped depict the area as one of negative change. Location I saw the development of a dam, and irrigated crops (probably vines) between 1986 and 2000. Locations J, K and L similarly saw substantial increase in the cultivation of irrigated crops, mainly vines, with J also recording the recovery from a fire early on in the series. Vineyard developments may be attributed to the increased availability of overseas markets since the 1994 elections and the declining profitability of wheat (Fairbanks *et al.* 2004). Locality M

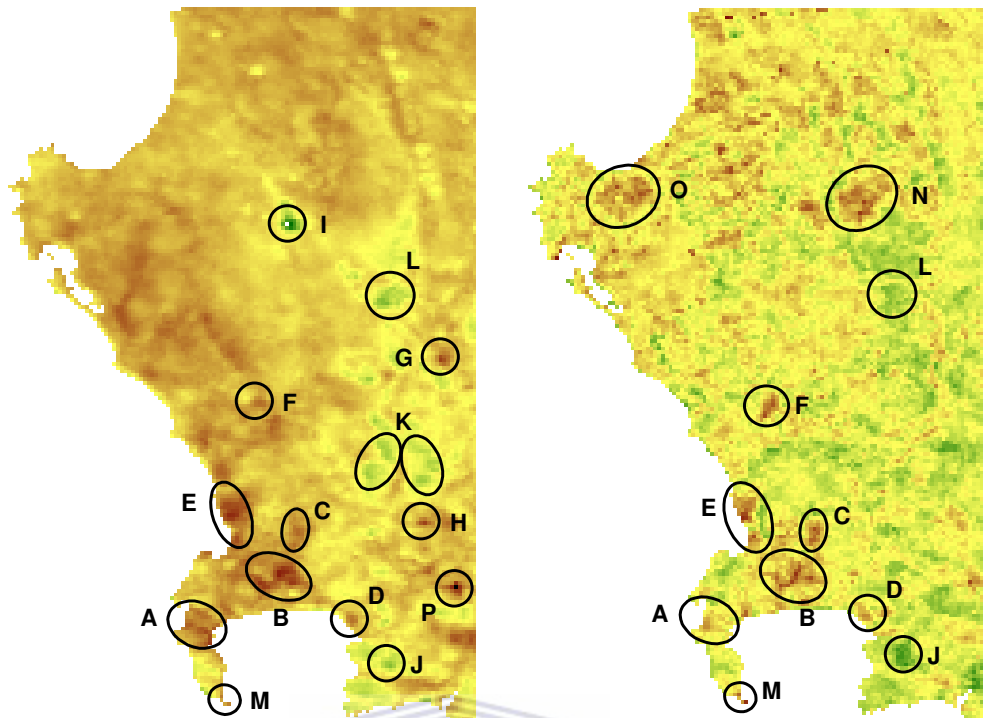


Figure 14. Comparing component four (left) and the change analysis image to show some of the changes identified by the two methods.

- A. The Fish Hoek-Kommetjie valley. Fires of 2000 show up in component four.
- B. Delft low-cost housing development.
- C. Suburban expansion in the Kraaifontein-Brackenfell area.
- D. Housing development in the Strand-Gordon's Bay area.
- E. Suburban expansion in the Table View/Bloubergrant area.
- F. Mamre – possibly caused by a fire.
- G. Plantation harvesting and pre-1989 fire, Waveren Valley.
- H. Plantation harvesting and a fire in the Franschoek valley.
- I. Dam and irrigated agricultural development, Wittewater, southern Piketberg.
- J. Recovery from a fire in the Kogelberg plus agricultural development.
- K. Development of vineyards in the Paarl-Wellington area.
- L. Development of vineyards to the south-east of the Heuningberg.
- M. Probably the effect of coastal cell misregistration.
- N. Unknown cause of change, northern Swartland.
- O. Vredenburg region. Cause of change undetermined.
- P. Theewaterskloof dam.

(Cape Point) is likely to be indicating coastal cell misregistration rather than any change in land use. Locations N and O identified areas of strong negative change in the northern Swartland, and close to Vredenburg respectively, but the reasons for these could not be established from the available imagery. Finally, locality P identified the Theewaterskloof dam. The imagery may have been identifying algal blooms, or simple the presence of a large body of water.

Component five has identified a number of items. The first appears to be coastal effects along the south-west facing coastlines. This is actually clearer in component one, but as the cause of this is probably related to the other factors noted in this component, it will be discussed here. The second is the course of the Berg River, particularly between Paarl and its confluence with the Klein Berg River. North of this the west facing slopes of the Olifantsrivierberge are distinct. When one examines the component graph, it will be noticed that there are changes in the characteristics of the plot between the satellite platforms used. It is therefore likely that this component is identifying regions where different alignments of the sensor pixels on the different platforms have resulted in big differences in the landscape they depict (georegistration errors). The best example of this would be the contribution of the ocean in the coastal pixels, which may be 50% for one platform, but only 15% for another, thus leading to apparent NDVI changes over time. Such shifts might similarly affect steep mountain slopes, or wide riverbeds. These would be more pronounced in a north-south direction, due to the east-west variations in satellite position over its nine-day orbital cycle. Of interest is that severe coastal cell misalignment was noted during a 7.6 km resolution analysis (unpublished data) of the 1982 to 1999 NOAA NDVI imagery produced by Clark Labs for their Global Change Series. In that set, these misalignments only became predominant in the 1998-1999 data. As this did not correlate with the launch of a new satellite platform, no reason could be determined for the problem.

If the average NDVI of each of the annual cycles of the component five graph are examined, it will be noticed that the cycles of the middle two satellite platforms have an overall positive slope. This phenomenon was reported by Eastman and Fulk (1993) in their shorter time series analysis of the African continent. They ascribed it to the orbital decay of the satellite (in their case NOAA-9), causing it to arrive over

the same geographical area at a later local time. The sun's rays are therefore travelling a longer path through the atmosphere compared to the equivalent day in the previous year(s) imagery. This results in a reduction in the amount of red light reaching the ground (and ultimately the satellite sensor), thus increasing the ratio of NIR to Red radiation and hence increasing the apparent NDVI value (Teillet *et al.* 1990, Tateishi and Kajiwara quoted by Eastman and Fulk 1993).

The remaining components are difficult to explain. Component six may be expressing the effect of annual rainfall on the vegetation, in that the period 1997 to 2000 had exceptionally low average rainfall, and this coincides with a dip in the average and maximum loading values over the same period.

While components one to six had a semblance of annual (or semi-annual in the case of component three) cycles, once we move on to components seven and eight, the "cycles" became irregular. Selecting images occurring at the extreme peaks or troughs usually showed little that was obviously "abnormal". The April 1990 image showed an area of missing data in the extreme north-east, and this has apparently been picked up in components seven and eight with an extreme peak and trough respectively, due to the tonal reversal between components (Lillesand and Kiefer 2000). There also appears to be some platform related effect in component seven, as the plot of each of the first three successive platforms shows an average downward trend over its lifetime. This is not obvious in the final platform (NOAA-16), and these trends may be due to the poorer quality data available for correcting for orbital decay and the like with the earlier imagery.

NDVI and Rainfall

Only one Region (three) and one Zone (Mixed) showed any significant relationship between rainfall and NDVI. Both of these areas have a substantial proportion of agriculture (54.1% and 37.6% respectively). Despite the lack of significance, the presence of dryland agriculture within a Region or Zone has assured relatively high levels of correlation, only falling marginally below accepted significance levels. Correlations fall within the range of those quoted in the literature consulted. Malo and Nicholson (1990) recorded correlations ranging from 0.22 to 0.95 in the Sahel, while Nicholson and Farrar (1994) reported values ranging from 0.19 to 0.90 in

Botswana. Eklundh (1998) found a maximum correlation of 0.36 between rainfall and NDVI in East Africa. Wang *et al.* (2003) recorded positive correlations of between 0.66 and 0.96 for forest and grassland on the Great Plains of the USA, but correlations for cropland varied from 0.93 to -0.91 on a year-to-year basis. However, they did not differentiate between dry and irrigated croplands. They observed that the vegetation response to rainfall events was extensive and depended upon the vegetation type, the time (month) of rainfall, whether the current or previous year had been extremely wet or dry *etc.* Strong NDVI-rainfall relationships were found at lags of up to 15 months (Wang *et al.* 2001, Wang *et al.* 2003) and even discrete precipitation events were found to have an effect upon NDVI (Wang *et al.* 2001). Figure 12 possibly suggests that there may be an up to two-year rainfall lag effect in the study area.

Comparing rainfall with NDVI between the months of February and August only, significantly improved the correlations. Nevertheless it is interesting to note that Regions two to four of component one, and the Mixed Zone of component two, had similar or higher correlations with rainfall than that of the Cereal Zone. One explanation for this is that the timing of the autumn rains is more important for crop production than the total rainfall (Talbot 1947). Therefore, rainfall in excess of that needed (the threshold effect) does not result in higher production, a factor that has been observed elsewhere (Malo and Nicholson 1990, Nicholson and Farrar 1994, Al-Bakri and Suleiman 2004). Thresholds vary, with figures of 500 mm in Botswana (Nicholson and Farrar 1994), between 400 mm and 600 mm in Jordan (Al-Bakri and Suleiman 2004) and 1000 mm per year in the Sahel and East Africa (Malo and Nicholson 1990) being reported.

A second explanation may be that NDVI is suddenly reduced with the harvest, while rainfall tends to fall off less sharply, thus reducing the correlation when the analysis period is extended beyond the start of the harvest. In addition it has been observed that maximum NDVI values usually occur a month or so prior to the harvest, due to the final month reflecting the opening and ripening of the grain (Maselli and Rembold 2001). A substantial presence of natural vegetation in Regions two to four and in the Mixed Zone ensures a continuation of greenness after the harvest, thus buffering the effect of the sudden reduction in plant biomass

observed in the Cereal Zone. Finally, differences in sowing and harvest times between, and within, the northern and southern parts of the Cereal Zone (as depicted by component three) may also be reducing the correlation.

Where the natural vegetation remains, it is mainly because the soils are nutrient deficient, especially in N and P (Hendey 1983a, Stock and Allsopp 1992). Growth in these areas is therefore probably limited by nutrients, rather than by water. Kruger (1977) noted that the greatest annual increase in the biomass of Fynbos occurred during the first two years following a fire (while the nutrients were still free in the system), and decreased as the vegetation aged. The natural vegetation is also predominantly shrubby, perennial, and adapted for summer-drought situations. This means that under normal circumstances the actual projected canopy cover would not vary greatly throughout the year. Winter and spring rainfall would promote fresh growth of the shrubs, as well as stimulating the growth of annuals and the resprouting of deciduous geophytes. Thus, provided the rainfall reached some threshold level, further rain would not increase the overall NDVI of the natural vegetation. This observation may be of importance when assessing the effects of climate change upon plant distributions.

There may also be technical factors reducing correlations between rainfall and NDVI. The relationship between NDVI and leaf area becomes non-linear once the canopy cover exceeds about 70% (Holben *et al.* 1980, Serrano *et al.* 2000) and saturates over closed canopy covers, such as forests or crops (Holben *et al.* 1980, Nicholson *et al.* 1990, Farrar *et al.* 1994, Lambin and Ehrlich 1997, Serrano *et al.* 2000). This may also be reducing rainfall : NDVI correlations in the Cereal Zone. The increase in NDVI of the natural vegetation in this area with rainfall may be more linearly related as the plants are less densely packed than is the case with cereals. Both Holben *et al.* (1980) and Serrano *et al.* (2000) have demonstrated that the use of the simple NIR/R ratio has a linear relationship with leaf area, and the use of this ratio is likely to result in improved NDVI : productivity correlations over dryland agricultural areas.

Finally, the correlation between rainfall lag and NDVI varies throughout the growing season, and can often be improved by time-slicing and applying different rainfall lag periods to the different time periods (Ji and Peters 2005).

It is clear that the relationship between rainfall and NDVI is complex and one needs to take into account a great deal more than simply the previous month's rainfall. Most studies have shown a correlation between the two, but at the resolution of the NOAA data, and the method of image degradation when LAC and degraded imagery is used, it is difficult to be precise about the actual physiological processes being monitored.

Change Analyses

Judged at the landscape level, there was a general increase in NDVI (60.9%) over the time series. Looking at Figure 12, two factors were noteworthy. The first was that annual maximum NDVI showed a gradual decline throughout the life of each satellite. However, the first year of the platform's life span did not always show the maximum annual NDVI. The second was that for most of the time series there was very little difference in the average annual maximum NDVI for any of the change classes. The differences are only apparent during the life of the first and last satellite of the series (2003 is an exception). This suggests that most of the regions of extreme change were due to transitory effects, such as fires, a short period of agricultural (in-)activity in the area, or a technical problem with a few pixels on one of the satellite platforms. One should therefore be cautious about declaring that the *overall* change noted is genuine, as it may at least be partly sensor related. Nevertheless, there was a strong general NDVI increase within the central and southern regions. It is not clear to what this can be ascribed, as no correlation between wheat production and NDVI could be established. If the effect is genuine, it may be that fields that were lying fallow were better vegetated in the later imagery than in the first. In general, one would not have expected a great deal of change. Figure 12 of Chapter 1 (page 54) compared three broad land-cover classes on the west coast lowlands in 1938 and 1999 and clearly showed that there had been relatively little change between those two time-periods. If we consider that the land-cover comparisons were done at high resolution (aerial photographs and 30 m resolution Landsat imagery) compared with the 1 km resolution NOAA imagery, then we would not expect to see any change at this scale.

However, some genuine changes were noted and these were discussed above in relation to component four, which identified changes (both permanent and transitory) occurring throughout the entire time-period, better than the simple change analysis (see Figure 14).

Land-cover and Productivity

To a large extent land-cover is subject to environmental constraints. Thus, cities rarely develop upon mountain peaks, and dryland cereals are more easily grown on flat fertile plains. In this study, land-cover was more important in defining the component two Zones, than the component one Regions. Only Region five could be defined as moderately reflecting actual land-cover. The other four Regions, while being modified by land-cover, were more climatically determined in that Regions two to four had similar land-cover constituents but distinct NDVI characteristics. On the other hand, the Zones of component two were predominantly determined by the land-cover component, principally the dryland agriculture : natural vegetation ratio. However, it has to be stressed that this ratio is substantially dependant upon a combination of rainfall, soil nutrients and topographical factors. Of relevance to the study of West-Coast Renosterveld is that the environmental factors that support this vegetation type, are those that are also beneficial for agriculture. Thus cereals have displaced most West-Coast Renosterveld, while deciduous orchards have replaced the Elgin Fynbos/Renosterveld Mosaic vegetation and the western patch of Overberg Coast Renosterveld (*sensu* Cowling and Heijnis 2001).

It was interesting to note that, there were no significant correlations between NDVI and wheat production, either at a regional, or local scale. Other studies have often found good correlations between crop yields (including wheat) and NDVI, even at country-wide scales and using degraded NDVI imagery (*e.g.* Fang *et al.* 1998, Fuller 1998, Lewis *et al.* 1998, Rasmussen 1998, Maselli *et al.* 2000, Liu *et al.* 2002, Kogan *et al.* 2003, Labus *et al.* 2002, Knudby 2004). One reason for this may be that, although the satellite data used here have been corrected for satellite-related perturbations, they have not been validated against ground data, such as was done with the NOAA Global Vegetation Index (Kogan *et al.* 2003). Nevertheless, even using uncalibrated imagery, the literature has often shown NDVI-crop yield

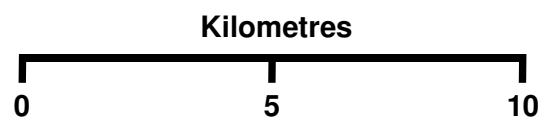
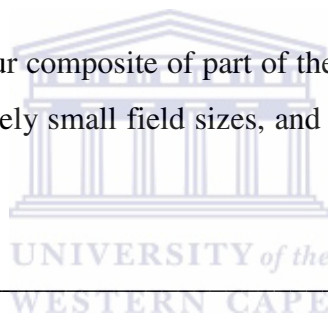


Figure 15. Landsat colour composite of part of the Cereal Zone taken in November 1999 showing the relatively small field sizes, and the mosaic of vegetated and bare lands.



correlations of 0.5 or better (*e.g.* Maselli and Rembold 2001). Why then is this not the case with the data presented here? Possible reasons are that the fields themselves are small (Figure 15), and adjacent fields may be in wheat or fallow cycles. Maselli and Rembold (2001) have pointed out that the phenological development of crops in temperate conditions is usually non-synchronous due to crop rotation. Nevertheless, Kogan *et al.* (2003) cite a number of references showing that under non-irrigated conditions, mixtures of crops and wild vegetation show similar responses to climate variations, and suggest that NDVI-biomass production should therefore still correlate. The geographic variations in sowing, growth and harvesting, as has shown up in component three may also be playing a part, although this would not be relevant for the local silo correlations.

Other possible reasons, relevant to this particular area may be the improvements in yield per unit area over the past 60 years (Anon. 1994). Serrano *et al.* (2000) noted

that, although the application of different levels of nitrogen fertilizer to Winter Wheat resulted in the harvest biomass of the experimental plants ranging between 1656 and 2807 g/m², the grain yields were not significantly different. It may be that tiller densities are beyond the linear portion of the NDVI : projected-canopy-cover relationship (*c.f.* Holben *et al.* 1980, Serrano *et al.* 2000). It is also possible that the grain production figures used are not representative of the actual production per unit area. Wessels *et al.* (2006), using the same data set, had a similar lack of success in correlating \sum NDVI with biomass production (estimated from field sampling) in the Kruger National Park (average r^2 of 0.26).

The lack of correlation between NDVI and wheat-yield is not of great importance as this relationship was not an objective of the study. However, a strong correlation would have helped support the hypothesis for productivity being a primary cause of the Regions developed from component one. There are no data available for Fynbos that can be used to assess to what extent NDVI and productivity are related. Studies of rangelands in other parts of South Africa and in Australia have shown that productivity and biomass estimates can be made from NOAA-NDVI imagery (*e.g.* Fuller 1998, Sannier *et al.* 2002, Hill *et al.* 2004, Wessels *et al.* 2006), but in all cases ground data were available for calibrating the imagery.

In Regions and Zones where irrigation is minimal, subtracting the average annual background (minimum) NDVI value for each class from either annual or growing season sums of NDVI, gave a reasonable correlation with the estimated primary productivity of that Region or Zone. In those Regions and Zones where irrigation is common, the result is an overall year-round level of greenness at NOAA resolutions, and there is no true growing season. While annual productivity clearly plays a part in distinguishing the five component one Regions, its contribution is not linearly linked. It might therefore be better to describe the pattern shown by component one as representing *overall* “greenness” (or annual \sum NDVI) levels. It is likely that the contribution of cereals to the overall geographic pattern of component one is responsible for the relatively large seasonal cycles displayed by that component.

It needs to be stressed that while there may be “overall” correlations between the Regions and biomass production, the Regions extend over extensive tracts of

“monotypic” vegetation (*e.g.* cereals OR Fynbos). If this component were measuring actual productivity, the cereals and the Fynbos would, based on the available data, be distinctly different as they are not finely intermixed. This may have shown up with finer regionalisation, but an examination of component one (Figure 5) shows that even the gross pattern does not accurately reflect land-cover as depicted on the NLC map (Thompson 1996) or on the Landsat classification of this study (Chapter 5, Figure 2, page 237). Component one of the time-series is therefore integrating, not only productivity, but overall seasonal “greenness” as well.

Correlations between estimated annual plant productivity and NDVI of the Zones was better than for the component one Regions when the background levels were subtracted, even when the Orchard Zone was included. However, if the background levels were ignored, then the correlations were much lower. This finding supports the proposition that the component two image depicts seasonal trends. Component one, which depicts a geographic picture, incorporates areas of different seasonality into each Region, thus reducing the seasonal correlation.

Other workers have found correlations between integrated NDVI (equivalent to the annual or seasonal \sum NDVI used here), and biomass production ranging up to 0.8, although over areas that were less complex than in this study (*e.g.* Tucker *et al.* 1985a, Prince and Tucker 1986, Prince 1991, Wessels *et al.* 2006). In those cases where the correlations were high the landscape was very arid. None of the workers referred to took into account background levels when regressing biomass against NDVI. As can be seen from Tables 5 and 6, excluding those Regions or Zones where irrigation is substantial, correlations between the estimated annual plant productivity and the annual or seasonal \sum NDVI values were better when background levels were subtracted. Including the irrigated classes gave a better correlation when the background was subtracted from the component two Zones. However, subtracting the background levels for the component one Regions changed the correlation from a substantial 0.7X (where X is some number) to zero. This difference between the classes of the two components is once again probably due to the more homogenous nature of the component two Zones.

NOAA NDVI imagery and West-Coast Renosterveld

The purpose of this thesis is to identify patterns occurring over that part of the west coast lowlands where West-Coast Renosterveld occurs, or occurred in the recent past. Along with the next chapter, it aims to give an indication of recent changes (*i.e.* within the life-span of the imagery used), to see if the situation is stable or if the amount of Renosterveld is declining. Information derived from the Landsat classification (chapters 4 and 5) indicated that only 133 sites of more than one square kilometre remained. The fact that remnants mostly occur in small, often linear, patches, scattered across the landscape, makes it impossible to use imagery at this scale to monitor it. Although at a nominal resolution of 1 km, the orbital characteristics of the satellite ensures that each monthly MVC pixel is the average of an area considerably larger than 1 km². Running a 3 x 3 minimum filter over the Renosterveld fragment map, contracted to a 1 km resolution, left only one pixel of Renosterveld remaining. Examining the vegetation within this 1 km pixel, as depicted on the Landsat 15 m resolution panchromatic layer, showed it contained a mixture of land-cover components, including firebreaks, and possibly some agriculture. Therefore, beyond observing that most of the landscape that once supported West-Coast Renosterveld has been transformed to agriculture, or, to a lesser extent, has been urbanized, little can be determined about that which remains from imagery at this resolution.

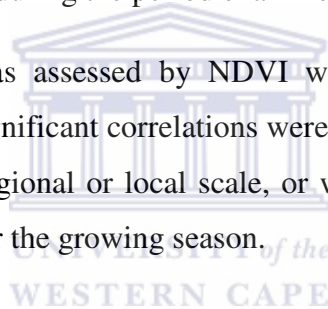
Conclusion

As mentioned in the introduction there are a number of areas where errors can creep in with this sort of study. Different authors have taken different stances on how these errors should be dealt with, and one should keep in mind the aims of the study when assessing the validity of the findings. This study for instance, was looking for vegetation patterns over the west coast lowlands that could be related to land-cover or land-use. The first two components of a PCA were divisible into classes. The first component pattern appeared to reflect the annual \sum NDVI (“greenness”) of the area, which in turn reflected the amount of rainfall received. Subtracting the background (minimum) NDVI level from the monthly NDVI values, led to the

depiction of a pattern that gave a possible representation of plant productivity within those Regions where irrigation was minimal. The second component reflected Zones of differing annual cycles, and could be better related to vegetation patterns, as perceived by humans. Once again, subtracting the background NDVI levels of those Zones where irrigation was minimal gave an indication of productivity.

There was a moderate correlation between rainfall and NDVI, which became stronger if restricted to the primary growing season, due to the harvesting of dryland crops creating an unnatural plant-rainfall relationship. The change analysis showed a general average increase in NDVI over most of the land area, although it was suspected that this might have been an artefact of the imagery. Nevertheless, some localities with strong positive or negative changes could be related to events occurring on the ground during the period examined.

Potential productivity, as assessed by NDVI was looked at within the cereal-growing areas, but no significant correlations were found between wheat production and NDVI either at a regional or local scale, or when using the annual maximum NDVI, or the \sum NDVI for the growing season.




CHAPTER 3.

A LOCAL TIME SERIES ANALYSIS: CHANGES IN THE AREA COVERED BY NATURAL VEGETATION OVER THE PAST 60 YEARS AT THE ELANDSBERG PRIVATE NATURE RESERVE, THE KORINGBERG-SWARTBERG AND THE KAPOKBERG-CONTREBERG.

The following paper, based upon the work described in this chapter has been published:

Newton IP and Knight RS 2005a. The use of a 60-year series of aerial photographs to assess local agricultural transformations of West Coast Renosterveld, an endangered South African vegetation type. *South African Geographical Journal* 87(1): 18-27.

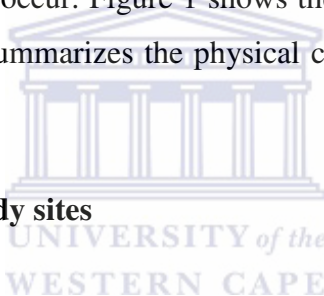
Abstract



Three Renosterveld areas (four sites) were examined using a series of aerial photographs taken at approximately ten-year intervals from 1938. Each area represented one of the three main geological formations, upon which West-Coast Renosterveld was considered to occur. Changes in the natural vegetation boundaries over this period were mapped and transformations of natural vegetation to agriculture were analyzed in terms of slope and aspect. The recent history of each area was obtained from local landowners. Only the Elandsberg Private Nature Reserve showed an increase in the area of natural vegetation present compared to the earliest photographs. At the other sites, there was between 19.5% and 47.6% less natural vegetation present than in 1938. On slopes of less than eight degrees, between 13.7% and 33.8% of the 1938 extent remained, while on slopes between eight and twelve degrees the amount remaining ranged between 38.0% and 74.7%. Most of these transformations occurred before 1988, suggesting that the Conservation of Agricultural Resources Act (Act 43 of 1983) has been effective in limiting the spread of agriculture onto the steeper slopes since then.

Introduction

John Duckitt (1995) claimed that the amount of natural vegetation remaining in the Darling area had increased since the introduction of tractors, due to slopes that were previously worked with horses being too steep to safely work with tractors. In this chapter, three areas (comprising four sites) historically accepted as being West-Coast Renosterveld by local ecologists, were examined to see if this was in fact the case, and whether other areas showed similar trends. For this, a sixty-year series of aerial photographs was used. Information relating to recent historical events that may have shaped the vegetation (and thus the interpretation of the aerial photographs) was obtained by interviewing local people, usually the landowner of part or all of the area of interest. Each area was representative of one of the three main geological/edaphic formations upon which West-Coast Renosterveld was previously considered to occur. Figure 1 shows the location of places mentioned in the text, while Table 1 summarizes the physical characteristics of each of the sites examined.



A description of the study sites

Elandsberg Private Nature Reserve

The Elandsberg PNR is the largest West-Coast Renosterveld conservation area in existence (Rebelo 1995). It lies at the foot of the Elandskloofberge, just to the south of Voelvlei (Figure 2). The reserve was proclaimed in 1973 (Anon. 1977) at which stage it had a total area of 2600 ha (Jarman 1986; Figure 2). Its original function was for the conservation of the Geometric Tortoise *Psammobates geometricus* (Mike Gregor *pers. comm.*). The size of the reserve was increased in 2001, with the addition of about 230 ha to its north-western corner. The official area of the reserve (as defined by the farm boundaries on the 1:50 000 topo-cadastral map [3319AC – Tulbagh, second edition, 1971], produced by the Chief Directorate, Surveys and Mapping) is now just over 3400 ha, although figures of 3900 ha (Midoko-Iponga *et al.* 2005) and 3606 ha (Shiponeni and Milton 2006) have been published.

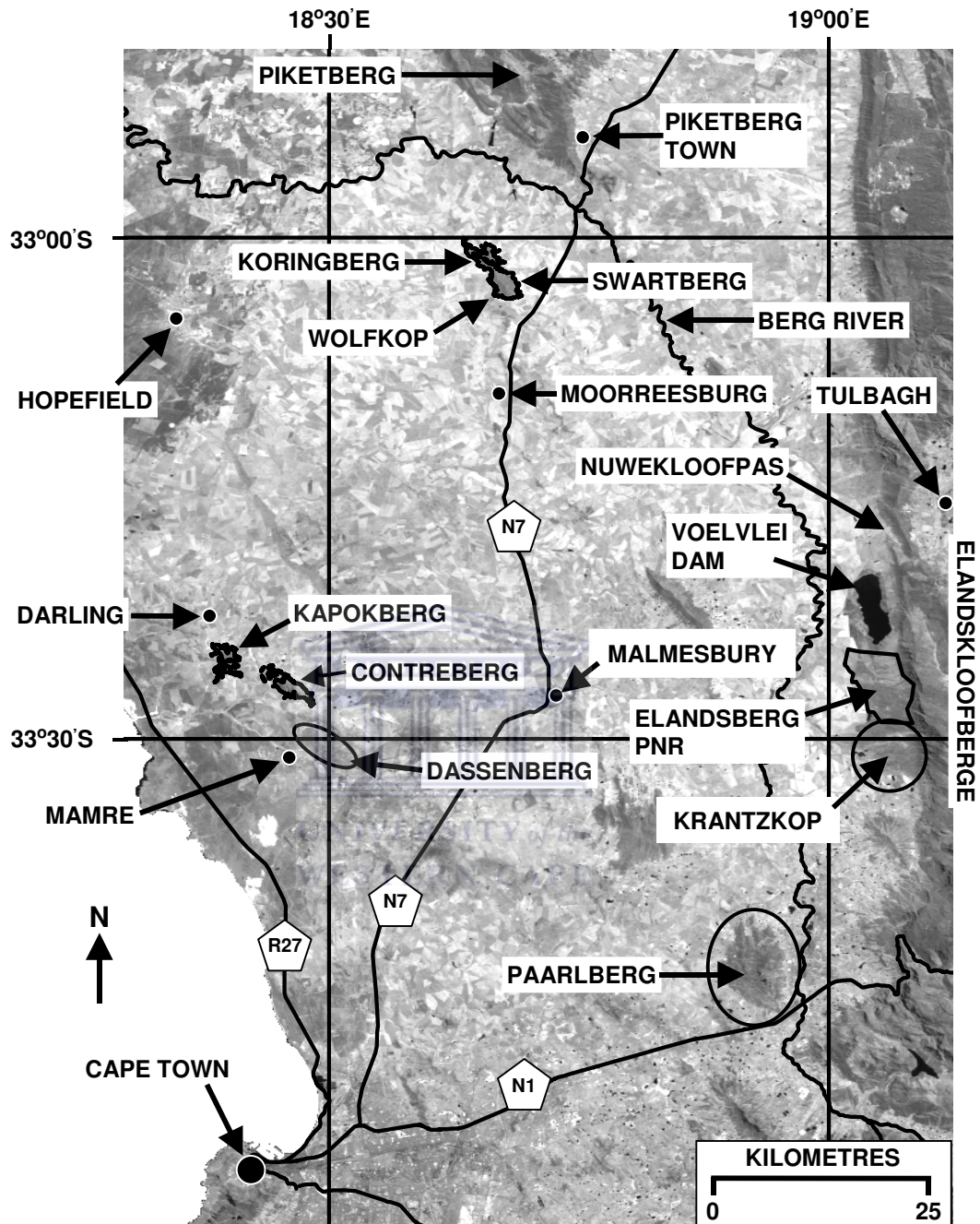


Figure 1. Landsat image of the Western Cape lowlands showing the location of the sites examined in this chapter, and other places mentioned in the text. The Berg River, national roads and west coast road are also shown.

Table 1. Summary of the physical characteristics of the three areas examined in this chapter (the Kapokberg and Contreberg together make up one of the areas).

	Elandsberg PNR	Koringberg-Swartberg	Kapokberg	Contreberg
Location	33°26'42"S; 19°02'42"E	33°01'07"S; 18°39'11"E	33°24'54"S; 18°23'53"E	33°26'49"S; 18°27'36"E
Ownership	Private	Private	Private	Private
Geology¹	Shale, terrace gravel, alluvium	Shale	Granite	Granite
Soil²	Sandy lithosols, coarse sand, poorly developed soils	Sandy lithosols, red kaolinitic loams and clays, poorly developed soils	Sandy lithosols, red kaolinitic loams and clays, poorly developed soils	Sandy lithosols, red kaolinitic loams and clays, poorly developed soils
Topography	Gentle slope NW-SE Slope range = .02° – 20.50°	Two peaks connected by low saddle; sides moderately steep Slope range = .06° – 54.46°	Steep NE slopes, other slopes moderate to gentle rolling Slope range = .07° – 42.36°	SW slopes and NE slopes at south end steep, rest gently rolling Slope range = 0.10° – 41.25°
Altitude³	Range = 60.7m – 283.14m	Max. spot height = 479.5m Range = 121.3m – 476.7m	Max. spot height = 460m Range = 145.9m – 452.6m	Max. spot height = 479m Range = 138.37m – 469.34m
Rainfall (mm)⁴	472.9 (Tulbagh –111 years) Range = 265.0 to 764.8 = 499.8mm C.V. = 0.2419	372 (Koringberg village – 32 years) Range = 115.8 to 534.1 = 418.3mm C.V. = 0.2665	475 (The Towers farm –90 years) Range = 193.4 to 746.1 = 552.7mm C.V. = 0.2368	475 (The Towers farm –90 years) Range = 193.4 to 746.1 = 552.7mm C.V. = 0.2368
Land-use	Nature reserve, grazing by indigenous ungulates.	Natural, some grazing, cereal fields at the top of the Koringberg, small gum plantation above Koringberg village.	Natural, grazing, vineyards, cereals, nursery specializing in indigenous plants.	Natural, grazing, mining, vineyards, cereals.

¹. Anon. 1990, 1997.

². Schloms *et al.* 1983.

³. Maximum spot height = trig beacon. Range = from digital elevation model. Elandsberg reserve = eastern boundary as geologically defined (see text).

⁴. South African Weather Services. Figure in brackets is the number of complete years of records, and the location of the weather station. C.V. = Coefficient of Variation

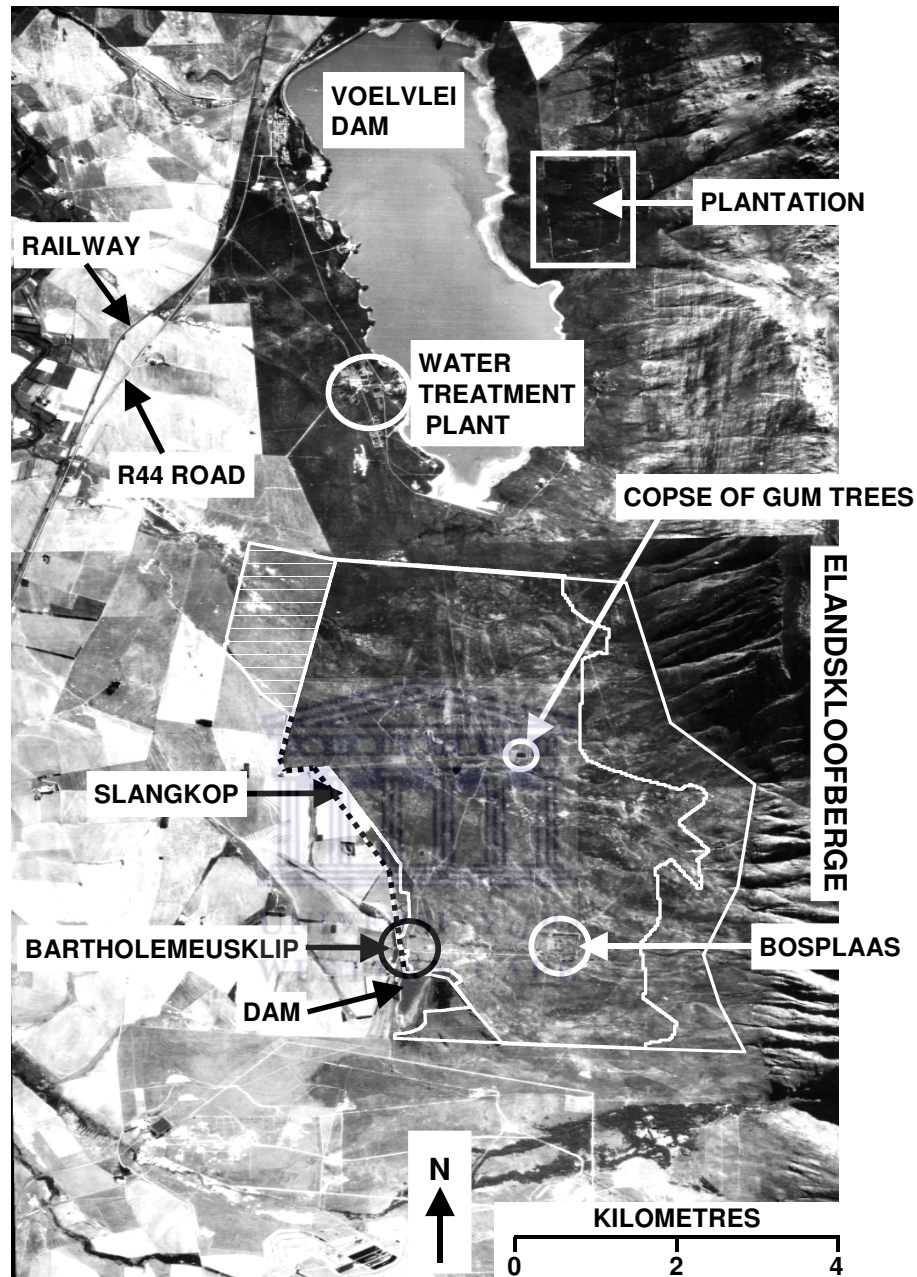


Figure 2. Annotated aerial photograph (1987) of the Elandsberg PNR, Voelvlei and the surrounding area. The official boundary of the reserve is shown as a white dashed line. For clarity, part of the western boundary has been enhanced in black. The 2001 extension of the reserve is shown horizontally hatched. The boundary used to define the 1942 extent of the lowland natural vegetation occurring in the reserve is shown as a solid white line.

The major geological formation within the reserve is Terrace Gravel, with a central area of Malmesbury shales (Anon. 1997, Table 1, Figure 3). At the foot of the Elandskloofberge in the east, it blends into the predominantly quartzitic sands derived from the nutrient-poor Table Mountain Sandstone (TMS) group. There are some scree slopes and small patches of shale along this interface (Anon. 1997). Much of the reserve is stony (*pers. obs.*), and this is probably the reason the area received little attention from the farming community (except for grazing), before its establishment as a reserve. Schloms *et al.* (1983) classified the soil type of almost the whole reserve as being derived from the adjoining mountains.

The topography is gently sloping. The altitude increases gradually from the north-west (approximately 65 m above sea level) to 460 m at the farm boundary in the south-east. In the north-east the Elandskloofberge rises steeply from about 140 m, while in the south-east, the steeper slopes begin around 300 m. Rainfall rises steeply at this escarpment. At the top of the Elandskloofberge rainfall levels between 1000 mm in the north and 1400 mm in the south are encountered (Schulze 1997). The run-off from the mountain would increase soil moisture levels in the reserve to above that which would be expected from local rainfall alone.

Between 1958 and 1983 it was used for the grazing of stock (Stander 1988). Two camps (north and south) were fenced-off to enable a stock-grazing regime to be followed. The fences of the south paddock were removed in 1984, while those of the north paddock were removed in March 1986 (Stander 1988). Five areas within the current reserve were used for growing oats for about twenty years in the 1960's and 1970's (Figure 3). This was used to supplement the grazing (Fish 1988). Indigenous ungulates have been introduced (Table 2), although some may not have occurred in the area in the recent past (see Skead 1980).

Four runaway fires, originating in the mountains have occurred in the last twenty years. In 1982 the whole reserve area was burnt. The other fires occurred in 1988, 1989 and in March 1999. Figure 4 shows the extent of these within the reserve boundaries, while Figure 5 shows the vegetation recovery within the section burnt in 1999. Bernard Wooding (*pers. comm.*) indicated that a burning regime was being planned, and would probably be implemented in 2003/2004.

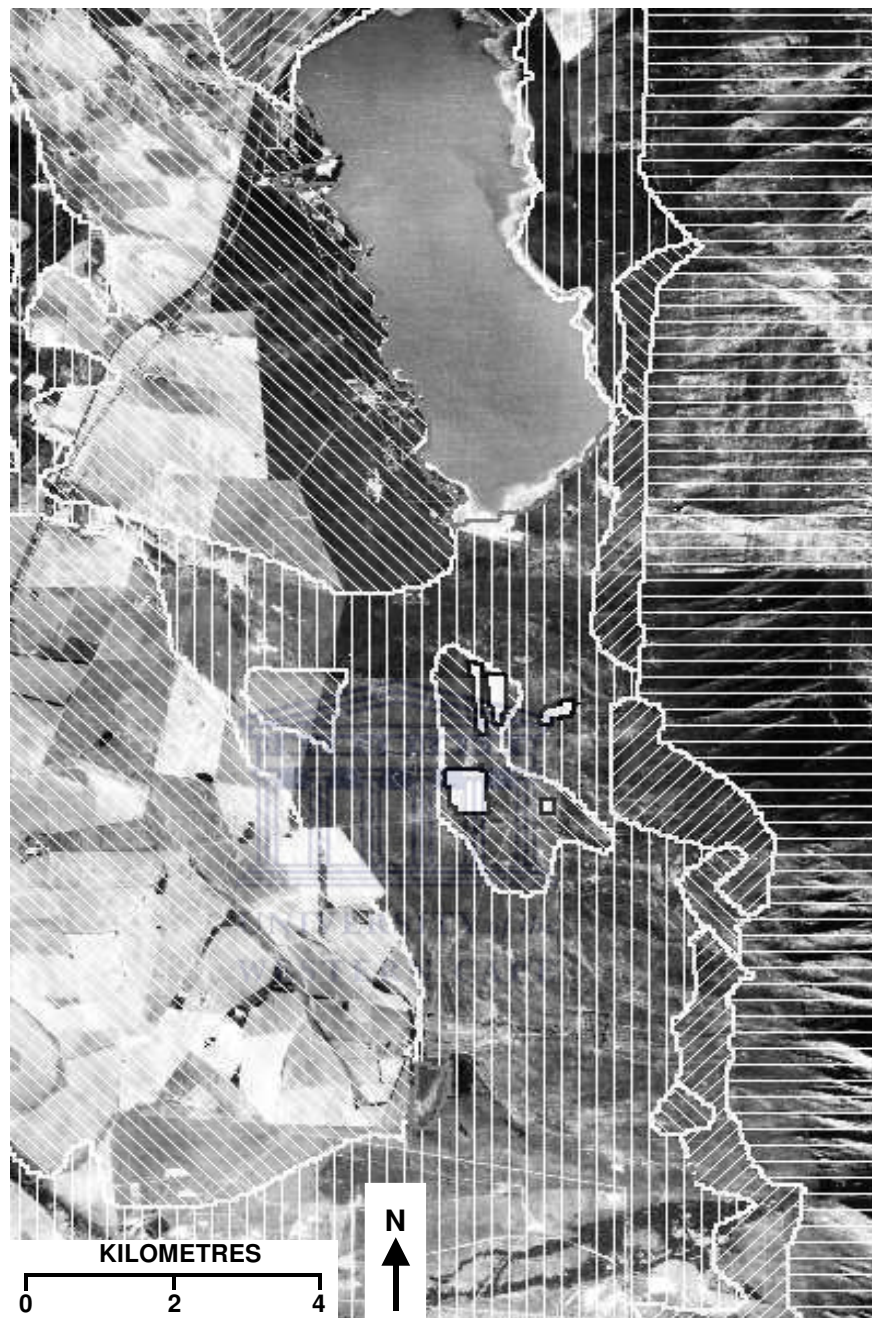


Figure 3. Geological formations occurring over the Elandsberg PNR, Voelvlei and the immediate surroundings. Oat fields of the 1960's and 1970's are shown solid white. Vertical hatching = Alluviums; Horizontal hatching = Table Mountain Sandstones; Forward diagonal hatching = Quaternary Sands (mostly scree); Backward diagonal hatching = Malmesbury Shales.

Table 2. Estimated number of large herbivores occurring in the Elandsberg PNR. The figures are the average of three vehicle counts and one helicopter count, carried out on four different days between 11th and 20th June 2001. (Source = Elandsberg Nature Conservator).

Species	Number
Eland (<i>Taurotragus oryx</i>)	90
Zebra (<i>Equus zebra</i> & <i>E. burchelli</i>)	30
Bontebok (<i>Damaliscus d. dorcas</i>)	100
Red Hartebeest (<i>Alcelaphus buselaphus</i>)	12
Blue Wildebeest (<i>Connochaetes taurinus</i>) ^a	75
Black Wildebeest (<i>Connochaetes gnou</i>)	40
Springbok (<i>Antidorcas marsupialis</i>)	120
Gemsbok (<i>Oryx gazella</i>)	11
Grey Rhebok (<i>Pelea capreolus</i>)	5
Ostrich (<i>Struthio camelus</i>)	45
Total estimated number of large herbivores	528
Total less the Blue Wildebeest	453

^a All have since been removed

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Parker (1982) wrote that the Elandsberg-Voelvlei complex was one of the last Renosterveld-Mountain Fynbos ecotones left in the west coast area. There are a number of studies under the auspices of Sue Milton's Renosterveld Restoration Project currently taking place in this reserve (see Krug 2004, for more details of these projects; also Shiponeni 2003, van Rooyen 2003, Walton 2006). In two earlier studies, Fish (1988) looked at the differences between the vegetation occurring on the land within the reserve that had been used to grow oats in the 1960's and 1970's, and the adjoining uncultivated land, while Stander (1988) examined differences in the vegetation growing on grazed and ungrazed (fenced-off) areas of the reserve.

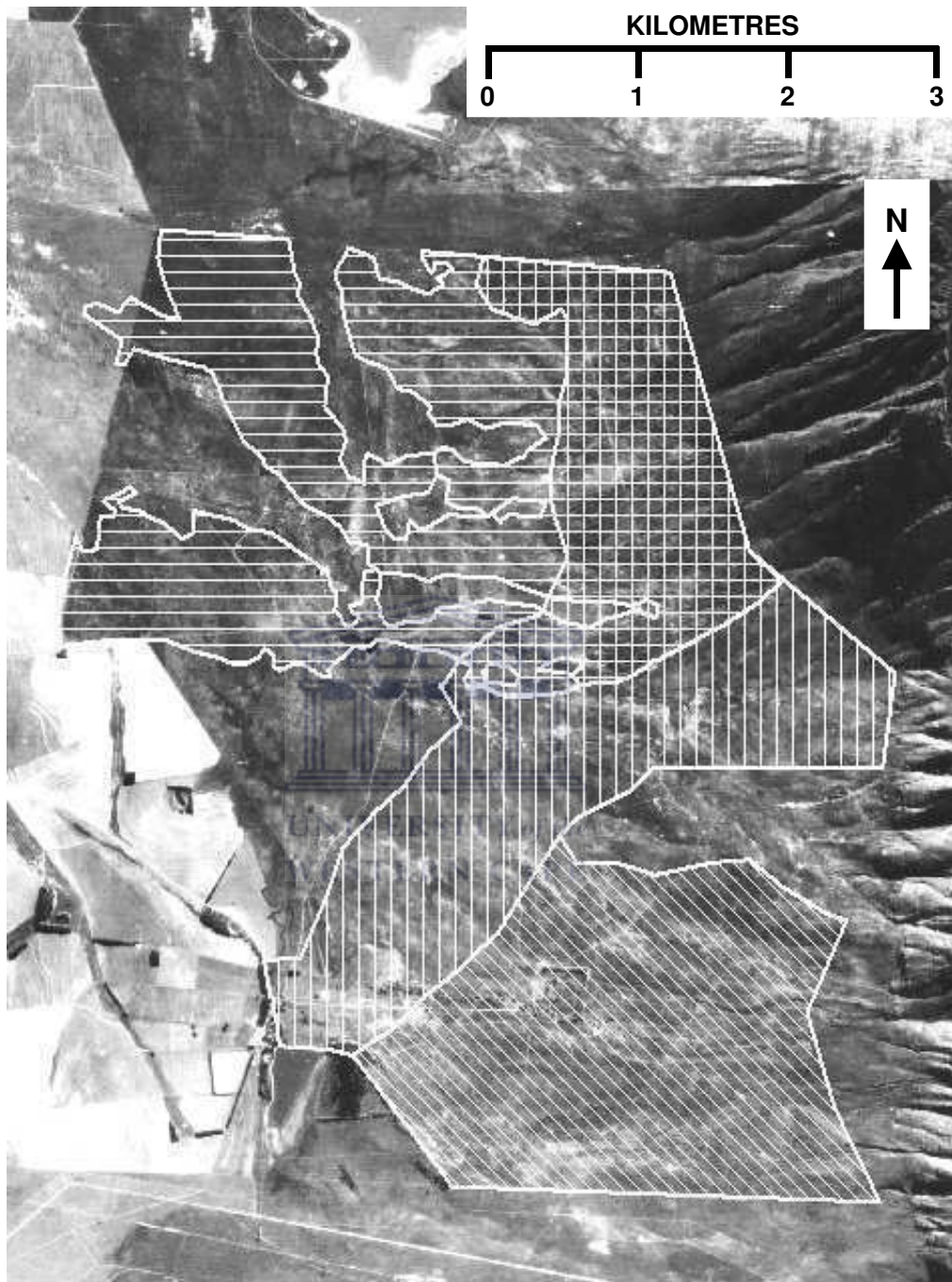


Figure 4. Extents of the 1988 (vertical hatch), the 1989 (diagonal hatch) and the 1999 (horizontal hatch) fires within the Elandsberg PNR. Mapping of the burn-extent files was done by Natalie Diemer.



Figure 5. Vegetation recovery on part of the section burnt in March 1999. Photograph taken October 2002.

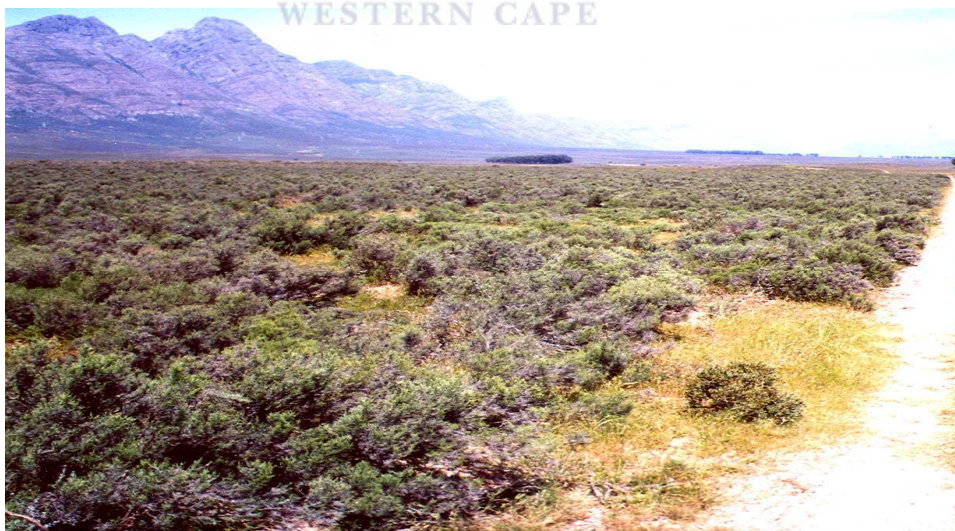


Figure 6. Renosterveld shrubland in the Elandsberg PNR.



Figure 7. Fynbos elements within the Elandsberg PNR.

Although the Elandsberg PNR conserves West-Coast Renosterveld, the actual amount has been subject to some debate. Tansley (1982) quoted Chris Burgers as saying that “less than 900 ha” of the reserve was Renosterveld. Rebelo’s (1995) estimate was 1000 ha, Krug (2004) allocated 1600 ha to Renosterveld, and Midoko-Iponga *et al.* (2005) ca. 1000 ha. The most recent vegetation map (Mucina and Rutherford 2004) has allocated much of the original reserve (all of the Terrace Gravel formation) to an Alluvial Fynbos class. They have not done this with the 2001 extension, where the entire area is mapped as Swartland Shale Renosterveld, despite about $\frac{2}{3}$ of the addition being of alluvial origin (Anon. 1997). Their classification of the vegetation on the alluviums as Fynbos is probably correct (*e.g.* see Figures 6 and 7 above, for Renosterveld and Proteoid aspects of the vegetation).

Elandsberg is bordered to the north by Voelvlei, which is managed by Cape Nature (Figure 2). Rebelo (1995) estimated that an additional 870 ha of Renosterveld was conserved there. The soils to the west of the Voelvlei dam are predominantly shales, while to the east they are mainly Terrace Gravel (Figure 3). Tansley (1982) ranked Voelvlei as the best Renosterveld site that she visited, and said that numerous botanists agreed that it was one of the highest quality coastal Renosterveld sites remaining. Jarman (1986) ranked Voelvlei second (one point behind the Dassenberg

Conservation area) in her assessment of the conservation value of Renosterveld sites proposed for conservation. Neither of these authors included Elandsberg in their assessment, Tansley due to a recent fire, and Jarman as she was assessing areas that were then unconserved. The original owner of the area around Voelvllei has grazing rights, but ploughing is forbidden (McDowell and Moll 1992). To the south of the Elandsberg PNR, the land (Krantzkop) is owned by the Department of Defence, and has mostly been left natural. Game stocking rates are higher than Elandsberg, and the condition of the vegetation there is poorer (Benjamin Walton *pers. comm.*).

Kapokberg and Contreberg

There are eight (nine if the Klein Dassenberg is included) main hills in the Darling area (McDowell 1988), all of granitic origin (Anon. 1990). Heydenrych and Littlewort (1995) did floristic surveys of seven of these (the Dassenberg was excluded, possibly due to a contemporary study being carried out by Kilian 1995). Most of these hills are used for the grazing of stock, as they are generally too steep and rocky to be ploughed. Some of the lowland areas at the foot of these hills are managed for wild flower production (Heydenrych and Littlewort 1995).

The two hills looked at in this study were the Kapokberg and the Contreberg (see Table 1 for a general description and Figures 8 and 9 for aerial views). Six farms share the Kapokberg, while the Contreberg is shared between two (3318AD Darling 1:50 000 topographical map, third edition, 1981). The geology of both hills is entirely Cape Granite, the formation being N-Cd (mainly coarse grained porphyritic, with porphyritic, biotitic, leucocratic, even-grained biotitic and tourmaline-bearing variants; also granodiorite [Anon. 1990]). Most of the Kapokberg is a series of gently rolling slopes, except in the north where the slopes are steeper and rocky (Figure 10). The northern slopes of the Contreberg are gentle, while the southern and the south-western slopes are steeper and more extensive (Figure 11). On the Contreberg, there are some large outcrops of granite, extruded as sheets in places (Heydenrych and Littlewort 1995).

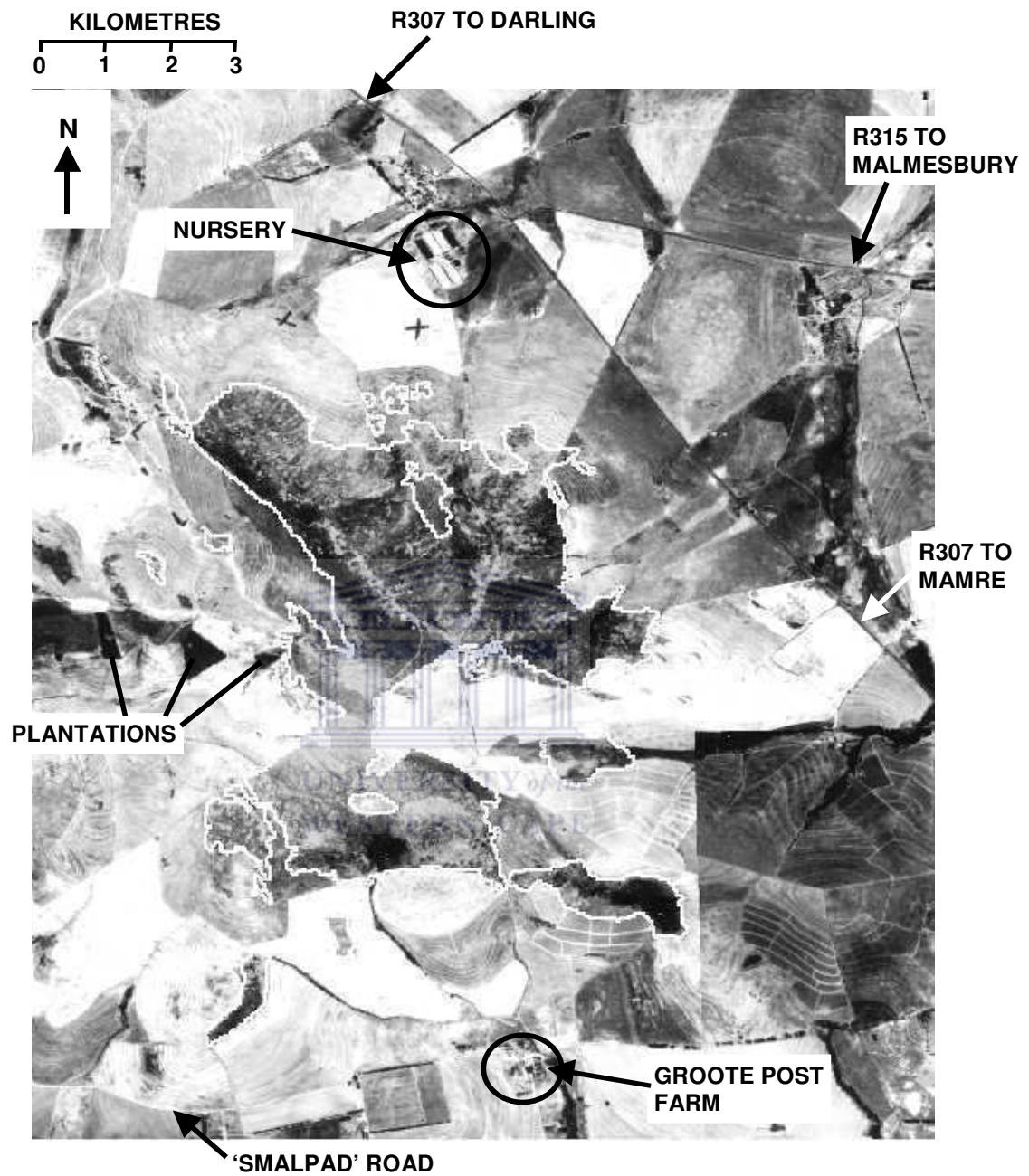


Figure 8. Annotated aerial photograph of the Kapokberg taken in November 2000. White line indicates the boundaries of the natural vegetation for this image.

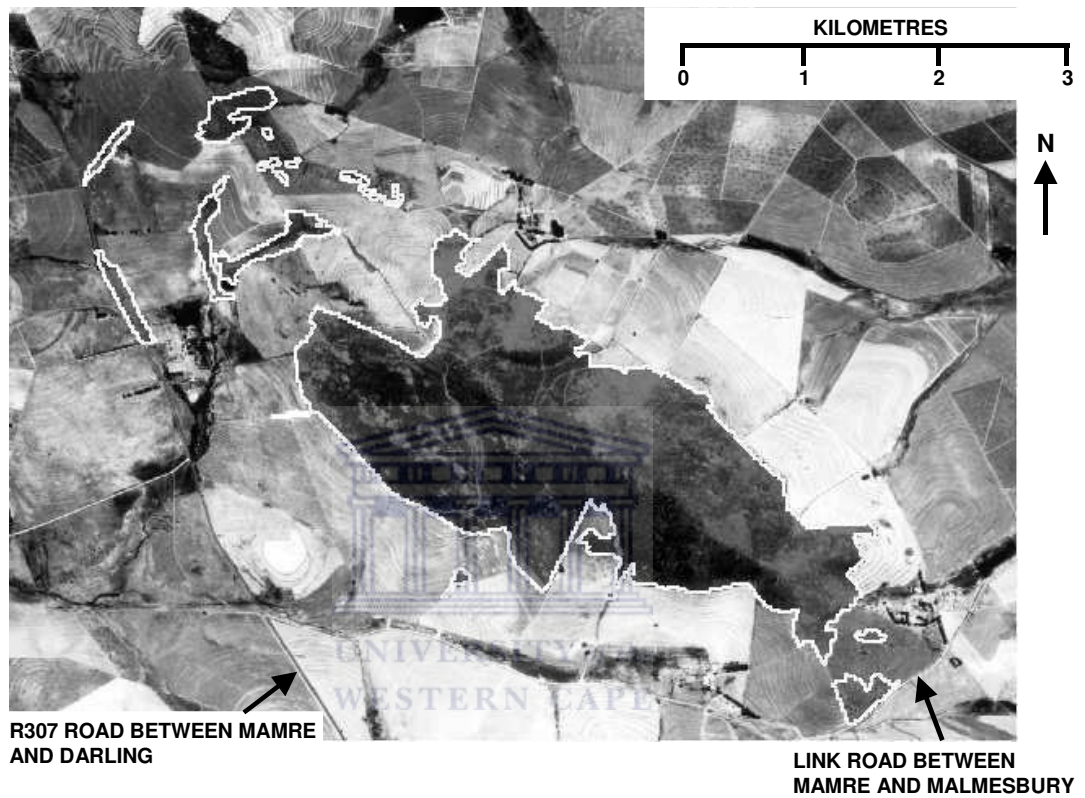


Figure 9. Annotated aerial photograph of the Contreberg taken in November 2000. White line indicates the boundaries of the natural vegetation for this image.



Figure 10. Top: The Kapokberg viewed from the north-east, showing the steep rocky aspect. Bottom: The Kapokberg viewed from the south, showing the rolling nature of the landscape.

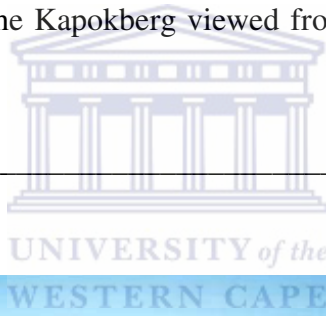


Figure 11. Top: The Contreberg viewed from the north-east, showing its low profile from this aspect. Bottom: The Contreberg viewed from the south-west, showing the steeper, more extensive slopes.

Unless otherwise stated, information in this paragraph was from an interview with Charles Duckitt. The Kapokberg got its name from the many kapokbossies (*Eriocephalus* sp.) occurring on the hill (Mentzel [1787] noted that it was overgrown with grass when he visited it in the 1730's). In the 1850's a fire swept through the Darling area, burning the vegetation upon all the hills. The vegetation on the Kapokberg then underwent a big change, being invaded by a dense growth of Renosterbos (*Elytropappus rhinocerotis*). Since that fire, the Kapokberg has never been burnt. In 1938, when Charles Duckitt started farming, the hill was covered with a six-foot (1.8 m) high monoculture of Renosterbos, which was largely impenetrable. At that time, ploughing was carried out using draught animals, mainly horses and mules, which were left to forage on the hill over the winter period. After the Second World War, tractors were introduced, and the Kapokberg was dragged with a heavy triangular block of railway line. Every section was dragged twice, in opposite directions. After this treatment, the Kapokbossie and other mountain vegetation returned (Heydenrych and Littlewort [1995] recorded 203 indigenous species). Although some Renosterbos was present, it never became dominant. It was then possible to graze about 300 sheep on the hill in the winter and spring periods. In the mid nineteen-eighties, a section on the western side was cleared by dragging a double rail over it with a bulldozer (John Duckitt *pers. comm.*). Heydenrych and Littlewort (1995) said that the vegetation of the Kapokberg was largely in good condition, with few alien plants. Tansley (1982) assessed the Kapokberg and four other hills in the Darling area only by means of aerial photographs. She concluded they were similar to the Contreberg, Dassenberg and Klein Dassenberg. Jarman (1986), similarly assessed the same Darling Hills as a group, and ranked them 10th (one point behind the Koringberg and Saronberg), but noted that insufficient information was available to produce an accurate assessment. On the north side, cereals and stock grazing are the main agricultural activities, while to the south vineyards are widespread.

Around the hills, fire is used as a management tool for keeping a field's grazing potential at its best. A cycle of five to seven years is considered optimal in this area (Duckitt 1995). Some farmers in the Darling area manage their stock grazing to encourage the growth of spring flowers (Heydenrych and Littlewort 1995), which benefits people in the area through the tourist trade. An example of this

management is that followed by John Duckitt. Cattle are introduced around November after the flowers have set-seed. Sheep are introduced in May and all the stock are removed in June. The veld is burnt once bush encroachment reaches a point where the vegetation becomes agriculturally unproductive. This is done in late autumn at four to seven year intervals (John Duckitt – communication at the 4th Renosterveld Information Sharing Session, Darling, 2003).

Part of the north-east end of the Contreberg was burnt in December 1993, and in 1999-2000 the south-east end was burnt, both fires accidental (John Duckitt *pers. comm.*). Tansley (1982) noted that part of the Contreberg had recently been burnt, while other parts showed signs of trampling and grazing. Heydenrych and Littlewort (1995) reported that some parts of the hill had been severely grazed, and only sparse vegetation remained. They also noted that alien plants were uncommon (Tansley [1982] did not record any aliens), and a number of Fynbos elements were present on the wetter southern slopes. Tansley rated the Contreberg as the eighth best Renosterveld site she visited. Jarman (1986) assessed it as joint sixteenth (with the Klipheuwelkop) in her rankings. Mining for sand occurs at the west end of the Contreberg. A wild flower reserve has been established at the south-western foot of the hill.

Koringberg-Swartberg

The Koringberg-Swartberg complex consists of two hills joined by a low narrow saddle and is mainly surrounded by cereal fields (Figures 12 and 13). Although not obvious from the photograph (Figure 13), the Swartberg (to the left) is the higher of the two hills by 56 m (Table 1).

The hills are derived from Malmesbury shales, with some Quartz and limestone inserts (Anon. 1990). Its geology is almost entirely composed of the “Nm” formation (described as greywacke and phyllite, with beds and lenses of Quartz schist, limestone and grit; Quartz-sericite schist with occasional limestone lenses (Anon. 1990)). The south-west section of the Swartberg is composed of the “Nk” formation (Quartz schist with phyllite beds and minor limestone and chlorite-schist lenses [Anon. 1990]). The soil is stony, at least on the saddle, which was personally visited.

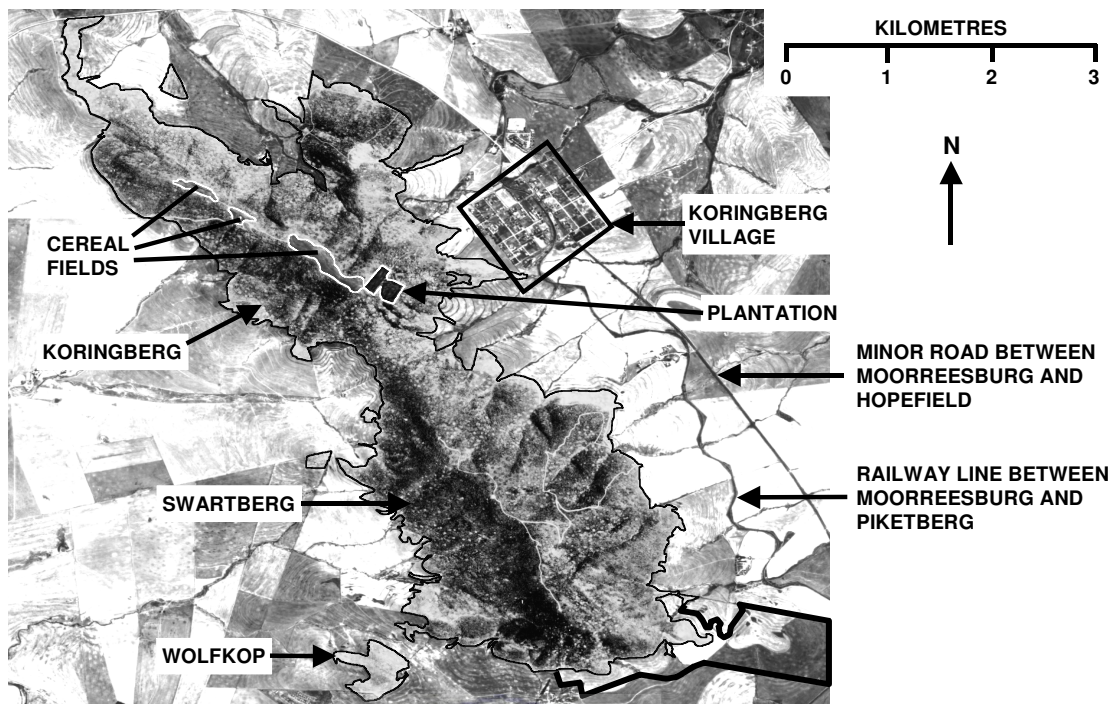


Figure 12. Annotated aerial photograph of the Koringberg-Swartberg taken in November 2000. The thin black lines indicate the boundaries of the natural vegetation for this image. The white lines identify the plantation and the wheat fields along the ridge of the Koringberg. The thick black line to the south-east of the Swartberg identifies the area that appeared natural in the 1968 photograph – see text for details.



Figure 13. The Swartberg (left) and Koringberg (right), viewed from the north-east. The gum plantation is indicated by the arrow.

Information in this paragraph was obtained during a telephone conversation with Pagel Dippenaar, a farmer in the area. Only one known major burn has occurred within living memory. That was “about 15 years ago” (~ 1988), when 150 to 200 hectares on the north side of the Swartberg, and some of the adjoining Koringberg was burnt. Fires along the railway line were frequent when steam trains were used, but these never reached the mountain. The farmers make very little use of the hill for grazing any longer. In the past, they used it for pasture during mid to late winter, but they now use clover meadows. One farmer regularly burns a small, secluded spot at the north end of the Koringberg and claims he gets “good results” as related to grazing potential. Tractors were phased in from the mid-1930’s, and by the end of the Second World War, draught animals were no longer used. His opinion of the soils in the area was that they were poor. Wheat is the major crop, and is alternated with legumes, Lupins, Australian clovers, or more recently, Canola. He said the advantage of using clovers as the alternate crop, was that farmers could spray for broad-leaved weeds when wheat was being grown, and for unwanted grasses during the clover phase.

Near the top of the Koringberg there is an informal gum plantation that appears to have been present as far back as 1938. According to Richard Diedrichs (*pers. comm.*), it was planted as part of a school project. Some of the trees have been harvested and the logs used to retain the soil on the short hiking trail that leads from the town to the top of the saddle between the two hills. The trees that are currently growing did not appear to be seventy years old, and so recruitment (either natural or artificial) is probably occurring. There appears to be very little in the way of botanical information relating to these hills. Tansley (1982) noted that the flora had a strong succulent element, suggesting karroid affinities. She rated it as number 14 in her assessment of 21 sites. Paths, ploughing, trampling and grazing were the negative factors she found. Gums were the only alien species mentioned. Jarman (1986) rated the Koringberg as the joint-ninth (with the Saronberg) most valuable unproclaimed site for the conservation of Renosterveld.

Methods

All analyses were carried out in Idrisi32 (©Clark Labs, Clark University, Worcester, MA.) except where otherwise stated. The programme's standard integrated modules were used for the processes and transformations that were undertaken.

Sources of data

Aerial photographs of the three regions were purchased from the offices of the Chief Directorate: Surveys and Mapping in Mowbray. Photographs were available at approximately ten-year intervals from the 1960's; there were also one or two series from the late 1930's or 1940's. Table 3 indicates the date of exposure, the job number and photo number of each of the photographs used, and the scale at which the exposures were made.



Data processing

The photographs were scanned into a digital bitmap format on a ScanMagic 9600 EPIII Scanner, using Adobe Photoshop (©1989-1998 Adobe Systems Incorporated) v.5.0 software. Scan resolution was set to 300 dots per inch (dpi). This gave a pixel resolution of five metres for 1:60 000 scale photos (1997 Elandsberg photos), 4.17 m for 1:50 000 photos (all other images exposed since 1960) and 2.5 m for the 1:30 000 scale photos (1949, 1942 and 1938 photos). Each image was cropped to remove borders and imported into Idrisi32. The radiometric quality of the older photographs was not constant across the photographs (and hence also across the scanned images). There was also a great deal of variation in brightness and contrast between photographs making up a particular area in a particular year. Each image was enhanced using a histogram stretch technique to make it more clearly visually interpretable. This was still not ideal, especially in the older photographs. It was, however, suitable for this study, as the original photographs were on hand to resolve problems.

Table 3. Date, scale and reference information for each of the aerial photographs used in this analysis.

Date	Scale	Job No.	Strip No.	Photo Numbers
Elandsberg				
09-1997	1:60 000	1004	5	7707
			6	7737
05-1987	1:50 000	911	6	1811
			7	1726
02/03-1973	1:50 000	719	4	19; 20
01-1967	1:30 000	534	8	610
			9	633
			10	682
01-1949	1:30 000	225	5	02735; 02736
			6	02747
			7	02830
1942	1:30 000	169	8	40436
			10	40419; 40421
			11	40335; 40337
			13	40313; 40320; 40322
			15	40184; 40185; 40187
			16	40165; 40167; 40169
			17	40040; 40042; 40044
Koringberg-Swartberg				
11-2000	1:50 000	1033	19	7282
08-1988	1:50 000	919	10	9353
04-1977	1:50 000	786	10	1383
10-1968	1:50 000	619	1	1118
			2	1144
12-1960	1:50 000	454	2	7879
1938	1:30 000	126	18	08404; 08406
			20	08467; 08469
			22	08602; 08604

Table 3 continued.

Date	Scale	Job No.	Strip No.	Photo Numbers
Darling: Kapokberg and Contreberg				
11-2000	1:50 000	1033	13	7423 14 7397
08-1988*	1:50 000	919	7	9614
01-1989*	1:50 000	919	8	9273
03-1977	1:50 000	786	7	0462
			8	0506
04-1968	1:50 000	619	8	412
			9	392; 393
12-1960	1:50 000	454	8	8134
			9	8163; 8165
			10	8177
03-1938	1:30 000	126	47	9825; 9826; 9827
			49	9846; 9848; 9850
			50	9875; 9877; 9879
			51	9888; 9890; 9892; 9894

* Photographs for the Kapokberg and Contreberg were not available from the same year in the 1980 series.

Initial geo-referencing was carried out by identifying ground control points (GCP), usually road junctions, that were visible on both a 15 m resolution Landsat-7 ETM+ panchromatic image (Landsat path 175, row 83, taken on the 2nd November 1999), and on the most recent aerial photographs from each area. Each of these aerial photographic images was then geo-referenced to the same projection as the Landsat image, at a resolution of five metres. This gave them a Transverse Mercator projection and a WGS 84 datum, with a central meridian of 19.0° E, and a parallel of origin of 0.0°. Where possible 15 to 20 GCP were used for each photo. Where there were less than 12 GCP, only a linear transformation was used. Where it was possible to locate more than 12 GCP, two transformed images were produced, one using the linear function, the other using the quadratic function. When adjoining

images were stitched together, the “best-fit” transformed image(s) were used. The “best fit” was determined at the boundaries of the major areas of natural vegetation.

Where the study area extended over two or more images, these were concatenated and the join examined at high magnification to determine the displacement error between them. If this was unacceptable, the process was repeated using the image produced by the other resampling technique, or more sample points were added and the process repeated. If one of the images was displaced by a constant amount across the join, then that image was manually shifted to get a more accurate join.

Once the best possible geo-referenced image had been created for the most recent aerial photographs from each area, these were used as reference images for the rectification of the earlier photographs. Photographs from the 1930's and 1940's had between 9 and 17 individual photographs covering each area (compared with one to three for the most recent series). The 1938 and 1942 photographs were also physically smaller (5" by 5") compared to those exposed since 1949 (9" by 9") and lacked many of the GCP that had been used for rectifying the more recent series. They were therefore allocated GCP from the image that was most recent, but which had identifiable points present on both images. Some of the oldest Elandsberg images covered areas that had no GCP that could be found in later photographs. In that case, GCP based upon corrected adjacent images of the same time-period were used. In the worst case, GCP had to be based upon geological features. These were difficult to determine with accuracy on adjacent photos, due to the change in viewing angle and shadowing, between photographs.

The assembled images were then transformed to a latitude-longitude format, using the same roads vector file (although different GCP) that was used to rectify the Landsat imagery. The resolution of all images was set to 5 m.

Once all the photographs had been geo-referenced and concatenated as accurately as possible, the areas of natural vegetation were determined. With the more recent photographs this was usually easy, although sometimes one discovered from the field visits, that an area thought to be natural vegetation was a pine plantation (these had the same tone and texture as natural vegetation). The older photographs proved to be a problem in some cases. This was because fields were often left fallow for a

number of years, during which time natural vegetation and weeds of cultivation would grow up in the fields. A decision had to be made as to whether these areas should be considered natural or should be thought of as agricultural. The factor used was whether or not there were (clear) indications of agricultural activity; *i.e.* if an indication of previous ploughing could be seen, then the area was considered agricultural. Scratches on the older photographs (from the negatives) sometimes made this task difficult. During these analyses, both the screen image and the original photographs were examined, the latter using a magnifying glass. It should be noted that the original photographs are of a better quality than the computer images produced. The areas deemed to be natural were digitized into a vector layer over each of the photographic images.

Some definition as to the extent of the Kapokberg needs to be made here. Heydenrych and Littlewort (1995) and McDowell (1988) referred to the Kapokberg as the area covered by the hills, that in plan, look roughly like a misshapen hourglass. John Duckitt (*pers. comm.*) indicated that the locals only consider the northern section as the Kapokberg. The 1:50 000 topo-cadastral map of the area (3318AD – Darling, third edition, 1981) produced by the Chief Directorate, Surveys and Mapping, also indicates that only the northern section is known as the Kapokberg. In neither case are the boundaries distinct. In this study, the hourglass extent was used. The boundaries were limited to the north and east by the R307 Darling-Mamre road, and to the south by the Groote-Post farm road and the “Smalpad” minor road. To the west the boundary was defined by the extent of the natural vegetation (Figure 8).

Absolute boundaries for the Contreberg were similarly vague. In this study the south-western boundary was defined by the R307 Darling-Mamre road. The old Malmesbury-Mamre road, separating the Contreberg from the Dassenberg, was used as the south-eastern boundary. The other boundaries were defined by the extent of the natural vegetation (Figure 9).

The eastern boundary of the Elandsberg PNR also posed a problem. As there was no clear boundary (the natural vegetation continues up the mountain), it was deemed to be at the interface between the alluvial/shale soils, and the soils derived from Table Mountain Sandstone (TMS). There were a few patches of Quaternary

sands between the TMS and the alluvial/shale soils of the reserve. The actual formation of these was “T-Qt” which is described as “scree and gritty sand” (Anon. 1997). It was assumed that these were colluvium from the mountain, and as such were derived from TMS. It was decided that these were incompatible with the edaphic definition of Renosterveld, and were excluded. The area of these scree soils was about 442 ha.

A digital elevation model (DEM) was created from the contour line layer purchased from the Chief Directorate: Maps and Surveying in Mowbray, at the same pixel resolution as the images. The method is described in Chapter 5. This was done to better relate land-use changes to topographical features and to perform slope-corrected estimates of the amount of natural vegetation remaining. Slope-corrected estimates were made by multiplying the projected area of a slope class by the reciprocal of the cosine of the median slope angle within each slope class.

The Agricultural Resources Act of 1983 (Anon. 1983a, 1984) allows land with a slope of less than 11.3° to be cultivated in this area. Kemper (1997) and Kemper *et al.* (2000), working in South-Coast Renosterveld, quote guidelines (unreferenced) stating that land of less than 1.8° may be worked without any restrictions. Slopes between 1.8° and 8.1° may be worked, but require measures to prevent erosion (*i.e.* by ploughing along the contours, or stepping the fields). Land steeper than 8.1° may not be worked. These references were taken into consideration when choosing the slope classes.

Results

Image Rectification

Alignment errors between adjacent images were generally less than 50 metres. In some cases, a final manual shift improved the fit (relative to the actual part of each scene being examined) over that of the concatenation on geographical co-ordinates alone. For example, if geographical concatenation resulted in a loss of area, due to overlap error, then the co-ordinates of one of the images was manually reset so that the “lost” area re-appeared.

The older photographs tended to have less certainty about the identification of ground control points, and the quality of the photographs was poorer. However, because the scale was finer, and the area covered by each photograph smaller, adjacent photographs were often better aligned than were the more recent photographs, which were of a coarser scale and covered a larger area.

Changes in the area covered by the natural vegetation at each site

Figure 14, which should be read in conjunction with Figures 15 to 18, shows the changes in the projected area (*i.e.* slope effects were not taken into consideration) of the natural vegetation occurring over time at each of the sites. Areas are given as a percentage of the natural vegetation occurring in the earliest aerial photographs available. Except for the Elandsberg PNR, the sites have lost between 20% and almost 50% of the natural vegetation that existed in 1938.

Table 4 (page 155) shows the area of natural vegetation existing at the time of each exposure, within different slope classes. The areas are slope-adjusted, as described in the methods section. Excluding the Elandsberg PNR, the main point to note is that, even in 1938 there was very little natural vegetation present on land with a slope of less than two degrees, and what little there was has now been mostly transformed to agriculture. On slopes between two and eight degrees the amount transformed is variable, but at the least affected agricultural site (Koringberg-Swartberg), almost two-thirds of the 1938 extent of natural vegetation in this class had been turned over to crops by 2000. By 2000, the Kapokberg had lost more than half, and the Contreberg just less than half, of the natural vegetation that had existed on slopes in the 8° to 12° class in 1938. Only the Kapokberg had lost any significant amount of natural vegetation in the twelve to twenty degree category (almost one-third). On slopes above twenty degrees, differences between years can probably be attributed to geo-registration errors (see methods). These differences will give an indication of the error levels associated with the methods used in this study.

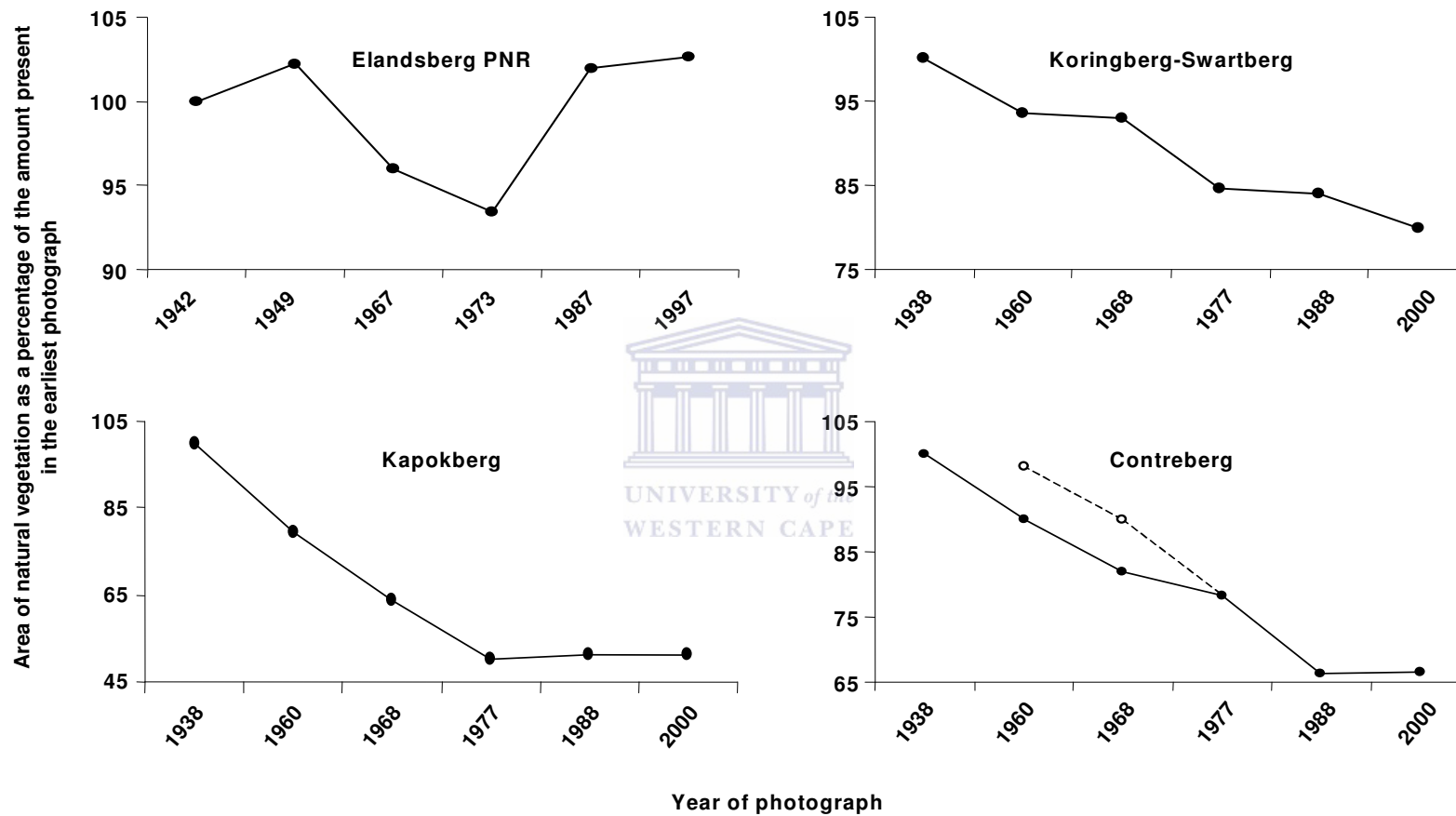


Figure 14. Change in projected area of the natural vegetation at four sites since 1938, as assessed from aerial photographs. The dotted line on the Contreberg graph represents the situation had the “long-term fallow” area (shown in Figure 17) been incorporated as untransformed land.

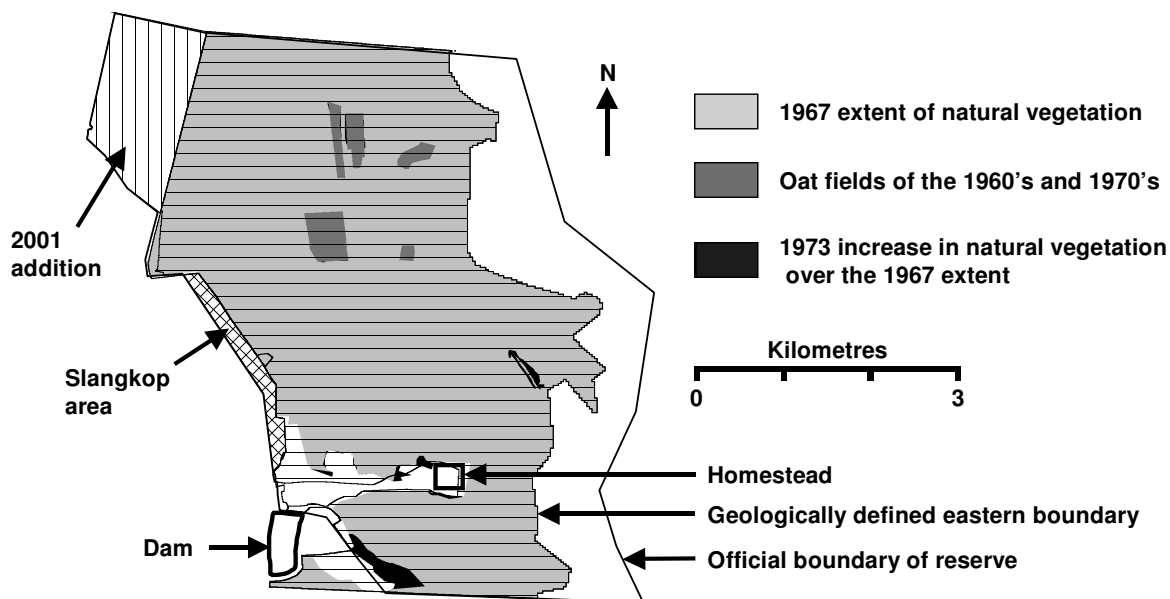


Figure 15. Simplified change image of the Elandsberg PNR. Horizontal hatching shows the extent of the natural vegetation in 1942. Unhatched areas in the south-west of the reserve represent areas where the vegetation was transformed in 1942; White areas overlain by horizontal hatching in the south-west indicates areas that were being used for agricultural purposes in the 1967 and 1973 photographs. Slangkop and the 2001 addition were excluded from the change calculations.

WESTERN CAPE

On the Kapokberg, the highest percentage loss of natural vegetation was from land with slopes of between 2° and 4° , where almost all the land in this class (54.4 ha in 1938) is now being cultivated. Between the north-eastern corner of the Kapokberg and the R307, a block of natural vegetation of approximately 142 ha was transformed to agriculture between 1938 and 2000. Of this block, 121 ha was on slopes of less than 12° , while 21 ha was on slopes of greater than 12° . Similarly, a block of natural vegetation of 59 ha (of which 47.7 ha was on slopes of less than 12°) adjacent to the “Smalpad” road, had been reduced to an area of 6.2 ha by 1977, ninety percent of which remained on slopes of greater than 12° . In both cases, one needs to consider whether some or all of these areas were in fallow cycles in 1938.

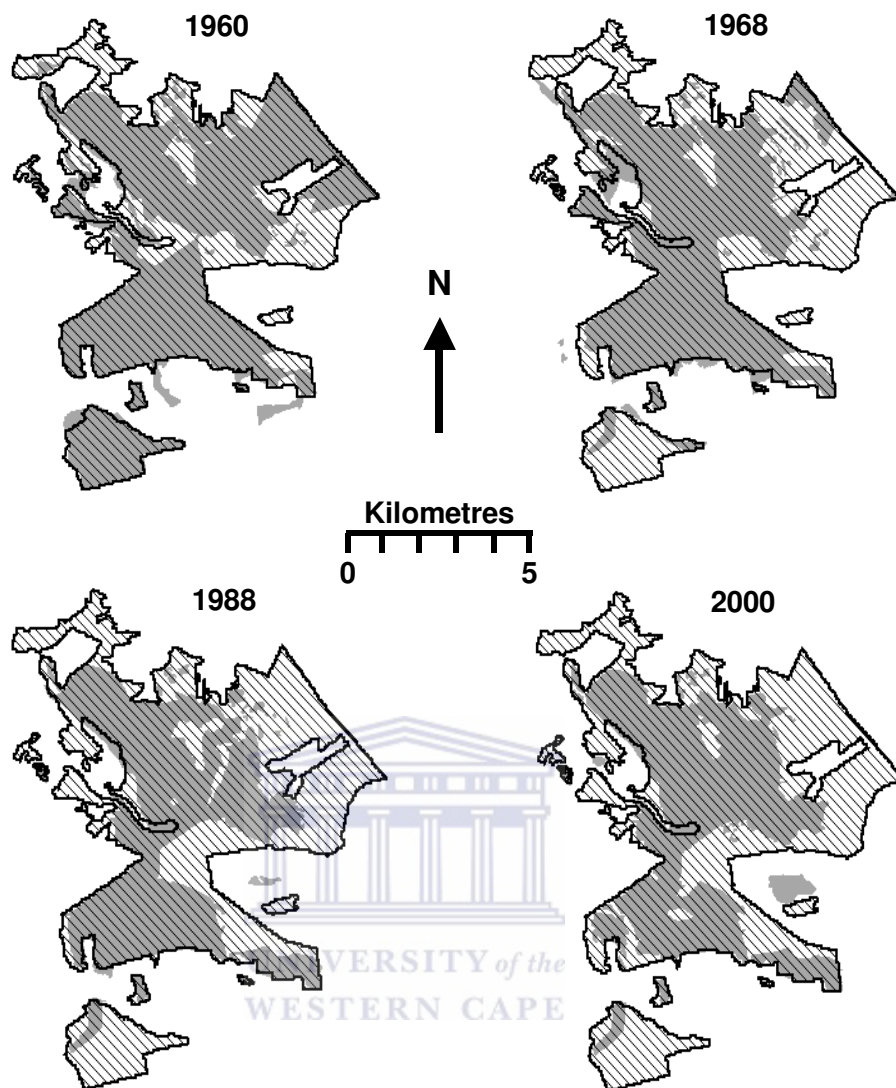


Figure 16. Changes in the extent of the natural vegetation on the Kapokberg. The extent of the natural vegetation for each year is indicated by the solid grey. The 1938 extent of natural vegetation is indicated by the diagonal hatching.

Although the Contreberg had less natural vegetation than the Kapokberg in 1938, more remained in 2000. This was because a greater proportion existed on slopes of greater than 12° , and has thus remained untransformed. However, Figure 20 (see later) shows that several blocks of natural vegetation growing on relatively flat land still remain at the west end of the mountain.

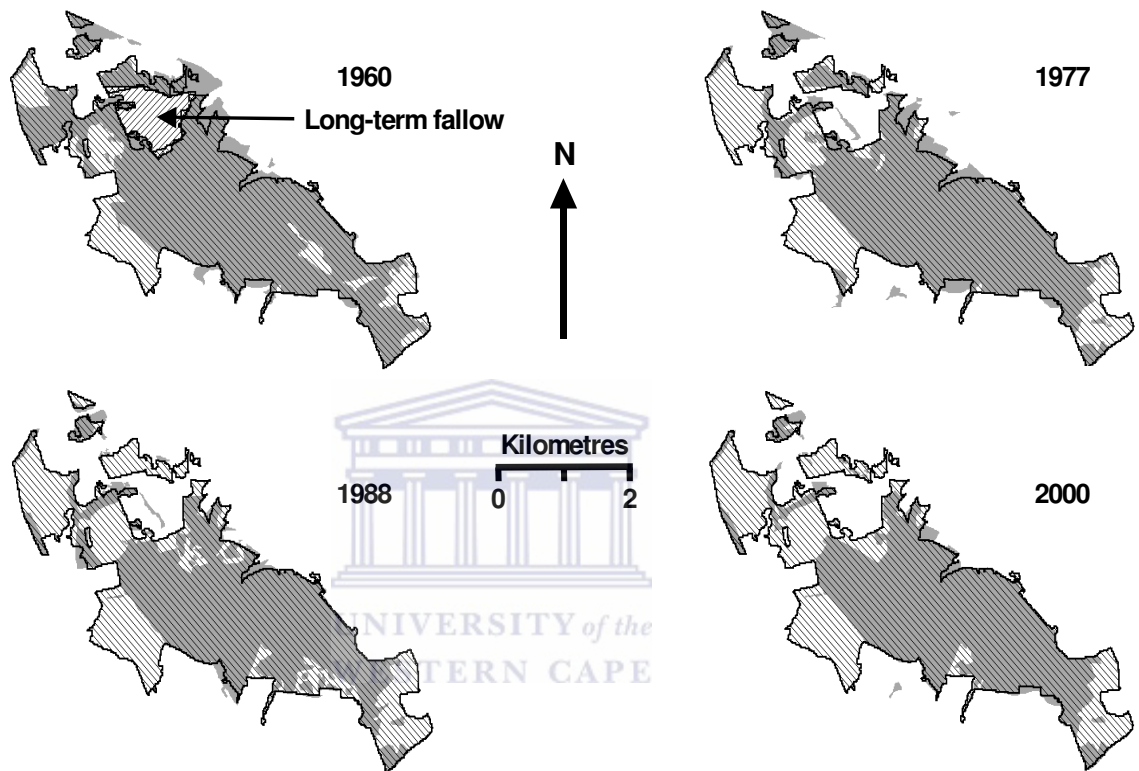


Figure 17. Changes in the extent of the natural vegetation on the Contreberg. The extent of the natural vegetation for each year is indicated by the solid grey. The 1938 extent of natural vegetation is indicated by the back-diagonal hatching. The “long-term fallow” area is identified by forward-diagonal hatching.

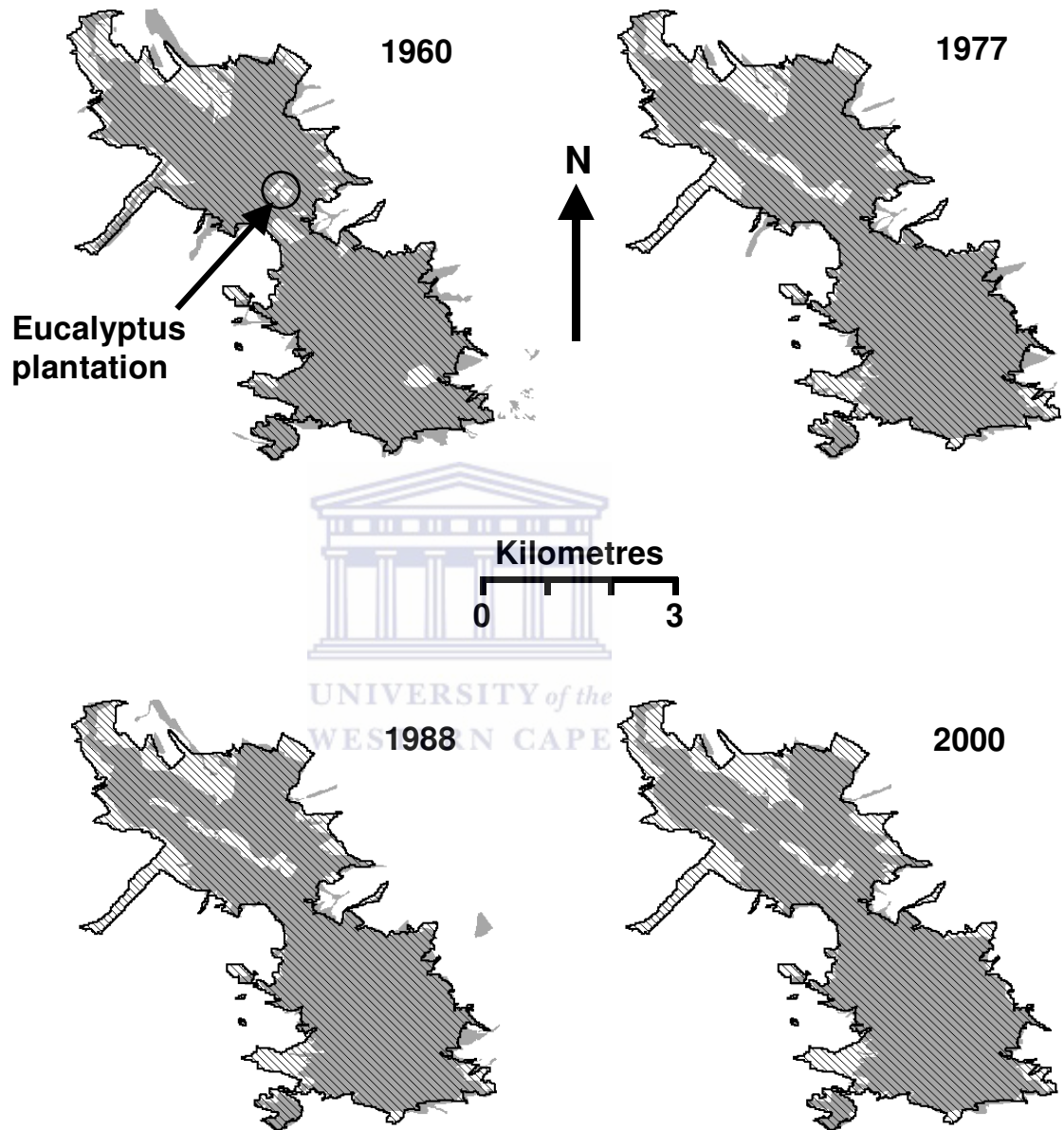


Figure 18. Changes in the extent of the natural vegetation on the Koringberg-Swartberg. The extent of the natural vegetation for each year is indicated by the solid grey. The 1938 extent of natural vegetation is indicated by the diagonal hatching.

Table 4. Changes in the area of natural vegetation within different slope classes with time, for each of the sites looked at. The areas given here are the slope-corrected values, in hectares - see the text for method. The % change column indicates the amount of natural vegetation remaining at the end of the series, as a percentage of the amount present at the start of the series.

Elandsberg PNR

Slope (degrees)	Year						% change 1942 to 1997
	1942	1949	1967	1973	1987	1997	
0-1	700.2	707.4	681.5	656.4	705.7	709.5	+1.3
1-2	733.8	748.6	695.9	658.7	746.5	749.6	+2.1
2-4	716.2	748.6	678.9	673.6	745.5	754.7	+5.4
4-8	275.5	275.6	270.1	274.7	275.6	275.6	0.0
8-12	25.6	25.6	25.6	25.6	25.6	25.6	0.0
12-20	4.0	4.0	4.0	4.0	4.0	4.0	0.0
Sum	2455.4	2509.8	2356.0	2292.8	2503.0	2518.9	+2.6

Koringberg-Swartberg

Slope (degrees)	Year						% change 1938 to 2000
	1938	1960	1968	1977	1988	2000	
0-1	4.9	1.5	0.1	0.2	0.4	0.2	-95.9
1-2	7.5	10.5	1.3	1.5	3.4	0.6	-92.0
2-4	75.6	66.5	45.8	29.8	32.8	14.7	-80.6
4-8	207.3	161.9	143.4	123.2	103.4	84.5	-59.2
8-12	289.1	270.5	241.6	241.6	234.7	216.0	-25.3
12-20	630.9	610.4	599.5	598.0	604.0	603.0	-4.4
20-30	269.8	264.0	265.2	260.6	268.7	268.9	-0.03
30-60	41.3	40.5	41.0	40.6	41.4	41.3	0.0
Sum	1526.6	1425.8	1337.8	1295.5	1288.8	1229.2	-19.5

Table 4 continued

Kapokberg

Slope (degrees)	Year						% change 1938 to 2000
	1938	1960	1968	1977	1988	2000	
0-1	0.1	0.1	0.1	0.0	0.0	0.1	0.0
1-2	2.5	1.0	0.7	0.1	0.1	0.2	-92.0
2-4	54.4	43.7	13.8	1.6	1.0	1.6	-97.1
4-8	156.7	113.8	48.9	21.6	22.9	27.3	-82.6
8-12	173.9	118.1	100.6	60.4	64.7	66.1	-62.0
12-20	291.8	244.4	237.5	209.9	211.6	208.5	-28.5
20-30	108.7	105.2	104.5	103.8	104.4	104.8	-3.6
30-60	9.0	9.0	9.0	8.9	8.9	8.8	-2.2
Sum	797.1	635.3	515.1	406.3	413.7	417.5	-47.6

Contreberg*

Slope (degrees)	Year						% change 1938 to 2000
	1938	1960	1968	1977	1988	2000	
0-1	0.2	0.2	0.1	0.1	0.1	0.1	-50.0
1-2	3.7	0.9	1.2	1.6	0.5	0.5	-86.5
2-4	108.8	51.6	24.7	22.7	21.2	13.7	-87.4
4-8	99.9	70.7	59.8	53.9	36.2	33.5	-66.5
8-12	121.7	127.6	111.3	90.7	70.9	65.3	-46.3
12-20	266.6	277.2	272.4	273.2	228.4	242.5	-9.0
20-30	146.1	146.2	145.5	146.4	140.3	146.2	+0.1
30-60	9.5	9.5	9.3	9.5	9.5	9.5	0.0
Sum	756.4	683.9	624.3	598.1	507.1	511.2	-32.5

* Figures exclude the "long-term fallow" section.

Table 5 gives the projected area of natural vegetation occurring in each of the octants of the compass. Of interest is that there was a slight increase in the area covered by natural vegetation on the north side of the Contreberg in the 1960's over that of 1938. Had the "long term fallow" section (see Figure 17) been included, the octants lying either side of north would have shown the presence of a further 23.5 ha of natural vegetation present in 1968. This will be discussed later in relation to sources of error in the determination of land-cover changes when aerial photographs are used to assess this. Comparing the change in total area for each site between tables 4 and 5 gives one an idea of the differences between slope-corrected and projected area calculations.

Probably of more interest is Table 6, which shows the change in the slope-adjusted area of natural vegetation occurring within each of the octants, for three slope classes. On slopes of less than 8° on the Koringberg-Swartberg, the west-facing slopes seemed to have suffered the most transformation; the 8° to 20° slope class had been minimally affected with most losses being from the east and north facing slopes. On the Kapokberg, it was the north-east facing slopes of less than 8° that were the most affected by agricultural encroachment. Most of this was due to the loss of the 142 ha between the Kapokberg and the R307 mentioned above. In the intermediate class, there is little pattern in respect to loss of natural vegetation. However, these are the slopes that have been proportionately the most affected, due to there being more land within this slope class in 1938. Most of these slopes have been transformed to vineyards in the south-eastern sector of the Kapokberg. Natural vegetation in the steepest slope class has been minimally affected.

On the Contreberg, most losses in the less than 8° class occurred on the south-west facing slopes, while in the intermediate class, most were on the north facing slopes. This might seem surprising, as the hill does not extend very much above the surrounding plains to the north-east (Figure 11, top). However, Figure 17 shows that the north-eastern boundary between formal agriculture and the natural vegetation had been established by 1938, and from Figure 20, one can see that very little land with a slope of less than 12° remained along this boundary.

Table 5. Changes in the area of natural vegetation within different aspect octants with time, for each of the sites looked at. Areas are given in hectares, and are projected area (*i.e.* not slope-corrected area). The % change column indicates the amount of natural vegetation remaining at the end of the series, as a percentage of the amount present at the start of the series.

Elandsberg PNR

Aspect octant	Year						% change 1942 to 1997
	1942	1949	1967	1973	1987	1997	
E of N	127.3	127.8	112.5	117.9	127.5	128.4	+0.9
N of E	88.1	91.9	87.6	86.8	90.7	92.0	+4.4
S of E	13.5	13.5	11.4	11.3	13.5	13.5	0.0
E of S	39.8	39.8	37.6	37.4	39.8	39.8	0.0
W of S	149.5	150.6	148.0	143.9	150.5	150.8	+0.9
S of W	660.6	682.4	635.5	605.6	681.7	683.3	+3.4
N of W	854.8	871.0	814.6	782.8	869.2	876.4	+2.5
W of N	518.4	529.3	505.5	503.7	526.7	531.3	+2.5
Sum	2452.0	2506.4	2352.7	2289.5	2499.6	2515.6	+2.6

Koringberg-Swartberg

Aspect octant	Year						% change 1938 to 2000
	1938	1960	1968	1977	1988	2000	
E of N	334.2	297.3	300.8	277.2	279.5	259.8	-22.3
N of E	210.7	204.8	223.9	200.2	198.0	180.8	-14.2
S of E	112.7	108.9	134.1	108.5	105.6	98.5	-22.6
E of S	86.0	89.6	131.0	84.7	80.8	79.0	-8.1
W of S	199.3	187.1	167.7	160.3	163.2	162.8	-18.3
S of W	250.0	224.3	176.6	191.0	188.3	187.3	-25.1
N of W	118.1	111.1	91.9	93.9	92.7	89.5	-24.2
W of N	147.1	140.6	128.0	116.4	115.4	106.6	-27.6
Sum	1458.0	1363.8	1354.0	1232.1	1223.4	1164.4	-20.1

Table 5 continued

Kapokberg

Aspect octant	Year						% change 1938 to 2000
	1938	1960	1968	1977	1988	2000	
E of N	235.3	157.9	119.8	94.8	99.6	103.9	-55.8
N of E	140.2	114.4	71.8	62.8	62.7	64.6	-53.9
S of E	67.1	58.1	35.7	30.8	34.1	28.1	-58.1
E of S	73.0	58.4	40.7	23.4	25.0	28.2	-61.4
W of S	61.6	56.1	57.4	42.2	37.4	39.3	-36.2
S of W	76.5	66.0	70.9	53.1	49.4	45.5	-40.5
N of W	49.7	47.0	44.5	38.2	39.1	39.6	-20.3
W of N	65.0	52.3	50.6	39.4	44.6	46.5	-28.5
Sum	768.4	610.3	491.4	384.8	392.0	395.8	-48.5

Contreberg*

Aspect octant	Year						% change 1938 to 2000
	1938	1960	1968	1977	1988	2000	
E of N	111.2	118.6	110.2	99.7	74.8	79.1	-28.9
N of E	109.0	107.1	100.5	100.3	96.1	96.1	-11.8
S of E	71.1	66.7	58.1	55.3	47.5	51.6	-27.5
E of S	81.4	73.3	54.5	50.6	39.3	41.9	-48.5
W of S	139.1	102.1	100.2	95.5	80.5	80.4	-42.2
S of W	133.6	106.4	97.5	93.7	91.1	86.6	-35.1
N of W	35.8	34.3	33.2	30.6	24.1	22.7	-36.5
W of N	37.9	44.6	40.8	36.0	23.6	23.9	-37.0
Sum	719.2	653.3	595.0	561.8	477.0	482.4	-32.9

* Figures exclude the “long-term fallow” section.

In the steepest slope class, the Koringberg-Swartberg had been effectively untouched, while on the Kapokberg and Contreberg, changes are small and can probably be related to changes in field borders, and geo-registration errors.

Table 6. Percentage of the 1938 extent of natural vegetation remaining in each aspect octant, within three slope classes in the year 2000. The figures have been slope adjusted. Elandsberg PNR has been excluded due to the minimal changes occurring.

Aspect	Slope (degrees)	Kapokberg		Contreberg		Koringberg-Swartberg	
		Percent remaining in 2000	1938 area in hectares	Percent remaining in 2000	1938 area in hectares	Percent remaining in 2000	1938 area in hectares
E of N	< 8	7.6	89.7	30.7	11.1	31.4	63.4
N of E	< 8	4.6	49.3	54.2	13.0	52.0	25.3
S of E	< 8	10.3	23.9	31.4	20.6	53.4	12.8
E of S	< 8	22.3	19.4	18.0	40.6	49.8	14.1
W of S	< 8	29.5	7.7	16.9	62.0	28.1	39.1
S of W	< 8	54.9	8.0	19.3	49.9	26.2	69.2
N of W	< 8	48.2	6.0	18.1	9.9	34.8	33.8
W of N	< 8	42.1	8.5	27.4	5.0	31.7	35.5
E of N	8 to 20	52.8	106.4	66.7	82.5	85.8	219.2
N of E	8 to 20	63.2	80.1	89.3	75.9	87.8	142.4
S of E	8 to 20	55.0	39.2	89.1	48.5	89.8	77.9
E of S	8 to 20	37.4	46.8	78.6	31.1	101.1	41.8
W of S	8 to 20	60.3	41.5	86.1	51.8	91.6	100.0
S of W	8 to 20	56.5	64.7	87.1	55.1	91.9	142.1
N of W	8 to 20	83.0	38.3	63.6	16.9	90.6	68.7
W of N	8 to 20	71.2	48.0	49.6	25.5	83.5	98.0
E of N	>20	100.0	49.2	99.9	25.8	100.4	51.5
N of E	>20	99.9	15.3	99.8	27.4	99.3	42.9
S of E	>20	90.1	6.0	90.4	4.3	98.9	21.9
E of S	>20	83.4	9.5	106.7	12.6	98.9	30.1
W of S	>20	93.0	15.8	99.1	31.7	100.0	60.2
S of W	>20	98.3	6.7	100.0	35.3	100.1	38.6
N of W	>20	90.2	7.6	100.0	12.3	99.8	15.6
W of N	>20	98.7	11.5	100.4	11.8	98.7	13.7

Table 7. The number of patches of natural vegetation of 1 ha or more at each of the sites examined, and their total area on slopes of less than 12 degrees, which could potentially be cultivated. See Figures 19-21 for patch locations.

Hill	Slope of 0 to 8 degrees		Slope of 8 to 12 degrees	
	Number	Area (ha)	Number	Area (ha)
Kapokberg	4	15.8	17	42.2
Contreberg	13	39.6	14	47.3
Koringberg-Swartberg	22	69.8	49	172.2

Areas available for agricultural expansion

Table 7, which should be read in conjunction with Figures 19-21, gives some indication of the agricultural potential remaining on the three hills. In some cases the “suitable areas” adjoin areas currently being cultivated, and therefore have a greater chance of being incorporated than would isolated patches higher up the hills. Of course, other factors need to be considered, such as soil depth and the level of stoniness, which were not assessed in this project. Both of the Darling hills have a strip of land, apparently suitable for agriculture, traversing the hills. At the Kapokberg there is an island of apparently suitable land to the east, while at the Contreberg the west side appears to have good agricultural potential. On the Koringberg, the north-western tip appears to have a high agricultural potential. Strips of natural vegetation leading down from the north-west side of this hill (towards the village) are badly eroded rills, caused by run-off from the mountain (see Figure 23 later), and as such have a low agricultural potential. Wolfkop (the small hill at the south end of the Swartberg) appears to be suitable for agriculture, and it is unknown why this has not yet occurred.

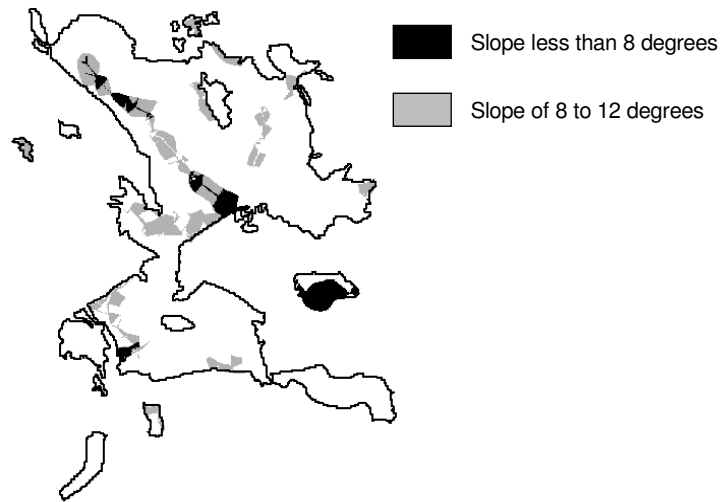


Figure 19. Patches of natural vegetation of greater than 1 ha present on the Kapokberg, which could potentially be used for agriculture. Boundaries of the extent of the natural vegetation in November 2000 are shown in black.

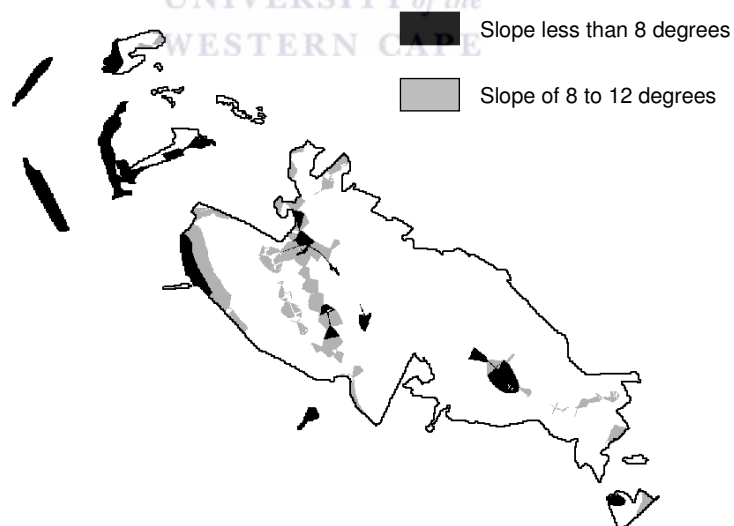


Figure 20. Patches of natural vegetation of greater than 1 ha present on the Contreberg, which could potentially be used for agriculture. Boundaries of the extent of the natural vegetation in November 2000 are shown in black.

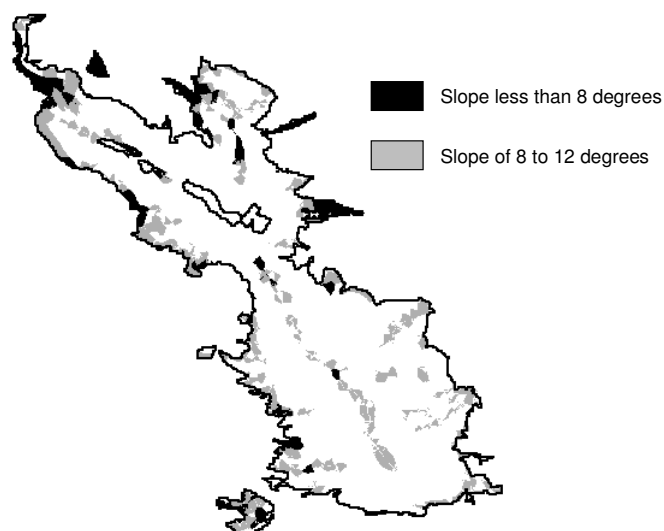


Figure 21. Patches of natural vegetation of greater than 1 ha present on the Koringberg-Swartberg, which could potentially be used for agriculture. Boundaries of the extent of the natural vegetation in November 2000 are shown in black.

Discussion

Processing and image interpretation errors

An exercise of this kind is subject to accumulative errors creeping in. There are distortions in each photograph due to the yaw, pitch and roll of the aeroplane at the time the photograph is taken. Each series of photographs is taken from a different angle and several scales were used. Hills and valleys introduce scale and locational distortions. Geo-referencing introduces further errors, as exactly the same point on the Landsat reference image and on the aerial photograph, or even on subsequent photographs cannot be perfectly established due to pixel resolution errors. Older photographs may appear to have road junctions (or other GCP used) at the same place, but there may have been subtle changes in the intervening time-period. Major displacements would be obvious on the photograph, or would show up during resampling, by an abnormally large root-mean-squared error for that point. Due to distortions within each photograph and changes in the GCP used at different times, the equation describing the same sites will be different, resulting in slightly

different resampling parameters. This will result in the boundaries of the natural areas not being perfectly aligned, even when no change has taken place from one time-period to the next. Errors produced by the concatenation of images to make up the scene also add to the potential problems. Many of these problems could have been ameliorated had full orthorectification facilities been available. However, it would not have solved all of the problems, particularly with the older photographs, due to the limited number of ground control points present on some of the photos. However, by overlaying the natural vegetation vector data over the most recent image, it was possible to check (and correct) vegetation boundaries, to ensure that all were referenced to the same aerial photograph.

It is possible that correcting the aerial photographs twice (initially to Transverse Mercator, and then to latitude-longitude format) has introduced an extra level of error. The reason for doing this was twofold. The first was that, at the time of correcting the photographs, the Landsat imagery had not been reprojected to a latitude-longitude format, and so was not available for directly transforming the photographs to this format. The second reason (and the reason why the images were not redone from scratch once the Landsat image had been transformed) was that the manual alignment of images when they were being concatenated was more easily carried out when the projection units were in metres. The reason for the second transformation to latitude-longitude format was so that overlays (*e.g.* geology, contour lines) could be used in this analysis. There will be some errors related to the change in pixel brightness (and hence resolution) during resampling, but this error will be less than that involved in the image alignment processes, and should minimally affect the results.

Carstensen and Campbell (1991) examined the effects of scanning aerial photographs and maps using commercial desktop scanners. Their conclusion was that the digital image produced showed no significant errors, relative to the original, with respect to location or resolution. This assumes a scanning resolution set to the same as that of the original image. The greyscale response closely followed that of typical panchromatic photographic paper. This implies that there were some problems resolving brightness differences at the bottom and top ends of the scale. The central 80%-90% of the greyscale was linear and resolved brightness

differences well. In this study, 300 dpi was used as a compromise between resolution and file size. The loss of resolution in the images would have affected the determination of the vegetation boundaries to a certain extent. In the case of other ambiguities, the photographs were available to resolve problems.

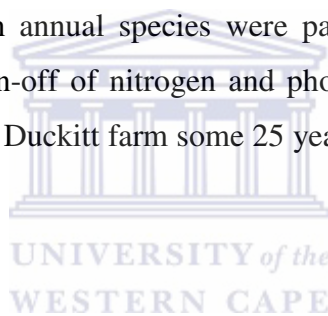
Despite the above-mentioned *caveats*, the level of change being looked for will show up clearly. A field enlarged by an extra few metres, while insidious, is below the threshold of this project. The replacement of natural vegetation by a new wheat field (or *vice versa*) is more important. There is also a problem in that, while an area may have remained as natural vegetation throughout the whole series of photographs, we can make no statement about the condition of the vegetation. Overgrazing, invasion by agricultural weeds or the seeding of the area with exotic species and their subsequent fertilization are all factors that cannot be resolved at the remote sensing level. What does need to be kept in mind, is that fallow periods tended to be longer in the past (Talbot 1947) than is the current practice (several *pers. comms.* – see Chapter 1 and acknowledgements). The apparent increase in natural vegetation on the northern Contreberg in 1960/68 (marked as “long term fallow” in Figure 17), and a similar increase between the railway and the south-eastern foot of the Swartberg in 1968 (see Figure 12) should alert one to the fact that some of the “natural vegetation” present in the 1938 photographs may have been land lying fallow. Mechanization appears to have been introduced around the time of the Second World War (*pers. comms.* from Charles Duckitt and Pagel Dippenaar), which means that farmers would have been obliged to provide grazing for draught animals in the 1930’s. These pastures would probably have appeared to be (and probably largely consisted of) natural vegetation in the 1938 photographs. From later photographs, one can make assumptions about areas that had probably been used for agriculture before 1938. Examples in this study are the block of land to the north-east of the Kapokberg (which had agricultural fields in the middle of it in 1938), as well as the “island” to the south of this hill. In the 1960 photograph, the north-eastern block appeared to be used for grazing, and so it is debatable as to whether the area was natural vegetation or not. The southern “island” still appeared natural (if somewhat sparser than the main section of the hill). In the rest of the photographs, there is no doubt that these areas have been agriculturally transformed. The block of land on the south-western side of the Contreberg that was identified as

natural in 1938 showed signs of bad overgrazing (very sparse vegetation), and so it is again debatable as to whether it was natural vegetation or a field lying fallow which had been overgrazed and trampled. The block of land at the north-western end of this hill has also been shown as natural vegetation for 1938, but once again, much of it appeared very sparse, suggesting over-grazing (or a recent fire), even if it had not been previously ploughed.

Changes in land management practices

Duckitt's (1995) argument was that steep slopes that could be safely ploughed with draught animals were too dangerous to plough with tractors is difficult to test, as he has not specified the slope at which it becomes too dangerous to plough with a tractor. Talbot (1947) indicated that slopes of 16.7° were being mechanically ploughed in the 1940's, usually up and down the slope. Assuming that the danger of steep slopes is the possibility of the tractor rolling while turning, a flat area at the top of the slope would only impose limits on the steepness of the slope worked in an up and down direction to the ability of the tractor to obtain enough traction to tow the plough. It was generally not possible to determine the direction of ploughing from the older aerial photographs (pre-1960). The photographs from the 1960's suggest that contour ploughing, or at least, ploughing across the slope was predominant. Talbot (1947) pointed out that ploughing across the slope (as opposed to true contour ploughing) did not necessarily result in less erosion, but this would presumably limit the steepness of the slope that was workable. Evidence of rill erosion can be seen on some early photos, the Koringberg being the worst affected. The coarser scale of the modern photos makes it difficult to determine to what extent these have expanded, or been repaired, but in some areas agriculture is taking place over old rills. This observation provides support to the recent thesis of Morel (1998) and the associated publication of Meadows (2003), which showed that gully frequency near the Kasteelberg declined by 85%, from 12.3 per km² in 1938 to 1.8 per km² in 1989. Although Morel's detailed study was restricted to an area of 55 km², it suggested that there had been a general decline in the spatial extent of degraded lands within the Swartland since Talbot's (1947) report.

Figure 14 suggested that by the mid-1980's, most of the land that was going to be cultivated was already under the plough. The remaining natural vegetation (with the exception of the Elandsberg PNR) was generally on land that was steeper than the legal limit. However, McDowell and Moll (1992) pointed out that, just because land is agriculturally unusable, this does not mean it is only useful for conservation. Alternative land uses include housing developments (*e.g.* see Figure 13 on page 68 of Chapter 1) and weapons storage/testing (*e.g.* at Krantzkop, south of Elandsberg PNR). Crop improvements may allow the use of marginal lands in future years. McDowell and Moll (1992) reported that several of the West-Coast Renosterveld farmers that McDowell interviewed were already (prior to 1988) planting exotic legumes which, when fertilized, raised the forage quality of the land considerably. Indigenous species are mostly disadvantaged by this treatment, and biodiversity is decreased. Vlok (1988), for example, noted that at Karweiderskraal (mesic Mountain Fynbos), alien annual species were particularly prominent in drainage lines enriched by the run-off of nitrogen and phosphate fertilizers. The effects of adding phosphates to the Duckitt farm some 25 years ago were described in Chapter 1 (page 57).



Elandsberg PNR

The land added to the north-west corner of the reserve in 2002 had been used for agricultural purposes over the previous few decades, and was therefore not included in the land change assessment carried out in this project. The Elandsberg PNR was therefore the only area looked at which showed an increase in the amount of natural vegetation between 1942 and 1997 (based on 1973 boundaries). However, the difference was small (65 ha) and was largely attributable to the area between the location of the current dam in the south-western corner of the reserve and the homestead (Bosplaas) being apparently badly degraded in 1942. There were indications of other agricultural practices occurring in this region of the reserve, prior to its proclamation, and these can be seen as the white areas below the horizontal hatching in Figure 15. These reached a peak in 1973, with an area of about 162 ha being transformed in this section. During the 1960's and 1970's there was also some agricultural activity within the central part of the reserve (see Figures

3 or 15). These fields were small (30 ha in the 1967 image; 64 ha in the 1973 image) and, as mentioned in the introduction, they were used to grow oats as supplementary feed for stock (Fish 1988). They were almost entirely confined to the shale soils of the north-central section of the reserve. In view of the fact that they were probably chosen to take advantage of the better shale soils, their overlap onto “Terrace Gravel” soils, as defined by the geological map (Anon. 1997), is probably an indication of the inherent error in these maps.

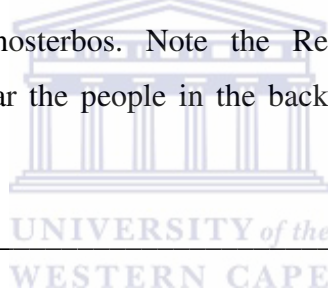
If one compares the official western boundary of the reserve with the western boundary of the natural vegetation (as defined in this project – Figure 2), one will notice a strip of “non-natural” vegetation in the region of Slangkop. This area was last cultivated in 1987 (Shiponeni 2003), and can therefore be referred to as “old lands”.

Looking at Figure 22, one can see the slow influx of shrubs into these old lands. To the east (left of photograph) is established Renosterveld shrubland. There is then an area being invaded by the yellow flowered shrub (*Relhania fruticosa*). Renosterbos shrubs are sparse in the old lands, and are mainly restricted to the furrows. The photograph indicates some of the problems of determining natural vegetation from remote sources in this area. Although these old lands had been uncultivated for 10 years, they still spectrally resembled cultivated land. They support a number of herbaceous alien species, but there is a substantial component of indigenous geophytes, with *Oxalis purpurea* being very common (Shiponeni 2003). Most of the land recently added to the reserve supports a similar low herbaceous shrubland, and would have been (correctly in 1997) defined as agricultural from aerial photographs (*pers. obs.*).

Voelvlei was not looked at in detail, but some comments are in order. The 1949 photo showed that the western side of Voelvlei dam was largely being cultivated, apparently for cereals. As mentioned above, the soils there are predominantly derived from shales, and would therefore be ideal for agriculture. The 1967 photograph showed the start of the construction of the water purification and pumping station. By 1973 the work appeared to have been completed, and by 1987 the natural vegetation had successfully re-established itself. There appears to have been no change in the area covered by natural vegetation on the western side of the



Figure 22. The Slangkop section of the Elandsberg PNR, showing the slow spread of shrubs from established Renosterveld into the “old lands” that were last cultivated in 1987. The yellow-flowered shrub is *Relhania fruticosa*. The dark green shrubs are mainly Renosterbos. Note the Renosterbos establishment in the “furrows” (the strips near the people in the background). Photograph courtesy of Benjamin Walton.



vlei since then. On the eastern side, a plantation has been in existence since the first photograph available (1942). This early photograph also showed quite extensive cultivation occurring between the plantation and the vlei. By 1967, agricultural activities were restricted to the area north of the plantation. It is still occurring there, although there is a buffer zone of natural vegetation between it and the vlei.

The current western boundary of the Elandsberg-Voelvlei complex appears to have been mostly static since 1967. By that time, almost all the natural vegetation outside of the reserve complex had been lost to agriculture. The necessity of having a buffer of natural vegetation around the vlei has led to a consolidation of natural vegetation, compared to the more fragmented pattern in the area in the 1940's. The difficulty in distinguishing between natural vegetation and agricultural land (see above) in a year of fallow should be kept in mind when making these observations. Of interest is the fact that the natural vegetation occurring on this land in the 1940's was mostly

occurring on the alluvial soils, while the shale areas had been largely cultivated. The enlargement of the Elandsberg reserve to the north-west is upon alluvial ($\sim 2/3$) and clay (remainder) soils.

Kapokberg

The photograph (Figure 10) shows some of the problems involved in assessing whether the transformations to agriculture, as described in the results section are genuine transformations. As mentioned in the introduction, the fields used for wild flower production in the Darling area are also used for the grazing of stock, as this promotes the flowering of annual and geophyte species. This agricultural use might therefore be considered as a reversion to a pseudo-natural situation rather than a threat to biodiversity. In fact, these fields may be conserving more of the endangered Renosterveld species (particularly geophytes) than do the typical Renosterveld shrublands. This would be because the interactions between the plants and grazing/browsing mammals would more closely resemble the situation under which they evolved (see Chapter 6, page 372 for a more detailed discussion). Neil MacGregor, in a presentation given at the Fynbos Forum symposium in 2001, said that on his farm near Nieuwoudtville (Mountain Renosterveld), flowering of geophytes was better in fields where grazing was allowed, than in fields that had been kept free of stock. The *pers. comm.* from Duckitt (Chapter 1, page 57) suggested that the addition of fertilizers to some of his grazing fields, had had a detrimental effect upon the growth and flowering of the indigenous bulbs and herbaceous annuals. However, McDowell (1995) was of the opinion that this input of Phosphate (200 kg/ha every 5 years) had, along with the other management practices (burning, grazing), led to the disappearance of the *Elytropappus* overstorey, and an increase in the abundance of geophytes, especially the Iridaceae. How the input of fertilizer benefits the geophytes is not clear, but the burning and grazing regime is probably more closely reflecting the conditions under which these species evolved. What is of importance in the context of this study is that, from a remote sensing standpoint, the quality of these rangelands could not be assessed in terms of their conservation worth.

Despite Charles Duckitt's description of the Kapokberg as being densely infested with Renosterbos in the 1930's, the 1938 aerial photographs showed the mountain apparently criss-crossed with numerous trails, and much of it very bare. The photographs were admittedly taken in March, at the end of the dry season, but this should merely emphasize the perennial element, which the Renosterbos would represent. It was the southern half of the "hourglass" (*i.e.* that part the locals do not consider as being part of the Kapokberg proper) that appeared to have the highest vegetative cover in the 1938 photographs.

Contreberg

The stabilization of the area of land given over to natural vegetation on this hill apparently occurred around the mid-1980's. Sixty-seven percent of the natural vegetation present on the Contreberg in 1938 still remained in 2000, compared with 52% on the Kapokberg. This is probably due to the Contreberg having a greater proportion of steeper slopes than the Kapokberg, rather than to a more conservation-minded approach. In 1988 there appeared to be cultivation, or at least severe clearing of the natural vegetation on the south-eastern and northern parts of the hill. By 2000, some of this patchwork had reverted to natural vegetation. Along the lower slopes of both the Kapokberg and Contreberg, the Kraalbos (*Galenia africana*) is common. This species is usually indicative of abandoned fields or of overgrazing, as it is unpalatable to small stock (Le Roux and Schelpe 1981).

Koringberg-Swartberg

The Koringberg-Swartberg has also suffered from a gradual reduction in the area of the natural vegetation over the 60-year period looked at. Only 11 ha of natural vegetation existed on lands of less than 2° in 1938, and these had effectively disappeared by 2000. The major item of note was the appearance of agricultural activity along the ridge of the Koringberg in the 1968 photograph (Figure 23 top), which cannot be seen from the surrounding lands, or from any point of the hiking trail. Some of this had apparently reverted to natural vegetation by 2000 (Figure 23 bottom). Nineteen sixty-eight was also of note in that there was around 150 ha of what appeared to be "natural vegetation" present between the railway line and the

farm road to the south-east of the Swartberg. This shows up as cultivated land in the other photographs. It may therefore have been burnt, either accidentally by passing trains, or purposely to prevent accidental fires reaching the mountain.

There was some water-related erosion in parts, particularly on the north-eastern side, near the village. There were dongas, rills and areas where the soil had been washed down and over the surrounding land. The worst of this erosion can be seen in Figure 23 as a tongue of natural vegetation leading away from the hill to the southern corner of the village. The 2000 photograph suggests that these runoffs are better vegetated, and there appears to be complete rehabilitation of the rill that diagonally crossed the field for which the number “8” identifies the north corner. The presence of less fallow land in the 2000 photograph has accentuated these watercourses.

From a personal visit, it appeared that there was a big difference between the vegetation on the north-east and on the south-west slopes. Slopes facing north-east had a high presence of succulent species *e.g.* *Euphorbia* sp., *Cotyledon* sp. and members of the Mesembryanthemaceae (Figure 24). *Eriocephalus* was common, and *Elytropappus* was present. This would agree with the findings of Tansley (1982). There appeared to be a phenomenon similar to that described by Linder (1976) on the Piketberg, in that a *Euryops* species (*speciosissimus*?) was present on the north-east slopes and where it occurred, Renosterbos was absent. South-west facing slopes had a characteristic Renosterveld shrubland structure, with a predominance of *Elytropappus* and dense grass clumps (*Merxmuellera* sp.?) (Figure 25). These different communities are not discernible on the aerial photographs.

The 1960 aerial photograph showed a bell-shaped area of agriculture on the saddle between the Koringberg and Swartberg. This was not seen in any of the subsequent photographs. There is a possibility that some sort of agriculture had occurred there before 1938, as the 1938 photograph in that area did not show the typical heuweltjie/bush clump texture noted over the rest of the hill. The effect of this agricultural use appears to have lingered on as the vegetation occurring in that area is grassier. These grassy areas appear to reflect the previous presence of heuweltjies (Figure 26). If examined closely, Figure 23 (top) shows the presence of the

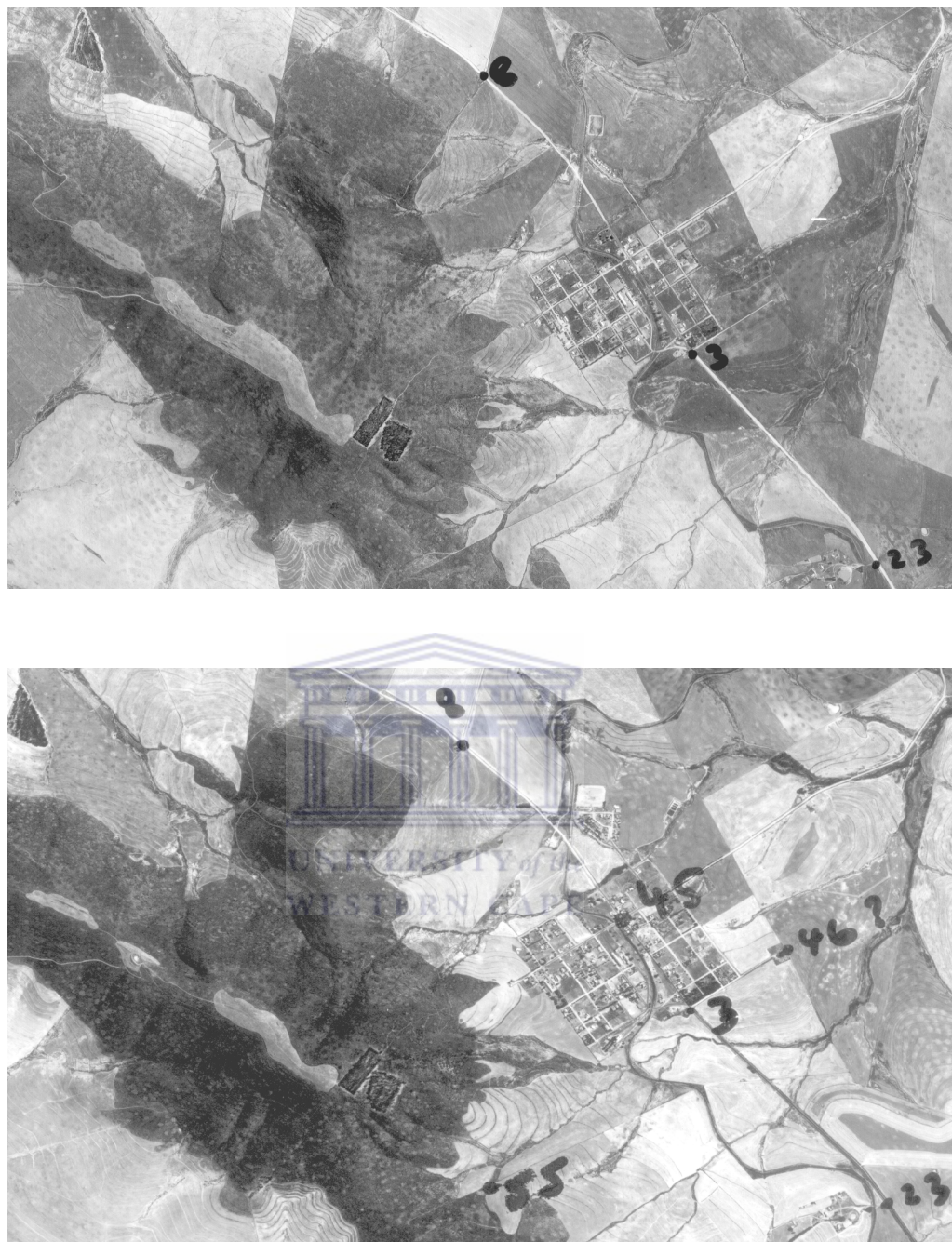


Figure 23. Aerial photograph of the Koringberg taken in 1968 (top) and 2000 (bottom), to show the reduction in the extent of cereal cultivation along its ridge. Numbers were used for rectification purposes and should be ignored.



Figure 24. Succulent character of the north-eastern slopes of the Koringberg.

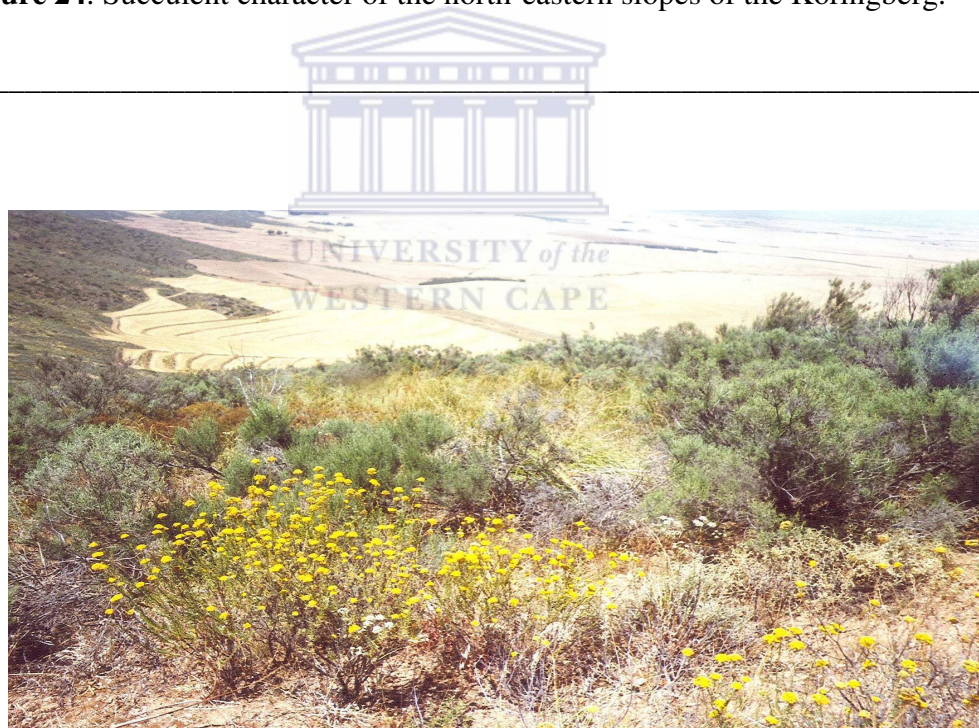


Figure 25. The shrubby Renosterveld character of the south-western slopes of the Koringberg.



Figure 26. Looking south-east towards the Swartberg, from the Koringberg. Note the circular grassy patches on the saddle.

heuweltjies (as dark or light spots) in the natural vegetation of the Koringberg. The aerial photographs were examined for evidence of the fire mentioned, but none were found. It is therefore likely that it occurred shortly after the 1988 photograph was exposed. Viewed from the hiking trail there was vague evidence of a vegetation boundary along the northern ridge of the Swartberg, but this does not show up in the photograph, and this boundary (if it is genuine) would need to be confirmed *in situ*. The aerial photographs from 2000, and the visit suggested that the vegetation had recovered.

Conclusion

This chapter looked at four Renosterveld sites, and how they had been affected by the activities of man over the past 60 years. Three of the four sites have a smaller area of natural vegetation now than in 1938, which conflicts with Duckitt's (1995) claim that the introduction of mechanization had led to an increase in the natural vegetation in the Darling area. The Elandsberg PNR was an exception, and the adjoining Voelvlei water-catchment reserve also had a larger area of natural vegetation than at the time the first photographs were taken. By 2000, the natural

vegetation on the Koringberg-Swartberg had decreased to about 80% of its 1938 extent, while the Contreberg was down to 67% and the Kapokberg to nearly half of its 1938 extent. All reductions in the surface area of natural vegetation after the introduction of the Conservation of Agricultural Resources Act (Act 43 of 1983) had been on land with slopes of less than the legal maximum.

What has not been assessed in this study is the quality of the remaining vegetation. Elandsberg is probably the area most resembling a pre-herder condition, although what the effect of two thousand years of intermittent stock grazing has been on that area is unknown. However, it has been mentioned that from a cursory examination (and the comments of other botanists), that much of the area would be better described as Fynbos than Renosterveld. The north-eastern slopes of the Koringberg have a definite karroid component, and could also not be described as typical Renosterveld. The return of the Kapokberg to a more diverse vegetation community after mechanically destroying a monoculture of dense Renosterbos was informative. The slow rehabilitation rate of previously ploughed lands back to Renosterveld shrublands in the Elandsberg PNR is a factor that needs to be considered when assessing new conservation areas. It will be interesting to monitor differences in the establishment of vegetation on the shale and alluvial soils of the new extension.

CHAPTER 4.

THE USE OF LANDSAT-7 ETM+ IMAGERY FOR LOCATING THE REMAINING FRAGMENTS OF WEST-COAST RENOSTERVELD.

A paper describing the development and verification of the fragment map described in this chapter has been published as:

Newton IP and Knight RS 2005. The use of Landsat imagery for the identification of the remaining West Coast Renosterveld fragments, Western Cape Province, South Africa. *South African Journal of Botany* 71(1): 67-75.

Abstract

The methods used to create a working map of the remaining West-Coast Renosterveld fragments larger than three hectares from Landsat-7 ETM+ imagery are described. Sources of various overlays (proposed original extents of Renosterveld, geology, soils, contours, roads, rivers etc.) are given. Rectification of the image and of the overlays used is discussed, and the artificiality of certain RMS (root mean square) errors identified. Field verification and classification errors are described. Sub-division of the Renosterveld class into three groups, based on the level of shrub cover helped to improve the classification. The results of several unsupervised classifications using seeding images made up of different spectral bands were examined. One of these was combined with the supervised classification to improve the fragment map. The problem of artefacts caused by a combination of early morning imagery and slope aspect was noted. Comparisons were made with other studies in the western lowlands, and it was concluded that the use of Landsat-7 imagery to identify West-Coast Renosterveld fragments was helpful, but not definitive.

Introduction

This chapter describes the methods, and the problems encountered, in the use of Landsat-7 ETM+ (Enhanced Thematic Mapper Plus) imagery to map the remaining fragments of West-Coast Renosterveld of three hectares or more in extent. The objectives of this map were:

1. To provide users with a tool to locate the remaining Renosterveld fragments for study or other purposes.
2. To enable estimates of the amount of West-Coast Renosterveld remaining to be made.
3. To provide a product that could be use for spatial and landscape analyses of the remaining fragments.

Landsat-7 ETM+ imagery has a moderate spatial resolution (30 m), and seven discrete spectral bands (Table 1). It has been used in numerous land-cover applications throughout the world, at a variety of scales, from the countrywide land-cover classification of South Africa (Thompson 1996) to the location of heathland fragments in Dorset (Veitch *et al.* 1995). It was first used within the Fynbos Biome to map vegetation boundaries in the Western Cape Province by Taylor and Boucher in 1973. The original publication was unobtainable, but a copy of the classification, which was predominantly of the western lowlands, was reproduced in Jarman *et al.* (1981). The imagery was classified using classical aerial photographic interpretation and mapping techniques. Ancillary data for vegetation (Acocks 1953) as well as soil and geological maps were used in its development (analysis methods from Margie Jarman, *pers. comm.*). In the early 1980's, Moll and Bossi (1984) used Landsat MSS (Multi Spectral Scanner) imagery to assess the area of natural vegetation remaining within the Fynbos Biome. They chose a minimum-mapping unit of 100 ha, and used both spectral (unsupervised and supervised) and manual interpretation techniques (Bossi 1983). Using this, they estimated that only 15% of the original extent of coastal Renosterveld remained, but this figure is for West, South and South-West Coastal Renosterveld combined (*sensu* Moll and Bossi 1984). In the mid-1990's, the Council for Scientific and Industrial Research (CSIR),

Table 1. Characteristics and uses of each of the spectral bands of the Landsat-7 ETM+ satellite (modified from Jensen 2000, and Lillesand and Kiefer 2000).

Band	Wavelength (μm)	Uses
1	0.45 to 0.52 (blue)	Designed for water body penetration. Useful for coastal water mapping. Supports land use analyses and soil/vegetation discriminations. Peak transmittance of clear water, and blue chlorophyll absorption levels both fall within this range.
2	0.52 to 0.60 (green)	Corresponds to the green reflectance of healthy vegetation. Also useful for cultural feature identifications.
3	0.63 to 0.69 (red)	Encompasses the red chlorophyll absorption band. Useful for soil boundary, geological boundary and cultural feature identifications. Less affected by the atmosphere than bands 1 and 2.
4	0.76 to 0.90 (near/reflective infrared)	Very responsive to vegetation type, biomass and vigour. Emphasizes soil/crop and land/water contrast.
5	1.55 to 1.75 (mid infrared)	Sensitive to water content of plants and soils. Can discriminate between snow and clouds.
6	10.4 to 12.5 (thermal infrared)	Thermal mapping applications – <i>e.g.</i> geothermal activity. Can also be used in vegetation stress and soil moisture studies.
7	2.08 to 2.35 (mid infrared)	Useful for geological discrimination between rock and mineral types. Also sensitive to vegetation moisture content.
8	0.50 to 0.90 (panchromatic)	Enhanced spatial resolution. Can be used to enhance the spatial resolution of bands 1 to 4 to 15 metres.

in conjunction with the Agricultural Research Council (ARC), produced a land-cover map of South Africa from Landsat TM imagery exposed between 1994 and 1996 (Thompson 1996). This was classified using manual interpretation techniques and had a minimum-mapping unit of 25 ha (except for a few very distinct features, such as dams, which were spatially resolved down to four hectares). An updated version was due for completion in 2005 (Anon. 2003c). The next Landsat classification of the Fynbos Biome was carried out by ARC for the Institute for Plant Conservation (IPC), in order to assess the Threats to the Biodiversity of the Cape Floristic Region (CFR) (Lloyd *et al.* 1999, Rouget *et al.* 2003). Although claimed to have a minimum-mapping unit of 25 ha (Lloyd *et al.* 1999, Rouget *et al.* 2003), the methods as described by Lloyd *et al.* (1999) suggested that a minimum-mapping unit of about three hectares would be more correct. This map was used in a number of studies related to the development of conservation plans for the CFR (*e.g.* Cowling *et al.* 2003, Pressey *et al.* 2003). A spin-off from this project was the mapping of the natural vegetation fragments remaining within the coastal Renosterveld regions for the Botanical Society of South Africa's lowland Renosterveld conservation project (von Hase *et al.* 2003). This was produced at single pixel (25 m) resolution, and a 3 x 3 majority filter was passed over it to remove isolated pixels (von Hase and Maze 2001).

Methods

The development of the fragment map was an iterative process. It was also a learning process for the author and so the steps that lead to the production of the final classification were probably not in the most efficient order. After each step, the results were examined and the next step was determined by the results obtained at that stage. Although the methods used were those described in the literature, each successive step was determined by what went before. For this reason, interim results are included within the methods section, so that the reader will know *why* the next step was carried out. The "results" section will concentrate upon the final fragment map. Unless otherwise stated, all analyses were carried out in Idrisi32 (©Clark Labs, Clark University, MA., USA.), using the integrated software modules.

Places referred to in the text are shown in Figure 1.

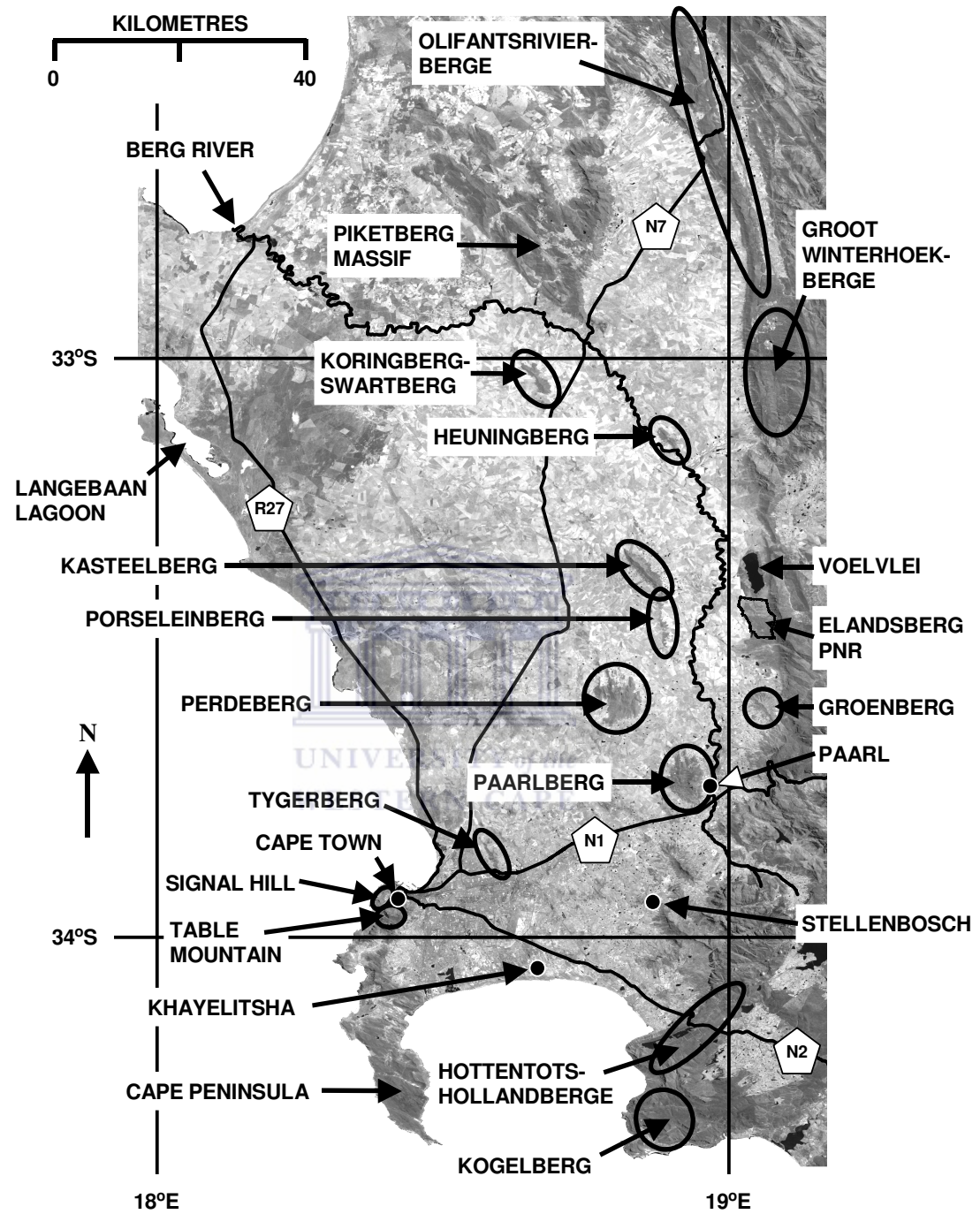


Figure 1. Landsat image showing the location of places mentioned in the text. National roads, west coast road and the Berg River are also shown.

Sources of data

The Landsat-7 ETM+ images were purchased from the United States Geological Survey (USGS) Eros Data Center, *via* their web site at <http://edcwww.cr.usgs.gov/eros-home.html>. The images were supplied as level 1 (systematic) corrected geotiff files. This level corrects for radiometric errors, orientates the image to north up (if required), geometrically locates the four corners of the image and provides a datum and projection (WGS 84 and Transverse Mercator in this case). The central meridian was set to 19.0° E, and the parallel of origin to 0.0° S. The scale factor was 1.0000. The images used were from Landsat path 175, rows 83 and 84, taken on the 2nd November 1999. A small amount (< 1%) of cloud cover was present over the south-central area, mostly to the west of, and over the southern part of, the Perdeberg. The images were imported Idrisi32, concatenated on geographic co-ordinates and cropped to exclude as much border, non west coast lowlands and ocean as possible. No radiometric corrections between the two images were made as they were taken within seven minutes of each other, and there were no visual differences between the two images along the join.

A digital elevation model (DEM), at a resolution of 60 m was donated by Cape Nature. This image was in Lambert Conformal Conic projection with two standard parallels (32° and 34° S). It was imported directly into Idrisi32, and resampled (RESAMPLE) to the same projection as the Landsat image. The RMS (Root Mean Square) error for this was 97 m. There were no direct transformation parameters available in Idrisi32, or in ER-Mapper (©Earth Resource Mapping Pty, Ltd, Perth, Australia) to rectify the DEM to the same projection as the Landsat image. It was used in the production of the initial field map, but was not used after that.

Topographic data at a scale of 1:50 000 (roads, rivers, 20 m interval contour lines) were purchased in Arc shape-file (©Environmental Systems Research Institute, Redlands, CA, USA) vector format, from the Chief Directorate: Surveys and Mapping in Mowbray. They were imported into MapInfo Professional version 5.5 (©MapInfo Corporation; USA) in order to “stitch” the files together, and to crop the product to the extent being looked at in this study. They were then exported to Idrisi32 in Mif/Mid format.

Geological maps at a scale of 1:250 000 (Anon. 1973, 1990, 1997) were purchased from the Council for Geoscience in Bellville. The relevant parts were digitized using a Calcomp (©Calcomp digitizer products division; Anaheim, Ca, USA) Model 34480 digitizer board and MapInfo software. The maps were converted to latitude-longitude format within MapInfo and exported in Mif/Mid format to Idrisi32. Two maps were produced, one depicting the actual formations (61 in all), the other combining the relevant formations into the six basic geological groups present in the area (Malmesbury Shales, Cape Granites, Alluvial soils, Table Mountain Sandstones [TMS], Quaternary Sands and Klipheuwel derivatives).

The soil map of Schloms *et al.* (1983) and the 1938 land-cover map of Talbot (1947) were digitized and imported in the same way as the geological maps. The soil map had no reference co-ordinates, and was therefore plotted as a non-earth coverage. It was resampled to a latitude-longitude format in Idrisi32. The RMS was 0.0026, equating to a positional error of approximately two metres. Talbot's (1947) map had a 15' interval co-ordinate grid and was digitized in latitude-longitude format.

The following published proposed original extents of West-Coast Renosterveld were used to help define the boundaries for this project.

1. The Broad Habitat Unit (BHU) vector map of Cowling and Heijnis (2001) was obtained from the Department of Biodiversity and Conservation Biology (BCB) at the University of the Western Cape (UWC). It was converted to latitude-longitude format in MapInfo and exported to Idrisi32. The image was rasterized, and (for the preliminary field map only) resampled to the same projection as the Landsat images. The RMS error for this was 67 m. It was used in latitude-longitude format for the analyses implying no user added positional error.
2. The "Vegetation of South Africa" classification of Low and Rebelo (1996) was also obtained in vector format from the BCB Department at UWC. It was converted to latitude-longitude format in MapInfo and exported to Idrisi32. It was not used for the preliminary map, as it was a sub-set of the two buffered classifications used.
3. The classification of Moll and Bossi (1984) was obtained by scanning the 1:1 000 000 scale map (Anon. 1983) into JPG format. It was imported into

MapInfo, and the west coast lowland regions were digitized on screen. Geo-referencing was carried out during the import procedure, as there was a 1° grid on the image. The main source of error in geo-referencing was due to the thickness of the co-ordinate lines, which made it impossible to determine precise crossing points. The poor print quality of the map was also a problem - the colours of different areas overlapped their apparent boundary lines, making it difficult to decide the true extents of the area. Further problems included the similarity between the colour code of West-Coast Renosterveld and of urban areas, as well as colour determination problems with small areas. This layer was used only for generalized comments about its author's results.

4. The West-Coast Renosterveld coverage from the map of Acocks' (1953a) veld types was digitized as described for the geology map. It suffered from the same misalignment problems between the veld-type boundary lines and the fill colours as the Moll and Bossi map (Anon. 1983).

5. For the preliminary map, the Renosterveld distribution map published in McDowell and Moll (1992) was scanned into bitmap format and imported directly into Idrisi32, where it was geo-referenced to the Landsat classification. The RMS error was in the region of 450 m. Although used for the preliminary map, It was decided that it was unsuitable for the later analyses. The original map (McDowell 1988) was therefore digitized in the same manner as for the soil map. The vector image was exported to Idrisi32, where it was geo-referenced against the Landsat panchromatic image (latitude-longitude format), this time to a RMS error of 0.0018, which relates to a ground error of approximately two metres.

The suggested original extents of West-Coast Renosterveld encompass a wide moisture gradient, from 300 mm per annum in the north-west to 800 mm in the south-east. Along the Cape Fold Mountains rainfall increases steeply and more than 2000 mm per annum is experienced. The eastern boundary of West-Coast Renosterveld abuts the lower slopes of these mountains. Apart from the localized high orographic rainfall that these border areas receive, there is also the question of run-off from the mountains. Wet and dry soils have different reflectance values, in particular in the red and near-infrared reflectance bands, which are important for identifying plant cover (Jensen 1996, Jensen 2000). In view of this, the west coast

lowland rainfall data for the period 1982 to 2001 was obtained from the South African Weather Services (see Chapter 2 for source details). These were examined to see what rainfall conditions existed before the exposure of the Landsat imagery, and before the field verification trips.

Classification of the preliminary field map

The success of a classification was determined by its apparent ability to reflect the true land-cover situation within those areas generally considered to be West-Coast Renosterveld. To perform the supervised classifications, it was necessary to create other classes in order to isolate the Renosterveld. To estimate the number of distinct land-cover classes present within the scope of the imagery, a number of quick, histogram-peak cluster analyses were performed. The option chosen was for a fine generalization clustering, with the least significant 1% of clusters dropped. Several 24-bit and 8-bit, three-band BGR (blue-green-red) composite images were produced using different combinations of the raw spectral layers, as well as using ratioed (*e.g.* Normalized Difference Vegetation Index [NDVI]) and component (Principal Component [PCA] and Tasseled-Cap [TC]) image bands. The 24-bit images were used for visual inspection of the area, while the 8-bit images acted as seeding images for the unsupervised classifications. This exercise suggested that 12 main classes existed within the full extent of the imagery used.

Classes other than Renosterveld were based upon logical land-cover units, but were coarsely defined. For example, the urban class was not divided into commercial, industrial and residential; Fynbos was not divided into Mountain and Lowland Fynbos, *etc.* The two agricultural classes defined were cereals, which had mostly been harvested at the time the image was exposed, and were thus represented by low and dead, or absent vegetation cover, and a “greener” vines/pasture/orchards/market-garden class. This second class was referred to as the “green/irrigated” class due to its high band four reflectance, relative to the heath and shrubland vegetation of the area. It also incorporated (due to the similar high moisture regime), broad-leaf forests, such as on the eastern slopes of Table Mountain.

The quality of the supervised classifications was assessed upon their agreement with visual (manual) interpretations of the Landsat panchromatic band, of the various 24-bit three-band colour and false colour composites produced, and upon the fragment map of McDowell (1988). A classification was considered good if the majority of McDowell's sites were classified as Renosterveld, and there were not too many obvious Renosterveld misclassifications (it must be remembered that the aim of this exercise was to locate Renosterveld remnants and not to produce a detailed land-cover map). The aim of the first classification was to identify the majority of the Renosterveld remnants and would be later refined, based upon the information gleaned from field verification. The preliminary map (described below) definitely identified 45 of the 55 sites mapped by McDowell (1988), and apparently located the other ten as well. The reason for the uncertainty of identification in the last ten cases was due to their location not being well defined.

The supervised classifications were carried out at the supplied pixel resolution of 30 m. In order to incorporate the thermal band into the classification, it was expanded to a 30 m resolution. No smoothing of this expanded layer was performed. The classification method used is a maximum likelihood procedure, based on Bayesian probability theory. Variance and co-variance information from the training site signatures is taken into account when classifying an image with this method (Eastman 1999). By using prior probabilities, the classifier is informed as to the relative amount of the image that is likely to be covered by a particular class. (Eastman 1999). Table 2 gives the prior probability values used in this classification. Classification was an ongoing process with the training areas being updated after each classification, until a satisfactory level was reached.

In addition to the supervised classification using the raw Landsat bands, eight classifications using bands that had been pre-processed with one of the low-pass (smoothing) filters mentioned below were tried. The filters used were:

1. Mean filters of 3 x 3 and of 5 x 5 cells.
2. Mode (majority) filters of 3 x 3 and of 5 x 5 cells.
3. Gaussian filters of 5 x 5 and of 7 x 7 cells.

Table 2. Classes used in the Landsat supervised classification, along with their prior probability values. The list is in class priority order (see text for explanation).

Land-cover class	Prior probability
Renosterveld	0.01
Fynbos	0.15
Thicket	0.03
Green/irrigated vegetation	0.02
Rivers	0.01
Agriculture (mostly harvested fields)	0.25
Plantations (conifer)	0.01
Urban	0.05
Open water	0.40
Sand	0.01
Beach (coastline)	0.01
Border (from orientation process)	0.05

4. Median filters of 3 x 3 and of 5 x 5 cells.

Pre-processing the raw bands with a Gaussian 7 x 7 or a median 3 x 3 filter appeared to give the best visual results, although the Gaussian 5 x 5 and median 5 x 5 filters also appeared good. The mean and mode filters allocated an unacceptable level of the “urban” class to areas that were undoubtedly agricultural, a problem that was also prevalent when the raw bands were used. None of the classifications using ratioed bands, Principal Component bands, or bands treated with textural filters improved the identification of Renosterveld fragments. Jensen (1996) reported that investigations into the incorporation of bands treated with textural filters into spectral classifications had concluded that most filters did not improve the classifications. Those that had helped were complex filters that were not available within the Idrisi32 package.

It was decided to use a classification based upon the combination of two separate classifications, one using bands that had been pre-processed with a Gaussian 7 x 7 filter, the other using bands that had been pre-processed with a median 3 x 3 filter. The two classifications were combined on a “priority” basis. To do this, the land-

cover types were ranked according to their importance to this particular study. The Renosterveld class was given top priority – if it occurred in a pixel in one of the classifications but not the other, that pixel would be classified as Renosterveld. To remove isolated land-cover pixels the combined classification was treated with a 3 x 3 mode (majority) filter.

Production of the preliminary field map

Three sets of ancillary data were used to establish the boundaries of Renosterveld in the preliminary field map. These were the vegetation maps of McDowell and Moll (1992) and of Cowling and Heijnis (2001), and the Cape Nature DEM. The preliminary field map was produced in the supplied Transverse Mercator projection, and the ancillary data were re-projected to fit. To ameliorate the errors developing from rectification, a mask was created by adding buffer zones around the projected extents. The boundaries of McDowell and Moll's (1992) proposed Renosterveld zone were enlarged by two and a half kilometres, while that of Cowling and Heijnis (2001) was enlarged by a 500 m. These two enlarged extents were added together using the logical OR operator, so that the final coverage was the sum of the two areas. This area was then multiplied (logical AND) with an elevation mask, to exclude all areas above 500 m. What remained was a mask that was considered to encompass the West-Coast Renosterveld area, and which was deemed suitable for field verification purposes. A vector line layer of this boundary was produced, converted to raster format (at the same resolution as the other images), and a buffer of 30 m (*i.e.* one pixel) established either side of the line to give it a final width of three pixels. This boundary image was then reclassified so that the background had a value of zero, and the line a value of 250.

The priority classification produced from the combined Gaussian 7 x 7 and median 3 x 3 classifications was then multiplied (logical AND) with the Renosterveld mask described in the previous paragraph. This removed all land-cover classes outside of the area of interest. This image was used to produce two separate images, one only showing fragments classified as Renosterveld, the other only showing fragments classified as Fynbos or Thicket. This was done by reclassing all the unwanted classes to the background value of zero.

The panchromatic image (band 8) of the area was contracted to a 30 m resolution by averaging. It was then histogram stretched to a range of 0 to 249. The boundary line image was then added, thus delineating the study area.

A 24-bit composite image was formed, using the contracted panchromatic image as the green band, to form a “background”. The Renosterveld and the Fynbos/Thicket images were added as the blue and red bands respectively. An attempt to use vector overlays had proved unsuccessful, as the polygons completely obscured the background. Although the blue and red raster layers were not as transparent as desired (unless the background was light), it was usually possible to “read” locations from the background, and thus relate fragments to their ground position. The image was divided into separate north and south region images, and exported as enhanced windows metafiles (EMF) to PowerPoint (©1987-1996, Microsoft Corporation). This was for A0 prints to be made at a commercial concern. The 30 m pixel resolution panchromatic image (without boundary lines) was similarly divided, exported and A0 prints made. The quality of the composite image prints was not as good as hoped, but they were suitable for field use.

It was this preliminary map, along with the 2001 field notes that were supplied to the Botanical Society for their Cape lowlands Renosterveld project (von Hase *et al.* 2003). They combined the northern part of this map with the southern part of the “Threats to the Biodiversity of the CFR“ map (Lloyd *et al.* 1999) to produce their working map.

Field Verification

Most field verification was carried out in the second half of November and early December 2001, although some areas were only visited in October and November of the following year. Harvesting was still in progress in some areas (2001), although most had been taken in. Approximately 80% of the identified remnants were cursorily checked for classification accuracy. Each “Renosterveld” area visited was classified into one of the basic vegetation types (described in Appendix B) with the naked eye, or with the use of 10 x 50 binoculars from the road. The community structure, and not the community composition, was recorded. The exact boundaries

of the Renosterveld patches were not established, as it was beyond the scope of this project to check the boundaries of every Renosterveld patch encountered. If a patch looked like it could have been Renosterveld in 1999, the classification was considered correct. It was considered incorrect when it was clear that the 2001 vegetation pattern could not have evolved from the 1999 pattern. For example, the stand of mature, open canopy Stone Pines on Signal Hill, classified as Renosterveld, had obviously not developed within the previous two years. The three areas at which the local time-series analyses were done (see Chapter 3) were visited in October 2002. Clarification of some of the areas checked in 2001 was also done at this time, as an improved version of the map was available by then.

Resampling the classification to decimal degrees

Although ground control points (GCP) were collected during field verification, they were not used to transform the imagery to a latitude-longitude format. For reasons discussed later, the “roads” vector layer was used. Eighteen major road junctions spread around the western lowlands were chosen. The co-ordinates of these junctions, both from the roads vector layer and from the panchromatic image were determined, entered into a correlation file and the panchromatic image resampled. The removal of four of the GCP resulted in a RMS error of 15.57 m, which was considered accurate enough for this project. A quadratic mapping function with bilinear resampling was used. The final image covered an area stretching between the co-ordinates of 32.404652°S, 17.966667°E and 34.4166985°S, 19.172291°E (32°24'16.75"S, 17°58'0.00"E, 34°25'0.11"S, 19°10'20.25"E).

The other Landsat bands, maps and images were re-sampled to a latitude-longitude format using the same correlation file and mapping functions. This means that, at the resolution (30 m) at which this study was carried out, the mean positional error is just over a half a pixel. It should also be added that, since the study was finally restricted to fragments of 3 ha or more (~ 34 pixels), the positional error is effectively insignificant.

Post field-verification processing

Following comments from interested parties, and information collected in the field, further classification methods were tried, in order to improve the classification. The south-eastern part of the region in particular had many small fragments classified as “Renosterveld” that might better be described as wasteland. These mainly consisted of combinations of alien grasses, alien *Acacias* or Eucalypts and weeds of cultivation *etc.*, although indigenous species such as the Renosterbos (*Elytropappus rhinocerotis*) were sometimes present. The Fynbos class had also incorporated many vineyards and dense stands of alien trees. It was also noted during the field trips that fragments classified as Renosterveld had varied from dense *Elytropappus* dominated vegetation (*e.g.* parts of Voelvlei), through open Renosterveld to almost pure grassland, in addition to the wasteland vegetation mentioned. This knowledge was used to modify the Renosterveld training sites into dense Renosterveld (> ~ 75% shrub canopy cover), open Renosterveld (~ 25% to ~ 75% shrub canopy cover) and grassy Renosterveld (< ~ 25% shrub canopy cover). The Maximum likelihood classifier with prior probabilities was run again (on the same pre-processed bands used for the preliminary map) and the result examined. This reclassification did not identify Renosterveld fragments with as much success as the preliminary classification. It did however provide a means of reducing the presence of the grassy wasteland fragments in the south-east of the region. To do this, the Renosterveld sub-classes from this second classification were incorporated into the preliminary classification, so that there was no loss of the original Renosterveld area, which the field verification had generally shown to be good. The original Renosterveld class and the “open Renosterveld” class of the second classification were combined into a “Renosterveld” class. The “dense Renosterveld” and “grassy Renosterveld” classes were then added, each having priority over all other land-cover classes, including the new “Renosterveld” class. This allocated many of the grassy wasteland areas of the south-east to the “grassy Renosterveld” class.

The spectral signature files (Figure 2) illustrates that the spread of the Fynbos class incorporated most of the other natural vegetation classes. In addition, the Fynbos class was still incorporating certain agricultural components, particularly vineyards. The diversity of Fynbos structure and community composition varies even more

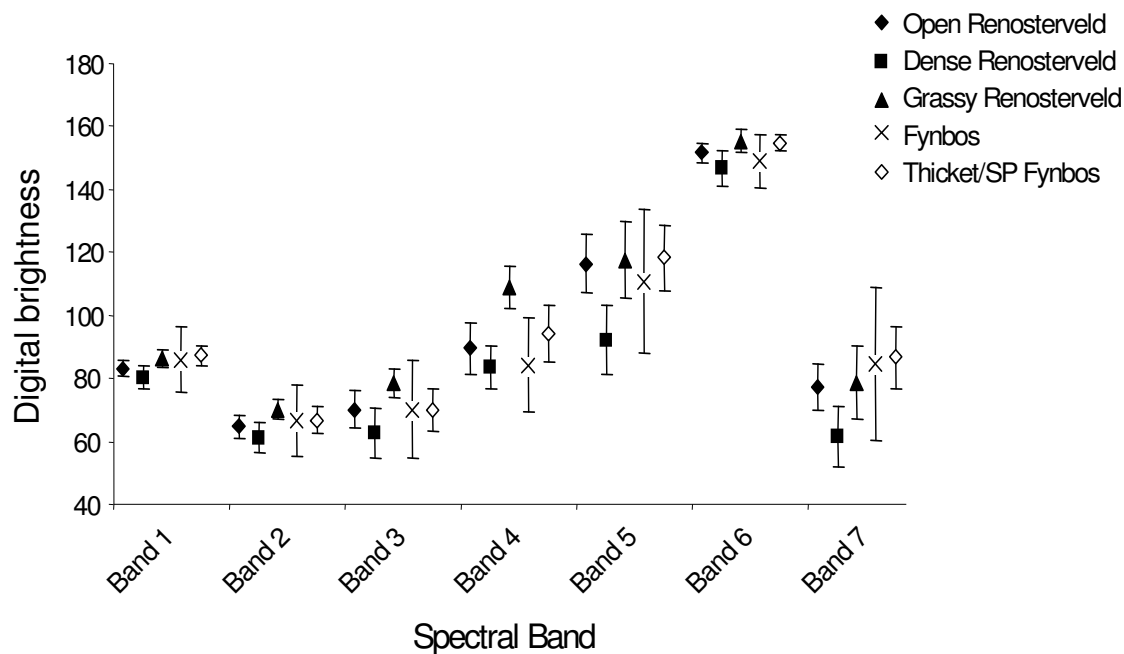


Figure 2. Spectral signatures (mean \pm 1 standard deviation) of the natural vegetation classes used in the revised supervised classification.

Thicket/SP Fynbos = Thicket and Sand Plain Fynbos.

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than that of Renosterveld, from grassy firebreaks, to areas dominated by Restioid type species, and from Ericoid heathlands to Proteoid woodlands. In terms of this project, there was neither the time, nor the necessity to delve into the spectral differences within Fynbos, but it was decided to use a series of unsupervised classifications to see to what extent Renosterveld (and its sub-divisions) were genuinely spectrally divisible from Fynbos proper.

The algorithm used by the Idrisi-32 software is based upon a combination of the ISODATA routine of Ball and Hall, and other cluster routines such as the H-means and K-means procedures (Eastman 1999). A three-band eight-bit composite seeding image is used to produce a histogram identifying the number and importance of the spectral classes identified within the extent of the image. Using the histogram as a guide, the user selects the number (N) of classes to appear in the classification and the "ISOCLUST" routine begins. A set of N clusters is arbitrarily located in band

space within the region of high frequency reflectances. The same maximum likelihood procedure used in the supervised classification is used to assign each pixel to a cluster. After all the pixels have been assigned to one or other of the clusters, new means are calculated for each cluster and the process of pixel allocation is repeated (Eastman 1999). With some software packages, the iterations continue until a minimum level of change between iterations is reached (Jensen 1996). Idrisi32 only offers the user the choice of the number of iterations to be performed. Three iterations of the "ISOCLUST" module are recommended in most circumstances (Eastman 1999). Nevertheless, an investigation into the effect of changing the number of iterations was carried out, using a 17-cluster, bands-2,3,4 seeding image and the raw Landsat bands. Three, six, ten, twenty and forty iteration unsupervised classifications were performed, and the results compared.

Two "ISOCLUST" analyses were also performed on imagery that had been degraded to resolutions of 0.8 ha and of 9 ha. To get the 0.8 ha resolution, each raw Landsat band was contracted by a factor of three in both the x and y directions, using an averaging routine. In the case of the 9 ha image a contraction factor of ten was used. In both cases this was done using both the raw Landsat bands, and the bands that had been pre-processed with a Gaussian 7 x 7 filter. The reason for trying the analyses using "degraded" imagery was twofold. The first was that, by degrading the image using an averaging routine, extremes of spectral values within each class should be further reduced, possibly leading to a better separation of classes. This would have a similar (but more dramatic) effect to the filter pre-processing procedures used. The second reason was to be able to directly compare the results (if different to the 30 m resolution analyses) with those of Jarman (1981) and Bossi (1983).

A further "ISOCLUST" classification was performed only within that area defined as Renosterveld by previous authors. Seventeen clusters were again requested. Because this area is smaller and incorporates less landscape variations (particularly relief) than the full image, the spectral classes could consider finer differences.

"ISOCLUST" classifications were also carried out on the south-eastern part of the image, to see if the wasteland patches were spectrally distinct within the sub-region.

Finally, an “ISOCLUST” analysis was carried out just on the Renosterveld class as determined from the first supervised analysis. That is, a mask was produced, which assigned a value of zero to all except the Renosterveld class. This mask was then used on all the raw satellite bands, converting non-Renosterveld areas to zero. A three-band colour composite was produced to act as a seeding image for an “ISOCLUST” analysis. Five clusters were defined (based upon a histogram of spectral groups) and the “ISOCLUST” module run. The masking and classification process was then repeated using only that area allocated to the main cluster identified (cluster 2). Four clusters were requested. Finally, the area defined by the major cluster (again cluster 2) from this second classification was masked and reclassified. The reason for this was to determine whether the wasteland in the south-eastern region, which had been classified as Renosterveld in the supervised classification, was genuinely spectrally indistinct from “true” Renosterveld.

The Idrisi32 “ISOCLUST” module appeared to have a problem with the algorithm, which sometimes caused it to abort or produce abnormal results when requests for 10 or more iterations were requested. For this reason, two unsupervised classifications were carried out in ER-Mapper. Although based upon the same principles as that used by the Idrisi32 module, no seeding composite image is used (all bands are used to calculate the initial seeding clusters). The technique differs in that, rather than setting the number of iterations to be performed (although this can be done), the process stops when a fixed percentage (98% was chosen in this case) of the clusters remain unchanged between iterations. In order to be able to directly compare the results with those of the Idrisi32 module, the process was run twice, using 17 and 25 clusters.

Production of the final fragment map

To produce the best possible map, information from both the supervised and the unsupervised classifications, as well as field information were used. The Fynbos class from the supervised classification had clearly included a lot of agricultural land, particularly in the south-east of the region. To correct this, the supervised Fynbos class was overlaid by the agricultural class (cereals, vines and orchards) of the “ISOCLUST” bands-2,3,4, 17-cluster unsupervised classification. Where there

was an overlap the area was classified as agriculture. This appeared to correct most of the original misclassifications and this modified Fynbos class was the one used in all the analyses.

None of the unsupervised classifications successfully discriminated between Fynbos and Renosterveld, and the results generally showed a class of natural vegetation that was predominantly found in highland areas (“Highland Fynbos”) and a class predominantly found in lowland areas (“Lowland Fynbos”). A third cluster, closely associated with steep south-west-facing mountain slopes was also frequently identified. It was rarely found in the lowland areas and was thus combined with the general “Highland Fynbos” cluster for the production of the fragment map. Further references to “Highland Fynbos” include this cluster. The characteristics of this south-west facing Fynbos class will be discussed later.

Of all the unsupervised classifications, the bands-2,3,4, 17-cluster one appeared to reflect the distribution of natural vegetation within the region the best, and was combined with the revised supervised classification to further improve the fragment map. The Fynbos classes, as identified in the bands-2,3,4, 17-cluster unsupervised classification were overlaid with the five natural vegetation categories of the revised second supervised classification (dense Renosterveld, open Renosterveld, grassy Renosterveld, Fynbos, Thicket). As there was so little of the Thicket class present within the Renosterveld area, it was combined with the supervised Fynbos class. This gave 14 different class combinations *e.g.* “Dense Renosterveld - Highland Fynbos” where dense Renosterveld from the supervised classification overlapped with Highland Fynbos from the unsupervised classification. Areas where the supervised and unsupervised natural classes overlapped were classified according to the nomenclature from the supervised classification. Patches occurring in only one of the classifications were temporarily considered as being of the class specified.

From this point, the Fynbos and the Renosterveld classes were processed separately. Within the Fynbos and Renosterveld classes, each fragment was allocated to a “high probability” or “low probability” class. Where the dense Renosterveld or the open Renosterveld classes overlapped with either of the Fynbos classes from the unsupervised classification, this was classed as high probability Renosterveld. In addition, all areas classified as dense Renosterveld in the supervised classification

(but which did not overlap with a Fynbos class in the unsupervised classification) were included as high probability Renosterveld. The map containing only “Renosterveld” fragments was then divided into two sections, north and south of the 33.8° S line of latitude. The areas classified as open Renosterveld in the supervised classification (but which did not overlap with a Fynbos class in the unsupervised classification), in the northern section only, were added as high-probability Renosterveld. In the southern section, they were added as low probability Renosterveld. The grassy Renosterveld class in the northern section (including its overlap with either of the unsupervised Fynbos classes) was added, but as low probability Renosterveld. All fragments classified as grassy Renosterveld in the southern section were deleted.

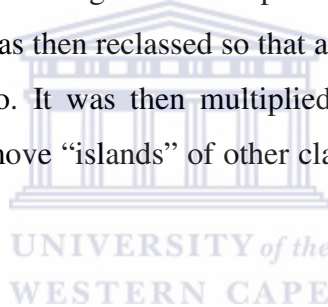
Where the Fynbos classes from the two classifications overlapped they were considered high-probability Fynbos. In addition, the Fynbos classes from the unsupervised classification, that did not overlap one of the natural vegetation classes from the supervised classification, were also considered high-probability Fynbos. The Fynbos areas (including Thicket) from the supervised classification, which did not overlap with Fynbos of the unsupervised classification, were added as low probability Fynbos. The Renosterveld and Fynbos probability maps were then recombined to produce the “Spectral Probability Map”.

A problem that became evident at this stage, was that there were patches of natural vegetation that were made up of more than one of the 14 natural vegetation sub-classes. Combined they were larger than 3 ha, individually they were less, and would therefore be lost from the final fragment map. To avoid this, a separate map was made which considered all of the natural classes as a single class (“natural”). This map was used for all the analyses that were carried out (except for the spectral probability analyses). This map was termed the “Revised Compound Map” and it defines the “natural” class used in the subsequent analyses. These two maps (and the geological/edaphic probability map developed in the next chapter) were used to discuss landscape patterns and definitions of Renosterveld (see Chapter 5).

The reason Renosterveld is so endangered is because it occurs on land that is ideal for agriculture, *i.e.* it is mostly flat, and the soils are relatively nutrient rich. Most of the remaining fragments are ostensibly on hills and slopes, usually too steep to

plough. In order to provide evidence for this hypothesis, it was necessary to obtain statistics from the agricultural areas to compare them with the Renosterveld areas. Therefore, two agricultural images were produced, also with a minimum fragment size of three hectares. One incorporated the predominantly dryland agriculture (cereal) areas, the other reflected pastures, vineyards and orchards (designated “vines” from here). The cereal classes from both classifications were combined (Boolean OR), while the pasture/vineyard class was taken only from the unsupervised classification, as it was felt that this category was not distinct enough in the supervised classification.

To remove patches smaller 3 ha, the three separate images of the major classes (natural, cereals and vines) were each processed in the following manner. The land-cover of interest was assigned a value of one, and other land-cover units a value of zero. A unique number was assigned to each patch and the area of that patch (in ha) calculated. This image was then reclassified so that all fragments less than 3.0 ha were assigned a value of zero. It was then multiplied by its original fragment image (“AND” operator) to remove “islands” of other classes occurring within a fragment of the designated class.



Results

Initial classification and field verification

The quick, preliminary unsupervised classifications using seeding composite images based on the raw image bands showed 11 to 15 main classes. The seeding composite made up of the three bands produced by the TC transformation (Wetness = blue, Greenness = green and Brightness = red) produced 20 classes. Ignoring the classes that fell outside of the land area (sea, image borders), the number of classes varied between 7 (bands-1,2,3 composite) and 13 (bands-7,3,4 composite), with 16 for the TC composite. When these classifications were examined, there were usually between one and three classes restricted to areas of intense agricultural activity and two to natural areas (although there were other classes that overlapped these and other land-cover types).

The initial supervised classification, based upon the raw image bands gave an unsatisfactory classification. A major problem was that the urban class was over-represented. This was due to two factors. The first was the high variability of urban areas. The second was initial, rather liberal, urban training sites, which included areas of greenery in the urban class. This probably accounted for a high “urban” presence along rivers. The refining of the urban (and other) training sites removed a great deal of this problem, but not to a satisfactory level, which was why the smoothing filters were used.

The level of agreement for each class in the two classifications that were combined to produce the preliminary land-cover map is shown in Table 3. It can be seen that, of the major classes, the natural areas in general, and the Renosterveld area in particular do not show a high level of agreement between the classifications. The biggest confusion was between Renosterveld and Fynbos. The reason for this will become clear when the spectral signatures (Figure 2) are examined, and the unsupervised classifications are discussed later. There was a small amount of confusion between Renosterveld and “green/irrigated” vegetation, which may be attributed to seeps or unresolved wet areas within the Renosterveld training sites. Alternatively, it may have been due to the presence of Thicket species (*e.g. Rhus*). Although the actual extent of confusion between Fynbos and the “green” areas was greater than between the “green/irrigated” and Renosterveld classes, it was proportionally less. The confusion between Renosterveld and cereals may be explainable in terms of the long borders between the two classes, leading to a difference in boundary allocations by the two different filters, as well as recently-burnt areas of Renosterveld, such as at Elandsberg. The cereal class appeared to be very distinct, with a maximum of about six percent disagreement between the classifications.

Field verification was largely confined to the Renosterveld remnants, with occasional notes on the other natural classes, where these were considered important (see Appendix B). A detailed description of the field verification and accuracy levels is given in Newton and Knight (2005). A summary (including Table 4, which is taken from Newton and Knight 2005) is given in the next three paragraphs.

Table 3. Cross tabulation of land-cover classification agreement between “MAXLIKE” classifications of the Landsat image after treatment with a 7 x 7 Gaussian filter or a 3 x 3 median filter. Columns are the Gaussian classification, rows the median classification. Values are in square kilometres. Areas are for the full extent of the image. The overall Kappa index of agreement is 0.9059.

	Renoster- veld	Fynbos	Thicket	Green	River	Cereal	Plantation	Urban	Sand	Beach	Total
Renosterveld	754.4	268.6	3.1	20.9	0.1	38.0	0.0	3.3	0.0	0.0	1088.4
Fynbos	105.6	5249.9	21.9	88.7	0.8	237.1	2.4	32.7	0.0	0.0	5739.1
Thicket	7.7	160.4	523.7	0.3	0.0	2.6	0.0	0.5	0.0	0.0	695.2
Green	30.5	196.4	0.6	1127.7	0.6	16.3	3.4	12.2	0.0	0.0	1387.6
River	2.4	7.6	0.0	6.1	90.7	1.9	0.0	1.1	0.0	0.0	109.7
Cereal	6.2	159.5	1.2	11.5	0.0	8148.6	0.0	10.2	0.0	0.0	8337.2
Plantation	0.5	14.8	0.0	38.3	0.0	0.0	64.4	0.5	0.0	0.0	118.4
Urban	13.5	112.9	0.2	15.6	1.2	116.7	0.0	616.6	0.0	0.0	876.8
Sand	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	7.6	10.1
Beach	0.5	13.6	0.0	2.6	5.2	50.4	0.0	7.7	0.2	0.3	80.5
Total	921.2	6183.6	550.7	1311.6	98.6	8614.1	70.3	684.7	0.2	7.9	18442.9

Once an image has been classified, it is normal to produce an error matrix, in order to determine the level of reliability that can be placed upon the result. It became clear during field verification, that this was not going to be easy. The first problem was that there were differences between regions. In the northern and central parts (Swartland), it was mainly shrublands with a predominance of fine-leaved shrubs that had been classified as Renosterveld. Shrublands with a preponderance of broader-leaved species (*Protea*, *Rhus* etc.) and alien vegetation (*Acacia*, *Eucalyptus*) were mainly classified as Fynbos, or as “green” vegetation if they occurred in wetter areas. In the south-eastern region, grassland with scattered trees (mainly alien *Eucalypt* and *Acacia* species) was often identified as Renosterveld. Apart from an area around Saron, very little woody alien invasion of Renosterveld was noted north of Malmesbury.

A second problem was the difficulty in assigning a weight to a classification. For instance, the eastern foothills of the Piketberg were examined from a series of selected points. As the Piketberg slopes are a mixture of Fynbos and Renosterveld, which according to Linder (1976) are strictly partitioned on soil type, does the presence of natural vegetation along the full extent of this massif count the same as a small patch in the Stellenbosch area? Table 4 shows that 78.8% of the “Renosterveld” fragments identified in the final fragment map were natural vegetation with a minimum amount of woody alien cover, and of those 69.5% could be described as “true” Renosterveld. Although 10.7% of the fragments identified as Renosterveld in the preliminary classification were found to be areas that had been significantly invaded by woody alien species, this had been reduced to 6.8% in the final fragment map. Other misidentified land-cover units were dense tree infestations (Pines, Eucalypts, Acacias), which were present in 8.7% and 5.1% of the sites in the preliminary and final classifications respectively. Grasslands with scattered indigenous bushes made up the remaining land classified as Renosterveld. When the area, rather than the number, of the fragments classified as Renosterveld was considered, the amount of “true” Renosterveld identified dropped to 60.4%, but the total natural vegetation increased to 81.6%, while natural grasslands also increased from 9.3% to 11.1%.

Table 4. Vegetation structure recorded at 149 sites classified as Renosterveld in the preliminary supervised classification, the number of these remaining in the final fragment map, and the number present in each class of the unsupervised classification that was combined with the supervised classification to form the final map. For the final fragment map, it also shows the total number and area of the fragments sampled within each structure class.

Vegetation structure	Preliminary Classification		Unsupervised classification				Final fragment map					
	Number of samples	% of total samples	Highland class		Lowland class		Number of samples	% of total samples	Number of fragments sampled	Total area (ha) of fragments sampled	% of total number of fragments sampled	% of total area of fragments sampled
			Number of samples	% of total samples	Number of samples	% of total samples						
Renosterveld structure ¹	64	43.0	12	42.9	33	45.8	56	47.5	50	14852	48.1	35.4
Dense Renosterveld ²	15	10.1	2	7.1	8	11.1	15	12.7	13	4925	12.5	11.7
Medium density Renosterveld ³	7	4.7	0	0.0	6	8.3	7	5.9	7	2898	6.7	6.9
Very sparse Renosterveld ⁴	1	0.7	0	0.0	1	1.4	1	0.8	1	1815	1.0	4.3
Succulent Renosterveld ⁵	4	2.7	0	0.0	4	5.6	3	2.5	3	852	2.9	2.0
Grassy/herbaceous	15	10.1	3	10.7	7	9.7	11	9.3	9	4661	8.7	11.1
Proteoid structure ⁶	5	3.4	2	7.1	1	1.4	4	3.4	3	2532	2.9	6.0
Low Fynbos ⁷	8	5.4	2	7.1	5	6.9	6	5.1	3	6339	2.9	15.1
Thicket ⁸	1	0.7	0	0.0	1	1.4	1	0.8	1	17	1.0	0.0
Trees predominating ⁹	13	8.7	4	14.3	2	2.8	6	5.1	6	1160	5.8	2.8
“Wasteland” ¹⁰	16	10.7	3	10.7	4	5.6	8	6.8	8	1892	7.7	4.5
Total	149	100.0	28	100.0	72	100.0	118	100.0	104	41944	100.0	100.0
Total Renosterveld	91	61.1	14	50.0	52	72.2	82	69.5	74	25343	71.2	60.4
Total other natural	14	9.4	4	14.3	7	9.7	11	9.3	7	8889	6.7	21.2
Total natural shrub	105	70.5	18	64.3	59	81.9	93	78.8	81	34231	77.9	81.6
Total “Wasteland”	16	10.7	3	10.7	4	5.6	8	6.8	8	1892	7.7	4.5
Total trees	13	8.7	4	14.3	2	2.8	6	5.1	6	1160	5.8	2.8
Total grass/herbaceous	15	10.1	3	10.7	7	9.7	11	9.3	9	4661	8.7	11.1

Table 4 footnotes

¹ A single stratum of shrubs, may have grass patches scattered within it. Where emergent shrubs occur, these are non-Proteoid (*e.g. Rhus, Chrysanthemoides, Olea, Euclea*). Shrub density not recorded.

² As for “1” above, but percentage canopy cover (PCC) of shrubs greater than 75%.

³ As for “1” above, PCC between 25% and 75%.

⁴ Total vegetation cover less than 20% - only encountered in the Elandsberg private nature reserve (PNR).

⁵ A substantial component of succulents (*Euphorbia, Cotyledon, Aizoaceae*).

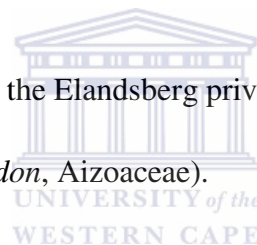
⁶ Two strata of shrubs, the emergents belonging to the Proteaceae.

⁷ Stratum of low shrubs, but typically non-Renosterveld groups (*e.g. Proteaceae, Ericaceae, Restionaceae*). In some cases the low height may have been due to fires within the previous three to four years.

⁸ Quite dense non-Proteoid shrubs, such as found along runnels on hills.

⁹ Large trees predominating. Either invasive species from nearby plantations (Pines, Eucalypts), dense growths of alien Acacias or suburban areas with many trees, the latter class mainly noted in the Stellenbosch region.

¹⁰ Typically grassland with less than 50% PCC of alien Acacias or Eucalypts.



These results suggest a user's accuracy of greater than 80%, the actual figure depending upon the user's search requirements. That is to say, 80% (or 90% if grasslands are also included) of the fragments identified could be considered reasonably "pristine". If degraded sites are also being considered, then the accuracy of the classification could be considered as greater than 95%. No natural vegetation patches of significance were seen during field verification that had not been identified by the classification. Fragments noted during the verification phase that had not been identified by the classification were found where strip farming was practiced (and hence the fragment was very thin), or along steep, but narrow hill slopes *i.e.* if viewed from directly above, their width would be less than 30 m, even though their width measured perpendicularly may be more.

The other land-cover classes were generally ignored. Nevertheless, it was clear that the major classes were correct, in that the Swartland was mainly classified as agricultural (cereals). Most of the mountain escarpments were classified as Fynbos, which is again typically the case, although in some areas conifer plantations and *Hakea* infestations may have been incorporated in this class. The urban sprawl between Cape Town and Paarl was largely correctly classified as urban. The south-eastern area had the most misclassifications, probably due to the greater complexity of land-use patterns that occurs there. The various classifications performed only on the south-east region, failed to produce an improved land-cover map of the area.

Classifications using degraded imagery or imagery restricted to the generally accepted Renosterveld area (as defined in the literature), did not give any obvious improvements upon those carried out at 30 m resolution, and no further use was made of them.

Resolving the problem of the grassy wasteland class

The sequential "ISOCLUST" analyses of just the Renosterveld class from the preliminary classification showed that the grassy wasteland areas of the south-east, and other "true" Renosterveld areas were not spectrally separable. The original Renosterveld class was represented by a little over 600 000 pixels, of which half occurred in cluster two of the first "ISOCLUST" classification of the area covered

by that class only. Within that cluster, 250 000 pixels made up cluster two of the subsequent classification. The final classification divided that cluster into four, of which cluster two had about 82 000 pixels and cluster three about 74 000. At that stage, the south-east scrub patches were divided about 50/50 between clusters two and three. Much of the north-eastern side of the Koringberg and parts of the Kasteelberg were incorporated within cluster two, while cluster three incorporated parts of the natural vegetation surrounding Voelvlei.

Discussion

Classification techniques

Both Wendy Lloyd and Amrei von Hase (*pers. comms*) have observed that the west coast lowlands appear difficult to classify accurately using Landsat imagery and spectral techniques. The ARC-IPC classification (Lloyd *et al.* 1999) used a stratified series of unsupervised classifications to reach their objectives, and further modified their maps using ancillary data and consultation with people knowledgeable about the relevant areas. Using these methods they obtained an overall classification accuracy of 93.9%. However, the three natural vegetation classes had accuracies ranging between 99.5% (for natural vegetation with low levels of alien infestation) and 25.0% for that with a medium level of alien infestation. They were of the opinion that a combination of supervised and unsupervised classifications may have produced better results, but they were limited by time. It is unknown what methods were tried by von Hase, but the map produced (von Hase *et al.* 2003) used the ARC-IPC classification, combined with the preliminary map described in this thesis.

Jarman (1981, 1985) pointed out that unsupervised classifications give a more valid spectral classification than do supervised ones. One of the problems of a supervised classification is that training sites are frequently not homogeneous. Areas that appear visually similar may be subtly different when all the spectral bands are considered. This study used part of the Elandsberg PNR as a Renosterveld training site. From field visits (after the classification), it became apparent that the training site had incorporated a mixture of Fynbos and Renosterveld, both with a variety of

structures. It was not visually apparent from the imagery where one began and the other ended (unsupervised classifications restricted to the Elandsberg PNR showed up at least five spectral classes). This means that this Renosterveld training site was not “pure”. Having said that, the various unsupervised classifications gave different patterns of vegetation within the reserve, which may be better described as a mosaic situation. Few of the Renosterveld fragments identified in any of the classifications had a homogeneous structure, suggesting that homogeneous training sites might have led to the omission of many of those sites identified using the heterogeneous training sites. Additionally the supervised classification performed here identified human-defined Renosterveld sites better than did any of the unsupervised classifications. Thus, while Jarman’s (1985) arguments for an unsupervised approach have merit, if the spectral classes identified cannot be interpreted in ecological terms, the value of the exercise becomes questionable.

Jensen (1996) pointed out that there is a fundamental difference between information classes and spectral classes. Information classes are defined by, and are meaningful to humans. Spectral classes are classes that are inherent in the remotely sensed data, and have to be interpreted in meaningful terms by the analyst. The aim of this classification was to determine where the remaining fragments of Renosterveld were situated. Although Renosterveld is generally described in terms of it being a shrubland predominated by fine-leaved shrubs (*e.g.* Low and Rebelo 1996), the time since the last fire, density, cover *etc.* all need to be considered. These will all affect the spectral reflectance. Voelvlei had areas of dense Renosterbos. The adjacent Elandsberg PNR had areas of an open mixture of grass and low-shrub, which might also be considered as Renosterveld. Tansley (1982) reported an area of pure *Themeda triandra* grassland at Voelvlei. These three areas would be spectrally distinct, yet still be defined by botanists as Renosterveld at different stages of succession. Lloyd *et al.* (1999) referred to the ERDAS manual, which suggested the use of an unsupervised classification to locate broad clusters of similar spectral reflectances, followed by supervised classifications to refine the classes. In the case of this project, the reverse procedure was used with reasonable success.

Image pre-processing and degrading

A problem with pre-processing imagery is that one is *changing* the original spectral values of each pixel. This implies that the results obtained are not a true reflection of ground conditions. The argument for the use of a pre-processing filter is that, at the resolution of the final map (3 ha is equal to a little over 33 pixels), the smoothing of the spectral values should provide a less fragmented classification. The classes specified are diverse within themselves, having variations in pixel brightness values. By using a smoothing filter of some kind, the pixels at the extreme ends of each class are drawn towards the average class value, which should make for a smoother classification. Lillesand and Kiefer (2000) explain it by saying that low-pass (smoothing) filters reduce local detail, but emphasize the larger area brightness regimes. It was these larger areas that were being sought. It should also be noted that the Landsat imagery as supplied would already have undergone a certain amount of “smoothing”, during rectification of the imagery as transmitted from the satellite. Due to the curvature of the earth, pixels at the centre of the imagery record a smaller land-surface area than pixels along the edge (excluding topographic effects). Resampling of the imagery to the requested resolution and projection formats further “smoothes” local brightness regimes. One advantage of such smoothing procedures is that random errors in the recording or transmitting of the image data are ameliorated. One potential problem is that boundaries between distinct land-cover classes become fuzzy with the use of these smoothing filters, although passing a modal window over the final classification may partially compensate for this.

There is a second aspect to the smoothing aspect, that relates to the “minimum-mapping” unit. The recent land-cover classifications of South Africa (Thompson 1996) and of the CFR (Lloyd *et al.* 1999) both specified a minimum-mapping unit of 25 ha. They considered this a reasonable area for a final map scale of 1:250 000. The land-cover classification of South Africa was manually interpreted, and was thus not subject to the effects of filtering (other than the effects of resampling to a projection and a 25 m pixel resolution). On the other hand, the Threats to Biodiversity within the CFR project (Lloyd *et al.* 1999) did use filtering techniques. A majority filter of 7 x 7 pixels was passed over their classification (which was in

Transverse Mercator at a 25 m pixel resolution). This technique not only enlarges widespread classes at the expense of small fragments (which is the aim of the exercise) but it also reduces the size of fragments that are intermediate in size between half the area of the filter and its full extent. Although this method results in a land-cover map “identifying” 100% of the region, it has not produced a map with a minimum-mapping unit equivalent to the area covered by the 7 x 7 pixel filter, as fragments of 18 to 35 pixels in size are reduced to fragments of one to 17 pixels in size. In this study, the aim was to find small fragments located within other widespread classes. It was therefore considered better to process land-cover classes relevant to this study separately, and remove the fragments of less than three hectares. The result is that the total area of the classification becomes less than 100%. The “missing” area could be assigned to an “indeterminate” class if it was necessary to produce a complete coverage.

Combining classifications to improve mapping accuracy

The effect of combining the two preliminary supervised classifications on a priority basis is likely to have led to an over-estimation of the amount of Renosterveld present in the area. It was decided that errors of commission (*i.e.* classifying non-Renosterveld as Renosterveld) were better than errors of omission, since it would be easier to find and delete an incorrectly identified fragment from the map, than it would be to find a patch of Renosterveld that had not been identified. In terms of the identification of Renosterveld, the main problem with the two supervised classifications was in discriminating it from Fynbos and (to a lesser extent) Thicket. In view of the wide variety of structural variation in, and species and physiognomic overlap between, Renosterveld and Fynbos, this is hardly surprising. If cognizance is taken of Boucher’s (1987) claim that half of West-Coast Renosterveld can be phytosociologically classified as Fynbos, and the other half as pseudo-Fynbos, and Taylor’s (1978) claim that Renosterveld is a transitional vegetation type, then the two vegetation types should theoretically not be separable at all. Excluding the wasteland fragments in the south-eastern region, most “misidentifications” (within the supervised classification) occurred along the foot of the mountains and along the boundaries with the coastal sands where mosaics of Fynbos and Renosterveld

tended to develop. In these crossover areas, misidentifications are inevitable. It should also be noted that since actual boundaries were not verified in the field, it is unknown how much misidentification had actually taken place. On the western slopes of Signal Hill the division between vegetation that had been classified as Renosterveld and that which had been classified as Fynbos was, to the human eye, and two years after the exposure of the imagery, subtle.

The south-eastern region was the area where the most severe misclassifications took place. Von Hase *et al.* (2003) noted that the “Threats to Biodiversity of the CFR” land-cover classification that they used for the southern part of their West-Coast Renosterveld map also showed a great deal of misclassification in this area. That most of these misclassifications were due to the genuine spectral indivisibility between Renosterveld and the grassy wasteland was proven here. In addition, this region is more complex in terms of its land-cover than further north. Land-use units are smaller, which may lead to adjacent units spectrally affecting each other. The close proximity of urban and industrial centres leads to the formation of smog on windless and near-windless days (*pers. obs.*). Many of the poorer communities use firewood for domestic fuel, leading to further haze. The light cloud cover to the west of the Perdeberg affected the spectral classifications, although one could easily make out the type of land-cover occurring under the cloud. The fact that the spectral classifications were unable to “recognize” the land-cover occurring beneath this cloud is an indication that even light atmospheric effects can affect spectral analyses in ways that the human observer might not anticipate.

Rationale for the use of the latitude-longitude format

Unfortunately for cartographers, the Earth is a sphere, and paper is flat. What this implies is that some form of distortion must occur when trying to represent all but the smallest extents of the earth on paper. A host of different mathematical models (projections) has been produced in order to represent the Earth, or portions thereof, as a flat surface and summaries of these can easily be found (*e.g.* Roblin 1969).

In view of this, the question had to be asked: “What was the basic aim of this classification?”. The author’s opinion was that there were two aims. The first was to provide biologists with a tool that would enable them to locate the remnant patches

of Renosterveld/natural vegetation identified by the classification. The second was to be able to estimate how much of the natural vegetation remained, and to analyse its spatial distribution within the landscape. The area under examination is not extensive in global terms, so distortion is unlikely to be a major problem. It is also relatively flat. Direction is only a minor consideration as access to an area would be largely be done *via* public or farm roads, using 1:250 000 or 1:50 000 topographic maps. Most field workers would have access to a GPS unit of some sort. The cheaper units use the WGS 84 spheroid as their base, and provide readouts in latitude-longitude format. Units that are more expensive have facilities for a choice of spheroids and projections (if the latitude-longitude format can be considered a projection). Therefore, it was decided to use this simple latitude-longitude format as the basis for the map, as it would make the final location of the patch much simpler. It would also make modification of patch boundaries or the addition of new patches easier, as complex mathematical transformations would not be required.

An objection that may be raised could be that the calculation of area and distance may be affected. The Idrisi32 module for calculating area takes into account latitude and longitude, when this format is used, so errors should be minimal (Eastman 1999). Taking into account other errors, such as the fact that there will be mixed-class pixels, and that the smoothing filters used will also have modified boundary pixels, then this area calculation error is probably insignificant. Two points to keep in mind are that this map was to form a base from which to begin, and that the map produced by the Botanical Society's lowlands project is now the one that is in general use. The cursory field verification showed that there were basic misclassifications, even before we take into account the fundamental conflicts as to where Renosterveld ends and Fynbos or Thicket begins. It needed to be as simple and user-friendly as possible, until it reached a level of confidence where more complex and accurate analyses could be made.

Image Rectification

There were three reasons for using GCP determined from the vector layer road map, rather than the points collected during the field trip. The first was that this layer (and the others purchased from the Chief Directorate: Surveys and Mapping) was

already in a latitude-longitude format (the preferred final format). Changing the projection of imagery by means of resampling introduces positional errors due to pixel resolution and to the equation used being a best-fit approximation. It is likely that rectifying the Landsat imagery to the GCP collected in the field would have led to misalignments between the imagery and the vector layers that were at least as big as those produced by using the vector layer as a reference. For landscape analyses to be carried out (next chapter), it was of more importance that the layers were referenced to one-another, than directly to the ground. United States national map accuracy standards require the RMS to be less than half the pixel resolution of the imagery (Eastman 1999a) and the other land-cover studies done in various parts of the world have reported similar levels of accuracy (*e.g.* Fuller *et al.* 1994, Thompson 1996). Nevertheless, one cannot refer to the spectral characteristics of the imagery, except in terms of the full extent of the pixel. If, as in the case of this project, areas of less than 3 ha are being ignored, the absolute accuracy of the location of a fragment of Renosterveld could be almost 150 m from true, and the fieldworkers would still find themselves within the fragment. Imagery used by the International Geosphere-Biosphere Programme (IGBP) land-cover programme using temporal NOAA imagery had a RMS of just over 1 km (for 1 km resolution imagery). Their argument was that it was more important to geo-reference the temporal images to each other than to their absolute position on the ground (Eidenshink and Faundeen 1994). The same argument might be used for the geo-referencing of the different physical layers used in this project to one-another.

The second reason for using the vector layer was that this sort of study is inherently fuzzy. We can (and indeed did) correct the Landsat image to give a root mean square positional error of 15.6 m from “true” (as defined by the vector layer). The problem is that the other elements are fuzzy. Plant boundaries are rarely sharp – even agricultural fields tend to have a border of a few metres with a mixture of crop, track and natural vegetation. Rock formations can overlay others, crumble and intermingle. The resulting soils intermingle; rivers wash soils down from other areas, there are movements caused by gravity, fossorial creatures, wind and rain. Pixels will straddle boundaries between land-cover classes. Most of the overlays (*e.g.* BHU, Geology, Soils *etc.*) were at a scale of 1:250 000, which translates to one Landsat pixel being equivalent to 0.12 mm on the map, which is hardly discernable

to the naked eye. Fairbanks and Thompson (1996) quoted the Arc/Info specification of 0.3 mm (= 2.5 pixels at a scale of 1:250 000) being equivalent to a standard line width on a map. The actual positional error of imagery rectified by these means may therefore be as much as 75 m at this scale. In the case of vector layers (as compared to physical maps), the intersection point of two lines can be magnified until their location (as measured on the computer screen) can be determined to within a few centimetres. How valid this is, would depend upon the mechanism (*e.g.* digitizing, scanning or land-survey points) whereby the vector layer data were originally developed. An example of this is the Renosterveld coverage digitized from the thesis of McDowell (1988). The RMS error for resampling this into latitude-longitude format was a little under two metres. While this sounds impressive, a moment's thought will indicate that it is absolute nonsense. The *equation* performing the transformation was that accurate, but what about outside sources of error? The map was about 22 cm by 32 cm and represented an area on the ground of about 125 km by 180 km. A typical line thickness of 0.3 mm represents an on-the-ground distance of about 171 m on the map of McDowell (1988). This is the *best* accuracy that is possible at that scale. To this "error" must be added digitizing errors (at least 0.5 mm). The original map was certainly a smoothed representation of the true situation. Thus, although the RMS error was extremely low, the true situation was probably 100 times that figure. Having said all that, laying the digitized map over the Landsat image showed that, on *average* the coastlines coincided; that is to say, there was not an overall shift of one coastline, relative to the other. The soil map of Schloms *et al.* (1983) had an original scale of 1:250 000. Line thickness and digitizing errors, would therefore be proportionally less *i.e.* a line thickness of 0.3 mm equates to 75 m on the ground. The two-metre RMS error for this map probably implies an actual average positional error of 125 metres. The geological overlay (Anon. 1973, 1990, 1997) was digitized in latitude-longitude format, and so only digitizing errors (and the implicit geological-formation boundary generalization errors) would have been relevant. The point being made is that any absolute positional errors introduced by using the roads vector layer (rather than the collected GCP points) as a reference layer, are not going to materially affect the final accuracy of the map.

The final reason was that the same roads layer could also be used to rectify the aerial photographs (Chapter 3). This means that the same vector layers (BHU, geology, soils *etc.*) could be used on both the Landsat image and the aerial photographs, thus simplifying comparisons.

The problem with the Cape Nature digital elevation model was the 60 m resolution. This reduces the accuracy of slope estimates at the 30 m resolution used. In the context of West-Coast Renosterveld, this is not too important as the elevation range is small (300 m was suggested by Acocks [1953], although in this study, a more liberal value of 500 m was used, which is backed up in the literature *e.g.* Linder, 1976). However, this did become a problem in the aerial photograph analyses (Chapter 3), where a pixel resolution of five metres was used. Although a smoothing filter was run across the DEM, to smooth the stepping, the rectification error (97 m) remained a problem. The use of the contour data to create a 30 m resolution DEM for the Landscape analyses ensured better geo-referencing between the DEM, the actual image and the other vector layers. The same contours were also used to directly create local DEMs, at a resolution of five-metres for each of the aerial photographs (see Chapter 5 for details of the method).

Scale

Townshend (1992) cited a 1988 study by Togliatti *et al.*, who concluded that TM data is unable to provide topographical information good enough to meet conventional cartographic standards at a 1:50 000 scale. Fuller *et al.* (1994) related the 1:50 000 scale to a minimum classifiable area of between 3 ha and 5 ha.

What therefore is the “true” scale of this fragment map? Technically the scale has to be derived from the coarsest level of data incorporated, as this defines the limits of accuracy where it is used. McDowell’s (1988) map of the proposed original extent of West-Coast Renosterveld was in the region of 1:570 000. The rainfall imagery of the CCWR was mapped in the form of a 1’ grid. Geology, soils, and the other published vegetation extents were at a scale of 1:250 000. Roads, rivers, contour lines (and by implication the DEM) were at a scale of 1:50 000. Rectification was

carried out using 1:50 000 data. Fragments were identified down to a 3 ha minimum.

The rainfall data was only used to approximate the 300 mm rainfall isohyet when the limits of the “Predictive” coverage were being produced (next chapter). At all other times it was used in a descriptive manner. McDowell’s (1988) coverage was used to identify potential Renosterveld sites in the Cape Peninsula that had not been identified by other authors, and to help determine the accuracy of the different classification methods. In most other cases, boundaries were defined in terms of 1:250 000 data. However, these boundaries tended to be generalizations of what they were representing (geology, soil, original extents *etc.*), thus reducing the level of confidence in the final product. The fragments themselves were identified down to a project-imposed limit of 3 ha, although fragment boundaries were fuzzy due to pixels straddling borders and the smoothing filters used. Three hectares is below the generally accepted minimum level of resolution of classifications at a 1:250 000 level (4 ha is the generally accepted minimum [Jensen 1996, Fairbanks *et al.* 2000]). If it was necessary to specify a scale to this study it would therefore be *more* correct to say it was *around* 1:250 000 rather than around 1:50 000. It might however be better to identify the map in terms of its resolution rather than its scale. Von Hase *et al.* (2003) observed that, while their data was at a working accuracy of 1:50 000, there were the inevitable generalizations of boundaries *etc.* They therefore stressed that their map, while being useful as a fine-scale planning guide, must inevitably be backed up by site visits and *in-situ* verification. The same argument should be applied to this classification.

Error levels and the success of locating Renosterveld fragments

Mather (1999) reported that, at a workshop in 1996, Wilkinson suggested that spectral classification accuracies of better than 80% were rare, and this may be the upper limit possible with remotely sensed data. Of course, this is somewhat dependent upon the resolution of the imagery and the scope of the classes used (*e.g.* water and land are usually 100% separable, whereas grass and Lucerne would probably have a much lower separability). Accuracy assessment can also be very misleading. Accuracy figures can be based upon the ability of a classifier to assign a

correct classification to the training site (this is not considered acceptable). It may be the producer's accuracy, which is the probability that a pixel classified as class X is actually that class. It may be the user's accuracy, which is the probability that a person going to a site classified as class X, will actually find class X at that spot. Finally, it may be the overall accuracy, which is the number of sampled pixels (pixel clusters, polygons) correctly classified divided by the total number of pixels sampled (Congalton 1991).

Within South Africa, classification accuracy assessments have been made of the two recent land-cover maps produced from Landsat imagery. That of the CSIR-ARC was regionally assessed in terms of the area covered by each of the 1:250 000 scale topographic maps produced by the Chief Directorate: Surveys and Maps, as well as over South Africa as a whole. Their overall level 1 classification accuracy was 79.7%, with local variations due to different local cover characteristics (Fairbanks *et al.* 2000). The Cape Town map (which is entirely incorporated within the study area) had an accuracy of 89.8%. The ARC-IPC Threats to the Biodiversity of the CFR project was independently assessed and given an overall accuracy of $93.9\% \pm 2.2\%$ at the 95% confidence level. Although the urban and water classes were identified with 100% accuracy, as mentioned above, the natural vegetation classes, which are the ones in which this study is interested, had a lower level of classification accuracy (25%, 52.6% and 99.5% for the three classes they specified). This compares with the 80% plus accuracy suggested for this study, as based upon the field verification exercise.

The problem of "weighting" the accuracy of the classification in this study was mentioned in the results section. Table 4 gave an estimate of the accuracy of this classification, as far as the natural vegetation falling within published proposed original extents of Renosterveld was concerned. Alternatively, the classification could be compared with previous maps of Renosterveld. The majority of McDowell's (1988) 55 Renosterveld sites were classified as Renosterveld. Forty-five definitely coincided. Nine sites had a somewhat vague description in his paper (*e.g.* "Waylands flats"). This study had an area classified as Renosterveld in close proximity to each of those areas (*e.g.* on the same farm), but it was impossible to determine if they were the same sites. The Perdeberg was the remaining site.

McDowell allocated the whole of its lower slopes to Renosterveld. The supervised classification allocated the northern third to Renosterveld and the rest to Fynbos. Notes made during field verification, indicated that, while Renosterveld was present in patches, there was a high presence of trees (indigenous as well as alien *Acacias* and pines), and the natural vegetation was mainly a mixture of a Proteoid and Thicket structure. In contrast to the supervised classification, most unsupervised classifications allocated the northern third to the “Mountain Fynbos” class and the southern section to the “Lowland Fynbos” class. As mentioned in the methods section, there was some light cloud over the southern half of the mountain and this seems to have caused this north/south division. Classifications carried out using February 2001 imagery did not show any such division. Barrie Low kindly supplied a copy of his personal list of 64 sites containing West-Coast Renosterveld. Many corresponded to those mapped by McDowell, but there was more definition in terms of farm names, and smaller fragments were defined. For example, where McDowell had “Tygerberg Hills”, Low had both the car park and the nature reserve listed. He also included areas such as the Corobrick quarry and the Phesantekraal airfield (both of which were picked up in this classification). Taken overall, it appears that the classification identified all the major West-Coast Renosterveld sites referred to by previous authors, as well as many smaller sites.

Community separation

Although the use of imagery from two different seasons or years often helps to improve land-cover classifications (*e.g.* the land-cover classification of Great Britain by Fuller *et al.* 1994), this was not the case when imagery from February 2001 was incorporated into the classification. The February imagery was not available for the entire lowland area (only Landsat path 175, row 83 was available), and less effort was put into this bitemporal classification. Nevertheless, a number of supervised classifications, and more than twenty unsupervised classifications using a combination of seeding images and mixed image bands (seven bands are the maximum allowed) failed to produce a classification that was an obvious improvement upon that developed using the November imagery alone.

Figure 3 shows that 1999 was the driest in 18 years, and was the third consecutive year with rainfall below the 20-year (1982 to 2001) average (489 mm; Mean = 731 mm). October was likewise the driest October of this period (4.4 mm; Mean = 39.5 mm), while the winter (July to October) rainfall was the second lowest recorded (216 mm; Mean = 303.5 mm). This low rainfall could potentially lead to a reduction in ground cover compared with years receiving a more normal precipitation, thereby making it more difficult to discriminate between harvested cereal fields and areas of sparse natural vegetation. On the other hand, annuals which grow between harvesting and planting of the following years crops may also be retarded, leading to fallow fields having a lower vegetative cover. The winter of 2001 had a total June to October rainfall of 508.5 mm, which may have resulted in a higher cover of annual species being observed during the field verification phase.

The graph of the mean spectral signatures of the natural classes used in this study (Figure 2) showed that the subdivision of the Renosterveld class in the second supervised classification was valid. The “grassy Renosterveld” class was distinctive in band 4, and the “dense Renosterveld” class in band 5. The major problem was the wide spread of the “Fynbos” class, which tended to encompass most of the range of the other natural classes within each spectral band. Had the Fynbos training classes been chosen more carefully, this might have been less of a problem. However, the unsupervised classifications showed that differences between the natural vegetation classes, as defined by humans, were not the same as those defined by the spectral classifications of the Landsat imagery. The visually distinctive (to the human eye) Thicket class to the east of the Langebaan Lagoon failed to be uniquely identified by any of the unsupervised classifications, although a 40-iteration unsupervised classification came close. It would need *in situ* examinations of community structure and species composition to see why an area so distinctive to the human eye, failed to be distinguished by the unsupervised classifications.

Where possible, the clusters produced in the unsupervised classifications were combined into meaningful classes. Within the various unsupervised classifications performed, one to six clusters represented cereal-farming areas, while one to four clusters identified the natural vegetation, the actual number usually being related to the total number of clusters requested. While most of the major Renosterveld areas

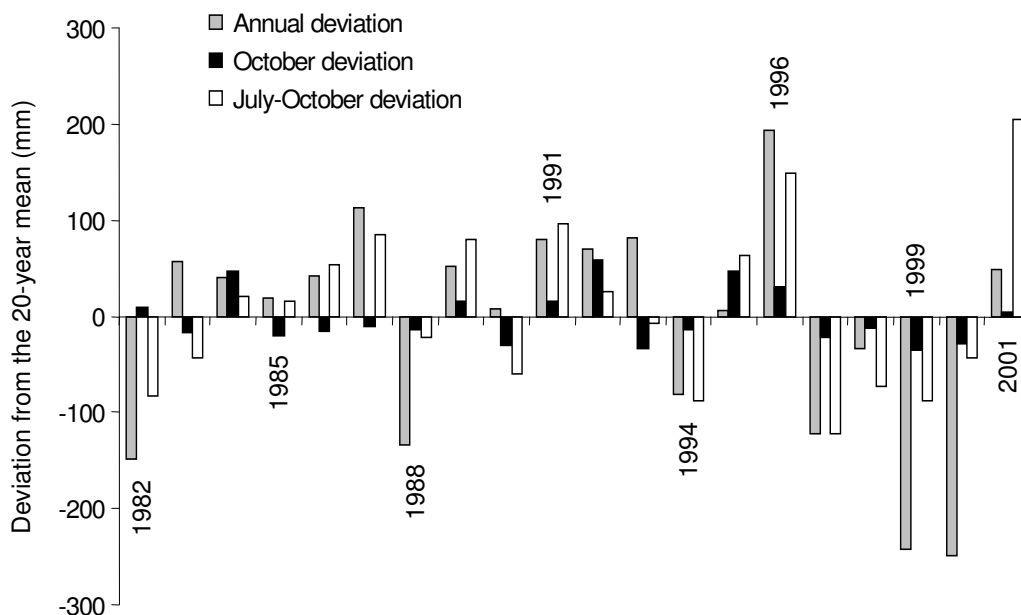


Figure 3. Deviations in rainfall from the 20-year mean (1982 - 2001) over the west coast lowlands. Graph shows deviations for the full year, for the winter season (July to October) and for the month of October only.

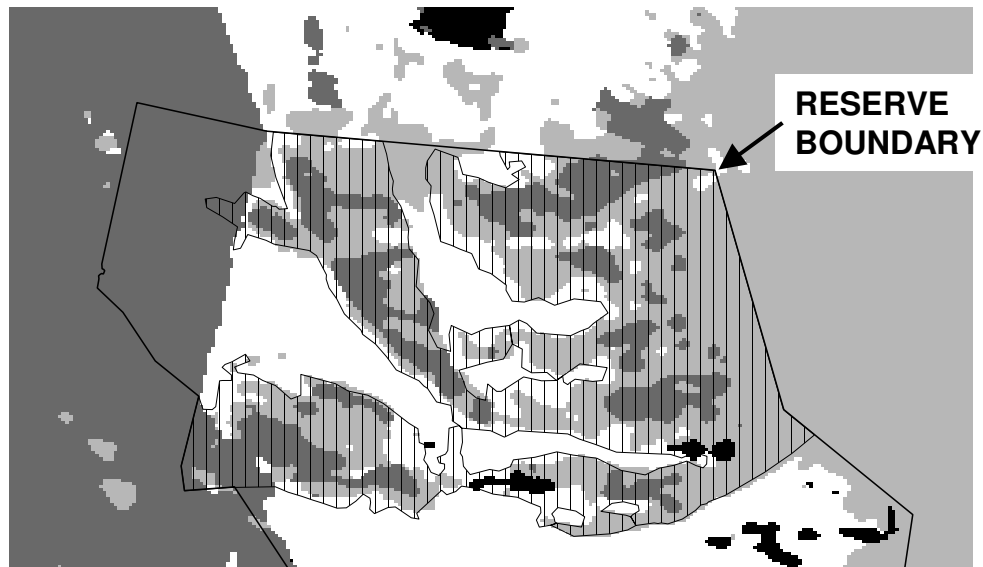
came out as a predominantly “natural” class (or classes), there were sometimes “agricultural” patches within them. The agricultural areas of the south-eastern region that were classified as Fynbos or Renosterveld are examples of where this problem arose. It may be that the extremely dry conditions that had prevailed in the area over the previous three years had had some effect, but this cannot be tested without equivalent imagery from a year with more normal rainfall.

One problem in identifying different agricultural practices in this area, using imagery taken in November, was that very different practices could have similar spectral signatures. For example, a recently ploughed field would have the same signature (assuming a similar soil type) to vineyards after the leaves have fallen, or to pivot-point irrigation areas after harvesting. Because these three alternatives are all agricultural this would not be too serious, except for affecting the landscape analysis figures as related to agriculture, presented in the next chapter. Isolated events also led to misclassifications. For instance, the northern section of the Elandsberg PNR had a mixture of Fynbos and cereal classes sweeping across it. A

comparison with the fire maps of the reserve showed this mosaic to be due to the fire of March 1999 (Figure 4). Another example was the classification of a recently burnt part of the Heuningberg as urban.

The 17-cluster bands-2,3,4 unsupervised classification that was used in the production of the final map had a cluster that incorporated both urban and agricultural land-cover classes. A separate “ISOCLUST” classification performed only on that cluster largely resolved this problem. The 25-cluster analysis using the same seeding image showed the same effect. This suggests that, in terms of reflected radiation within those particular bands, at a resolution of 30 m, certain suburban areas are indistinct from certain agricultural practices. Suburban settlements, such as Khayelitsha (a low-income, high-density settlement), not only have a high cover of unvegetated sand, but many of the roofs are of corrugated iron, which is also highly reflective. These results also indicate that a single classification of an extensive area using more clusters does not necessarily produce an improved classification.

The attempt to separate out the grassy wasteland fragments from the Renosterveld class, as determined by the supervised classification, was largely unsuccessful. It proved that these wasteland areas of the south-eastern region were (in the imagery used) spectrally the same as certain well-accepted Renosterveld areas. At the first “ISOCLUST” classification of this Renosterveld class, the Elandsberg PNR (which had initially been almost entirely classified as Renosterveld) was divided into four distinct areas that might be meaningful at a plant community analysis level of the reserve. As only five clusters were identified over the whole region, the presence of four of them in the reserve reflects the diverse community structure observed. Despite this (or maybe because of this), its use as one of the Renosterveld training sites appears to have been quite effective in spectrally defining “Renosterveld”, or at least, the natural vegetation occurring in the region. The “ISOCLUST” classification of the cluster 2 area made little difference to that cluster within the Elandsberg reserve, but the final classification broke this cluster into a further four clusters which occurred in the reserve.



White = Renosterveld class

Light Grey = Fynbos class

Dark Grey = Cereal fields after harvesting

Black = Water and other classifications

Vertical stripes = extent of the 1999 fire

Figure 4. Northern half of the Elandsberg PNR showing how a fire which occurred seven months prior to the exposure of the imagery affected the land-cover classification. Fire map and reserve boundary were prepared by Natalie Diemer.

There are three possible reasons for the distinct Mountain Fynbos cluster that had a close relationship with the south-west mountain slopes. The first is a shadow effect. The sun at the time of exposure of the image is situated to the north-east of the image. Its inclination would be approximately 58 degrees (with only a slight variation over the total image area). Steep south-west facing slopes would therefore be receiving sunlight at a very low angle. Shadows would be long, shading of the lower plant strata would be exaggerated, and the overall effect would be an area of reduced photosynthetic activity and shade. The next two reasons are water related. The first is that this class was predominantly found on the higher ridges of the Western Fold Mountains. It was also common on the Cape Peninsula and in the

Hottentots-Holland – Kogelberg areas, both of which receive precipitation in the form of sea spray and cloud. Cloud and fog can increase the effective annual precipitation of an area by up to three times (Nagel quoted by Schulze and McGee 1978). These areas may therefore have received more “precipitation” than the surrounding areas and the vegetation there might be proportionately less water stressed. The second possibility is that, since these slopes have received little direct solar radiation by 9:45 am, they would have remained wetter (from night-time dew *etc.*) than the eastern facing slopes, which would have had more time to dry out. Plants on these shaded slopes would therefore be under less transpirational stress.

Of interest is that this “shadow Fynbos” class was more extensive in the imagery from November 1999 than from February 2001, despite the sun being lower in the sky in February. Due to the summer drought conditions experienced in the Western Cape Province, it is likely that by February, water stresses would be higher than in November, suggesting that this “shadow” was more a function of water relations (and its effect upon spectral reflectance characteristics) than of light conditions. As mentioned in the methods, this “shadow Fynbos” class was incorporated into the high probability Fynbos class. Ripp (1978) identified two shadow clusters in the southern Cape Peninsula, while Lloyd *et al.* (1999) identified one.

Although this phenomenon is of interest, in the context of West-Coast Renosterveld it is of little importance, as there are few steep, south-west facing slopes in the area (7 km² of south-west facing slopes greater than 60 degrees in the entire image area). Within the extents of West-Coast Renosterveld, as defined by Low and Rebelo (1996), just over 28% of the landscape faces the south-west quadrant (*i.e.* between 180° and 270°). However, almost 75% of these slopes are less than 4° and only 1.6% of these slopes are greater than 20°.

Comparison of the results of this classification with that of other Landsat classifications within the Western Cape

As mentioned in the introduction, it was Taylor and Boucher’s (1973) study which first threw doubt upon Acocks’ (1953) tongue of Renosterveld situated just to the east of the Langebaan lagoon, as the imagery did not show any spectral

differentiation in that region (Boucher and Jarman 1977). However, Boucher and Jarman (1977) noted the presence of a “dark pattern” on the imagery to the east of the Langebaan lagoon, which is probably analogous to the “Thicket” class of the supervised classifications of this project.

Ripp (1978), in his Landsat classification of the southern Cape Peninsula concluded that it identified structural-physiognomic classes, which did not always agree with the community classifications, as mapped by Hugh Taylor in 1969.

Lane (1980) recognized 16 distinct spectral classes in her Landsat classification of the Verloren Vlei area. She found only a partial relationship between community composition or structure and its spectral classification. Although only 40 km north-west of the Renosterveld study area, conditions were considerably more arid. She concluded that vegetation cover was more important than community or structure for determining the spectral classes, and that that soil colour had played a large role in the classification.

Jarman (1981) indicated that her classification failed to identify any of the floristically defined communities determined by Boucher and Jarman (1977) in the Langebaan area, but eight of her 14 spectral classes corresponded closely to the communities defined by re-analysing the area in terms of the community structure description of Campbell *et al.* (1981).

In the above three cases, community structure has apparently been more important in determining spectral classes than has community composition. The classification of the Elandsberg PNR as Renosterveld in the preliminary classification also suggests that structure has played a role in this classification. However, based upon the unsupervised classifications it was clear that there was considerably more involved than just structure, as low density shrublands and high density shrublands had often been put into the same spectral class, while other areas, such as on the north-west slopes of Signal Hill, had classified vegetation that looked structurally similar into separate classes.

Bossi (1983) degraded her imagery by averaging each 10 x 10 matrix of pixels into one, resulting in a cell size of approximately 44 ha. This was further reduced to a minimum-mapping size of 100 ha when the map of the Fynbos Biome was

produced (Anon. 1983). Classification was by spectral techniques, combined with manual interpretation (Moll and Bossi 1984). Her study found that each Landsat image produced one (occasionally two) Fynbos class(es). If we consider that the image used in this study is equivalent to a single Landsat image, a similar situation exists. At Landsat scales, there does not appear to be a great deal of spectral difference between the different Fynbos communities. As mentioned earlier, classifications using imagery degraded to 0.8 ha and 9.0 ha showed no improvements over the classifications carried out at the 30 m pixel resolution used here.

In the fourth chapter of her thesis, Bossi (1983) showed the mean reflectance values in each MSS band, for 11 vegetation classes (her Figure 4), as well as for five Fynbos areas (her Figure 2). These graphs would seem to imply that many of these classes are easily separable. However, she does not show ranges or standard deviations, so it is difficult to tell to what extent they overlap. It should also be remembered that these signatures have been taken from 14 different Landsat images, and so they may not be directly comparable.

Comparing classification problems encountered here, with those of Bossi (1983), are interesting. Her “Transitional Shrublands” (Renosterveld) were not distinct in her classification and usually included some Strandveld (*sensu* Acocks 1953) and/or good cover karroid shrubland. Her four classes of Renosterveld (two mountain and two coastal), her Strandveld and her karroid shrublands were usually differentiated on the level of ground cover. Probably because of this, some wheat lands, ploughed lands and heavily grazed areas were classified as natural vegetation, especially as low-cover Renosterveld and karroid shrublands. In this study, recently burnt natural vegetation in the northern part of the Elandsberg PNR was classified as cereal, which is the opposite situation to what Bossi recorded. Cultivated lands, green crops, vineyards and orchards were classified as one class, which is similar to this study (the “green/irrigated” class). This class represented vegetation with a strong “green” (band 4) reflectance compared to Fynbos vegetation, which has more of a “grey-green” hue. Bossi (1983) found that plantations were allocated to the forest, Fynbos or agricultural class, depending upon the growth state of the trees. In this study, a similar situation was found. For example, the plantation to the east of

Voelvllei was classified as “green” vegetation, while on Table Mountain plantations were allocated to both the plantation and the Fynbos classes. The reasons for this were not pursued. She found that Fynbos was spectrally distinct and easily separated from other vegetation classes. She had trouble, however, distinguishing between dry, mesic and wet Fynbos. In this analysis, Fynbos was usually distinctive, although alien and broad-leaved shrub areas were also included in this class, as was a great deal of agricultural land in the south-east region. This was probably due to the rough Fynbos training-class used as the unsupervised classification did a better job of discriminating between Fynbos and agriculture. No attempt was made to differentiate between the different types of Fynbos, although the unsupervised classifications did this to some extent.

Her mesic grassy Fynbos areas were usually classified as a mosaic of mountain Fynbos, Renosterveld and good cover karroid shrubland. Although this community does not occur in this area, it is likely that this class is structurally analogous to the grassy wasteland that was classified as Renosterveld in the south-eastern parts of this classification. Her classification had difficulty distinguishing between high-density urban areas and bare agricultural ground, while low-density urban areas were generally included in the cultivated land class. In this analysis, the “urban” classification was also widespread before pre-processing the bands with the smoothing filters. Some of the unsupervised classifications also failed to differentiate between urban areas and certain agricultural lands. Summing up, she said that areas of low vegetation cover produced more spectral classes than could be recognized in the field (*cf.* Lane’s study, above), while good vegetation cover produced fewer. Only 16 West-Coast Renosterveld fragments were mapped by Moll and Bossi (Anon. 1983), although the whole area from Voelvllei to Du Toits Kloof, including the northern side of the Groenberg was counted as one continuous area in their classification. For comparison, 90 fragments of > 100 ha were identified in this study.

Although the land-cover classification of South Africa by the CSIR-ARC included the Fynbos Biome, the next study specifically concentrating upon the CFR was that developed for assessing Threats to the Biodiversity of the CFR (Lloyd *et al.* 1999, Rouget *et al.* 2003). For this, the natural vegetation class was divided into three

levels of alien cover. Some of the problems they encountered that are relevant to this study are worth mentioning. They had problems with shadows on south facing aspects, and with areas of cloud cover. Indigenous bush clumps and certain *Leucadendron* species had similar spectral signatures to some alien vegetation species. This is analogous to the incorporation of alien *Acacia* clumps into the Fynbos class of the supervised classification. They also had a similar problem with orchards and some vineyards, which had to be recoded from high-density alien vegetation to agriculture. Urban areas were manually digitized, so they did not have problems with that class.

As mentioned in the introduction, a spin-off from the Threats to Biodiversity project was the mapping of the natural vegetation fragments remaining within the Overberg and Elgin Renosterveld regions, for the Botanical Society of South Africa's lowlands conservation project (JW Lloyd, *pers. comm.*). The West-Coast Renosterveld fragment map was produced from a combination of the Threats to Biodiversity map and the preliminary fragment map produced for this project (von Hase *et al.* 2003). Field verification similar to that carried out in this project was undertaken, and an estimated accuracy of better than 80% was claimed.

Kemper (1997) (published as Kemper *et al.* 2000) took six hectares as the minimum size in her study of fragmentation in South-Coast Renosterveld. She also restricted her classification to three classes, namely "Renosterveld", "agriculture" which included pasture, and "other" which took in water bodies, non-Renosterveld vegetation, residential and industrial sites and quarries. As her study used the digitized vector layer used to develop the CSIR-ARC land-cover classification map. Therefore, no comments were made about spectral classification problems and, while not specifically stated, it appears that any area classed as "Shrubland and low Fynbos" (Thompson 1996), and occurring on Bokkeveld shales or Cretaceous sediments, was considered to be Renosterveld.

Landsat imagery – How useful is it?

The previous sub-section reviewed the other land-cover classifications of the Western Cape lowlands, and the major theme running throughout is that there is a limit to the ability of Landsat imagery to spectrally discriminate between the

different vegetation classes, as determined by field ecologists. The maps produced by spectral classification can be improved with the input of expert advice, and ancillary data. Fairbanks *et al.* (2000) claimed that manual classification techniques were superior to spectral classifications, but they required more skills and knowledge, and then the full range of spectral information within the imagery was not fully utilized. The regional land-cover classifications incorporating the Western Cape have been at scales of 1:250 000 or more, that is, at a 25 ha or coarser resolution, and the natural vegetation classes have been described in terms of structure, rather than community composition (Thompson 1996).

For this study, 25 ha would have been too coarse, as there are few Renosterveld fragments in excess of this. On the other hand, to analyse it at single-pixel level, as was done by Ripp (1978) and Lane (1980) in their local classification studies, would have been meaningless, both in terms of field verification, and because small patches are often spectral artefacts of the surrounding land classes (Richard Knight *pers. comm.*). The Botanical Society's lowlands Renosterveld study was aimed at a scale of 1:50 000 (Von Hase *et al.* 2003) and fragments down to a size of 0.08 ha were included. They identified 9715 fragments smaller than 0.5 ha in Overberg Renosterveld. In West-Coast and Elgin Renosterveld 453 and 693 were found; such numbers make adequate field verification impossible. In addition, small fragments are likely to be unviable in ecological terms. In this study, the preliminary classification identified 6840 "Renosterveld" fragments of one pixel or greater in size, within the limits of West-Coast Renosterveld as defined by Low and Rebelo (1996). Passing a 3 x 3 majority filter over the image reduced the number to 4828. Of these, 1010 fragments were greater than 3.0 ha, and 161 greater than 25.0 ha. In the final map, 1098 fragments of natural vegetation greater than 3.0 ha and 215 of greater than 25.0 ha were recorded within the same extents.

Overall, it appears that Landsat imagery can be useful in identifying the natural vegetation in the area with a reasonable level of confidence. However, it is limited in its ability to differentiate between the vegetation types recognized by the field ecologists. It is nevertheless, probably the most cost-effective way to produce a land-cover map over an extended area. While the SPOT imagery has better resolution, it has fewer spectral bands (Brel *et al.* 1998). Hyper-spectral imagery

would probably discriminate between the vegetation types better, but the costs would be prohibitive.

Do land-cover classification systems recognize Renosterveld?

A number of land-cover classification schemes have been developed for the classification of Landsat (and other) imagery. In some cases, these have been divided into more than one category, with Landsat (and SPOT XS) imagery being confined to level one (*e.g.* the USGS system [Campbell 1996, Jensen 1996] and the CSIR-ARC land-cover classification [Thompson 1996]). Level one tends to be a relatively coarse system with the USGS system identifying only nine categories and the CSIR-ARC twelve. Nevertheless, Landsat imagery has been used to map land-cover at a much more detailed level, with 25 categories being specified for the classification of Great Britain (Fuller *et al.* 1994).

In the case of this study, the CSIR-ARC classification scheme should be used as a reference, since it was developed by remote sensing and other experts based in South Africa, and included the study area (Table 5). In terms of the natural vegetation, it took cognizance of Edwards' (1983) physiognomic classification scheme (Thompson 1996). The classification was aimed at a minimum mapping size of 25 ha, but like the USGS scheme, it also resolved certain distinct features (*e.g.* dams) to a finer resolution (Fairbanks *et al.* 2000). Most Renosterveld would fall under the "Shrubland and low Fynbos" category. Within this category there were two level 2 classes; shrubland and Low Fynbos (heathland). Level two categories are defined as being those which can be identified from remote sensing data without the use of ancillary data, but which requires an analysis of seasonal imagery or band combinations. As such, Landsat imagery may be considered suitable for identifying most level two categories. At this level, the "Low Fynbos (heathland)" category best describes the physiognomic characteristics of Renosterveld, although their reference to infertile soils does not fit. After describing it as being defined by typically small-leaved (nanophyllous) species, they then go on to say that Proteaceae, Ericaceae and Restionaceae frequently dominate. None of these families is common in Renosterveld.

Table 5. The twelve CSIR-ARC level 1 (Landsat resolvable) land-cover classes (from Thompson 1996).

Forest and Woodland
Thicket, Bushland, Scrub Forest and High Fynbos
Shrubland and Low Fynbos
Herbland
Grassland
Forest plantations
Waterbodies
Wetlands
Barren lands
Cultivated land
Urban/built-up land
Mines and quarries



However, it is not only in satellite classification schemes that Renosterveld poses a problem. Campbell *et al.* (1981) were forced to give coastal Renosterveld the same structural classification as low ericoid open heath (one of the Fynbos categories). In their paper, they said that users should define their own categories. Field ecologists are able to do this relatively easily, as they will be able to identify the dominant species.

The conclusion to be drawn from this is that Renosterveld is not discernable solely by remote sensing methods. It cannot even be identified from a purely physiognomic description made in the field. As such it would fall into the level three category of the CSIR-ARC classification scheme. This level is defined by the user, and requires the use of non-remote sensed data, such as edaphic parameters. It was mentioned in Chapter 1 that most coastal Renosterveld descriptions invariably referred to the relatively nutrient rich soils upon which it occurs. The recent analyses of coastal Renosterveld (*e.g.* Kemper 1997, Kemper *et al.* 2000, von Hase *et al.* 2003) have all used geological maps to discriminate Renosterveld from other natural vegetation. Although Reyers *et al.* (2001) and Rouget *et al.* (2003) used the

boundaries of Low and Rebelo (1996) and Cowling and Heijnis (2001) respectively to define their Renosterveld boundaries, the boundaries proposed by the mappers took cognisance of the nutrient quality of the soils in their development.

The decision to map the fragments within the general boundaries of Renosterveld as natural vegetation, rather than trying to discriminate between Renosterveld, Fynbos and Thicket is therefore probably reasonable. In the next chapter, the natural vegetation fragments are redefined into Renosterveld and Fynbos, based upon ancillary data, namely geology, soils, rainfall and altitude. The spectral signatures of the Renosterveld and Fynbos classes are also examined in relation to the landscape parameters.

Conclusion

Dicks and Lo (1990) pointed out that there is a growing demand for digital thematic maps depicting land-use and land-cover characteristics. They also pointed out that, due to funding and time constraints, and the apparent ease with which they can be produced, even by neophytes, many classifications of doubtful accuracy were being produced. Furthermore, many were not properly assessed for error levels. These are all criticisms that can be levelled against this product. From receiving the Landsat images to the production of the preliminary field map took about two months. This was the first classification undertaken by the author. Attempts have been made to improve the accuracy of this classification using data collected during the field trips. The combined use of data from a revised supervised and an unsupervised classification appears to have produced a map that locates most patches of natural vegetation within the region considered to be home to West-Coast Renosterveld. The unsupervised classifications indicated that the natural vegetation in this area could be divided into two or three main spectral clusters, but these did not correspond directly to Fynbos and Renosterveld. They further indicated that the information inherent within the imagery used was not enough to absolutely determine the differences between Renosterveld, Fynbos and grassy wasteland. As well as the inherent heterogeneity of the different vegetation classes (as defined by humans), there was a further complication in the presence of mosaics of different vegetation types. Field trips showed that Renosterveld was highly variable, and

much of it could easily be classified as Fynbos or Thicket. The Elandsberg PNR is a good example of this, having areas of low vegetative cover that were structurally similar, but with differing species compositions, some having typical Renosterveld shrubs, others typical Fynbos shrubs (*pers. obs.*, see Chapter 3, Figures 5, 6 and 7, pages 133 and 134). Some Renosterveld fragments had characteristic grass patches (even circles – see Chapter 3, Figure 26, page 175), which could cause the fragment to have a mixed spectral response.

The revised compound map resolved many of the classification problems in the south-east of the region. It also resulted in a map that better incorporated the whole of each fragment (*i.e.* there appeared to be less of a “boundary” effect). The earlier classifications, while locating the fragments, did not always incorporate the whole patch. Combining the supervised and unsupervised classifications gave a better overview of the full extent of each fragment, rather than emphasizing vegetation differences within them. The effect of using different parameters to estimate the actual number and location of Renosterveld fragments will never be completely known, as the system is dynamic, with patches being ploughed up, or invaded by aliens. However, the final compound map better reflects the true situation for the period 1999 to 2002 than would one based upon a single classification.

Comparisons of the methods used for image transformations, classifications and rectifications in this project with those of other workers, have shown that they were at least as good as those professionally produced. The problems encountered with the spectral identification of information classes were similar to those of other workers, suggesting that, in this area, there is a limit to the ability of Landsat imagery to identify all land-cover units. Based on the available literature, it was shown that Renosterveld as an entity cannot be uniquely identified by remote sensing methods, and that even a physiognomic description made in the field is not sufficient to be definitive.

Jensen (1996) pointed out that maps produced solely from remote sensing imagery are based upon the classification of a rather rudimentary, single variable. This needs to be compared with a manual photo-interpretation analysis, where the analyst has at his/her disposal a package of colour aerial photographs, maps and knowledge of soil, geology, vegetation, hydrology and geography, a contextual knowledge of

many of the areas being mapped, and historical knowledge (Mason *et al.* quoted by Jensen 1996). The recent land-cover classification of South Africa (Thompson 1996) and the Threats to the Biodiversity of the CFR project (Lloyd *et al.* 1999, Rouget *et al.* 2003) both used experts in the fields of remote sensing, and in the fields of botany.

The land-cover map produced in this study is far from perfect. Nevertheless, within the context of the aim of this exercise, namely “where are the Renosterveld fragments on the west coast lowlands situated?” it has apparently performed well. Most of the recent studies of coastal Renosterveld using maps developed from satellite imagery have used geology to define the boundaries. The most recent vegetation map produced by the South African National Biodiversity Institute (Mucina and Rutherford 2004) has also tightly defined its coastal Renosterveld vegetation distribution on the geological maps produced by the Council for Geoscience. Therefore it should be asked if a community composition description is relevant to Renosterveld? If the suggestion that Renosterveld is a transitional vegetation type (*e.g.* Taylor 1978) is true, then by definition, it would be impossible to define as an entity, either in terms of community composition, structure or spectral reflectance, as these would form a continuum from veld type A to veld type B.

Finally, it should not be forgotten that spectral classification is a tool, and not the “Final Word” in land-cover mapping. The map produced can be used as a basis from which a more detailed field-verified distribution can be developed, which will take into account species richness, levels of transformation, fire regimes *etc.* Fragment boundaries can be accurately determined by GPS readings in the field, and changes can be mapped. The system is dynamic, the map can never represent the true state of the area; it can only give a reasonable approximation.

CHAPTER 5.

LANDSCAPE ANALYSES OF WEST-COAST RENOSTERVELD.

Abstract

Four published West-Coast Renosterveld extents were analysed to determine the different geological and soil formations they covered, and the annual rainfall received. This information was used to develop a “Predictive” Renosterveld distribution, in order to identify areas where there was a high probability that the natural vegetation would be Renosterveld, and to suggest other areas where the vegetation was more likely to be Fynbos. Natural vegetation fragments identified by the land-cover classification described in the previous chapter were analysed in terms of their presence on different slope and aspect classes. Although slopes of greater than 12° made up only 5.5% of the Renosterveld landscape, 38% of the remaining fragments were found on such slopes. In contrast, 98.8% of all cereals and 97.3% of all vineyards and orchards occurred on slopes of less than 12°. Renosterveld fragments were more common on west-facing slopes than on other aspects, while vineyards and orchards were proportionately more common on east-facing slopes. The distribution of cereals approximated aspect availability. Three natural vegetation classes, defined entirely on spectral characteristics were analysed to determine the extent to which landscape parameters (geology, slope, aspect etc.) might have been responsible for their spectral identities. The spectrally defined high probability Renosterveld class was found predominantly on shales, while the high probability Fynbos class was more common on granites and sands. Spectrally defined low probability Renosterveld occurred on shales, sands and (to a lesser extent) alluvium. Both high probability classes followed the slope and aspect distribution pattern described above. The pattern displayed by the low probability Renosterveld class was opposite to that of the high probability classes. Comparing the Botanical Society’s Lowlands Renosterveld project planning domain, with the “Predictive” extent developed in this chapter, suggested that nearly 30% of their buffer area had soils that were edaphically compatible with Renosterveld. Their study excluded only a small amount of the Renosterveld compatible soils of the

western lowlands, and these were mainly situated on Signal Hill, within the Piketberg and in patches along the west coast. The fractal dimension of the remaining fragments, as calculated from area : perimeter ratios, suggested that a mixture of natural and human-induced factors had determined the shape of these fragments. Patchiness of the fragments showed a fractal relationship between the different sized fragments. The Hurst exponent suggested that most fragments were unlikely to persist.

Introduction

It was mentioned in Chapter 1 that descriptions of coastal Renosterveld invariably included the observation that it occurs on lowland soils that receive moderate rainfall, and which are relatively nutrient rich compared to the surrounding nutrient poor acid sands. Chapter 1 also showed how different authors viewed the original extent of West-Coast Renosterveld. The first objective of this chapter is to compare four of these (Acocks 1953, McDowell 1988, Low and Rebelo 1996, Cowling and Heijnis 2001) with the available environmental data (geology, soil, rainfall and altitude), to see if there has been an improvement in the agreement between the proposed boundaries of West-Coast Renosterveld and environmental parameters. The South African National Biodiversity Institute's (SANBI) Vegetation Map of South Africa (Mucina and Rutherford 2004) was published in its beta format as this project was ending. They divided the area covered by West-Coast Renosterveld, as approximated by earlier publications, into six separate units, and the total extent was increased. The units equivalent to West-Coast Renosterveld have predominantly been delimited by geological boundaries, as mapped by the Council for Geoscience (Anon. 1973, 1990, 1997).

The second objective of this chapter was to develop a "Predictive" extent, based upon the characteristics determined from the first section. This would suggest where the natural vegetation on the west coast lowlands was likely to be Renosterveld, or might support Renosterveld endemic or rare species. A "Compound" extent, based upon an amalgamation of the proposed original extents of McDowell (1988), Low and Rebelo (1996) and Cowling and Heijnis (2001), was developed for comparative purposes. The reason for using a compound extent, rather than just that of a single

author was because the three extents used all excluded certain important Renosterveld areas. For example, Cowling and Heijnis (2001) excluded Signal and Blouberg Hills; Low and Rebelo (1996) excluded some of the granite hills of the Darling area; McDowell's (1988) map, while adding some small Renosterveld sites on the Cape Peninsula, did not extend north of Eendekuil. Acocks' (1953) extent, while discussed, was excluded from the "Compound" extent because it included large areas that are no longer considered to be Renosterveld. The two extents developed were used to describe the West-Coast Renosterveld landscape in terms of rainfall, altitude, slope, aspect and land-cover. The boundaries used by the Cape Lowlands project (von Hase *et al.* 2003) was a (mainly geological) modification of the extents proposed by Cowling and Heijnis (2001). They also defined a core Renosterveld area, and a buffer area. The Cape Lowlands map was therefore compared with the "Predictive" extent developed here, in order to see how the two distributions differed.

The spectral classification of the natural vegetation, as described in the previous chapter, suggested that Renosterveld, as a human defined entity, was not uniquely identifiable, using Landsat imagery. Using a combination of supervised and unsupervised classifications, four spectral classes of natural vegetation were identified in chapter 4 (high and low probability Renosterveld, high and low probability Fynbos). The third objective of this chapter was to relate these four spectral classes to the physiographic parameters of the landscape, to see to what extent the spectral classes may have been defined by non-vegetative parameters.

The final objective of this chapter was to use fractal mathematics to describe the pattern of the remaining fragments of natural vegetation within the "Predictive" and "Compound" extents of West-Coast Renosterveld. Two aspects were examined; patchiness, which relates to persistence, and patch dimension, which describes the pressures (human, natural) determining the shape of the fragment.

Korcak (discussed in Hastings and Sugihara 1993) described the cumulative frequency distribution of the areas of islands in the Aegean and noted a power (fractal) relationship:

$$\text{Number of islands of area } > a = \text{const} * a^{-B}$$

If the log of the area (a) is plotted against the log of the accumulative number of fragments, then B (the Korcak exponent of patchiness) is the slope of the curve. D (the fractal dimension) is simply calculated by the formula $D = 2B$.

Krummel *et al.* (1987) noted that the perimeter (P) of a polygon is related to the area (A) of the same polygon by the formula:

$$P \approx \sqrt{A^D} \text{ (i.e. } \log P \approx \frac{1}{2} D \log A \text{)}.$$

For a plane, D can vary between one, as in the case of a circle, where the boundary is a smooth line (Sugihara and May 1990, Hastings and Sugihara 1993), and two, where the perimeter of the polygon is so complex it completely fills the polygon (Hastings and Sugihara 1993). In order to identify changes in the boundary dimension of fragments as the size of the fragments increases, an approximation can be obtained by regressing the log of the perimeter of the fragments against the log of the area of the fragments and evaluating D , which is twice the slope of the line (Krummel *et al.* 1987).

It is necessary to stress that the results of these analyses are based upon the fragment map developed from the various classifications of the Landsat-7 ETM+ imagery as described in the previous chapter. An alternative fragment map (that of von Hase *et al.* 2003) had a similar estimate of accuracy (~ 80%), and used part of the preliminary fragment map described in the previous chapter.

Figure 1 is a spatially degraded Landsat image showing the location of all places mentioned in this chapter. It also delimits the west coast *lowland* area as used here; this includes areas of Sand Plain Fynbos and Thicket vegetation occurring on the lowlands, and Mountain Fynbos occurring along the lower slopes of the surrounding mountains and on the Piketberg. This boundary was designed to include all recently published West-Coast Renosterveld distributions, as well as all potential Renosterveld sites suggested by the “Predictive” extent developed. To the north-west, it roughly follows the 300 mm isohyet, as determined from the South African atlas of agrohydrology and climatology (SAAAC) rainfall image (Schulze 1997). It specifically excluded the granite hills around Vredenburg, which were classified as Renosterveld by Acocks (1953). The reasons for this were that these

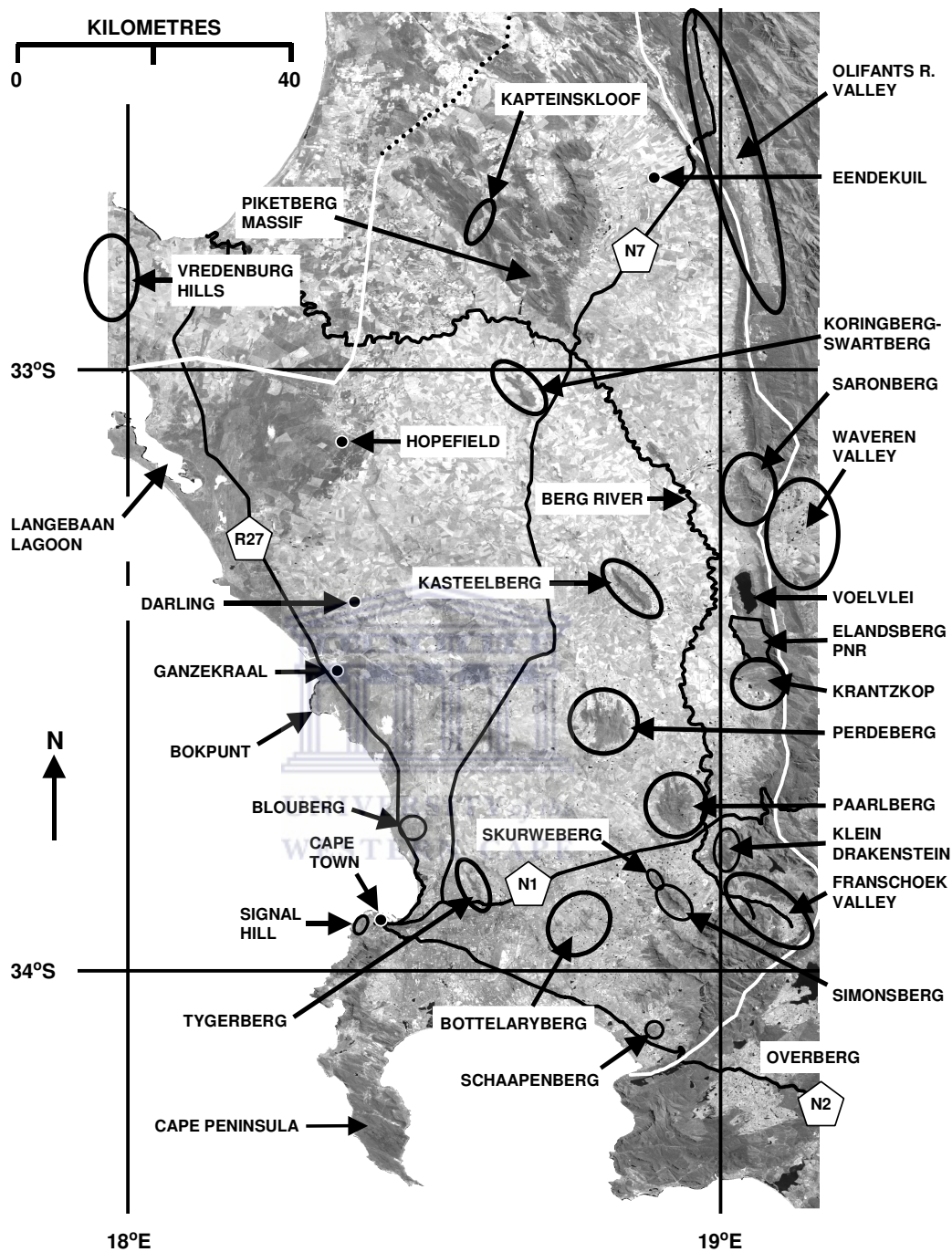


Figure 1. Landsat image showing the location of places mentioned in the text. National roads, west coast road and Berg River are also shown. The white line delimits the lowland area used in the analyses. This is enhanced in the extreme north by the black dotted line.

hills have since been defined as Strandveld (Boucher 1981), as Dune Thicket (Low and Rebelo 1996) and as a Fynbos/Thicket mosaic (Cowling and Heijnis 2001), they receive less than 300 mm rainfall *per annum* and the imagery was unavailable. To the east, the lowland area includes the coastal Renosterveld – Mountain Fynbos interfaces considered important for the maintenance of ecological processes by Cowling *et al.* (2003) and von Hase *et al.* (2003). In the north, the Piketberg massif is a mixture of Fynbos and Renosterveld (Linder 1976) and has therefore been included as a whole.

Figure 2 shows a basic land-cover classification over the full extent of the imagery. The Renosterveld sub-divisions have not been shown (the scale is such that they would not be clear). To allow for the incorporation of the Franschoek valley into the analyses, it was necessary to extend the imagery eastwards, onto the Western Fold Mountains. This extension allows one to make some general observations about land classified as Renosterveld outside of the lowland area. To the north-east there is vegetation classified as Renosterveld in the Olifants River valley. Cowling and Heijnis (2001) classified this as Olifants River Mountain Fynbos. This area was not examined in the field, and so the reason for its classification as Renosterveld is unknown. In the central-eastern part of the image is the Waveren valley, where the natural vegetation was classified by Cowling and Heijnis (2001) as Waveren-Bokkeveld Inland Renosterveld. Most of the valley has been transformed to agriculture, but the remaining natural vegetation has mostly been correctly classified as Renosterveld. In the south-east (the Overberg region), the classification indicates the presence of more Renosterveld, clumped around two areas designated as “Vines/forests/orchards” (in this case it is mostly deciduous fruit). These correspond to the “Overberg Coast Renosterveld” and “Elgin Fynbos/Renosterveld Mosaic” Broad Habitat Units (BHU) of Cowling and Heijnis (2001). The remaining major block of Renosterveld outside of published extents is in the southern Cape Peninsula. A possible explanation for this is that there are heathlands present in that area and, as mentioned in the previous chapter, Renosterveld and heathland are structurally similar (Campbell *et al.* 1981).

The rest of this chapter will be concerned only with the lowland region as defined in Figure 1. In terms of area, the vegetation classified as Renosterveld (in the first

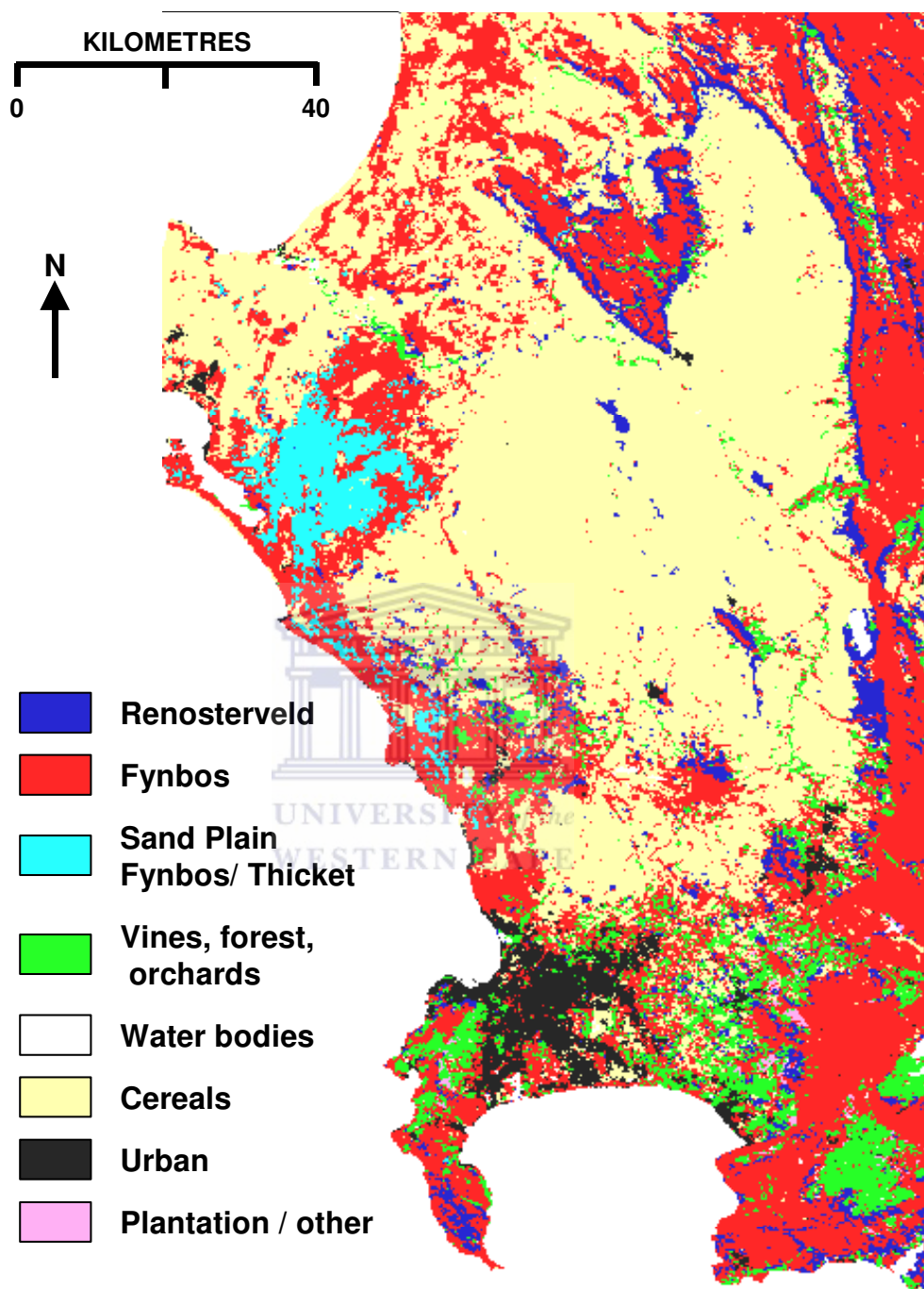


Figure 2. Simplified land-cover classification of the western lowlands and surrounding mountains of the Western Cape (this study).

supervised classification) covered approximately six percent of this lowland area. Almost a third of the lowland area was classified as some other type of natural vegetation (Fynbos, Thicket), while 58% was allocated to agriculture (mostly cereals and vines). The various published original extents of West-Coast Renosterveld (see later) cover approximately half of the land area of these western lowlands, and agriculture currently covers almost 80% of them.

Methods

Unless otherwise stated, all analyses were carried out in Idrisi32 (©Clark Labs, Clark University, Worcester, MA.) using the relevant integrated modules.

Chapter 4 described the sources and importation procedures for most of the vector overlays used in these analyses. Vector layers (in Arc-Shape format [©Environmental Systems Research Institute, Redlands, CA, USA]) for the Botanical Society's Lowlands Renosterveld Conservation project were downloaded from <http://cpu.uwc.ac.za/default.asp?gopage=lowlands/planningdomain.htm>. Where necessary, the vector files were rasterized to the same resolution (30 m) as the land-cover classifications for analyses.

It was noted in the previous chapter that the digital elevation model (DEM) obtained from Cape Nature was not suitable for these analyses, because of the rectification errors, and because the resolution (60 m) was too coarse. A new DEM at a resolution of 30 m was therefore constructed.

DEM construction

The contour data (in Arc-Shape format) were imported into MapInfo Professional version 6.5 (©MapInfo Corporation, New York). Here the data were cleaned up as far as was practical. This involved the joining of broken contour lines and the re-assigning of correct altitudes to those lines that were wrong – generally this was confined to line segments incorrectly classified as zero, or -9999. Other height errors were occasionally noticed (*e.g.* a 1960 m classification for a contour that should have been 960 m). Line segments were also found to be missing in places,

usually along very steep inclines, such as cliffs. In terms of the practical applications of this project, the joining of lines that were broken because of cliffs or overhangs would not affect the analyses performed. To thoroughly check every line would have been impossible – the initial number of “objects” (*i.e.* contour lines or portions of lines) was greater than 30 000. After cleaning and trimming the borders to more closely represent the area encompassed by the Landsat image, the number of these had been reduced to around 15 000. The file was then imported into Idrisi32, using the MIF/MID data transfer format. A problem encountered after importation was that a contour line that looped out of the selected area, and again returned to it (and thus the two parts of the line were physically separated) were recognized as a single line by MapInfo. However, Idrisi32 interpreted the two sections as separate lines and read the “second” part of the line as having no value (*i.e.* height). This meant that when the height vector file was created, those line segments were excluded, and valid lines occurring later in the database were allocated incorrect heights. This was overcome by disaggregating the contour lines before exporting.

Once the contour file had been successfully imported, it was generalized to reduce the number of vertices on the contour lines. A generalization factor of 0.00002 degrees (approximately 2 m) was used. This removes those vertices causing a deviation of less than the specified value between its two neighbouring vertices (Eastman 1999). This reduced the number of vertices in each of the quarter sections (see below) by about half, leaving between 500 000 and 1 000 000 vertices remaining in each quarter section.

An initial attempt to construct the Triangulated-Irregular Network (TIN) surface model for the whole area in one process was aborted as it was going to take a week or more of continuous processing time. The area was thus divided into four sections (north, north-central, south-central and south), each of which generously overlapped its adjoining section(s). This was done in MapInfo and each section was again disaggregated before export. It took about twelve hours to produce a TIN file for each of these quarter-sections. These quarter-sections were then joined into a single DEM covering the entire area of the image.

The “TIN” module creates a TIN vector image, as well as an image of “critical points”. Critical points are created at the top of hills and along the bottom of valleys. These remove “flat spots” in areas that are bounded by contour lines having the same value. It thus “rounds-off” hilltops and valleys. The critical points are based upon the slopes leading up to the hilltop, or down into the valley (Eastman 1999). If the contour lines are far enough apart, this can lead to erroneous points (pits or peaks) being produced which are vertically further removed from their nearest contour line, than the contour interval. As the integrated module to correct this did not work with the DEM created, some manual corrections were performed.

Analyses of published extents

Four proposed Renosterveld extents (Acocks 1953a, McDowell 1988, Low and Rebelo 1996, Cowling and Heijnis 2001), as well as the “Compound” extent, were analysed to determine the various physiographic classes each incorporated. The results were compared with the total availability of each class over the western lowland region as defined in Figure 1. A Boolean mask of each proposed original extent was used to delimit each physiographic layer, and the area of each class within the layer was calculated.

Although 44 different geological formations occurred in the west coast lowland area, the initial analyses were based upon the six geological groups identified in the previous chapter (Malmesbury Shales, Cape Granites, Alluvial soils, Table Mountain Sandstones [TMS], Quaternary Sands and Klipheuwel derivatives). In the light of these analyses, further analyses were undertaken on the Quaternary Sand and the shale groups.

Similar analyses were performed using the soil map of Schloms *et al.* (1983). In this case there were no major groupings and the soils were analysed at the unit level (equivalent to the geological formation level). Although this map was not quite as extensive as that of the geological map, it did incorporate all but the most northerly parts of the West-Coast Renosterveld areas.

The SAAAC median rainfall image (from the compact disc) of Schulze (1997) was similarly analysed to determine rainfall variations within the five extents. This

image is based upon median rainfall data from stations with over twenty years of records (Dent *et al.* 1989). The original data was supplied as a 1' grid, but was resampled to a 30 m resolution for the analyses, during which process the data was smoothed. Although information was extracted from this data, its only function in the development of the "Predictive" map was to define the 300 mm isohyet that was used to approximate the north-west boundary.

Altitudinal analyses were performed using the DEM developed above.

From the results of the above analyses, a "Predictive" extent was developed. The factors used, and the reasons therefore, are described in the next section.

Aspect and slope images were created using the DEM developed for this study. The aspect image was divided into nine classes, being the eight octants (0° to 45° ; 45° to 90° ; 90° to 135° *etc.*), plus flat land. The slope image was reclassified into nine classes (0° - 1° ; 1° - 2° ; 2° - 4° ; 4° - 8° ; 8° - 12° ; 12° - 20° ; 20° - 30° ; 30° - 60° ; $> 60^{\circ}$). The slope and aspect images were used to calculate the area covered by natural vegetation fragments, cereals and vines/orchards within each of the designated classes.

Development of a "Predictive" Renosterveld extent

In view of the suggested correlations between Renosterveld and physiographic parameters, both in the literature and as derived from this study, a "Predictive" map was developed. This was done using the relationships derived from the four published Renosterveld extents analysed. Four parameters were used, the first being rainfall. It was decided that a 300 mm per annum rainfall would be used as the lower boundary. The reason for this was that this appeared to be the median amount based on the literature (*e.g.* Acocks 1953, Taylor 1978, Low and Rebelo 1996, von Hase *et al.* 2003). This rainfall boundary was approximate due to the coarse scale (a 1' grid) used by the developers of the rainfall imagery (Schulze 1997). Where natural vegetation fragments occurred outside of, but very close to, the 300 mm isohyet, the boundary line was modified to include those fragments. It was decided to have no upper boundary, as Renosterveld stretches to the foot of the Western Fold Mountains where there is a steep increase in rainfall. The coarse-scale and interpolation technique used in the development of the rainfall image means that, in

such areas boundaries become unreliable, or at least, no more reliable than the method used here. The effect of runoff onto the adjacent plains from the mountains themselves is also unknown.

The second parameter used was altitude. Analyses showed that 93% of all published Renosterveld extents occurred below 500 m. In the literature, Acocks (1953) has suggested 300 m and Kruger (1979) 400 m as the maximum altitude for Renosterveld, while von Hase *et al.* (2003) suggested 450 m. Linder (1976) indicated that pure Renosterveld was found on shales on the Piketberg at 500 m. Low and Rebelo (1996) allocated a Fynbos classification to the higher regions of the Perdeberg and Paarlberg, while Cowling and Heijnis (2001) assigned these to a Renosterveld/Fynbos mosaic (both were included as Renosterveld within the “Compound” extent). It was therefore decided to use an upper limit of 500 m as the boundary.

The third and fourth parameters used were soil and geology. Analyses showed that most of the soils and the geological formations upon which the published extents of Renosterveld occurred were those with a higher nutrient content than is generally encountered under true Fynbos. These were the soils derived from clays and granites, and those sandy soils with a high loam content. Soil and geological formations that had 70% or more of their area (within the coastal lowland area defined earlier) present under the “Compound” extent were considered important indicators of Renosterveld (see Tables 1 and 3 for a description of the geological formations and Table 4 for a description of the soils). These soil units and geological groups were each divided into a “greater than 90%” class and a “70% to 90%” class, based upon their occurrence under the “Compound” Renosterveld extent. They were then overlaid to create a matrix of probabilities (*e.g.* a greater than 90% geology and greater than 90% soil region was considered a very high Renosterveld probability area). Less than a 70% presence of a formation under the “Compound” extent suggested the formation was not compatible with Renosterveld.

Only one of the Malmesbury Shale formations, the Nt formation, had less than 90% of its lowland extent included under the “Compound” Renosterveld distribution. Its low presence was due the fact that much of it had been urbanized. From early records (*e.g.* Thom 1952), it is known that these areas were often grassland,

Table 1. Area and percentage of total presence in the lowland area defined by Figure 1, of the nine formations of Shales, the eleven formations of Granites and the single Nama formation occurring under four published Renosterveld extents, plus the “Compound” extent (see text for details). Formation codes and descriptions are from Anon. (1973, 1990, 1997).

A. Shale formations

Area (km ²)						
Geological formation	Acocks 1953a	McDowell 1988	Low & Rebelo 1996	Cowling & Heijnis 2001	"Compound"	Description
Npo	1135.2	851.5	1192.9	1220.6	1232.6	Phyllitic shale, fine to medium grained greywacke.
Nb	99.8	100.5	100.5	100.5	100.5	Sericitic & chloritic greywacke-occasionally with conglomerate or gritstone, basal conglomerate, poorly developed phyllite; highly sheared meta-andesite.
Nk	103.2	105.3	97.2	105.3	105.3	Quartz schist with phyllite beds & minor limestone & chlorite-schist lenses.
Nbr	31.7	24.8	31.9	31.7	31.9	Greenstone with dolomite & chert lenses.
Nm	1837.7	1837.1	1764.9	1895.1	1910.0	Greywacke & phyllite with beds & lenses of quartz schist, limestone & grit; quartz-sericite schist with occasional limestone lenses.
Nt	334.0	306.4	258.2	247.6	311.1	Quartz-chlorite-sericite phyllite; minor fine grained greywacke; hornfels.
Nf	58.6	69.3	71.4	73.5	77.0	Pale weathering massive quartzite, subgreywacke, polymictic conglomerate, dark slate, phyllite.
Nn	67.8	77.2	90.6	92.8	93.2	Phyllite, medium grained to gritty greywacke, feldspathic & sericitic quartzite, limestone, dolomite & gritstone; greenstone, highly sheared & partly replaced by calcite & chert.
Total	3667.8	3372.1	3607.6	3767.0	3861.6	

Total area of the nine Shale formations listed above over the western coastal lowlands = 4094.2 km²

Table 1 continued

B. Granite and Nama (MaQg) formations

Area (km²)

Geological formation	Acocks 1953a	McDowell 1988	Low & Rebelo 1996	Cowling & Hejnis 2001	"Compound"	Description
N-CI	4.2	-	-	-	-	Granite; mainly coarse grained porphyritic with porphyritic biotitic & fine- to medium-grained leucocratic variants; quartz monzonite; adamellite; quartz porphyry.
Ny	10.3	10.3	8.5	10.29	10.3	Diorite & gabbro.
N-Cd	226.5	260.0	233.8	321.22	331.1	Granite; mainly coarse grained porphyritic with porphyritic biotitic, leucocratic, even-grained biotitic & tourmaline-bearing variants; granodiorite.
N-Ca	196.1	200.2	140.7	211.56	212.8	Granite, mainly coarse grained porphyritic with fine grained leucocratic, fine- to medium-grained porphyritic & medium grained biotitic variants.
N-Cp	33.0	20.3	27.2	52.04	52.0	Granite, mainly porphyritic & biotitic with fine- to medium-grained & hybridic variants.
N-Ck	70.8	73.9	71.3	71.61	76.3	Granite; mainly coarse grained porphyritic with porphyritic biotitic, fine-grained leucocratic, hybridic & medium-grained tourmaline-bearing variants.
N-Cs	34.7	57.6	47.3	50.59	69.6	Granite; mainly coarse grained porphyritic with medium- to coarse-grained, fine-grained porphyritic, fine-grained leucocratic, hybridic, fine- to medium-grained tourmaline-bearing & coarse-grained biotitic variants.
N-Cc	-	35.4	0.4	-	35.4	Granite, mainly porphyritic, biotitic with fine-grained & hybridic variants.
N-esp	-	4.6	5.0	5.12	6.5	Coarse-grained biotitic granite; medium- to fine-grained, greenish brecciated granite; coarse grained to porphyritic, reddish granite.
N-ewg	-	0.5	-	-	0.5	Sheared granite, granite gneiss, mylonite, phyllite gneiss, quartz-chlorite augen schist; possibly rhyodacite.

Table 1 continued

B. Granite and Nama (MaQg) formations

Area (km²)

Geological formation	Acocks 1953a	McDowell 1988	Low & Rebelo 1996	Cowling & Heijnis 2001	"Compound"	Description
N-ewp	34.5	39.1	64.4	64.12	64.4	Coarse-porphyratic to coarse-grained biotitic granite; medium-grained porphyritic granite, fine-grained muscovitic granite.
MaQg	96.7	94.5	100.2	95.9	101.5	Feldspathic grit, greywacke, quartz, schist, conglomerate & limestone beds with thin lenses of phyllite.
Total	706.8	796.6	698.7	882.5	960.3	

Total area of the eleven Granite formations listed above over the western coastal lowlands = 1148.7 km²

Table 1 continued – percentage of the total lowland presence of each shale, granite and Nama formation within each specified Renosterveld extent.

A. Shale formations

Geological formation	Acocks 1953a	McDowell 1988	Low & Rebelo 1996	Cowling & Heijnis 2001	"Compound"
Npo	89.5	67.1	94.0	96.2	97.1
Nb	99.3	100.0	100.0	100.0	100.0
Nk	98.0	100.0	92.3	100.0	100.0
Nbr	99.3	77.7	100.0	99.3	100.0
Nm	94.1	94.1	90.4	97.1	97.8
Nt	73.3	67.2	56.6	54.3	68.2
Nf	69.2	81.8	84.3	86.8	91.0
Nn	71.8	81.9	96.1	98.4	98.8

B. Granite and Nama (MaQg) formations

Geological formation	Acocks 1953a	McDowell 1988	Low & Rebelo 1996	Cowling & Heijnis 2001	"Compound"
N-CI	12.0	-	-	-	-
Ny	100.0	100.0	82.9	100.0	100.0
N-Cd	65.6	75.4	67.8	93.1	96.0
N-Ca	91.9	93.8	65.9	99.2	99.7
N-Cp	63.4	39.0	52.3	100.0	100.0
N-Ck	80.1	83.6	80.6	81.0	86.2
N-Cs	33.3	55.3	45.3	48.5	66.7
N-Cc	-	81.3	0.9	-	81.3
N-esp	-	42.3	46.0	47.0	59.2
N-ewg		100.0	-	-	100.0
N-ewp	46.7	53.0	87.3	86.9	87.3
MaQg	56.5	55.2	58.5	56.0	59.3

equating them to other areas of typical Renosterveld at that time. In addition, Signal Hill and the Tygerberg (which are predominantly of this formation) are generally accepted to support Renosterveld (*e.g.* Low and Rebelo 1996), and so it was included as a high probability geological formation.

Three granite formations having less than 67% of their total lowland presence under the “Compound” Renosterveld extent were also included in order to suggest areas where Renosterveld outliers may be present. Two of these (N-esp, NCI) were uncommon and scattered away from the main Renosterveld area. The third (N-Cs), along with the sole representative of the Nama formation (MaQg), both covered more than 100 km² of the lowland area and had 66.7% and 59.3% respectively of their lowland presence included in the “Compound” Renosterveld extent. The N-Cs formation occurred in the extreme south-east and straddled the “Compound” Renosterveld boundary. The MaQg formation occurred along the eastern foot of, and within, the Piketberg massif. Both formations were represented by soils that were predominantly (> 75%) found under Renosterveld. All four of these formations were therefore included in the “70%-90%” geological categories.

After the field verification phase, doubts were raised as to the validity of including the Terrace Gravel formation as a Renosterveld-compatible formation. In the case of the Elandsberg Private Nature Reserve (PNR), an observation supported by the comments of Chris Burgers (quoted by Tansley 1982) and by the publications of Jarman (1986), Rebelo (1995) and Krug (2004). Although described as “River Terrace Gravel” (Anon. 1997), most of this formation is along the foot of the Western Fold Mountains. These soils might be better described as colluvial, rather than alluvial (*e.g.* Schloms *et al.* 1983); in either case they were apparently derived from the adjacent nutrient-poor TMS (Anon. 1997) soils of the mountains, and were therefore excluded from the “Predictive” extent, due to their being incompatible with the edaphic description of Renosterveld. This view has been supported by the authors of the SANBI vegetation map (Mucina and Rutherford 2004), who allocated the Terrace Gravel formations to an “Alluvial Fynbos” class.

Analyses of the spectrally defined natural vegetation classes

The four spectrally defined natural fragment units (see previous chapter) were analysed with respect to their geological, pedological and aspect/slope components, to see what part these physiographic factors might have played in their spectral identification. These four classes were 1: High probability and 2: Low probability that the vegetation was Renosterveld, and 3: High probability and 4: Low probability that the vegetation was Fynbos. The technique used was the same as that described for the above analyses of the four published Renosterveld extents.

Fractal analyses

As this study is based upon a raster system, one can never get a “perfect” circle. The relationship between a perfect circle of infinite size and the actual (raster-based) circle, also of infinite size, will vary from 1, when the perimeter of the circle is continuous with the horizontal, or vertical edge of a pixel; *i.e.* at the 0, 90, 180 and 270 degree portions of the circle, to 1.414 at the 45, 135, 225 and 315 degree portions of the circle. At these latter points, the perfect circle perimeter follows the diagonal across the pixel. As a pixel can only be included or excluded as a whole, it means that the actual circle perimeter will follow the two inside (or outside) edges of the pixel, giving it a length 1.414 times longer than it should be. At intermediate angles, the error will lie between 1 and 1.414. To correct for this, it was assumed that the average error was 1.207 – a value midway between the upper and lower bounds. The perimeter length was therefore corrected by multiplying the measured perimeter by 1/1.207. The area would be similarly affected, in that a pixel can only represent one class. One would expect that the majority class would be the one allocated to that pixel, but spectral and statistical interactions do not guarantee this. For the purposes of this exercise, it was assumed that *on average* the number of mixed land-cover pixels allocated to a particular class were the same as the number excluded from that class, and no corrections were made.

The area (square metres) and perimeter (metres) measurements of each fragment were calculated and imported into a Microsoft Excel spreadsheet (©1985-1999, Microsoft Corporation). Data were sorted by area, with perimeter length as a

secondary sort factor. The patch boundary dimension (based on the area : perimeter ratios of fragments of different sizes) was determined by successively plotting the slope of \ln (perimeter) versus \ln (area) of 50 fragments ranked according to area (smallest to largest). The first point of the slope was from the 50 smallest fragments (fragment 1 to fragment 50). The next point was obtained by excluding the smallest fragment (fragment 1) and adding fragment 51 *etc.* (see Krummel *et al.* 1987). Due to the results obtained, this was repeated using groupings of 100, 200 and 300 fragments to determine successive points on the graph.

In addition, the sites (still ranked in terms of area) were divided into discrete size classes and the slope (and thus D) was derived from plotting \ln (perimeter) against \ln (area) for all the fragments within each size class.

To determine the level of patchiness (the Korcak exponent), the fragments were sorted in reverse order (largest area first) and divided into size classes based upon the area a , and $a\sqrt{2}$ (Hastings *et al.* 1982, Hastings and Sugihara 1993). The accumulative number of patches of size of at least “ a ” was determined. The accumulative number and the area were both log transformed and the slope of the \ln of the accumulative number of fragments versus the \ln of the area “ a ” was calculated.

Results

Readers will note small discrepancies in total areas for the same extents of Renosterveld where different physiographic categories are tabled. This is because small amounts of data were missing (or undefined) from some of the physiographic layers.

Geological analysis

Table 2 shows the area of each geological group occurring under the Renosterveld extents analysed in this study. It should be remembered that the maps of Acocks (1953a) and McDowell (1988) were not perfectly geo-referenced, and so those figures should be treated with caution. McDowell’s (1988) map is also truncated in the far northern section, not quite reaching the latitude of Eendekuil. The

Table 2. Area and percentage of total presence in the lowland area defined by Figure 1, of the main geological groups occurring under four published Renosterveld extents plus the “Compound” extent (see text for details). The Alluvial group includes Terrace Gravel; the Malmesbury Shales group includes the MaQg formation from the Nama group.

Area (km²)

Geological group	Acocks 1953a	McDowell 1988	Low & Rebello 1996	Cowling & Heijnis 2001	"Compound"
Malmesbury Shales	3764.5	3466.7	3707.9	3863.0	3963.2
Cape Granites	610.1	702.1	598.5	786.6	858.9
Alluvial	412.6	510.0	457.8	484.3	570.5
TMS	54.5	78.2	59.5	44.2	113.6
Quaternary Sands	1635.1	1191.4	1207.8	1284.4	1648.9
Klipheuwel derivatives	95.8	92.4	83.9	86.3	94.0
Total Area	6572.7	6040.9	6115.3	6548.8	7249.0

Total lowland area = 12742.1 km²

Percentage of presence in lowland area

Geological group	Acocks 1953a	McDowell 1988	Low & Rebello 1996	Cowling & Heijnis 2001	"Compound"
Malmesbury Shales	88.3	81.3	86.9	90.6	92.9
Cape Granites	62.4	71.8	61.2	80.5	87.9
Alluvial	65.3	80.8	72.5	76.7	90.3
TMS	3.2	4.5	3.4	2.6	6.6
Quaternary Sands	32.5	23.7	24.0	25.5	32.8
Klipheuwel derivatives	89.1	85.9	78.0	80.3	87.4

Vredenburg Hills have been excluded from all calculations involving Acocks' (1953a) extent. As expected, the lowland shales, granites and Klipheuwel derivatives were largely found under the proposed extents of Renosterveld (> 60% of their lowland presence included). The Table Mountain group (mostly sandstones) was generally excluded, and it can be assumed that inclusions were due to data collection errors, generalizations of geological and botanical boundaries, soil mixtures, scale and digitizing errors *etc.* It was clear however, that the Quaternary Sands group had a definite association (24-33% of their total lowland presence) with Renosterveld. This group was therefore analysed at formation level to determine which of them was important. Nine formations occurred under the published Renosterveld extents, but only four (Qd, Ts/Tf, T-Ql, Qgg) were predominantly (> 84%) associated with Renosterveld (Table 3). These were all edaphically acceptable, as they included a loam and/or clay component that was compatible with the “eutrophic sands” description of Boucher and Moll (1981).

The Qd (Fill, reclaimed area) formation had only 4 km² of extent in the whole lowland area, and all but 0.1 km² occurred within the “Compound” Renosterveld area. Since this formation was entirely located around Cape Town dockyard, and was built upon, it was excluded from the “Predictive” extent. Although less than 50% of the T-Qt formation (scree) occurred under the “Compound” Renosterveld extent, the actual amount (110 km²) was high. However, most of this occurred along the foot of the mountains, and was thus considered to be derived from TMS. It was therefore deemed incompatible with the edaphic definitions of Renosterveld and excluded.

A maverick formation was the Qg (Springfontein) formation, described as being a light grey to pale red sandy soil (Anon. 1990). Although only 22.3% of its total presence on the west coast lowland area occurred within the “Compound” extent, this still amounted to an area of 627.2 km². Even excluding the Vredenburg hills, Acocks' (1953a) extent incorporated 838.1 km² of this formation, 12.8% of its total area. Much of this was due to the “tongue” situated along the east side of the Langebaan lagoon.

Table 3. Area and percentage of total presence in the lowland area defined by Figure 1, of nine formations of Quaternary Sands occurring under four published Renosterveld extents and the “Compound” extent. Formation codes and descriptions are from Anon. (1973, 1990, 1997).

Area (km ²)						
Geological formation	Acocks 1953a	McDowell 1988	Low & Rebelo 1996	Cowling & Heijnis 2001	"Compound"	Description
Ts/Tf	69.3	58.7	59.9	63.2	64.1	Silcrete (Ts) & ferricrete (Tf)
T-Qt	39.9	84.3	63.2	57.1	109.7	Scree & gritty sand; scree
T-Ql	445.0	518.9	477.6	477.6	614.4	Loam & sandy loam
Q-Sr	56.6	5.7	1.3	-	6.1	Unconsolidated white sand with shell fragments & pebbles locally along beach; fixed dunes
Ql	66.1	-	-	0.1	0.1	Limestone & calcrete, partially cross-bedded; calcified parabolic dune sand
Qgg	116.6	183.5	205.7	186.3	215.2	Gravelly clay/loam soil
Qg	838.1	331.1	395.0	498.9	627.2	Light-grey to pale red sandy soil; wind blown sand
Qd	-	1.5	3.9	-	3.9	Fill, reclaimed area
Qb	3.6	7.6	1.2	1.3	8.1	Brackish calcareous soil
Total area	1635.1	1191.4	1207.8	1284.4	1648.9	

Total area of the nine Quaternary Sands listed above over the western coastal lowlands = 5033.9 km²

Table 3 continued.

Percentage

Geological formation	Acocks 1953a	McDowell 1988	Low & Rebelo 1996	Cowling & Heijnis 2001	"Compound"
Ts/Tf	90.9	77.0	78.7	82.9	84.2
T-Qt	16.8	35.5	26.6	24.1	46.3
T-Ql	62.0	72.3	66.5	66.5	85.6
Q-Sr	12.7	1.3	0.3	0.0	1.4
Ql	14.0	-	-	-	-
Qgg	46.1	72.5	81.2	73.6	85.0
Qg	29.9	11.8	14.1	17.8	22.3
Qd	-	38.1	97.7	-	97.7
Qb	16.9	36.0	5.6	6.0	38.5

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The Qg formation is the most widespread formation (2806.6 km²) within the lowland area as defined here. On the "Clanwilliam" map (Anon. 1973), the Ql and Qg formations were not clearly differentiated between. This means that north of 33°S the Ql formation is included within the Qg formation. The Ql formation is largely restricted to the coastal areas, and the distribution of its soil analogue (B1) suggests that little, if any, of this formation occurred within Renosterveld areas north of 33°S. In addition, the amount of Renosterveld assigned to the Ql formation within the bounds of the Cape Town map (Anon. 1990), where the Qg and Ql formations were clearly differentiated, was effectively zero, except in the case of Acocks' (1953a) extent. Therefore, any errors introduced by the incorporation of the Ql formation into the Qg formation are likely to be insignificant. Only 11.3% of the land covered by the two agricultural classes (cereal and vineyards) in the lowland area was on the Qg formation and only 0.02% was on the Ql formation,

suggesting low nutrient levels. For these reasons both the Qg and Ql formations were excluded from the “Predictive” extent.

Soil Analyses

Eight soils had more than 75% of their west coast distributions overlain by the “Compound” Renosterveld extent (Table 4). The clay content of these soils varied from 0% to 55% (MacVicar *et al.* 1977), but spatial data was not available to subdivide the soil units into their component soil types, from which a more accurate clay content estimate may have been possible. Three of these soils (C1, C2 and IL) had more than 1000 km² associated with the “Compound” Renosterveld area, while the F2, F3 and D4S soil classes each had more than 500 km² associated with the “Compound” area.

Most of the natural vegetation remnants occurred on the J class, which was allocated to most of the major hills (including the Piketberg) in the Renosterveld area, and along the lower slopes of the Western Fold Mountains from the Saronberg southwards. This soil class incorporated most of the Voelvlei-Elandsberg-Krantzkop (VEK) complex.

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Rainfall Analyses

The result of overlaying the CCWR rainfall with the published Renosterveld areas (Table 5), showed that all but the extents of Acocks (1953a) and McDowell (1988) received a maximum rainfall of over 2500 mm, although in all cases 92% or more received less than 800 mm. Less than 3% of any extent received more than 1000 mm, suggesting that figures above this can probably be attributed to interpolation errors.

A breakdown of rainfall distribution within the three Renosterveld habitat units of Cowling and Hejnis (2001), occurring within the west coast area, showed that only the Swartland unit could be said to have a “typical” Renosterveld rainfall. Forty-three percent of the Boland unit had above the usually quoted maximum of 600 mm, while all of the Perdeberg Fynbos/Renosterveld mosaic area received between 600 mm and 1000 mm. At the low end of the rainfall scale, the extent of

Table 4. Area and percentage of total presence in the lowland area as defined by Figure 1, of the different soil types occurring under published Renosterveld extents and the “Compound” extent. Soil codes are from Schloms *et al.* (1983). Description codes are from MacVicar *et al.* (1977).

Area (km²)

Soil code	Acocks 1953a	McDowell 1988	Low & Rebelo 1996	Cowling & Heijnis 2001	"Compound"	Description
URBAN	79.9	129.3	79.3	64.6	135.1	
K1	-	-	0.5	0.5	0.5	Soil type undefined by Schloms <i>et al.</i> 1983.
K	3.5	-	-	-	-	Soil type undefined by Schloms <i>et al.</i> 1983.
J	214.2	325.7	316.2	344.2	437.8	Very shallow sandy lithosols found on mountains: Ms10; Cf 30, 20; Hh 30,20.
IL	916.6	948.0	981.5	1007.0	1135.7	River valleys: Weakly developed soils dominant; generally hydromorphic: Du, We, Oa, Ya.
H5	-	0.1	-	-	0.1	Sandstone benches: Sandy podzolic and hydromorphic soils: Hh30, 20; Cf30, 20; Kd14
F2	658.9	612.9	636.5	705.8	729.6	Red apedal soils: Red kaolinitic loams & clays: Hu26, 25.
F3	428.7	464.0	412.0	452.4	510.9	Red apedal soils: Red kaolinitic loams & clays: Hu16, 27.
D2S	72.5	93.1	90.4	71.5	156.4	Medium sand duplex soils: Kd21; Es41.

Table 4 continued.

Area (km²)

Soil code	Acocks 1953a	McDowell 1988	Low & Rebello 1996	Cowling & Heijnis 2001	"Compound"	Description
D3S	82.5	209.1	173.3	172.0	212.8	Coarse sand duplex soils: Kd22; Es42.
D4S	807.4	519.1	615.3	760.0	786.6	Coarse sand duplex soils: Kd22; Es42.
D1L	22.0	33.4	16.8	17.1	33.4	Duplex soils with fine sand or loamy topsoils: Es33, 34; Kd21; Ss24
C1	1494.5	1410.0	1473.7	1541.8	1557.3	Poorly developed residual soils on convex slopes & duplex soils on plain remnants: Ms10; Gs13; Sw31; Ss23.
C2	1239.9	1214.2	1209.9	1279.4	1331.2	Poorly developed residual soils on convex slopes & duplex loams on concave mid-footslopes: Ms10; Gs13; Sw31; Ss23.
C4	5.1	1.8	-	1.6	1.9	Red duplex residual loams: Va 20, 21, 40, 41
B1	349.3	23.5	65.4	84.9	134.7	Yellow & Grey acid sands & podzols: Lt11; Ct11; Fw11; Cv21.
B2	18.7	37.0	40.2	36.8	57.0	Grey acid sands and podzols: Lt11, 12; Fw11, 12; Ct11, 12
A1	8.6	-	-	-	-	Grey calcareous coastal sands: Fw20, 21
A2	148.8	0.1	-	6.2	6.3	Pale neutral to calcareous coastal sands: Fw20, 21; Ms22
Total	6551.1	6021.3	6111.1	6545.9	7227.3	

Table 4 continued.

Percentage

Soil code	Acocks 1953a	McDowell 1988	Low & Rebello 1996	Cowling & Hejnis 2001	"Compound"
URBAN	17.2	27.9	17.1	13.9	29.1
K1	-	-	29.3	26.1	29.3
K	100.0	-	-	-	-
J	13.3	20.2	19.6	21.3	27.1
IL	66.5	68.8	71.2	73.1	82.4
H5	0.0	0.2	-	-	0.2
F2	81.5	75.9	78.8	87.4	90.3
F3	75.4	81.7	72.5	79.6	89.9
D2S	19.1	24.5	23.8	18.8	41.1
D3S	33.2	84.3	69.9	69.3	85.8
D4S	77.2	49.7	58.9	72.7	75.2
D1L	54.2	82.0	41.2	42.1	82.0
C1	93.9	88.6	92.6	96.8	97.8
C2	86.7	84.9	84.6	89.4	93.0
C4	100.0	35.8	-	32.1	37.5
B1	23.9	1.6	4.5	5.8	9.2
B2	13.0	25.8	28.0	25.7	39.7
A1	20.7	-	-	-	-
A2	16.6	-	-	0.7	0.7

Total area of the soil types listed above over the coastal lowlands = 12191.6 km²

Table 5. Rainfall distribution over four published Renosterveld extents, plus the “Compound” extent, expressed as the percentage of each extent receiving rainfall within the limits of each class. Rainfall data were extracted from the SAAAC CD (Schulze 1997).

Rainfall classes	Acocks 1953a	McDowell 1988	Low & Rebelo 1996	Cowling & Heijnis 2001	"Compound"
0-300 mm	3.5	1.8	2.6	2.5	2.4
300-600 mm	84.2	77.5	79.6	80.1	77.8
600-700 mm	7.1	8.7	8.1	7.8	7.6
700-800 mm	3.2	5.1	4.3	4.4	4.5
800-1000 mm	1.7	4.8	3.8	3.8	5.2
1000-1500 mm	0.3	1.9	1.4	1.3	2.3
1500-2000 mm	-	0.2	0.1	0.1	0.3
2000-2500 mm	-	-	< 0.04	< 0.04	< 0.05
> 2500 mm	-	-	< 0.001	< 0.001	< 0.001

McDowell (1988) had the lowest percentage (1.8%) of area that received less than 300 mm per annum, while Acocks (1953a) had the highest (3.5%). The other three extents had around 2.5%. In the Cowling and Heijnis (2001) extent, all of this low rainfall fell within the Swartland Coastal Renosterveld unit, and comprised 3.9% of that unit. Once again, errors of interpolation and generalization need to be taken into account when considering these figures.

Altitudinal analyses

Using the “Compound” Renosterveld extent, the maximum altitude recorded was 1478 m, which came from the Boland Coast Renosterveld unit (Cowling and Heijnis 2001). The Low and Rebelo (1996) extent gave a maximum altitude of 1303 m, Acocks (1953a) a maximum of 1138 m and McDowell (1988) a maximum of 959 m but account must be taken of geo-registration errors in these last two extents.

Only 10.5% of the “Compound” Renosterveld extent occurred above 400 m, and 6.7% above 500 m. The Perdeberg and Paarlberg Fynbos/Renosterveld mosaic units

(75% higher than 400 m, 50% higher than 500 m) accounted for just over a third of the “Compound” Renosterveld area occurring above 500 m, and a quarter of that above 400 m.

Aspect and slope analyses

Considering aspect availability over the lowlands as a whole, 56.8% of the slopes faced west. This figure is reasonable, considering the existence of the Western Fold Mountains along its eastern boundary. Within the Renosterveld extents, aspect availability (per octant) was always within 1.4% of the lowland area as a whole. “Compound” Renosterveld slopes facing the south-west quadrant were under-represented by 1.4% compared to those available, while slopes in the octant to the west of north (315° to 360°) were over-represented by 1.3%. These values cannot be considered to be of significance in the light of inherent errors present within the data, and the arbitrary manner in which the “total lowland” area was defined.

Slopes of less than 1° had a 5.3% higher presence in the lowlands as a whole, compared to the “Compound” Renosterveld area. This again is reasonable, considering the fact that much of the lowland area outside of the typical Renosterveld areas is composed of sands that were deposited by the higher ocean levels in the past (Hendey 1983a). Such depositions would not be favourable for the creation of hills, such as occur within the Renosterveld region. Within the various proposed original extents, slopes of greater than 8° were under-represented by 2.5% or less, relative to the lowland area as a whole. This is probably explained by the exclusion of much of the Cape Peninsula mountain chain, and the interior of the Piketberg massif from published Renosterveld extents. However, the intermediate slopes were over-represented in the “Compound” Renosterveld area by between 2.5% and 6.7%.

Restricting the analyses to the “Compound” Renosterveld area, the percentage cover within nine aspect and nine slope classes of three land-cover classes is shown in Table 6. Natural vegetation occurred with a 4.5% higher presence than would be expected on south facing slopes, and with a similar lower than expected presence on those facing north. The east-west difference was more pronounced, with an

Table 6. Percentage cover* of natural and agricultural land-cover units under the “Compound” Renosterveld extent, as related to aspect and slope. The Aspect and Slope Availability columns show the percentage of the land within the “Compound” Renosterveld extent with the row’s characteristic.

Aspect octant	Natural	Cereal	Vines/ Green	Aspect availability	Slope (degrees)	Natural	Cereal	Vines/ Green	Slope availability
E of N	10.6	14.4	15.1	13.9	0-1	13.2	24.6	19.6	22.4
N of E	9.3	11.5	12.7	11.2	1-2	11.0	26.3	25.5	24.5
S of E	7.9	9.0	10.5	9.0	2-4	12.0	30.5	27.4	27.8
E of S	8.6	10.2	10.7	10.1	4-8	14.0	14.9	19.1	15.6
W of S	15.1	13.4	12.4	13.7	8-12	11.8	2.6	5.6	4.2
S of W	20.6	14.2	13.5	15.0	12-20	20.6	0.9	2.4	3.4
N of W	15.9	13.2	11.4	13.4	20-30	12.9	0.2	0.3	1.6
W of N	11.7	13.7	13.4	13.5	30-60	4.4	0.1	0.0	0.5
Flat	0.2	0.4	0.2	0.3	60-90	0.1	0.0	0.0	0.0
Hemispheres					Coarser slope division				
All north facing slopes	47.6	52.8	52.6	52.0	0-2 degrees	24.2	50.9	45.1	46.9
All south facing slopes	52.2	46.9	47.1	47.7	2-8 degrees	26.1	45.4	46.5	43.4
All east facing slopes	36.4	45.1	49.1	44.2	8-12 degrees	11.8	2.6	5.6	4.2
All west facing slopes	63.4	54.5	50.7	55.5	12-30 degrees	33.5	1.0	2.7	5.0

*Columns may not add up to 100% due to rounding.

almost 8% higher than expected presence on the west-facing slopes, and an equivalently lower presence on those facing east. Cereal farming closely reflected aspect availability, while vineyards appeared to be about 5% more common on the east-facing slopes and 5% less common on the west-facing slopes, than would be expected from a representative distribution.

The relationship between slope and land-cover was more spectacular, although somewhat expected. Over 90% of the agricultural activity in the “Compound” area was occurring on slopes of less than 8°. In contrast, only 50% of the remaining natural vegetation was found on such slopes. One-third of all the natural vegetation fragments remaining occurred on slopes of greater than 12°, even though these represented only 5% of the land available.

Comparison of the “Predictive” and “Compound” extents

Figure 3 shows the outcome of the “Predictive” analysis.

Table 7 compares the geology and pedology of the “Predictive” and “Compound” extents, both in relation to those natural fragments of greater than 3 ha remaining in these areas, and in relation to each of their potential full extents. The highest probability category (geology and soil both > 90%) had very similar areas of potential extents. In most other categories, the total “Predictive” areas were substantially higher than in the “Compound” area. Despite this, only 5.8% of the “Compound” area fell upon “unsuitable” substrate, the major culprits being Quaternary Sands (especially the Qg and T-Qt [scree] formations) and Terrace Gravel.

Although the total amount of natural vegetation remaining in both extents was similar, almost one-third of that in the “Compound” extent was occurring on non-compatible substrate. This was due to the exclusion of much of the VEK complex from the “Predictive” extent where it occurred on Terrace gravel or scree. The presence of natural vegetation on the Qg formation along the western boundaries of the “Compound” area, which was excluded from the “Predictive” extent, was the other major source of dissension.

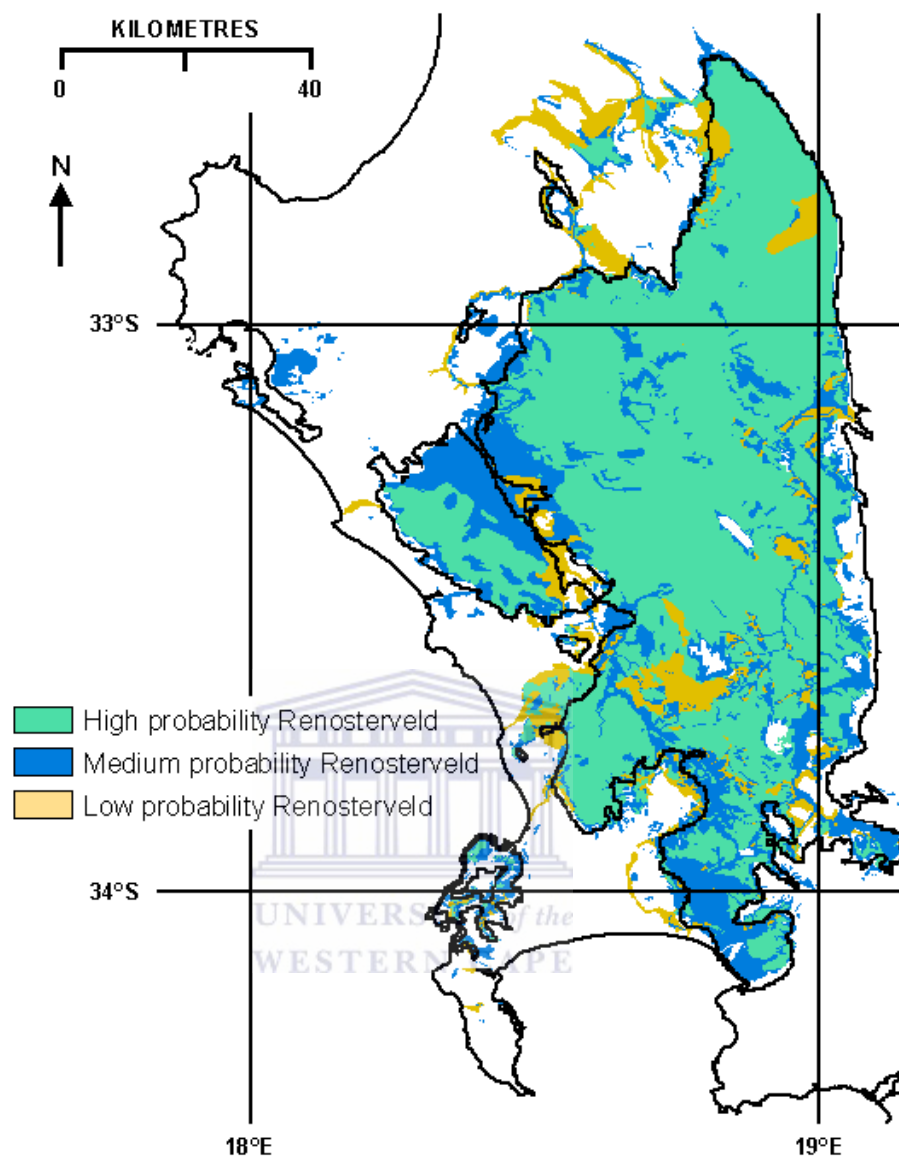


Figure 3. A three-class version of the “Predictive” analysis. Black line delimits the “Compound” extent. See text for detailed categories and overlays used. White areas do not support Renosterveld.

High probability = Geology *and* soil are > 90% compatible with Renosterveld, or one is > 90% compatible and the other is 70% to 90% compatible.

Medium probability = Geology *or* soil is > 90% compatible, or geology *and* soil is 70% to 90% compatible.

Low probability = Either geology *or* soil is 70% to 90% compatible.

Table 7. Comparison of the “Compound” and “Predictive” Renosterveld extents, in relation to the remaining fragments of natural vegetation, and to their potential coverage.

Category	Fragments > 3 ha				Potential coverage			
	“Compound” (km ²)	%	“Predictive” (km ²)	%	“Compound” (km ²)	%	“Predictive” (km ²)	%
Geology & soil > 90%	114.2	16.3	133.7	17.8	2733.3	37.6	2810.0	35.2
Geology > 90%, soil 70-90%	47.2	6.8	62.3	8.3	1569.6	21.6	1677.5	21.0
Soil > 90%, geology 70-90%	31.1	4.4	34.8	4.6	444.0	6.1	462.6	5.8
Geology only > 90%	113.3	16.2	180.1	24.0	319.9	4.4	521.7	6.5
Soil only > 90%	44.9	6.4	72.6	9.7	212.2	2.9	291.3	3.7
Soil & geology 70-90%	49.8	7.1	65.2	8.7	854.2	11.7	939.7	11.8
Geology only 70 – 90%	35.6	5.1	68.9	9.2	275.8	3.8	415.4	5.2
Soil only 70-90%	51.9	7.4	131.8	17.6	440.8	6.1	855.5	10.7
Not compatible	211.0	30.2	-	-	423.8	5.8	-	-
Total area	698.9		749.5		7273.8		7973.6	
Fragments as a percentage of their total potential extent:					9.61		9.40	
Fragments in the “Compound” extent that are edaphically/geologically compatible with Renosterveld (percentage is compatible fragments as a proportion of total “Compound” area):							487.9 km ²	= 6.71%

Spectrally defined classes

Due to the very small amount of the spectrally defined low probability Fynbos class, it was generally ignored. The geological and pedological components of the three remaining spectrally defined classes (Tables 8 and 9) shows that both Renosterveld classes had their highest presence upon shales, compared with the Fynbos class which was more common on granites and Quaternary Sands. The C2 soil class was favoured slightly more by the High Probability Renosterveld class, while the F3 soil class was favoured by those fragments classified as Fynbos.

Table 6 showed that most natural vegetation fragments remained on the south and west facing slopes. While the two high probability classes also followed this pattern (Table 10), the low probability Renosterveld class did not, and this class was almost non-existent on the steeper south and west facing slopes. In the 8° to 20° slope class, its pattern of presence on the different aspects was approximately opposite to that of the two high probability classes. The two high probability classes both show similar patterns of distribution, but in the less than 8° slope class, the high probability Fynbos class showed a smaller difference between the eastern and western aspects.

Table 8. Geological component of each of the four spectral probability classes, expressed as a percentage of the total area covered by the fragments remaining in that class.

“Compound” area

	High prob. Renosterveld	Low prob. Renosterveld	High prob. Fynbos	Low prob. Fynbos
Total area of fragments in “Compound” area (km²)	355.5	70.7	272.4	0.4

Percentage of each spectral class occurring on each geological group

Malmesbury Shales	27.7	34.8	12.8	15.2
Cape Granites	26.0	13.8	32.2	7.5
Alluvial	16.9	20.0	7.4	21.2
TMS	10.3	2.6	16.5	31.5
Quaternary Sands	20.7	27.4	30.6	24.5
Klipheuwel derivatives	1.1	3.4	0.5	-

“Predictive” area

	High prob. Renosterveld	Low prob. Renosterveld	High prob. Fynbos	Low prob. Fynbos
Total area of fragments in “Predictive” area (km²)	354.8	89.4	302.4	0.3

Percentage of each spectral class occurring on each geological group

Malmesbury Shales	35.7	34.6	18.1	20.6
Cape Granites	21.8	11.3	31.9	28.7
Alluvial	7.6	18.4	7.2	24.6
TMS	4.5	1.7	7.4	0.8
Quaternary Sands	19.8	31.7	34.0	25.4
Klipheuwel derivatives	3.5	2.8	0.8	-

Table 9. Soil component (from Schloms *et al.* 1983) of each of the four spectral probability classes, expressed as a percentage of the total area covered by the fragments remaining in that class.

	“Compound” area				“Predictive” area			
	High prob. Renosterveld	Low prob. Renosterveld	High prob. Fynbos	Low prob. Fynbos	High prob. Renosterveld	Low prob. Renosterveld	High prob. Fynbos	Low prob. Fynbos
Total area (km²)	354.0	70.5	264.8	0.3	342.7	88.8	296.8	0.3
Percentage of each spectral class occurring on each soil type				Percentage of each spectral class occurring on each soil type				
URBAN	0.6	1.7	1.2	-	0.5	1.3	0.9	-
K1	< 0.05	-	0.1	-	< 0.05	-	0.1	-
J	45.5	12.4	40.5	29.8	28.8	8.4	21.8	17.8
IL	8.1	27.6	9.1	9.9	13.9	32.6	16.7	12.6
H5	-	-	< 0.05	-	-	-	-	-
H2	-	-	-	-	0.1	-	0.1	-
F2	3.1	9.3	1.6	-	4.0	8.8	2.6	1.2
F3	7.9	1.7	19.0	13.3	8.4	1.5	21.6	14.6
D2S	0.5	0.1	0.5	-	0.3	0.2	0.3	-
D3S	0.6	1.9	0.4	-	1.2	2.2	0.6	-
D4S	7.7	18.1	4.1	27.7	12.7	20.4	10.8	30.5
D1L	0.2	-	0.2	-	0.2	-	0.2	-
C1	4.5	7.9	1.4	17.8	5.0	7.0	1.7	19.6
C2	15.6	13.8	11.3	1.6	20.1	12.9	12.8	0.9
C4	0.2	0.2	0.1	-	0.3	0.3	0.3	-
B1	3.9	4.3	9.0	-	3.8	3.9	4.9	2.9
B2	1.7	1.1	1.6	-	0.5	0.6	0.2	-
A2	< 0.05	-	0.1	-	0.2	< 0.05	4.5	-

Table 10. The percentage composition of the four spectral probability classes related to aspect within three slope classes.

A: Fragments on slopes of less than 8 degrees

	“Compound” area				“Predictive” area			
	High prob. Renosterveld	Low prob. Renosterveld	High prob. Fynbos	Low prob. Fynbos	High prob. Renosterveld	Low prob. Renosterveld	High prob. Fynbos	Low prob. Fynbos
Area of each class (km²)	186.1	59.4	105.2	0.3	176.9	76.6	146.8	0.2
Percentage of fragments on slopes of less than 8 degrees, falling within each aspect octant								
E of N	8.2	16.2	8.9	9.2	10.8	15.8	11.3	6.3
N of E	6.2	11.6	8.0	8.6	8.4	11.7	8.3	4.1
S of E	4.5	8.3	9.4	6.7	6.3	8.8	7.2	5.2
E of S	6.4	8.5	10.1	40.5	8.3	9.5	10.0	42.4
W of S	14.7	13.7	14.8	10.8	15.1	13.5	16.3	11.8
S of W	26.8	15.2	20.8	6.7	22.8	14.7	19.4	8.5
N of W	20.5	14.1	15.7	13.9	16.1	13.3	15.7	16.6
W of N	12.2	12.3	12.3	3.8	11.8	12.5	11.9	5.2
Flat	0.5	0.3	0.1	-	0.5	0.2	0.1	-

Table 10 continued.

B: Fragments on slopes of between 8 and 20 degrees

	"Compound" area				"Predictive" area			
	High prob. Renosterveld	Low prob. Renosterveld	High prob. Fynbos	Low prob. Fynbos	High prob. Renosterveld	Low prob. Renosterveld	High prob. Fynbos	Low prob. Fynbos
Area of each class (km²)	117.1	9.1	100.0	< 0.02	127.3	10.6	103.5	< 0.015
Percentage of fragments on slopes of between 8 and 20 degrees, falling within each aspect octant								
E of N	12.1	21.2	7.9	36.9	12.3	20.5	7.8	6.7
N of E	11.9	22.3	7.8	31.6	10.5	21.0	7.4	0.0
S of E	9.1	16.7	8.8	15.8	7.4	16.1	8.1	6.7
E of S	6.9	10.2	10.7	10.5	7.1	11.0	11.0	13.3
W of S	13.9	10.7	17.3	-	15.6	12.1	19.4	26.6
S of W	20.0	7.1	21.0	-	21.8	7.9	20.6	-
N of W	15.1	3.8	15.7	-	15.3	4.0	15.5	6.7
W of N	10.9	8.1	10.9	5.3	10.1	7.5	10.3	40.0

Table 10 continued.

C: Fragments on slopes of more than 20 degrees

	“Compound” area				“Predictive” area			
	High prob. Renosterveld	Low prob. Renosterveld	High prob. Fynbos	Low prob. Fynbos	High prob. Renosterveld	Low prob. Renosterveld	High prob. Fynbos	Low prob. Fynbos
Area of each class (km²)	52.2	2.2	67.2	0.1	50.6	2.2	52.1	0.1
Percentage of fragments on slopes of more than 20 degrees, falling within each aspect octant								
E of N	18.0	32.8	8.5	0.8	15.2	36.9	8.9	0.6
N of E	16.1	28.3	8.3	-	10.8	27.6	7.1	-
S of E	10.1	15.5	8.6	-	6.8	12.1	7.7	-
E of S	9.0	7.6	11.1	-	9.8	7.8	12.9	-
W of S	13.3	4.8	19.3	11.0	17.1	4.9	22.6	18.9
S of W	11.9	0.4	17.6	56.7	16.6	0.5	17.7	69.2
N of W	10.4	0.9	13.7	23.6	13.2	0.9	13.3	4.1
W of N	11.2	9.8	12.8	7.9	10.4	9.3	9.9	7.1

Fractal analyses

The change in the fractal dimension (D) of the area : perimeter ratio with increasing fragment size, showed that using less than 300 fragments to determine each point of the slope led to D having values out of the accepted range of $1 \leq D \leq 2$. Among the smaller fragments, the slope was often negative (the last negative slope occurred with a maximum fragment size of 62.25 ha – see inset in Figure 4). It was only once 300 points were used that, with the exception of the first three points, the oscillations remained within the expected range. Figure 5 shows the results of the rolling regression of the \ln of the area against the fractal dimension for the “Predictive” data set (the “Compound” set gave a similar pattern and is not shown). Each point was plotted at the average area value for the 300 points used to determine the D value. The extreme oscillations present at the lower end of the X axis makes it difficult to assess whether the increase in D between the \ln area of about 12.3 and about 13.2 (~ 22 ha to ~ 52 ha) is genuine, or an artefact of the method. It was however supported by the data in Table 11, which shows the result of estimating the value of D by dividing the fragments into discrete size classes.

Although the general plot of the rolling regressions for the “Compound” and “Predictive” extents were similar (due no doubt to the large number of shared fragments), there were some interesting differences when they were divided into discrete size classes (Table 11). Of note is the very low D in the 50 ha to 100 ha class in the “Compound” extent, and that the last three size classes of the two extents appear to cycle asynchronously, with the 100 ha to 500 ha index being higher than the adjoining classes in the “Compound” extent, and lower in the “Predictive”. Also of note is the big difference in D for the 50 ha to 100 ha class in the two extents.

The Korcak exponent (B) showed that there was a strong relationship between the fragment size and the number of patches within each size class (Table 12). Plotting the results (Figure 5) suggested that the set could have been divided into two groups. When this was done, B for fragments larger than 547 ha was 1.636, while for fragments less than 547 ha it was 0.837. This suggests that, for the larger fragments, there was no fractal relationship between the number remaining and their area.

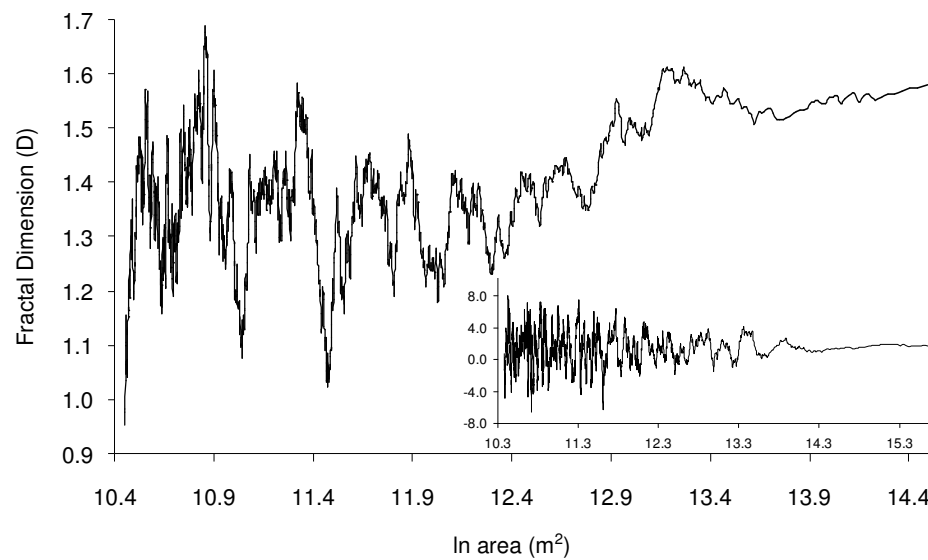


Figure 4. Changes in the fractal dimension of the remaining West-Coast Renosterveld fragments as determined from successive regressions of \ln perimeter on \ln area. The main graph plots this relationship using 300 fragments to determine each point. The inset shows the same data when only 50 fragments were used to determine each point. Axis titles for the insert are the same as for the main graph.

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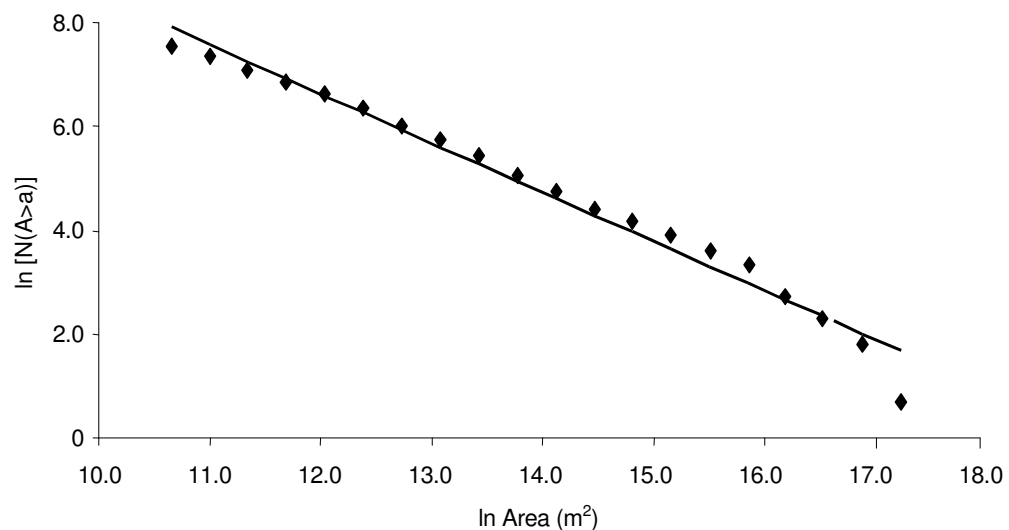


Figure 5. The accumulative number of fragments of area $A > a$, with increasing fragment size. Points are the actual data; the line is the fitted regression for all points ($y = -0.9485x + 18.0109$).

Table 11. Mensural summary of the remaining fragments of natural vegetation of > 3 ha within the “Compound” and “Predictive” extents of West-Coast Renosterveld.

A. All natural vegetation fragments identified within the “Compound” area.

Size class (ha)	N	Average area (ha)	Average corrected perimeter length (m)	Average A:P ratio	Fractal Index	% of total no. sites	% of total area
3-5	416	3.9	954.9	42.0	1.26	30.8	2.3
5-10	370	7.0	1433.2	50.0	1.20	27.4	3.7
10-25	284	15.8	2492.4	65.3	1.31	21.0	6.4
25-50	130	35.4	4359.7	84.8	1.49	9.6	6.6
50-100	60	68.6	6995.6	102.9	1.10	4.4	5.9
100-500	65	214.7	16210.3	134.1	1.48	4.8	20.0
> 500	25	1536.0	71513.7	238.6	1.28	1.9	55.0
All	1350	51.7	4046.9	63.3	1.42	100.0	100.0

Total area of fragments analysed = 69799.8 ha

B. All natural vegetation fragments identified within the “Predictive” area.

Size class (ha)	N	Average area (ha)	Average corrected perimeter length (m)	Average A:P ratio	Fractal Index	% of total no. sites	% of total area
3-5	536	3.9	959.7	41.6	1.21	28.4	2.8
5-10	514	7.1	1447.0	50.3	1.30	27.2	4.9
10-25	444	15.9	2478.4	65.8	1.33	23.5	9.4
25-50	175	35.0	4270.5	86.2	1.58	9.3	8.2
50-100	107	67.2	6975.6	101.6	1.66	5.7	9.6
100-500	81	198.5	15634.3	129.7	1.36	4.3	21.5
> 500	32	1017.5	62344.3	166.2	1.57	1.7	43.6
All	1889	39.6	3765.8	63.1	1.42	100.0	100.0

Total area of fragments analysed = 74765.1 ha

Table 12. Cumulative probabilities of fragments of greater than a certain size existing within the “Predictive” extent.

Fragment size (m ²) = a	No. of fragments (A) of area > a = (N[A > a])	ln (N[A > a])	ln area a
> 30000000	1		
30500571.2	2	0.69	17.23
21566947.7	6	1.79	16.89
15023131.1	10	2.30	16.53
10658653.8	15	2.71	16.18
7751289.3	28	3.33	15.86
5474316.4	37	3.61	15.52
3815931.6	50	3.91	15.15
2700413.2	65	4.17	14.81
1926602.5	82	4.41	14.47
1356761.0	115	4.74	14.12
956856.1	157	5.06	13.77
678631.3	231	5.44	13.43
477560.7	307	5.73	13.08
338282.0	415	6.03	12.73
238941.7	566	6.34	12.38
168253.7	746	6.61	12.03
118978.1	959	6.87	11.69
84146.2	1209	7.10	11.34
59993.1	1528	7.33	11.00
42426.4	1889	7.54	10.66
		r²	0.9774
		Slope (-B)	-0.9485
		D = 2B	1.897

B = Korcak exponent of patchiness

D = Fractal dimension

Discussion

Renosterveld and its substrate

It would appear from the analyses carried out here that, with one exception, Renosterveld has been predominantly mapped over soils derived from shales, granites and eutrophic sands. However, Table 2 showed that the four distributions looked at here did not chronologically “improve” the accuracy of the mapping in relation to the mapped geological boundaries. A probable reason for this was that each of the authors had their own objectives. At the same time, technological improvements (such as satellite imagery and computer analyses) allowed better mapping in terms of these objectives. The latest vegetation map (Mucina and Rutherford 2004) has closely followed the geological map, to the extent of mapping geologically defined vegetation units smaller than 1 ha. Nevertheless, within-formation anomalies, such as vegetation boundaries on the Paarlberg and the Perdeberg remain in this latter map. It should be pointed out that the geological boundaries are also approximations and, as was shown in this study where the soil map of Schloms *et al.* (1983) was included, they do not allow for soil heterogeneity and mixing.

It was worrying that large areas of all published Renosterveld extents included substantial amounts of a nutrient-poor sand (the Qg formation). This geological type is clearly one that needs further investigation. Although it is *mainly* analogous to the B1 soil unit of Schloms *et al.* (1983), which was not Renosterveld compatible, it was also mapped over the D4S soil unit, which was. In certain forms of the B1 sub-unit (Constantia form) the clay content of the lowest horizon may be as high as 15%, although the clay content of the middle horizon is always less than 6% (MacVicar *et al.* 1977). However, Schloms *et al.* (1983) mentioned that the upper sand layer of this unit is often deeper than 1200 mm. The D4S unit also has a low clay content in its middle horizon, but in the lowest horizon it is greater than 25% (MacVicar *et al.* 1977). A cursory examination of these Qg areas often showed the presence of dense alien *Acacia* infestations and sand mining was noted in some parts (*e.g.* to the south-west of the Perdeberg). Where natural vegetation was present, it tended to have either a Thicket structure, and/or a high presence of

Restioid species. Cowling (1984) noted that, in the Humansdorp region of the Eastern Cape, thicket species were confined to the deeper well drained soils, while Renosterveld was found in the shallower soils. It might be interesting to examine the relationships between Fynbos, Thicket and Renosterveld in these transitional areas, to determine the effects of soil depth upon community development.

The Qg formation was analysed with respect to other vegetation types, and was found to be largely associated with the Sand Plain Fynbos BHU of Cowling and Heijnis (2001). Overlaying the Sand Plain Fynbos unit with the geological map showed that, within the west coast lowland area, 72.1% (2023.8 km² of 2806.3 km²) of this formation was covered by this vegetation type. Where the Ql formation had been determined and mapped as a separate entity, 39.7% of it was allocated to Sand Plain Fynbos (*c.f.* 0.01% occurring within the “Compound” Renosterveld area). The Ql formation was mainly associated with the A2 soil sub-unit, which was predominantly (63.7%) associated with the Fynbos/Thicket Mosaic units of Cowling and Heijnis (2001).

When analysed with respect to the soil map, then 81.4% (1185.9 km² of 1457.3 km²) of the sub-unit B1 was under Sand Plain Fynbos. The other soil type that was largely associated with Sand Plain Fynbos was D2S, which had 81.2% (308.8 km² of 380.3 km²) of its area covered by this vegetation type. The remainder was found under the Swartland Coastal Renosterveld BHU. This soil is derived from aeolian sands and occurs on fluvial and residual clays (Schloms *et al.* 1983). The high level of clay (> 25%) in the lowest horizon of D2S suggests that, like the D4S soil discussed above, its compatibility with Renosterveld is related to the depth of the upper sand layers. It was therefore not surprising to find a substantial proportion of this soil type under the “Compound” Renosterveld area (41.1%). Agriculture on these nutrient poor soils was very low. Only 2.2% of all lowland agriculture occurred on B1 soils, 3% on D2S soils and 0.7% on A2 soils. This supports the proposal that where Renosterveld has been mapped onto these soils it has mainly been due to boundary generalizations.

The lack of detailed soil maps, and the variation in soil structures, such as described above, means that an accurate prediction of whether the vegetation will lean towards Renosterveld or Fynbos becomes impossible in such areas. Thwaites and

Cowling (1988) noted that, on the Agulhas Plain, topsoils under the Renoster Shrublands were sometimes leached and infertile, but they were underlain by clays, rich in exchangeable bases. These areas were also home to a Mesotrophic Asteraceous Fynbos. Nutrient differences between the two communities were small, and appeared to be related to level of Calcium (and perhaps Magnesium), Renoster Shrublands occurring where these were higher. This example indicates how relatively small differences may lead to large differences in plant community composition. In the case of the heterogeneous soils described above, it may be the variations in the depth of the sand covering the clay layers that leads to the development of Renosterveld/Fynbos mosaics, as described by Boucher and Moll (1981).

Alluvial extents will vary with the type of river, the slope and the soil type in the region from which it is coming. Alluvium is often nutrient rich, due to organic matter washed into the river (natural and fertilizer runoff), as well as to processes occurring in the river itself. Most of the lowland area looked at has only gentle slopes ("Compound" area = 62% less than 2.9°, 84.4% less than 5.7°). This implies that the rivers are sluggish, and that particulate matter in the river is likely to be deposited, rather than eroded. Since Renosterveld prefers soils with a high nutrient content, it is likely that it will occur along the flood-plains of rivers, unless excluded by vegetation that can make better use of the higher water availability, such as alien and indigenous *Acacias* and other trees. Comparing the Renosterveld distributions with alluvium on the geological map gave no indication that Renosterveld was excluded from these areas. The main problem with this formation is that it usually occurs in strips which are too narrow to be included on maps produced at regional scales.

It may seem strange to see that the major soil classes in the Renosterveld area were generally comprised of a high level of sand, as this does not tie in very well with the belief that Renosterveld occurs on fine-grained soils with high nutrient levels (Kruger 1979). It should be noted that the clay soils, while having a high nutrient level compared to the surrounding acid sands, do not rate very highly when compared with the better soils of South Africa, as found in the north-east, or even central Karoo regions. Using the method devised by Fey, which is based upon the

soil's clay content and its base status and has a range of one to ten, Schulze (1997) rated the fertility of the soils of the Swartland as "3-4 low+". This compares with the soils of the Sandveld (Sand Plain Fynbos) which have a rating of "1-2 very low+". The soils of South Coast Renosterveld (*sensu* this thesis) were rated as "5-6 average+", giving the south coast a higher agricultural potential than the Swartland (see Chapter 1, pages 56 and 58 for typical fertilizer levels used on the west and south coasts respectively). It may therefore be that endemic West-Coast Renosterveld species are adapted to lower nutrient levels than South-Coast Renosterveld species, thus making the differentiation between West-Coast Renosterveld and Sand Plain Fynbos more difficult. With respect to this, Boucher (1987) noted that many of the species occurring on the heavier granite soils of Jonkershoek (Mountain Fynbos) were also present in West-Coast Renosterveld, and Cowling (1984) similarly suggested that the Fynbos influence in West-Coast Renosterveld was stronger than in the case of South-Coast Renosterveld.

In an undergraduate botany project (no copies available) at the University of Cape Town in 1985, David Lawton rated the soils of the west coast lowlands in terms of their agricultural potential. He used information from MacVicar *et al.* (1977) and from the Elsenburg agricultural college. These ratings were later used by McDowell (1988, published as McDowell and Moll 1992) to analyse the agricultural threat to remnants of lowland vegetation. They found that the seven "best" soils (in terms of agricultural potential) were almost entirely occupied by West-Coast Renosterveld (those areas that had not been turned over to agriculture, that is). About one third of the remaining fragments of Renosterveld occurred on soils which had an agricultural potential of greater than 50 (they rated potential on a scale of 1 to 100); 38% fell within the 25 to 49 rating, and the rest (23%) on shallow, rocky soils and outcrops. These soil ratings were used along with the gradient of the slope upon and the amount of rainfall to derive an agricultural threat index for the 55 Renosterveld fragments they examined.

The conclusion that can be drawn from the above observations is that West-Coast Renosterveld has essentially been defined (and mapped) on edaphic conditions, but that certain soils have levels of heterogeneity that do not allow one to make definite predictions about the communities developing upon them. The overlap in species

composition with other communities, such as with Fynbos and Thicket, often makes the determination of community boundaries difficult where soils of different quality grade into one-another. These mixed-soil boundaries are the ones most likely to maintain communities of natural vegetation, simply because their agricultural worth is borderline. The processes leading to the development of these boundaries, namely colluvial action along the foot of the mountains, and wind and oceanic deposition along the southern and western borders have lead to fuzzy boundaries. However, where the soil boundaries are sharp (such as TMS-shale boundaries on the Piketberg) changes in community composition may be abrupt (*e.g.* Linder 1976). There are few areas of natural vegetation remaining on pure shale soils, and all of these will have been affected by the surrounding agricultural activities and alien invasions. The absence of undisturbed Renosterveld sites may be the reason why Renosterveld has been considered an ecotone (*e.g.* Taylor 1978, Day 1983), rather than a community in its own right.

Rainfall

Dent *et al.* (1989) discussed the development of the SAAAC rainfall images used in these analyses. Although much effort was put into correcting for the various physiographic effects of the landscape upon rainfall, the 1' grid (approximately equivalent to 1.75 km) still means that along the Western Fold Mountains the rainfall mapped will be an approximation. In addition, the effect of run-off from the mountains has not been accounted for, thus the effective precipitation received close to the mountains is unknown.

The generally published range of rainfall for Renosterveld is between 300 mm and 600 mm *per annum*, although low values of 250 mm (Boucher 1983) and high values of 500 mm (Acocks 1953) and 650 mm (von Hase *et al.* 2003) are in the literature. McDowell and Moll (1992) recorded a number of West-Coast Renosterveld sites (in the south) receiving more than 800 mm of rainfall. The highest figure quoted was 875 mm for the western slopes of the Paarlberg. Four other sites received more than 800 mm and eleven received between 600 mm and 800 mm. This means that 16 of the 55 (29.1%) major West-Coast Renosterveld sites remaining receive more than the “normally accepted” maximum. Low (*pers. comm.*

to Richard Knight) has suggested 700 mm might be better as a general upper level. This would exclude only six of McDowell and Moll's sites (Schaapenberg, which Moll and Bossi [Anon. 1983] mapped as Fynbos; Skurweberg west slopes; Paarlberg west slopes; Perdeberg foothills; Signal Hill; Simonsberg west slopes). As all of these sites are on hillsides, it might be argued that the soils would dry quicker than would soils on flat lands. This may mean that the *effective* water supply to the vegetation on these slopes would be equivalent to a lower rainfall received in flatter areas. Their slope (note three west-facing slopes in the list) may also be subject to higher solar radiation levels, thereby increasing evaporation and transpiration and hence effectively lowering the available water. On the other hand, the vegetation may effectively be receiving more precipitation, due to the percolation of rainfall from the higher areas of those hills upon which they occur.

Apart from its absolute availability, other factors can affect the water relations of the vegetation. The fine-grained soils typically found under Renosterveld develop a much lower water-potential during the summer drought period than do the equivalent coarse-grained sandy soils (Bidwell 1974). The ability of a species to withstand this water stress in summer probably determines whether it can grow on these soils. In the southern regions, where the rainfall is higher, and due to orographic rainfall and cloud, the summer drought is less severe, typical Fynbos species can invade these clay soils. Added to this would be the greater leaching effect of the higher rainfall, thus increasing the competitive advantage of those species that can subsist under lower available-nutrient regimes. This factor is particularly relevant on granite soils (Kruger, quoted by Cowling and Holmes 1992), which have a lower nutrient status than Malmesbury Shales (Talbot 1947). Of relevance to this is Boucher's (1995) observation that the vegetation on Bottelary Hills (mainly granite) would *revert* to Fynbos under the right management regime.

Altitude

Linder (1976) appears to be the only person to have provided firm evidence of coastal Renosterveld occurring at altitudes of 500 m. A problem with determining the maximum altitude at which West-Coast Renosterveld occurs from published vegetation maps is the presence of steep slopes along the proposed western

boundaries. As discussed in the previous chapter, a typical line on a 1:250 000 scale map represents 75 m on the ground, which can equate to substantial altitudinal errors along steep slopes. Add to this the errors of generalization and re-projection and it is not surprising that all the proposed extents analysed gave maximum altitudes of 900 m or more along these boundaries.

Low and Rebelo (1996) classified the higher regions of the Paarlberg and Perdeberg as Fynbos, while Cowling and Heijnis (2001) allocated them to a Fynbos/Renosterveld mosaic. Van Wilgen (1974) mapped Renosterveld communities on the Paarlberg, but did not include altitudes. About half of Cowling and Heijnis' (2003) Fynbos/Renosterveld mosaic unit was above 500 m. Mucina and Rutherford (2004) have "Renosterveld" (actually Swartland Granite Bulb Veld) reaching to almost 700 m on the Paarlberg, but rarely to more than 300 m on the Perdeberg. Their choice of vegetation unit boundaries on these two hills could not be related to any of the physiographic factors normally used to delimit Renosterveld, nor could it be related to any previous publications.

It may therefore be concluded that, in the absence of detailed geological or vegetation maps covering a substantial amount of this area, the choice of 500 m as an upper limit in the "Predictive" Renosterveld distribution was reasonable. While genuine high altitude Renosterveld may exist in suitable niches, it should be considered a curiosity rather than typical coastal Renosterveld. One could also argue that, since Renosterveld in the Waveren valley, which in terms of the generally accepted physiographic parameters fits the definition of West-Coast Renosterveld, has been excluded by all recent authors, these higher altitude pockets should also be excluded.

Aspect

It was noted above that cereal crops showed no preference for any aspect. On the other hand, vineyards were preferentially found on eastern slopes. Ruth Parker (*pers. comm.*) said that wine farmers prefer to use the cooler east-facing slopes as the grapes grown there have a better taste. Natural vegetation appeared to be more common on west facing slopes. There are two possible explanations for this, both of which are probably valid. The first could be that there is very little agriculture along

the western Fold Mountains due to the colluvial creeping of the nutrient-poor (and stony) TMS soils along the lower slopes of these mountains. This means that a relatively large proportion of these west-facing slopes are covered by natural vegetation. The Voelvllei-Elandsberg-Krantzkop complex is one such example. Although this complex is relatively flat, it still has an overall west-facing aspect. Unlike the scattered hills, such as Kasteelberg, Paarlberg, Perdeberg *etc.* this escarpment is not “balanced” by an equivalent length of east-facing aspect. The other explanation would be that, since the east-facing slopes are preferentially used for vineyards, there are fewer east-facing slopes available for natural vegetation.

In terms of using aspect and slope as a factor in the development of a “Predictive” extent of Renosterveld, it was noted that there were few steep slopes in the region and where they occurred the geology or soil was often incompatible with Renosterveld. In addition, there have been no detailed studies relating community structure to aspect in the region. Nevertheless, differences in community structure on different aspects were noted, especially on the Koringberg, where the rainfall is relatively low. The north-east aspect had a drier karroid-type community, compared with the south-west aspect where Renosterbos (*Elytropappus rhinocerotis*) and grass were more common. Other authors have also noted differences in community composition on different aspects (*e.g.* Tansley 1982, Heydenrych and Littlewort 1995) and this will be examined in terms of the spectral classification section later in this chapter.

Slope

Four-degrees appears to be the borderline between the choice of cereals or vineyards. The steeper slopes have a higher proportion of vineyards compared to the flatter slopes. However, the *actual* area covered by cereals on slopes of between eight and twenty degrees was greater than that covered by vines, because of the big difference in the total area covered by each of these crops.

There is a general assumption that more natural vegetation remains on the steeper slopes than on the flatter areas, because the flatter areas are more easily (and legally) cultivated. This study (Table 6) showed that over 60% of the natural

vegetation remaining was actually on slopes of less than 12° , a figure supported by the work of McDowell and Moll (1992 – see below). Some of these flatter areas occur in reserves (*e.g.* the top of Paarlberg, the VEK complex), are occurring on soils of borderline agricultural worth (*e.g.* Terrace Gravels), or along river valleys. Nevertheless, the aerial photograph analysis (Chapter 3) showed that flat areas that were agriculturally viable might be worked, even if a road has to be built to reach these areas (*e.g.* the Koringberg). Steep slopes in this region, while relatively uncommon, are difficult to cultivate, hence a greater *proportion* of these areas remain untransformed. Species restricted to these steeper slopes are therefore under less threat than species restricted to flatter areas, where *relatively* less natural land remains.

McDowell and Moll (1992) sampled the gradients of 55 remnant Renosterveld sites, as well as eighteen 400 ha control sites, randomly distributed throughout their proposed Renosterveld extent. Table 13 compares their results with those obtained by re-analysing the “Compound” Renosterveld extent in terms of their slope classes. The overall trends in available slope were similar, although this analysis allocated more available land to regions with a slope of greater than 5%. In contrast, proportionately more fragments were recorded on land with a slope of less than 20%. However, it is not possible to say whether these findings were genuine, or the result of different slope measurement techniques. The technique used in this study would have allocated small areas of flat land on otherwise steep slopes, to its appropriate slope class. McDowell and Moll used a ruler and contour lines, thus producing a more generalized estimate. In this study, there are a number of “flat” (low-slope) remnants conserved along the boundaries of the “Compound” Renosterveld area in the west. These areas tended to be located on the Qg Quaternary Sand formation and their status as genuine Renosterveld remains questionable. This problem did not arise with McDowell and Moll’s study, as the remnants they looked at were chosen *in situ* as sites that contained Renosterveld as defined by the botanists of their time. However, they made no distinction (or comment) between Renosterveld and Fynbos as it occurs within the Elandsberg reserve.

Table 13. Comparison of the proportion of different slope classes existing over West-Coast Renosterveld as estimated from this study, and from the study of McDowell and Moll (1992). The slope classes are those used by McDowell and Moll. The figures for this study are based upon the extent of the “Compound” area; fragment figures are from all natural vegetation fragments of > 3 ha identified within the “Compound” area. McDowell and Moll’s figures are for the extent defined in their paper, and for the 57* remnants identified by them.

Slope class	This study		McDowell and Moll's (1992) figures
	Area (km ²)	Percent	Percent only
Original extent			
0-5% (0° to 2.9°)	4506.79	61.96	74.33
5-10% (~ 2.9° to 5.7°)	1631.72	22.43	15.35
10-20% (~ 5.7° to 11.3°)	698.20	9.60	8.93
20-40% (~ 11.3° to 21.8°)	313.65	4.31	1.24
> 40% (> ~ 21.8°)	123.43	1.70	0.15
Sum	7273.79	100.00	100.00
Remnants			
0-5% (0° to 2.9°)	212.83	30.45	26.34
5-10% (~ 2.9° to 5.7°)	86.19	12.33	10.57
10-20% (~ 5.7° to 11.3°)	120.67	17.27	15.19
20-40% (~ 11.3° to 21.8°)	181.66	25.99	37.74
> 40% (> 21.8°)	97.55	13.96	10.15
Sum	698.90	100.00	100.00

* Table 4 of McDowell and Moll (1992) (from which their figures come) states a figure of 57. The rest of their paper, and that of McDowell’s 1988 thesis, in which this work first appeared, refers only to 55 remnants.

Redefining Renosterveld

West-Coast Renosterveld has been defined in terms of floristics by a number of authors (*e.g.* McDowell 1988, Low and Rebelo 1996). It has also been referred to as an ecotone (Taylor 1978, Cowling and Holmes 1992); as a mixture of Fynbos and pseudo-Fynbos (Boucher 1987); and as being present only because of disturbance (Marloth 1908, Adamson 1929, Levyns 1929, Taylor 1978, Boucher and Moll 1981, Boucher 1983). Coastal Renosterveld has been shown to vary from pure grassland (Tansley 1982, Kruger and Bigalke 1984, Rebelo 1992), through typical Renosterbos shrubland to, potentially, scrub forest (Britton and Jackelman 1995). Heydenrych and Littlewort (1995) reported the presence of thicket with tall trees in kloofs in the Darling area. It is therefore clear that any attempt at defining its extents on floristics alone will be difficult.

The alternative question is: To what extent can a floristic community be defined in terms of physiographic factors? Thwaites and Cowling (1988) compared floristically defined communities on the Agulhas Plain, with the same communities defined in terms of substrate and topography and found a strong relationship. Chapter 1 looked at the literature discussing the character of coastal Renosterveld communities, and in most cases there was a reference to the fertility of the soils they occurred upon. On the other hand, the analysis of communities carried out in the next chapter shows that there is a great deal of species heterogeneity within “Renosterveld”. Had this study been carried out during one of the glacial periods (which might be said to be the “normal” climatic condition of the past million or so years), what communities would people have mapped? If the expected levels of human-induced global warming occur, what communities will be mapped in 500 (or even 100) years time? In a situation such as the Fynbos Biome, where levels of local endemism are so high that communities separated by a kilometre or two may share only half their species, at what point does a vegetation community cease to represent its constituent parts?

The single invariable factor (in terms of shorter geological time spans) is the substrate and topography. It has already been noted that the lowland region is relatively flat, yet consists of a variety of substrates. The region could be analysed

in terms of substrate characteristics and a separate community assigned to each sector. In gross terms, this was done by the farming community, who identified areas where agriculture was a viable proposition. Acocks (1953) mapped the area in terms of farming potential, and essentially defined the term “Renosterveld”. The mapping of floristic communities up to 2001 refined the boundaries, but not the basis of the definition. The latest vegetation map (Mucina and Rutherford 2004) has substantially sub-divided “West-Coast Renosterveld” to the point where it has become a generalization itself. Nevertheless, these sub-divisions are still essentially based upon the fact that the soils are relatively nutrient-rich, compared to the surrounding sands. As such, the natural vegetation communities existing upon them are threatened by agricultural transformation. It was for the identification of such fragments that the “Predictive” distribution was developed.

Differences between the “Predictive” and other extents would be due to a number of factors. The first would be the reduced generalization of the boundaries to those defined by specific physiographic parameters. The incorporation of outlying sites (*e.g.* around Ganzekraal) that were previously excluded due to their small size would be another. Along the west coast road, these smaller sites were instantly identifiable (in November 2002), due to the presence of an *Eriocephalus* sp. that was in seed. Other additions included sites in the Piketberg. At the top of the Kapteinskloof road, which passes through the central Piketberg, there was an extent of Renosterbos (Figure 6). Since the aim of the Renosterveld project is to identify areas for floral conservation, these outliers should be examined, as they may be a source of species that are endangered within the main Renosterveld area. They might also provide an opportunity for studies of genetic drift or physiographic adaptations.

The high probability of Renosterveld categories combined both soil and geology that were compatible with the general nutrient-rich soil definition of Renosterveld. It is likely that these categories are correctly mapped. In the case of the lower probability areas (*e.g.* a 70% to 90% probability determined by soil *or* geology) it is likely that these are due to boundary generalizations at the 1:250 000 mapping scale, or to the presence of one of the heterogeneous soil/geological types and would need to be examined in the field.



Figure 6. Renosterbos community at the top of the Kapteinskloof road in the northern Piketberg.

Most of the “geology only 70% to 90%” category was represented by formations that were compatible with Renosterveld (as opposed to the “doubtful” formations such as the Qg formation). In these cases the equivalent soil unit tended to be J (around the mountains), “Urban” (as around Paarl) or, in the area between Darling and Hopefield, D2S or D3S. These latter are coarse sands overlaying lower horizons with a greater than 25% clay content and are likely to consist of the mosaics described by Boucher and Moll (1981) which would have to be allocated to an ecotone or mosaic category.

The “soil only 70% to 90%” category was mostly representative of the D4S unit which coincided with the Qg geological formation. The description of the D4S unit is similar to that of the D2S and D3S units mentioned in the previous paragraphs. This category is likely to belong to the ecotone/mosaic class, with the vegetation community being determined by the depth of the upper sand layer. From a quick scan of these areas done during the 2002 field trips, it was noted that these areas were often infested with alien *Acacias*. The presence of these aliens suggests that the quality of the soil is low (*i.e.* deep sands) and so the farmers do not bother to clear it.

The Cape Lowlands Renosterveld project – How does it compare?

Von Hase *et al.* (2003) used a modified version of the BHU West-Coast Renosterveld extent developed by Cowling and Heijnis (2001). Their aim was to include all coastal Renosterveld, while excluding adjacent vegetation types. For this they used geological maps and field observations. As mentioned in their technical report, there are many ways to ‘cut the cake’, and we need to consider this, along with such problems as the generalizations inherent in many of the data layers when assessing the results. More than 25% of their fragments were less than 0.1 ha, which means that it only requires a boundary error of 100 m (easily within the bounds of *e.g.* digitizing errors, or the distance-equivalent of typical line thicknesses) to transfer a fragment from one side of a boundary to the other. However, although 78% of the fragments were less than 3 ha, these made up less than 2% of the total fragment area, and are therefore insignificant. The small fragments have been retained in this analysis of the Botanical Society data.

Table 14 gives a comparison of the two studies. Their core area contained little in the way of incompatible substrate, these being mostly TMS and alluviums on the Piketberg, the Saronberg and in the Elandsberg PNR, and Quaternary sands at the foot of the Klein Drakenstein mountains. However, almost 30% of their buffer area was Renosterveld compatible, and covered an area almost 15% of that found in their core area. Apart from the Signal Hill-Groote Schuur region, most of the Renosterveld-compatible areas that they excluded were outliers situated in the northern and western Piketberg, and along the west coast. In total, an area equivalent to just over 5% of their planning domain was “missed”.

Interestingly, a larger percentage of their core fragments fell on Renosterveld incompatible soils, than would be expected from the very low level of such soils in their core area. This was probably due to some of the largest core area fragments (such as the Elandsberg PNR and Saronberg) occurring on the less compatible soils, such as Scree and Alluvium. Of more concern was the small amount (< 50%) of fragments identified in this study that fell within the core area of the Botanical Society study. Field trips had shown that most of these did in fact support a Renosterveld structure. Just over 84% fell within the core and buffer areas

Table 14. Assessment of the conservation plan of von Hase *et al.* (2003), with respect to the “Predictive” extent of West Coast Renosterveld, as described in this chapter.

	Planning Domain (ha)	% of total study area	Area of all natural fragments (ha)	% of natural fragments	Area of Renosterveld fragments (ha)	% of Renosterveld fragments
Botanical Society study						
Core area						
Renosterveld-compatible substrate	651022.9	97.6	31476.0	83.4	31417.8	83.5
Non-compatible substrate	15695.4	2.4	6247.7	16.6	6205.5	16.5
Total in core area	666718.3		37723.7		37623.3	
Buffer area						
Renosterveld-compatible substrate	94350.3	29.1	39844.0	20.8	46.1	52.2
Non-compatible substrate	230196.3	70.9	151863.4	79.2	42.3	47.8
Total in buffer area	324546.6		191707.5		88.4	
Area “missed” by the Botanical Society	51984.8	5.2				

Table 14 continued

	Area of all natural fragments (ha)	% of natural fragments	Area of Renosterveld fragments (ha)	% of Renosterveld fragments
This study				
Combined "Predictive" and "Compound" area	95947.2	100		
"Predictive" area only			74945.0	100
Fragments* identified in this study occurring in Botanical Society Core area	44411.8	46.3	36861.6	49.2
Fragments* identified in this study occurring in Botanical Society Buffer area	36873.5	38.4	26349.4	35.2
Fragments* identified in Core and Buffer areas combined	81285.3	84.7	63211.0	84.3
Fragments* "missed" by the Botanical Society	14661.9	15.3	11734.1	15.7

* Natural fragments = all natural vegetation fragments of > 3 ha identified in this study;

* Renosterveld fragments = all fragments predicted to be Renosterveld in terms of the "Predictive" definition developed in this thesis.

combined. A further $\pm 5\%$ would have been added, had they included the Signal Hill – Groote Schuur area. In total, this suggests a 10% disagreement between the two studies, which, in view of the problems associated with the definition of Renosterveld, and the difficulties involved in the satellite classification in this area, is probably acceptable. If any serious criticism can be levelled at the Botanical Society's study it is their omission of the Signal Hill-Groote Schuur area from the analyses, although it may be argued that since these are under the protection of the South African National Parks board, their inclusion was not necessary.

Spectral Probability classes

When the final compound map was produced from the combination of the supervised and unsupervised classifications, four categories of natural vegetation fragments were identified. These categories were a function of the spectral classification processes *only* and their relationship with the vegetation occurring in the field was unknown. Their spectral identities would be related to a combination of vegetation structure, vegetation cover, soil colour, slope, aspect and water relations. These factors would interact with each other to extents that may be difficult to define. The presence of a "Mountain Fynbos" cluster restricted to steep south-west facing slopes was noted in the previous chapter. Here some of the more easily definable aspects of the three spectral classes are examined (the low probability of Fynbos category is largely ignored because of its very low total coverage).

High probability Renosterveld classifications occurred more frequently on shales, compared with the Fynbos, which was more predominant on granites and sands (Table 8). A pixel brightness analysis was carried out using band 7 (geologically the most sensitive band [Jensen 2000]) of the imagery, to see if there were differences in brightness between the geological groups that may explain these differences. Shales and Quaternary Sands had very similar average brightness levels (110.8 ± 28.4 and 109.7 ± 36.8 respectively). Granites tended to be darker (94.5 ± 33.0) but not significantly so. It seems unlikely therefore, that geology alone was responsible for the differences between the spectral classes.

Where the slope gradients were low there did not appear to be much difference between the spectral categories, although the low probability Renosterveld class (the “grassy” Renosterveld) showed a higher percentage occurrence on north-east facing slopes, than did the other two classes (Table 10). However, because the fragments making up this spectral class were small, numerous and widely distributed, it was not possible to associate them with any specific ecological factor. It was noted in the previous chapter that individual fragments tended to be made up of more than one spectral class. It may be that this class often represented pixels straddling shrubland - agricultural boundaries. The high probability Renosterveld class moved from having a predominantly west-facing presence at low slope angles, to a more widespread, but predominantly north-east facing occurrence on the steepest slopes, while the high probability Fynbos class remained predominantly (south-) west facing in all slope classes. Within the low and intermediate slope classes, many of the east facing slopes have been preferentially cleared for vineyards, thus reducing the potential extent of Renosterveld on these aspects.

On the south-westerly facing slopes, the phenomenon mentioned in the previous chapter, of a Fynbos “class” being identified in terms of slope orientation and gradient is probably making itself felt. The presence of this class on the steeper slopes might explain why the high probability Fynbos class was found predominantly on these aspects. A number of people (*e.g.* Heydenrych and Littlewort 1995, Gwen Raitt University of Stellenbosch departmental seminar 2002) have referred to the fact that Fynbos elements tended to occur on the wetter south-west facing slopes of hills in the coastal Renosterveld areas. Figure 7 show that the high probability Fynbos class tends to occur in the wetter southern sectors of the region, on the sands in the central western region, and in the northern Piketberg. In the southern regions, this class mainly represents Fynbos or indigenous forest. The class in this region would therefore be supporting the observations of various authors (*e.g.* Boucher and Moll 1981, Low and Rebelo 1996) that in the higher rainfall regions, Renosterveld blends into Fynbos (and ultimately into forest - Britton and Jackelman 1995). This has been noted as being particularly true on granite (Boucher 1995), and it can be seen that on the Paarlberg, the southern and higher central regions have largely been allocated to his spectral class. In the case of the Perdeberg, the allocation of different classes to the northern and southern

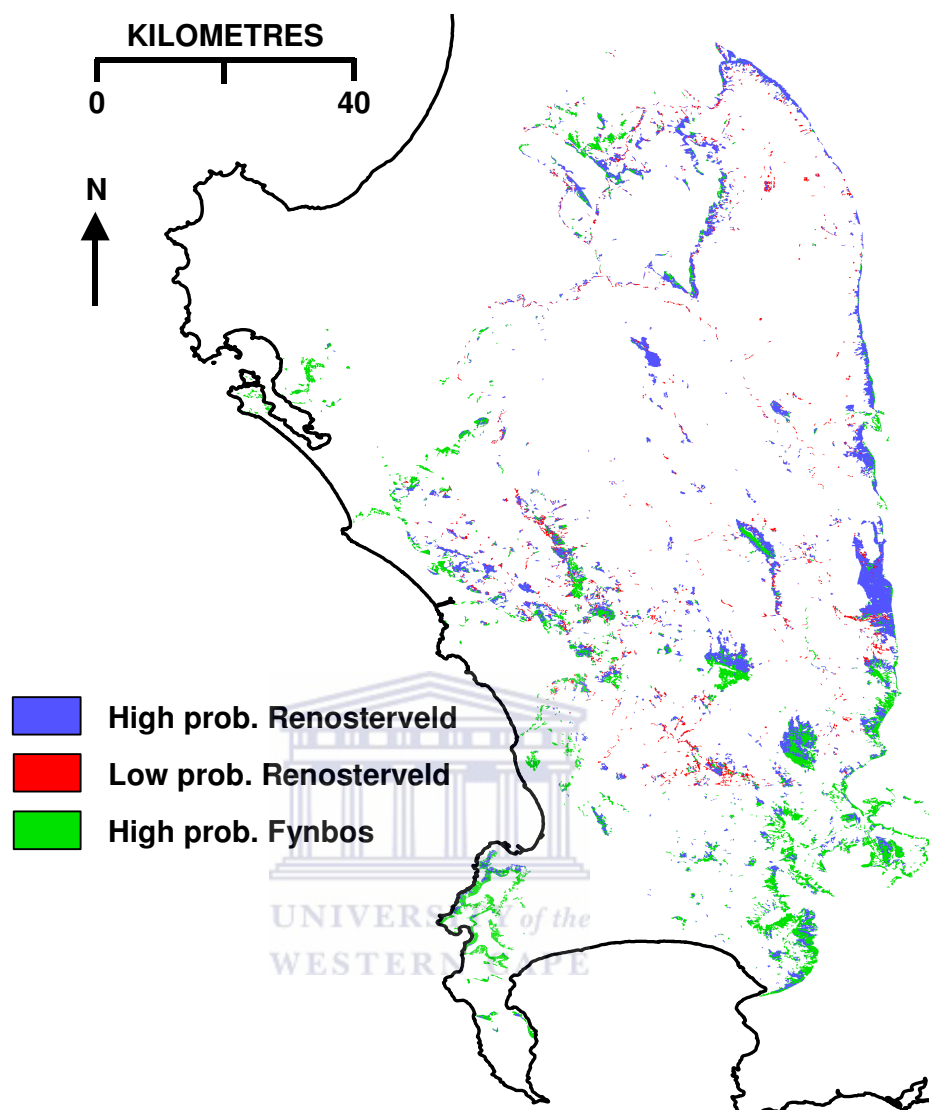


Figure 7. Spectral classification of the remaining fragments of West-Coast Renosterveld, showing the distribution of three of the four spectral probability classes. The low probability Fynbos class is not shown due to its very small extent.

sections is almost certainly due to the light cloud cover present over the southern half, as classification of imagery from February 2001 did not identify any north-south spectral division.

In the central western regions, the vegetation changes from Renosterveld to Sand Plain Fynbos or a Fynbos-Thicket Mosaic vegetation as the soils change from granites to sands. Changes in spectral class allocations are largely associated with these changes in vegetation communities (and structure) across these edaphic boundaries. In the northern Piketberg there were areas of tall shrubs and small trees that were classified as Renosterveld or Fynbos. The exact reasons for the different spectral classifications in that area were not resolved, but may have been due to the steep slopes affecting radiation levels.

It is therefore likely that the two high probability classes are primarily based upon plant structure, and secondarily upon the water relations existing in the area. The two factors are inextricably linked, in that on the wetter, leached and less drought-stressed southern slopes, typical Fynbos species may be expected to develop, while on the drier northern slopes, the drought-tolerant Renosterveld shrubs may be better adapted. In the northern, drier areas (away from the Piketberg), the northern slopes may be drought stressed to the point where even typical Renosterveld species are challenged, and in these regions the succulent karroid-type species may become dominant (such as on the Koringberg – see Chapter 3, Figure 24 on page 174).

Relating the fragment classes to soil classes was not very enlightening. Many of the fragments occur on the hills, which Schloms *et al.* (1983) mainly allocate to the J class, irrespective of their soil characteristics. Two other soils (C2 and F3) were predominantly associated with hills. Nineteen percent of the spectrally identified Fynbos fragments in the area were found on the F3 soils. Apart from the fact that much of the Paarlberg, which has a large Fynbos component, was allocated to the F3 soil type, it was difficult to explain why so many high-probability Fynbos fragments were found on this soil. The low probability of Renosterveld class had a wider spread of preferred soil types. Apart from a 14% presence on the C2 soil, most appeared to be on soils that had a low slope, such as alluvium and sands.

Finally, it needs to be remembered that the four probability categories are to a certain extent artificial, being biased by the categories chosen in the supervised classification, which were based upon pre-conceived ideas, rather than upon floristically defined vegetation classes.

Fractal description of the landscape

Two factors need to be considered when assessing the results of the area : perimeter fractal relationship. The first of these is the influence of the “ruler” (pixel size) on the estimation of the fractal index D (Krummel *et al.* 1987). The fractal dimension of small patches (relative to pixel size) can change substantially by the addition of one or two pixels, or by small rearrangements of the existing pixels. Milne (1991) examined the effects of such additions and rearrangements, and objectively defined “small” and “large” fragments. For an unbiased estimate of the fractal dimension of a single patch, to two decimal places, a minimum fragment size of 482 pixels (≈ 43.38 ha in this study) was required. The study of Krummel *et al.* (1987) used a “ruler” that was more than three orders of magnitude smaller than the smallest fragment (10 m x 10 m pixel; smallest patch $\sim 160\,000$ m²; 482 pixels = 48 200 m²). The use of multiple fragments to estimate the fractal dimension ameliorates these problems to a certain extent (Milne 1991). However, it is apparent from the wide fluctuations in D derived from the fragments of less than about 25 ha, that the “ruler” used in this study was too coarse for an accurate assessment of D among the smaller fragments.

The second factor to be considered is that changes in area between the ranked fragments were very small between successive fragments in the smaller categories (536 fragments between 3 ha and 5 ha), but perimeter lengths varied greatly (between 674 m and 1930 m). It was only once the fragment sizes became more spaced-out in terms of area (*e.g.* 81 fragments between 100 ha and 500 ha), that the probability of a larger fragment having a shorter perimeter than a smaller fragment became less common. Although a finer “ruler” than the actual pixel resolution used may have helped reduce this problem, it was a fact that the smaller fragments had a wide variety of shapes. It might therefore be more correct to say that, within the smaller fragments, their boundary dimensions do not have a true fractal relationship.

Krummel *et al.* (1987) used a rolling regression of the slope of 200 patches to estimate the change in the fractal dimension of forest patches ranging in size from 16 ha to 62866 ha. In total, they plotted 306 points. In this study, 1589 points were

plotted using fragments ranging between 3 ha and 3081 ha. The larger number of points (300) that were required to obtain values of D , such that $1 \leq D \leq 2$, has probably not affected the average values at the low end of the scale (the first 300 fragments encompassed those fragments ranging between 3.0 ha and 4.03 ha). However, the last point plotted incorporates fragments ranging in size from 35.06 ha to 3080.81 ha. Dividing the fragments into discrete size classes showed a similar pattern to the graph, suggesting that the fundamental plot was correct where the fragments were larger than 25 ha. The object of plotting such graphs is to identify where breaks in the scaling (and hence changes in processes shaping the fragments) are occurring. For example, Krummel *et al.* (1987) noted a distinct transition in the fractal dimension from ~ 1.15 to ~ 1.4 between 60 ha and 73 ha. They described the smaller patches as typically representing deciduous woodlots within agricultural land, while the larger patches were found under floodplain and hilly conditions, and represented naturally defined boundaries. In this study, a similar transition occurred between 22 ha and 52 ha.

Although the fractal dimensions of those fragment classes of less than ~ 10 ha might be considered unreliable, the larger classes deserve some interpretation. The fractal dimension described here is usually used to assess to what extent the landscape has been influenced by human activities. For example, city blocks, farm fields *etc.* all tend to be square or rectangular as this makes surveying and mechanized farming methods more efficient (O'Neill *et al.* 1988, Turner and Ruscher 1988, de Cola 1989). This squaring-off leads to a D close to one, while natural landscapes tend to have convoluted perimeters and a higher D (Krummel *et al.* 1987, quoting Mandelbrot). In this study, it might be suggested that the smaller fragments (with a lower D) represent land that has been put aside for grazing on farms where the soils are generally good and intense agriculture is practiced. Their general compactness may help buffer the effects of external influences, but it remains likely that these fragments have been highly modified by livestock grazing and the surrounding agricultural practices (fertilization, spraying, burning *etc.*). Larger fragments (with a higher D) exist due to some natural condition (soil infertility, stoniness, slope) that precludes them from being used for growing crops. The largest fragments are typically found around the perimeter of the region, or around the major hills in the area. As such, their boundaries are mainly determined

by natural factors, although the squaring-off of fields that typifies large-scale farming (and the generalization of boundaries during mapping processes), has probably reduced their fractal index from that which may have been imposed had the “true” boundaries been directly measurable. The reason for the drop in D in the 100 ha to 500 ha size class (which also shows up to a lesser extent in the graph) could not be fully explained.

Although the general plot of the rolling regressions for the “Compound” and “Predictive” extents were similar (due no doubt to the large number of shared fragments used to make up each point on the graph), there were some interesting differences when they were divided into discrete size classes. The most striking difference was that in the 50 ha to 100 ha group. By examining (and temporarily removing) the fragments with the three highest area : perimeter ratios, the fractal index of the “Compound” extent was raised to 1.43. The three fragments concerned had been “squared-off” by farming activities (two were essentially triangular), and two had also been delimited by the generalized Renosterveld boundary. In the same class of the “Predictive” extent, one fragment was the same as the “Compound” fragment (the one that was not bisected by the Renosterveld boundary). A second fragment was delimited by the generalized geological map boundary, and the third was squeezed between a dam and the 500 m contour line on the Paarlberg. The removal of these three fragments raised the “Predictive” fractal index in this class to 1.87. The lower fractal index in the > 500 ha fragment class in the “Compound” extent was similarly due to the Renosterveld boundary delimiting their extents, as all but four of these 25 fragments were abutting the boundary. What this shows is that one or two fragments with “abnormally” low or high area : perimeter ratios can significantly change the overall fractal index, and hence its interpretation.

The Korcak exponent (B) mathematically defined what was already intuitively suspected, that is, the region is very patchy. According to Hastings and Sugihara (1993), classical models restrict B to the range $\frac{1}{2} \leq B \leq 1$. As such, the B values calculated here for all fragments ($B = 0.949$ – Figure 5, Table 12) and for all fragments of less than 547 ha ($B = 0.837$) fall within this range. Limiting the calculation to fragments of greater than 547 ha alone, this was not the case ($B = 1.636$), suggesting that there is no fractal relationship between the larger fragments

(Meltzer and Hastings 1992). The ecological importance of B is that a number of authors (Hastings *et al.* 1982, Sugihara and May 1990, Meltzer and Hastings 1992, Hastings and Sugihara 1993) have proposed that the degree of patchiness can be related to the probability of those patches persisting. Although from a single snapshot in time it is difficult to assess what is happening, the basic theory is that very patchy situations have come about by the cutting up of one or more larger areas. In this case, the original extent of pristine Renosterveld has been cut into small patches of degraded Renosterveld, mainly by farming activities. The assumption is that this process will continue until no more Renosterveld remains.

A description of the relationship between fractal scaling and Markovian (random) behaviour over time, as related to Brownian motion is described in Hastings and Sugihara (1993). The Hurst exponent (H) is used to describe this, taking a value of $\frac{1}{2}$ where the process being described is random. Where there is a positive correlation between events at time t and time (t + 1) then H has a value of $> \frac{1}{2}$, and the process is described as persistent. When H has a value of $< \frac{1}{2}$, then there is a negative correlation between events at time t and time (t + 1) (Sugihara and May 1990, Meltzer and Hastings 1992). H is related to B by the formula:

$$H = 2 - 2B.$$

Using the values of B determined here gave very low H values for all fragments combined (0.103), and for the < 547 ha fragments alone (0.326). The value for the > 547 ha fragments alone becomes negative (-1.272) and again supports the non-fractal relationship suggested above. The relationship between patchiness and reduced persistence was demonstrated by Meltzer and Hastings (1992), and Sugihara and May (1990) reported a number of studies also supporting this hypothesis. Chapter 3 noted that the three agricultural sites examined by means of aerial photography had both shown reductions in the extent of natural vegetation over the past 60-years. However, it is necessary to incorporate knowledge of the events leading up to the patterns described. In the case of West-Coast Renosterveld, the fragments remaining largely do so because they have some property (slope, stoniness) about them that reduces their value for formal crop production. It might therefore be suggested that, while the events leading up to the current pattern describe a situation that should theoretically lead to their total demise, those

processes leading to the current pattern has changed. Most of the remaining fragments are not suitable for formal agriculture, and with efforts to enlighten the farming community about the value of Renosterveld along with legislation forbidding the ploughing of virgin land without a permit (Anon. 1983a, 1984), further destruction should diminish. This is not to say they are (or will remain) pristine. McDowell and Moll (1992) noted that these patches were sometimes being fortified with fertilizers and dryland legumes to improve their grazing potential. In South-Coast Renosterveld, Donaldson *et al.* (2002) noted that small patches of Renosterveld tended to be sprayed and burnt as if they were part of the agricultural matrix. Burning can be considered a natural part of the ecology in the Western Cape Province, but the effects of spraying insecticides and the runoff of fertilizers from the surrounding wheat fields will certainly be upsetting the natural ecological processes.

The calculation of the fractal dimensions D and B from discrete size classes (such as was done by Hastings *et al.* 1982) was criticised by Hastings and Sugihara (1993), because each size class usually has a different number of samples. They preferred the technique of rolling regressions as this allowed for the identification of different scaling regions. In the case of the patch dimension, the problems with the wide range of area : perimeter ratios in the smaller size classes have been discussed. In addition, although breaks in the scaling are possibly better observed when plotted graphically, the question of the area to which a particular point refers becomes problematic as each point on the slope is determined by a range of areas. In this study, both methods identified a break in the scaling, but the discrete class analysis placed it in a smaller size class than the rolling regression, probably because each point was allocated to the largest fragment size for each calculation in the latter case. To test for grouping anomalies when calculating the Korcak exponent of patchiness, the exercise was repeated using every point as a class. The overall slope was less (-0.831 as against -0.949), but the r^2 value was better (0.989 compared with 0.977). The change in slope remained noticeable and was within 100 ha (~ 642 ha compared with ~ 547 ha) of the multiple samples per class plot. Although the actual change point was less clearly defined when all the points were used, it is likely that the change in slope is closer to 642 ha than 547 ha. Plotting the slope of the two segments gave a slope of -0.804 for fragments of less than 642 ha when

every point was used to determine the slope (against -0.836 for discrete classes of less than 547 ha) and -1.732 for fragments greater than 642 ha (-1.799 for discrete classes of less than 547 ha). In view of the fact that these methods are approximation techniques, and one can only discuss the results in terms of trends in the data, it is felt that both methods are equally valid.

Conclusion

The analyses performed in this chapter have shown that the amount of West-Coast Renosterveld remaining is slightly less than 10% of its original extent. Using a definition based upon physiographic (as opposed to community) characteristics, and an original extent defined by the “Compound” area, then this figure is more likely to be just under 7%. The use of geological and soil maps to identify areas where Renosterveld is likely to occur has two drawbacks. The first is the generalized mapping of soil and geological boundaries and the second is that certain formations may encompass a wide variety of conditions (*e.g.* soil depth, clay content). Such formations will probably lead to mosaic or ecotone situations which are impossible to map at landscape scales.

Although slopes of greater than 12° made up only 5.5% of the total land available, 38% of the remaining natural vegetation fragments were found on such slopes. The distribution of natural vegetation fragments on slopes of different aspects was not greatly different, although in the lower slope categories there was proportionally less on the north-east facing slopes, probably due to the preferred use of these slopes for vineyards.

Analysing the distribution of the four spectral probability classes representing the natural vegetation in the region suggested that the main cause of the spectral differences was due to structural differences in the vegetation. The predominance of the High Probability of Fynbos class on the steeper south-west facing slopes (as compared with other classes) can probably be related to water relations affecting the plant communities that develop there.

The fractal analyses provided support for intuitive feelings about fragment structure and distribution. The wide range in fragment shapes, and the size of the “ruler”

used, suggests that the fractal dimension obtained for the area : perimeter relationships in the smaller fragment-size groups is questionable. There was an apparent overall change in pressures shaping the fragments, from predominantly human to predominantly natural, as their size increased from 25 ha to 75 ha. The size distribution of the fragments was shown to be patchy, and showed patterns typical of unstable situations – *i.e.* the fragments are not expected to persist for very long before being transformed. However, there is hope, as many of the remaining fragments are on land unsuitable for formal agriculture, and there are efforts to encourage the owners of these fragments to conserve them (Botha and Winter 2003).



CHAPTER 6.

CONSERVATION OF WEST-COAST RENOSTERVELD – A SPATIAL AND TEMPORAL PERSPECTIVE

Abstract

West-Coast Renosterveld is one of the most transformed vegetation types in the world and all the remaining fragments have been identified as being irreplaceable. Due to the publication of a conservation plan for the area by the Botanical Society of South Africa, the analyses done in this chapter were planned to provide a complementary view. A brief review of the debate surrounding the application of island biogeography and connectivity theories to real landscapes concluded that each situation is unique and there was no “one size fits all” answer. The local situation was discussed in terms of classical island biogeographical theory, and landscape metrics, and connectivity analyses were performed. From the small amount of local information available, it was concluded that corridors of the width typically associated with roads and fencelines in the area were of little use for the conservation of the local flora. In addition, an important component, in the form of large herbivores, had been removed from the system, and the small size of the remaining fragments meant that their re-introduction was impractical. However, observations suggest that this loss may be compensated for by the judicious use of domestic stock. Pollination studies have suggested that reduced seed set in small or structurally homogeneous fragments, or fragments isolated by urban developments might be leading to the extinction of certain species, but the short period of time since fragmentation commenced, plus the longevity of most of these species is masking this. An analysis of published species lists from various sites suggested that possibly half the plant species existing within coastal Renosterveld are highly localized, but their presence in a locality is based upon the local micro-habitat, rather than general macro-environmental conditions. Matters related to management and conservation noted that coastal Renosterveld benefits from disturbance. The most important item to arise out of this study was the lack of field studies upon which to base management plans.

Introduction

The Cape Floristic Region (CFR) is one of the world's 25 biodiversity hotspots with 8200 plant species, 5682 of which are endemic (Myers *et al.* 2000). The large mammalian fauna have mainly been exterminated, and information on the smaller vertebrates and invertebrates is poorly known (Cowling *et al.* 2003, quoting several authors). It would therefore be logical to concentrate on how the fragmentation of West-Coast Renosterveld has impacted (or should theoretically impact) upon the plant species. One might also assume that the maintenance of fragments of natural vegetation of a reasonable size would be likely to support the majority of the small animals that live there (Cowling *et al.* 2003, quoting several authors). However, this is not always the case. The endemic Geometric Tortoise (*Psammobates geometricus*) has become increasingly rare within the Elandsberg Private Nature Reserve (PNR) within the last few years, due to runaway fires (Boycott and Bourquin 1988) and to predation by feral pigs (Dr Ernst Baard and staff of the Elandsberg PNR, 5th Renosterveld information sharing session, 17 October 2003). As the conservation of this tortoise was a major impetus for the reserve being established (Mike Gregor *pers. comm.*), this trend is worrying.

West-Coast Renosterveld has been described as one of the most transformed vegetation types in the world (McDowell and Moll 1992). Reyers *et al.* (2001) classified it as the most transformed vegetation type in South Africa, while Rouget *et al.* (2003) placed it second. Recent estimates of the total area remaining untransformed have ranged between 3% (Low and Rebelo 1996) and 16.2% (Rouget *et al.* 2003), although this last figure is the only one above ten percent. The most recent published estimate was that of von Hase *et al.* (2003) who quoted a figure of 5%. This study (Chapter 5) has suggested that between 6.7% and 9.6% remains, the actual figure depending upon the boundaries used to delimit the region and whether all the natural vegetation is included, or if geology, soil, altitude, rainfall and/or spectral data are used to further refine the natural vegetation into Renosterveld and "other".

Although the remaining fragments have been classified as "natural", it is almost certain that most have been affected to some extent by the surrounding agricultural

and other activities (Hendey 1983). Alien species are likely to have invaded most, if not all the remaining fragments, upsetting ecological processes and competing with the indigenous organisms (*e.g.* Krug *et al.* 2004). Fertilizers and pesticides applied to the adjoining croplands have the potential to affect the floristic composition and phenology of adjoining fragments (*e.g.* Vlok 1988, McDowell 1995). Donaldson *et al.* (2002) noted that South-Coast Renosterveld fragments smaller than 10 ha in extent were treated as part of the agricultural matrix, being burnt and sprayed, as and when the surrounding fields were. It is notable that of the 1175 fragments of West-Coast Renosterveld identified by von Hase *et al.* (2003), 902 (76.8%) were less than 10 ha in extent. Their equivalent figure for Overberg Coastal Renosterveld was that 15 203 of the 16 003 (95%) fragments identified were less than 10 ha, while in the Elgin Fynbos/Renosterveld mosaic unit only 13 of the 791 (1.6%) fragments were *greater* than 10 ha.

The small amount of West-Coast Renosterveld remaining is less than the (rather arbitrary) IUCN recommendation that 10% of each habitat type be conserved (Rebello 1995). Studies by Pressey *et al.* (2003), using C-plan software (Ferrier *et al.* 2000) to assess conservation targets for the preservation of biodiversity within the CFR, concluded that none of the coastal Renosterveld Broad Habitat Units (BHU) of Cowling and Heijnis (2001) reached that target. In the case of the Swartland and Overberg Coastal Renosterveld BHU, they estimated that over four times the current extant area was required to provide adequate conservation. For this reason, von Hase *et al.* (2003) did not re-assess the conservation-worth of the fragments identified in their study. Using a mixture of local biodiversity data and expert opinion, they drew up a five-year action plan and a twenty-year conservation vision for coastal Renosterveld. This was done in collaboration with Cape Nature, which is the organization that will largely be responsible for implementing the plans. The development of the South African National Biodiversity Institute's (SANBI) vegetation map (Mucina and Rutherford 2004), might suggest that the region needs to be re-assessed in terms of conservation priorities.

This chapter will attempt to provide insight into four aspects of Renosterveld conservation, three of them based upon spatial distribution parameters, and the fourth, an amalgamation of information gleaned from the literature.

1. Is fragment size and distribution likely to affect the persistence and dispersal of typical Renosterveld endemic species?

One of the major effects of fragmentation is the reduction in size of habitat available for indigenous organisms and the concomitant problem of inbreeding due to the isolation of populations. This is examined in the context of coastal Renosterveld, using autocorrelation analyses, combined with published field observations on the pollination and dispersal mechanisms of localized endemic plant species.

2. Do natural corridors exist within West-Coast Renosterveld, and where are they likely to be situated?

The study of von Hase *et al.* (2003) identified one hypothetical coast to interior gradient, and nine upland-lowland gradients on the west coast lowlands. Coast to interior gradients (the south coast was also assessed by the Botanical Society), were identified as paths of intact lowland habitat connecting the coastline with the inland Cape Fold Mountains. Upland-lowland gradients were defined as areas where 2 km of intact habitat existed on each side of an upland-lowland interface. Generally these represented Renosterveld-Fynbos interfaces, although transitional habitat areas (such as on the Piketberg, Paarlberg or Perdeberg) were also identified. While the identification of these gradients are of use in determining areas of ecological importance, they do not identify the pattern of connectivity (if any) that exists between the Renosterveld fragments on the western lowlands. This section of the chapter attempts to objectively map distribution pathways between fragments of West-Coast Renosterveld of greater than 3 ha in extent.

3. What is the level of beta and gamma diversity within West-Coast Renosterveld?

Rebelo (1992) noted that there were no records of plant species in West-Coast Renosterveld having become extinct since listings began in the sixteenth century. His suggestion was that Renosterveld was a homogeneous vegetation type and isolated endemic species were rare or absent. Published species lists were used to assess to what extent plant species were confined to a particular locality.

4. What sort of management regime should be applied to West-Coast Renosterveld?

In the past, Renosterveld was seen as having little in the way of commercial value (other than for ploughing up for crops), and was considered rather dull compared to the highly visible diversity of Fynbos, with its Proteas, Ericas and Restios. Gradually this view has changed, and in some areas it has been found that with the correct management, a spectacular array of (especially) bulbous flowers can be produced to add to the economic value of a farm or community. Meanwhile, the high level of fragmentation drew scientists' attention to an opportunity to study an extreme case of a fragmented community. The final objective of this chapter is to amalgamate the scientific, practical and historical data available to suggest ways of conserving that which remains. It also draws attention to the phenomenon of "persistence" of many plant species, which may be masking a low or absent reproductive output.

This chapter begins with a brief general review of fragment ecology and the value of dispersal corridors. This will pave the way for the spatial analyses performed, and allow a critical review of the literature and data relevant to coastal Renosterveld.

Fragmentation, Dispersal and Island Biogeography – the debate rages

In 1967, MacArthur and Wilson's monograph on Island Biogeography was published. Since then, it has constantly been used as the basis for fragmentation and dispersal studies within transformed habitats. Yet MacArthur and Wilson themselves only alluded to the *possible* relevance of island biogeography to fragmented habitats in a single paragraph in their introductory chapter (Haila 2002). Haila (2002) has suggested that the use of the theories of island biogeography for fragmentation studies had developed into an "intellectual attractor", and the results of such studies were often manipulated to conform to "traditional" concepts of island biogeography.

Debates about the application of island biogeographical theories to fragmented habitats can be broadly divided into three sections: Does fragmentation have an effect other than that caused by habitat loss alone? Is one large reserve (fragment)

better for conserving species than several smaller reserves (fragments)? Are corridors necessary?

Are fragmentation effects genuine?

Estimates made in this and other published studies (first paragraph of the introduction above), have established that the amount of West-Coast Renosterveld remaining lies between five and ten percent of some original extent. Reviews (*e.g.* Andren 1994) and management studies (*e.g.* McIntyre and Hobbs 1999) have suggested that there is a critical threshold value of 10% to 30% of the original extent, at which the viability (ecological functioning) of an ecosystem breaks down. If this is the case, then it is clear that West-Coast Renosterveld is beyond redemption, and would better be described as a relictual landscape (*sensu* McIntyre and Hobbs 1999). However, Fahrig (2002) has pointed out that these estimates depend upon the model used. Colonization-extinction models may increase extinction thresholds from requiring less than 5% of the original landscape to remain unfragmented (in the case of clumped fragments), to more than 80% in the case of widely distributed fragments. The birth-immigration-death-emigration models on the other hand, suggest that landscapes with scattered fragments only require 10% to 20% more untransformed land than the same landscape with clumping. Fahrig (2002) reviewed some empirical studies (mainly of forest birds), which found that in most cases, total area was far more important than fragment distribution in determining species abundance. Monkkonen's and Reunanen's (1999) view of the critical threshold hypothesis was that it varied according to the species and the landscape being studied. For example, thresholds might be measured in centimetres for insects but in kilometres for large birds; agricultural landscapes might need more than the 10% to 30% of untransformed land that Andren (1994) estimated was sufficient for forest. Fahrig (1997) modified this view to some extent, saying that if more than 20% of the original *breeding* habitat remained untransformed, survival of a species was ensured, irrespective of the pattern of fragmentation.

Bender *et al.* (1998) disagreed with the concept of a "critical threshold level" noting that there were three main groups of organisms: edge species, interior species and

generalists. Their presence in an area was not only affected by the availability of suitable habitat (*i.e.* more interior habitat in a fragment = more interior individuals), but there was also an observer effect. Species : area ratios are generally presented in terms of *total* fragment area which is only relevant for generalist species. They said edge and interior species should be assessed on “edge” and “interior” areas separately, but acknowledged this was very difficult to do. A small patch will have a larger proportion of edge area than a larger patch of similar shape, thus leading to the relative density of edge species being overestimated in the smaller patch. In the case of interior species (or edge species relative to large patches), the opposite effect would occur, thus masking the reduced richness/abundance of interior species (which may be the ones we wish to conserve) in small fragments. Fahrig (2002) also referred to a literature review by Kremsater and Bunnell, who found that many species showed positive edge effects, a factor that is not considered by models.

A difference between oceanic islands and vegetation fragments is that islands exist in a matrix (ocean) that is relatively “hostile” to the island dwelling species, compared to fragmented habitats, where the matrix may provide habitat and resources for many of the fragment dwelling species. For example, studies have shown that many invertebrate species can survive just as well in the agricultural matrix as in their original habitat (several authors quoted by McIntyre and Hobbs 1999), while others will venture to cross it (Fahrig and Merriam 1994, several studies quoted by Beier and Noss 1998). Certain species can adapt their range to the landscape pattern (several authors quoted by Fahrig and Merriam 1994), although there comes a point, relative to the size of the animal where the inter-fragmentary distances are simply beyond its dispersal ability (*e.g.* Saunders and de Rebeira 1991, Mader quoted by Saunders *et al.* 1991). In the case of coastal Renosterveld, Bowie and Donaldson (in prep) showed that certain species of butterflies would cross the agricultural matrix, while others were never observed in it. Cameron (1999) and Randrianasolo (2003) both concluded that birds in coastal Renosterveld were unaffected by distances between fragments, an observation previously reported by Loyn (1987) for south-eastern Australia. Some species may benefit from the presence of an agricultural matrix. For example, both Blue Cranes (*Anthropoides paradiseus*) and White Storks (*Ciconia ciconia*) are making extensive use of the agricultural landscape of the Overberg region (Young and

Harrison 2000, Young 2001). In the case of West-Coast Renosterveld, the presence of contiguous Fynbos habitat alongside many of the remaining fragments may reduce the effects of fragmentation on the Renosterveld. Boucher (1983) noted that many of the plant species found in coastal Renosterveld were also found in Fynbos and Thicket. Finally, the majority of fragmentation studies have focused on forest conditions. In the case of coastal Renosterveld, the smaller structural difference between fields of cereals and low grassy shrublands may be less important.

Criticisms of studies of fragmented landscapes have included the fact that most were “point-in-time” studies, that there were no control situations, or that manipulative experiments had not been undertaken. There are ethical considerations with respect to the last mentioned criticism (Beier and Noss 1998), although a positive input (the addition of corridors across a landscape) may show that isolated fragments are not functioning in an ecologically balanced manner (*e.g.* a study of Mansergh and Scotts quoted by Beier and Noss 1998). Long-term studies are similarly difficult to perform, due to funding restraints and personnel availability (Saunders and Hobbs 1991). Control situations may be difficult to come by in landscapes such as coastal Renosterveld, which have no substantial amount of original habitat left. However, despite the majority of fragmentation studies having been undertaken in boreal woodlands, few compared the situation with unfragmented extents of woodland. Nor have they taken into account the natural random movements and distributions of populations and individuals that occurs, even in “pristine” conditions (several authors quoted by Fahrig and Merriam 1994). Using published data, Fahrig and Merriam (1994) showed that even in extensive habitat, local extinctions might affect as much as 20% of the local bird population per year. When applied to fragment studies, this natural turnover is usually ascribed to the effects of fragmentation. Lynch (1987) for example, reported that the forest bird communities of the fragmented Maryland forests had turnover rates of 10% to 25% *per annum*, and put this down to the effects of fragmentation. Finally, population (metapopulation) analyses of fragments do not always distinguish between habitat specialists and habitat generalists; the results are therefore often an analysis of the landscape *as a whole*, rather than the fragment as an entity (Andren 1994).

It is clear that we need long-term studies in order to distinguish fragmentation effects from natural randomness. For example, what is the effect of seasonal differences, as bird (or other species) behaviour and local distributions may vary according to their breeding cycles? Similarly, migratory birds will be absent for part of the year, and upon returning it may be reasonable to suggest that inter-fragmentary distances are probably insignificant in relation to the total migratory distance travelled (*e.g.* see conclusion five of Bender *et al.* 1998). The reproductive success of a species may also be varying in relation to macro-climatic events in the year studied, rather than fragment size, so a fragment with riparian habitat may be less affected by an exceptionally dry year compared to one without permanent water.

Is one large reserve (fragment) better for conserving species than several smaller reserves (fragments)?

Diamond (1975) suggested optimal reserve layouts, based upon available land considerations. His ideal reserve would be as large, and as round as possible as this provides the largest-area : smallest-perimeter ratio, thereby minimizing external influences. In real-life however, borders of reserves and fragments tend to follow natural lines, for example rivers, geological boundaries or slope, or they may be a function of man-made structures such as roads, fence lines or political boundaries. There is very little that can be done to create “ideal” round reserves from the available fragments. Most coastal Renosterveld fragments exist because they have some feature that makes them unsuitable for agriculture, such as steepness of slope or an abundance of rocks.

Diamond (1975) also suggested that one reserve was better than several smaller reserves. However, Simberloff and Abele (1976) pointed out that several smaller reserves would theoretically conserve more species than a single reserve of equivalent area (see also the review by Quinn and Harrison 1988), and would help prevent a catastrophic event destroying an entire population. Lynch (1987) noted that, while vertebrate species tend to require a “critical minimum habitat size”, plants were less sensitive to fragment size, and a number of relatively small reserves, each incorporating an example of the various habitats in the region, might

be adequate for plant conservation. He did note however, that such a system might fail to maintain all the functions of the larger intact ecosystem. Tschardtke *et al.* (2002) observed a similar phenomenon in their study on butterflies in calcareous grassland fragments in an agricultural matrix in Germany.

Burkey (1989) concluded that the “single-large or several-smaller” reserves (SLOSS) debate was largely centred upon the *aims* of a particular author. He said that those who wished to minimize extinction rates were in favour of large unfragmented reserves, while those who wished to maximize species richness advocated several smaller reserves. His conclusion however, appears to contradict the “several smaller” reserves to ameliorate the effect of disease wiping out an entire population, which is an argument for smaller reserves *reducing* extinction rates. When one considers the comment that several smaller reserves may support more species than a single large reserve of similar area, one should take into account the longer edge the smaller reserves would normally have over the single large reserve of equal area (the ratio is shape dependant, so maverick situations are possible). This reduces the core area (and hence the area of “pristine” habitat), and increases the area available to those species that benefit from edge effects, which may not be the ones in need of conservation, or worse, may be invasive species (*e.g.* Bender *et al.* 1998). It also increases the length of the interface subjected to the impact of external influences (*e.g.* Schonewald-Cox and Bayless 1986). For example, a number of studies have shown that there is greater predation of bird nests along fragment edges (*e.g.* Gates and Gysel quoted by Fahrig and Merriam 1994, Paton 1994), although this is not always the case (*e.g.* Langen *et al.* 1991).

Are corridors necessary?

Another of the “Great Debates” surrounding fragmentation relates to the necessity of corridors for dispersal (*e.g.* Soulé 1984, Fahrig and Merriam 1985, Noss 1987, Simberloff and Cox. 1987, Hobbs 1992, Simberloff *et al.* 1992, Taylor *et al.* 1993). Even the term “corridor” in the context of conservation studies has been the source of much confusion, with Simberloff *et al.* (1992) recording six distinct meanings. Although corridors have sometimes been defined as linear strips of habitat (Soulé quoted by Bentley and Catterall 1997), it is usually understood to mean a linear

strip of vegetation connecting at least two fragments of non-linear habitat that would have been continuously connected in historical times (*e.g.* Hobbs 1992, Bentley and Catterall 1997). Although any strip of vegetation could be viewed as a “corridor”, Hobbs (1992) emphasized that it must allow movement *from* somewhere *to* somewhere. Bentley and Catterall (1997) used the term “linear remnant” to refer to an isolated strip. Additionally, studies into the use of linear *habitats* have been misinterpreted as corridor dispersal studies (*e.g.* see Nicholls and Margules [1991] comments about the misinterpretation of the work of Eldridge by a number of authors).

Most corridor studies have proven anything *but* their necessity for the dispersal of the organism being studied. Control situations (matrix dispersal rates, comparisons of fragments connected and not connected to source habitats *etc.*) have often been ignored (*e.g.* MacClintock *et al.* 1977, Simberloff *et al.* 1992 referring to works of Bennett and of Saunders and Ingram). However, some species have been shown to definitely *benefit* from corridors (*e.g.* Mansergh and Scotts quoted by Beier and Noss 1998, Brooker *et al.* 1999, Smith and Hellmann 2002), while many studies have shown that these strips can act as conservation units *per se*, irrespective of their connectivity function (*e.g.* Way 1977, Bentley and Catterall 1997). Most authors agree that there is no such thing as a “universal corridor” (*e.g.* Hobbs 1992). Different species (and even different sexes of the same species *e.g.* Bowie and Donaldson, in prep) may react so differently to plant structure, corridor width, edge effects, the presence of other species *etc.* that corridors have to be “designed” with target species in mind (*e.g.* Hobbs 1992, Bentley and Catterall 1997, Malanson and Cramer 1999).

Dispersal studies within fragmented populations have generally ignored plants. There are a number of reasons for this. Long time-periods are generally involved for substantial movements of plant species, and isolated individuals found at a distance from their usual location might be overlooked, or their presence considered to be the result of some anthropogenic factor, such as a garden escapee. Studies have therefore been mostly related to point-in-time sampling, and seed dispersal mechanisms. Forman (1991) briefly reviewed the role of corridors in the spread of plant species in Europe and the United States, and concluded that dispersal along

hedgerows was usually not progressive, but rather proceeded in a saltatory fashion, usually aided by wind or animal vectors. Additionally, time scales were generally measured in terms of decades or centuries, a factor that needs to be considered, both in terms of climate change corridors, and in terms of the relatively *short* time periods involved in transformations within the Fynbos Biome. Studies within the Fynbos Biome have shown that seed-dispersal distances of localized (endemic) species are usually less than 50 m (*e.g.* Bond and Slingsby 1983, Cowling *et al.* 1992). Renosterveld appears to support a greater proportion of plants that have relatively long-range seed dispersal mechanisms than Fynbos. Although the number of plant species adapted for wind dispersal in “west renoster shrublands” is slightly higher than the CFR average, these make up > 50% of the typical percentage canopy cover (PCC) found here, which is more than double that of most other CFR communities (Le Maitre and Midgley 1992). Bird-dispersed seeds are more common in Renosterveld (13% to 17%) than in Fynbos (10%) (Le Maitre and Midgley 1992). Although dung-dispersed seeds are relatively common in Renosterveld (Shiponeni 2003a) they are now likely to have had their dispersal severely limited, due to the absence of the larger indigenous herbivores, and to the restricted movements of domestic stock. The high level of local endemism in the Fynbos Biome, combined with short-distance seed dispersal mechanisms, therefore suggests that most species are minimally affected by fragmentation *per se*, except where their locality is physically transformed.

Hobbs (1992) suggested that we can probably never know for sure if a corridor is essential for connecting two fragments of habitat. Beier and Noss (1998) similarly concluded their review on corridors and connectivity by acknowledging that the scientific evidence supporting the necessity of corridors was weak, but suggested that, rather than proponents of corridors being forced to prove their necessity, opponents should be required to prove that the destruction of corridors would not harm the target populations. Simberloff *et al.* (1992) were far more critical of corridors. They systematically dismantled research conclusions suggesting that corridors were of use for the maintenance of genetic diversity, for counteracting climate change or for the movement of individual animals. They pointed out that small populations have existed for millennia on isolated islands and that there is no evidence that “inbreeding” leads to a loss of genetic fitness. Similarly, they pointed

out that most corridors proposed as a means of counteracting extinctions caused by global warming were probably misplaced, due to the slow dispersal rate of many plant species. The type of widths proposed (300 m in the case they quoted; Pressey *et al.* [2003] have suggested 1 km wide corridors for the CFR) moved them from the definition of being a corridor into being habitat *per se*.

Soulé (1984) pointed out that corridors might act as “...one way passages to annihilation for the individuals that use them.” His main concern was the high edge length to area ratio, and he was predominantly looking at tropical areas with large mammals and poor human populations and the opportunities that narrow corridors provide for poaching operations. Corridors may also be seen as conduits for invasive species and pests that would otherwise have been unable to spread (*e.g.* Simberloff and Cox 1987, Hobbs 1992, Simberloff *et al.* 1992, all quoting various studies by other authors). The maintenance of corridors of doubtful worth may absorb funding that could be better used to maintain biodiversity by other means *e.g.* larger reserves, or manual intervention (Simberloff *et al.* 1992). Noss (1987) questioned the practicality of manual translocation, and suggested that the ethics of such methods might be open to philosophical debate (yet manual translocation has been extensively and successfully used in southern Africa for the conservation of Rhinoceros and other large mammalian species). Beier and Noss (1998) on the other hand, while agreeing that money could often be better spent on high quality isolated patches than on corridors of dubious worth, noted that in some cases the purchase and maintenance of a corridor might be cheaper than some alternatives. Finally, Noss (1987) pointed out that the best argument for corridors was that the landscape was interconnected in the past.

Methods

All spatial analyses were performed in Idrisi32 (©Clarklabs, Clark University, MA, USA.) using the relevant integrated modules, unless otherwise stated. Perimeter lengths were corrected as described in Chapter 5.

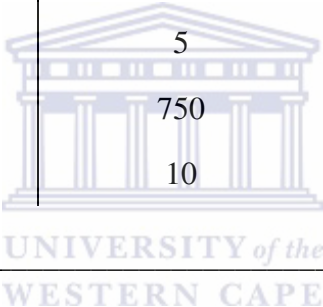
Distance and dispersal-cost images

Two methods were used to analyse dispersal potential. The first was a simple distance analysis, which creates an image showing for each pixel, the distance to the nearest target pixel. In this case, a target pixel is one that makes up part of a Renosterveld fragment. For this exercise the “Compound” extent was used to define the bounds of Renosterveld (see Chapter 5), and all natural vegetation fragments of 3 ha or more occurring within these bounds were considered to be Renosterveld. The resulting image was classed into six distance categories. It was not practical to get a list of distances between every fragment, as the total number of values would be $(N-1)+(N-2)\dots(N-[N-1])$, where N = the number of fragments in the image. For 1350 fragments this would be unmanageable. However, this was done for the 202 source fragments used for the corridor analysis. MapInfo Professional version 6.5 (©MapInfo Corporation; USA) was used to extract the coordinates of each source fragment point, and the data was exported to a Microsoft Excel (©1985-1999, Microsoft Corporation) spreadsheet. Three matrices were constructed. The first calculated the difference in longitude between each point, the second the difference in latitude, and the final one took the square-root of the sum of the squares of each of those differences to obtain a straight line distance between every fragment. For the purposes of this exercise, one degree was considered equivalent to 100 km.

A second method for assessing dispersal potential is to create a series of cost-images, which, in the context of this project, assesses the probability (“cost”) of a Renosterveld endemic plant species being able to disperse across the landscape. Each land-cover type present within the area being considered is assigned a value, based upon its assumed (or relative) compatibility for supporting Renosterveld species for a period long enough for them to disperse across that land-cover type to another fragment of natural vegetation. Using this frictional image, a series of cost images are constructed, in which the value of each pixel represents the “cost” to the organism of reaching that pixel, from a defined starting point. One can then use this cost image to trace the least-cost path between the defined starting point, and any other point or line within the image. Once a suitable number of these pathways have been developed, they can be combined to produce a map showing potential

Table 1. Frictional values assigned to the different land-cover types present within the region analyzed. See text for details.

Land-cover	Frictional value
Renosterveld	1
Fynbos/Thicket	2
Agriculture	100
Plantations	500
Urban	750
Open water, Dunes, Beach	1000
Ocean	Total barrier
Roads	5
Urban Roads	750
Rivers	10



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dispersal corridors present in the landscape. The module used takes into account absolute barriers such as oceans (Eastman 1999).

Construction of the first cost image at the original resolution of 30 m was aborted after six days of continuous CPU and hard disk time, (almost 300 images, one for each site and each endpoint, needed to be produced). Clark Labs suggested contracting the image (*i.e.* reducing the resolution of the image). In view of the extended use of processor time, and because the image was simply representing an *example* of potential corridors, the resolution of the friction image was halved to 60 m x 60 m pixels, making the file a quarter the size of the original. This sped up the processing considerably with each image taking around five hours to produce.

For the friction image, Renosterveld patches were defined as in the distance analysis, and were allocated a frictional value of one (Table 1). A value of one is taken as the base cost for movement across the landscape (Eastman 1999). The

other natural vegetation types (Fynbos, Thicket) were allocated a frictional value of two. This was because there are species common to Renosterveld and the other natural vegetation types. On the other hand, Renosterveld plant endemics would be at a disadvantage, both from competition and from edaphic effects, when trying to use Fynbos or Thicket areas for dispersal. A value of two indicates that it is twice as “costly” to disperse across Fynbos or Thicket as across Renosterveld. Agricultural areas were given a value of 100. Although perennials and geophytes may have trouble dispersing across this land category, annuals would potentially be able to make use of them (*e.g.* see Kemper 1997). There are also often “corridors” of uncultivated land between fields and along fence lines and tracks, which could be used for dispersal, but which do not show up at the resolution used. Plantations were given a value of 500 because, while the trees were growing, the potential for species to disperse through them would be very low, but after felling, there would be a period of one or more years during which time Renosterveld plants might be able to make use of them. Their availability would however be infrequent. Urban areas would have a very high resistance to dispersal, although open ground (undeveloped plots *etc.*) could potentially act as stepping-stones. They were allocated a cost of 750. Open water (dams and lakes), sand and beach areas were given a cost of 1000. The ocean was allocated a value of -1 , indicating a complete barrier to dispersal.

Road and river vector files (see Chapter 4 for source and processing details) were also used to develop the friction image. Roads were allocated a frictional value of five. This value was used as roadside verges are potentially good dispersal areas, but they suffer from random verge mowing exercises and competition from other species, particularly alien weeds. However, the road image also included roads within urban areas, which generally do not have verges suitable for plant dispersal. Although not the perfect answer to this problem, the urban class of the land-cover image was used to mask-out roads in urban areas.

Rivers were processed in the same manner as the roads, but they were given a value of ten. Riparian areas may be useful for the dispersal of birds and generalist species, but they often support a different vegetation community to areas away from rivers.

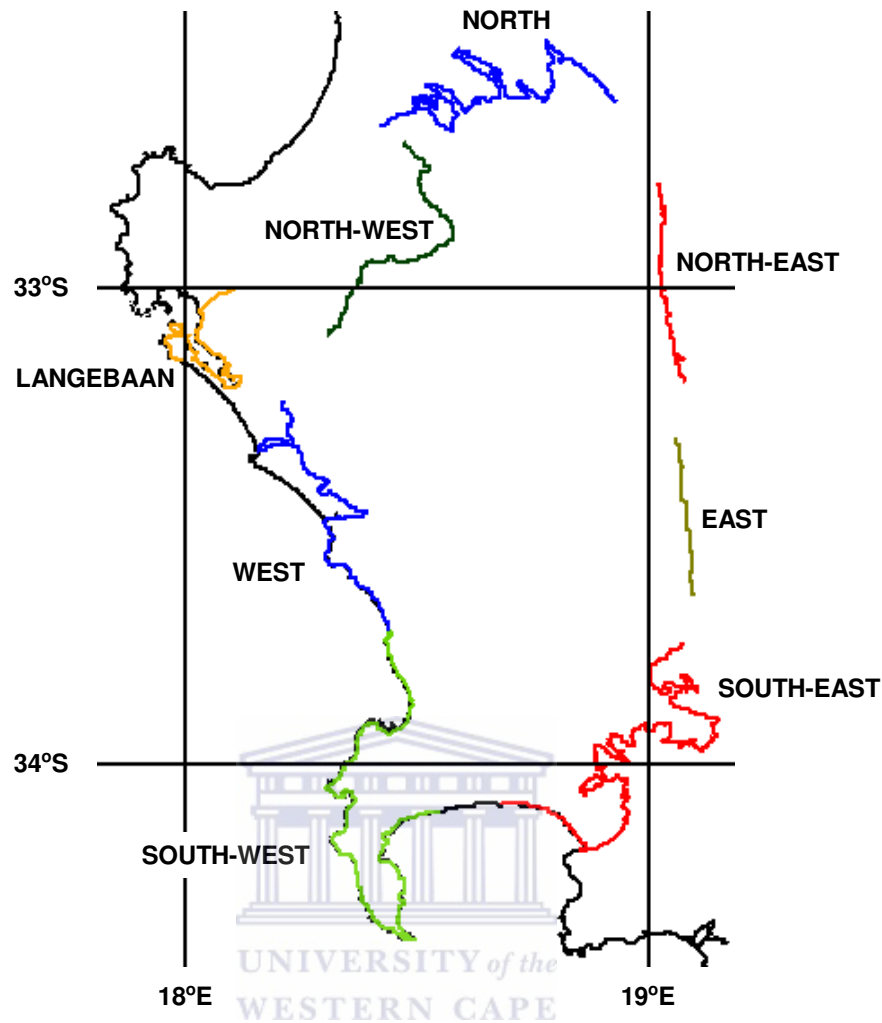


Figure 1. The eight boundary lines used for the corridor analysis.

Three groups of fragments were chosen to act as points of origin for these cost analyses. The first included all the sites of greater than 3 ha identified by McDowell (1988), plus the Rondeberg (sampled by Heydenrych and Littlewort 1995). The second consisted of all natural vegetation fragments of greater than 50 ha within the combined “Compound” and “Predictive” extents (see Chapter 5 for definitions of these two extents). The final group was all natural vegetation fragments of greater than 25 ha defined as being high probability (geological/pedological) Renosterveld (see Chapter 5). In total, 202 fragments were used.

Least-cost pathways were mapped between the 202 sites and each of eight boundary lines (Figure 1). The eight pathways produced from each of the cost images (1616 pathways in total) were combined to produce a corridor map. Each corridor section was assigned a value equivalent to the number of paths making up that section of the corridor. A “section” is defined as the line occurring between intersections. Once this had been done, the points where these corridor lines reached the boundary lines (84 points in total) were treated as points of origin, and the whole process repeated, except that pathways were only constructed to the seven boundary lines that were not abutting the point of origin. These “corridor” lines were added to the corridor lines from the fragment source images.

Autocorrelation

Autocorrelation is a method of assessing fragmentation at different scales. Taking a random “point” in the landscape, it describes the probability of that “point” being adjacent to another “point” that shares the same characteristics as the original point. In this exercise, each “point” was represented by a pixel, and the exercise was repeated using pixels of increasing size. This allows the pattern across the landscape to be determined for increasing distances, thereby simulating the region as “seen” by organisms operating at different scales. In this study the Moran Index (I) was used. This is calculated (Sokal and Oden 1978) as:

$$I = \frac{n}{2A} * \frac{\sum_{ij} w_{ij} z_i z_j}{\sum_{i=1}^n z_i^2}$$

Where:

n = the number of pixels in the image

A = the number of joins (for the Kings case this is 8, being 4 edges and 4 corners per pixel). As the joins are bidirectional, this number is doubled (hence $2A$).

\sum_{ij} = the sum (value) of every pixel (i) against every other pixel (j) in the image.
Since we are only concerned with the eight adjacent pixels, the number of comparisons are greatly reduced.

w_{ij} = the weight of the joins. In this case pixels above, below and to either side of the pixel being assessed are given a weight of 1. Pixels diagonally adjacent are given a weight of 0.7071 (Eastman 1999).

z_i = the value (y) of the pixel (i) being assessed (where $y = 1$ for Renosterveld; 0 for other) minus the average value (y_{mean}) of all the pixels in the image. So $z_i = (y_i - y_{\text{mean}})$.

$z_j = (y_j - y_{\text{mean}})$, where z_j is the pixel adjacent to z_i .

This was done to the 100th lag, initially at single lag intervals, but increasing incrementally from the 30th lag up to every 10th lag from the 60th lag. As there was an apparent “step” between the 50th and 55th lags, lags were single-stepped between these two values. Lags were created by contracting the original fragment image by n in the X and Y directions, where n = the lag number (Eastman 1999). Two sets of autocorrelation measurements were made. The first assumed that all natural fragments in the “Compound” area were Renosterveld and that no other Renosterveld existed within the lowland area. The second assumed that Renosterveld occurred only where predicted by the “Predictive” map developed in the previous chapter. A mask of the Western Cape lowlands (see Chapter 5, Figure 1, page 235) was used to delimit the total area assessed. Due to a limitation on the image size in the autocorrelation module, the Moran’s Index for the 30-metre resolution image (Lag 1) had to be calculated manually. This may have minimally affected the result compared to that which may have been obtained using the Idrisi-32 software.

Local endemism analyses

Two sets of data were used to estimate the level of homogeneity within West-Coast Renosterveld. In the first case species lists, mainly from published sources, were used (see Table 2). The data were entered into an Excel spreadsheet, their taxonomy checked (Harvey and Sonder 1859-1860, 1894, 1894a, Thiselton-Dyer 1896, 1897, 1904, 1909, 1912, 1913, 1925, Gibbs Russell *et al.* 1985, 1987, 1990, Arnold and de Wet 1993, Goldblatt and Manning 2000) and aliens excluded. In total, 1912 indigenous species were identified. Sixty other species could not be traced to recent taxonomic works and were excluded from the analyses.

Table 2. Species lists used for the cluster analyses.

Site	Author	Type and Quality
Blouberg	Tansley 1982	Very superficial
Darling Hills	Heydenrych and Littlewort 1995	Authors estimated a 13% error
Dassenberg and Klein Dassenberg	Kilian 1995	Amalgamation; “relatively good, but missing many species”
Eensaamheid	McDowell 1995	Detailed study; Good
Elandsberg PNR	Mrs Elizabeth Parker	Private list; Detailed
Fairfield Farm	Kemper 1997	Detailed study; Good
Humansdorp	Cowling 1982	Detailed study; Good
Paarlberg	Prof. Suzanne Milton	Private amalgamation; Good
Riversdale	Muir 1929	Detailed study; Good
Riversdale	Rebelo <i>et al.</i> 1991	Widespread study; Renosterveld sites poorly sampled.
Riversdale	Levyns 1936	4373m ² site; Good within site
Signal Hill	Joubert and Moll 1992	Detailed study + other published lists; Good
Stellenbosch	Duthie 1930, 1930a	Detailed studies; Good
Stellenbosch	Levyns 1929	1022m ² site; Good within site
Tienie-Versfeld Reserve	Hilton-Taylor 1993 ¹	NBI field excursion list; Reasonable
Tygerberg, Meerendal, Hoogekraal, Kanonkop	Wood and Low 1993	Amalgamation; Good
Voelвлеi	Tansley 1982	Very superficial

¹ List reproduced in Heydenrych and Littlewort 1995

To determine plant-community relationships between the different sites, resemblance matrices for each of three groups (see below) were constructed using the Sorenson Coefficient method. This method ignores 0-0 similarities when performing pair-wise comparisons, and doubly weights 1-1 agreements. The presence of a species in a pair of sites counts as a definite similarity, whereas its absence may be due to a genuine absence, or to collecting effort. The sites were clustered using the “unweighted pair-group method using arithmetic averages” (UPGMA) as described in Romesburg (1984). Distortions introduced by the clustering method were tested for by using the cophenetic correlation coefficient, which is identical to the Pearson product-moment coefficient (Romesburg 1984). The calculations for these cluster analyses were performed in Microsoft Excel. Three groups of sites were analysed. In the first, two regional sites (Darling and South-west) and eight other well-sampled sites from West-Coast and South-Coast Renosterveld (*sensu* Low and Rebelo 1996) were compared. The individual sites within the two regional sites of the first analysis were then analysed separately to determine site relationships within the two regions. Ten sites made up the Darling region and six the Southwest region. In addition to using all species, the same sites were compared in terms of Red Data Book (RDB) species and Geophytic species. RDB species were determined from Hilton-Taylor (1996, 1996a, 1997) and Golding (2002). Geophytes were identified in terms of typical family traits, rather than in terms of individual species. For this, Kemper (1997) and Ruiters (2001) were used.

The second set of data used was that collected by the Botanical Society for their lowland Renosterveld conservation project, as well as that maintained by the CREW (Custodians of Rare and Endangered Wildflowers) project. Due to the large number of sites, the low number of species recorded per site, and the sensitivity of the CREW data, the analyses were confined to simple observations on how the species were distributed across the available sites.

Figures 2 to 5 show the places mentioned in the text.

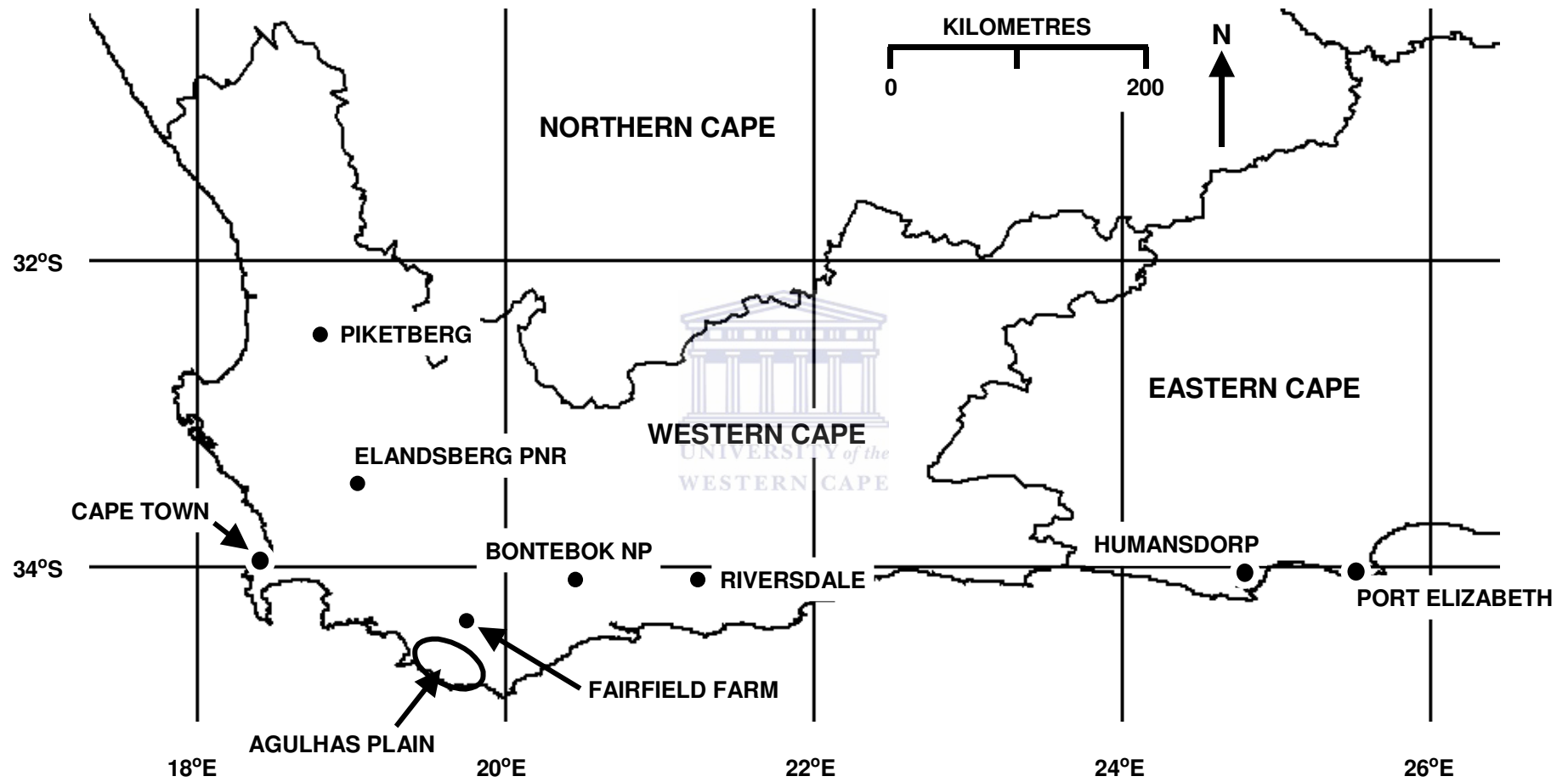


Figure 2. Map of the southern Cape coastal districts, showing the location of some of the places mentioned in the text.

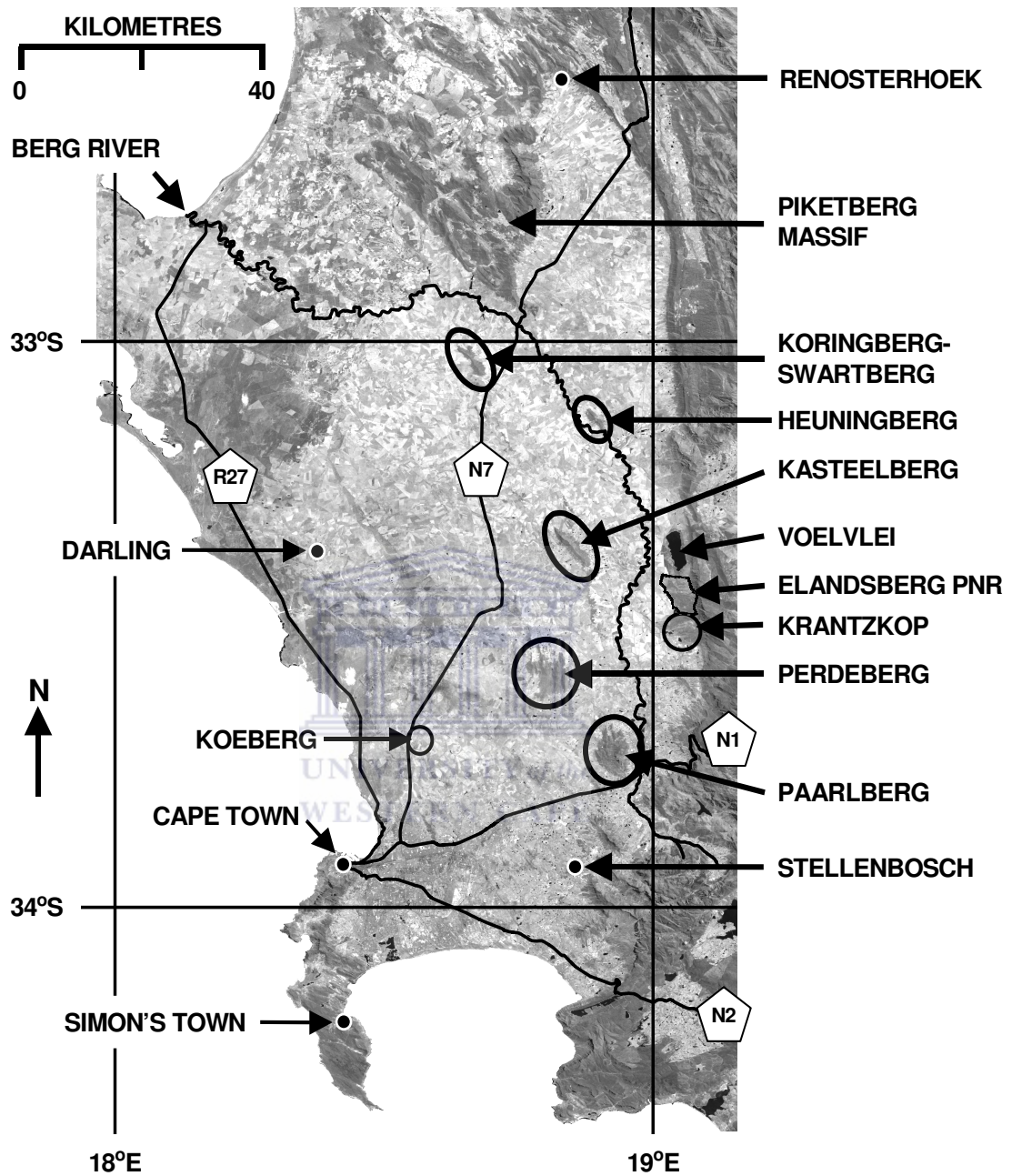


Figure 3. Landsat image of the Western Cape lowlands showing the Berg River, national and west coast roads, and the location of some of the sites mentioned in the text.

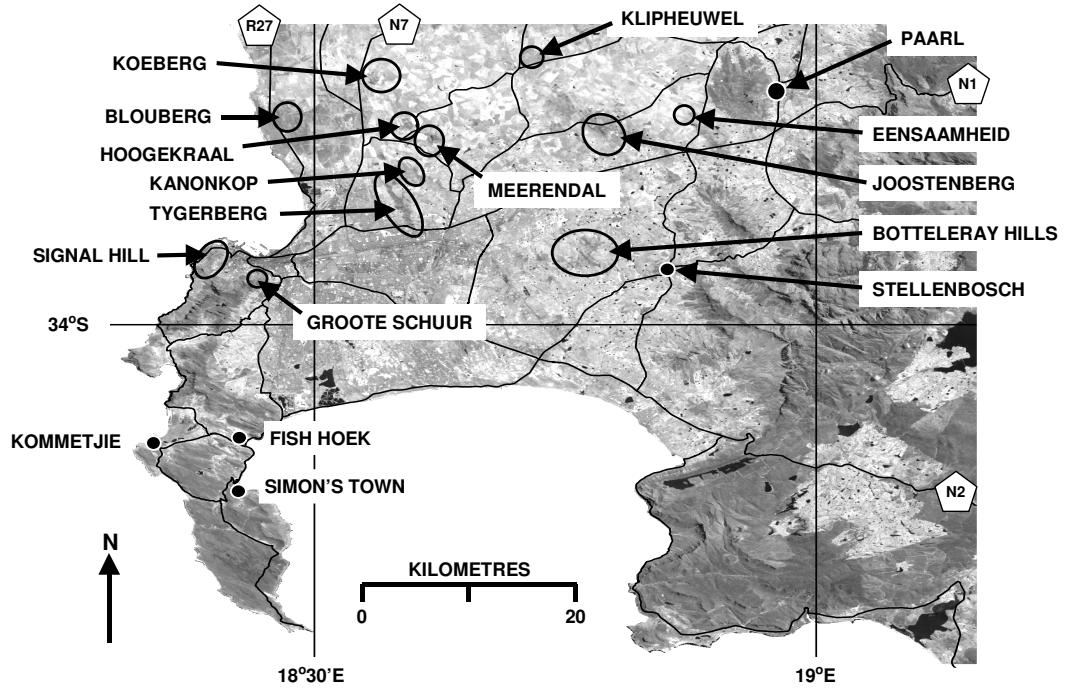


Figure 4. South-western region of the Western Cape lowlands, showing places mentioned in the text and major link roads.

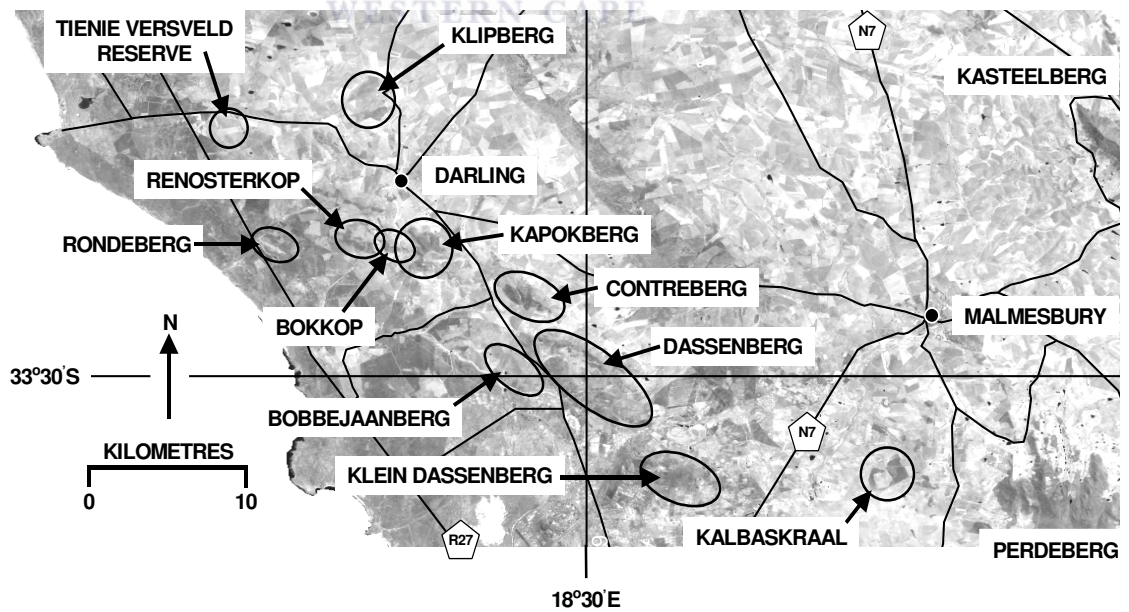


Figure 5. West-central region of the Western Cape lowlands, showing places mentioned in the text and major link roads.

Results

Distance and dispersal-cost images

The distance image (Figure 6) gives an indication of the isolation of fragments or groups of fragments from each other, in terms of distance alone. This image suggests that within the “Compound” extent, few fragments are more than 1 km and none more than 10 km from any other. A group of outlying fragments exists upon the Cape Peninsula, and these are potentially more isolated from the main group than their distance suggests, due to the intense urban development between the two groups. Distances between the 202 fragments used for the cost analysis ranged between 1.15 km and 164.8 km, with an average of 59.47 ± 33.25 km and a median of 55.15 km.

The land-cover friction image produced (Figure 7) should be considered subjectively, for two reasons. The first is that the frictional values applied to the different land-cover classes were subjective, due to a complete absence of experimental data. The second is that every species will experience the land-covers differently. Since this thesis focuses upon plant communities, the frictional values were estimated in terms of plant dispersal potential. The image again emphasizes the isolation of the Peninsula fragments, and that the fragments are predominantly situated around the perimeter of the “Compound” extent. This image also emphasizes the isolation of the major hills lying within the agricultural matrix (Kasteelberg, Perdeberg, Koringberg, Paarlberg and Heuningberg).

Dispersal corridor analysis

A great deal of editing was required to produce the corridor map (Figure 8), as there were often several lines parallel to each other, separated by less than 300 m. For example, nine lines ran north-south through the Voelvlei-Elandsberg-Krantzkop (VEK) block. This was due to minor calculation differences inherent in an image as large as the one used (7 354 900 pixels). Lines representing the “same” corridor were combined into a single line to enhance legibility and were given a

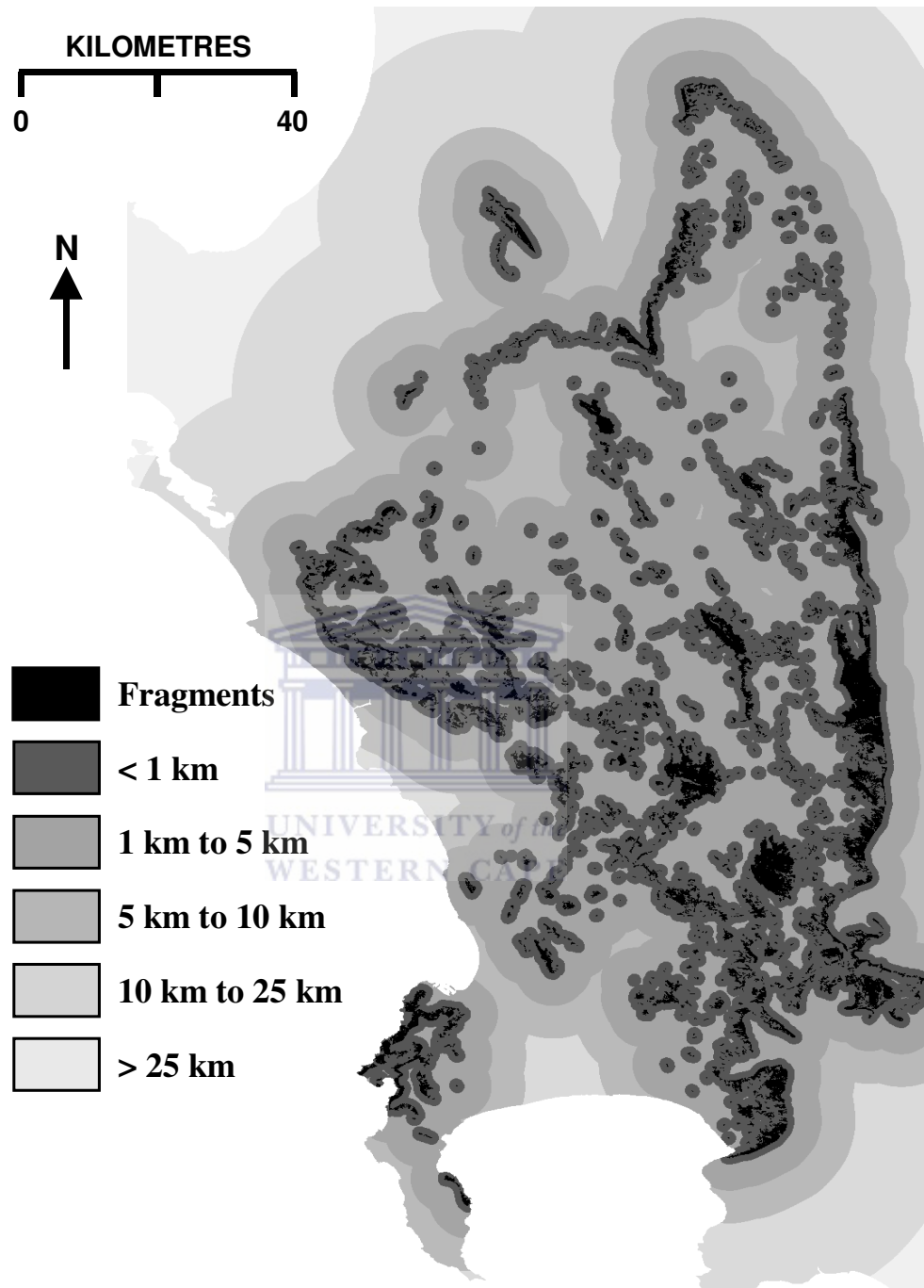


Figure 6. Distance image of fragments of natural vegetation falling within the “Compound” area.

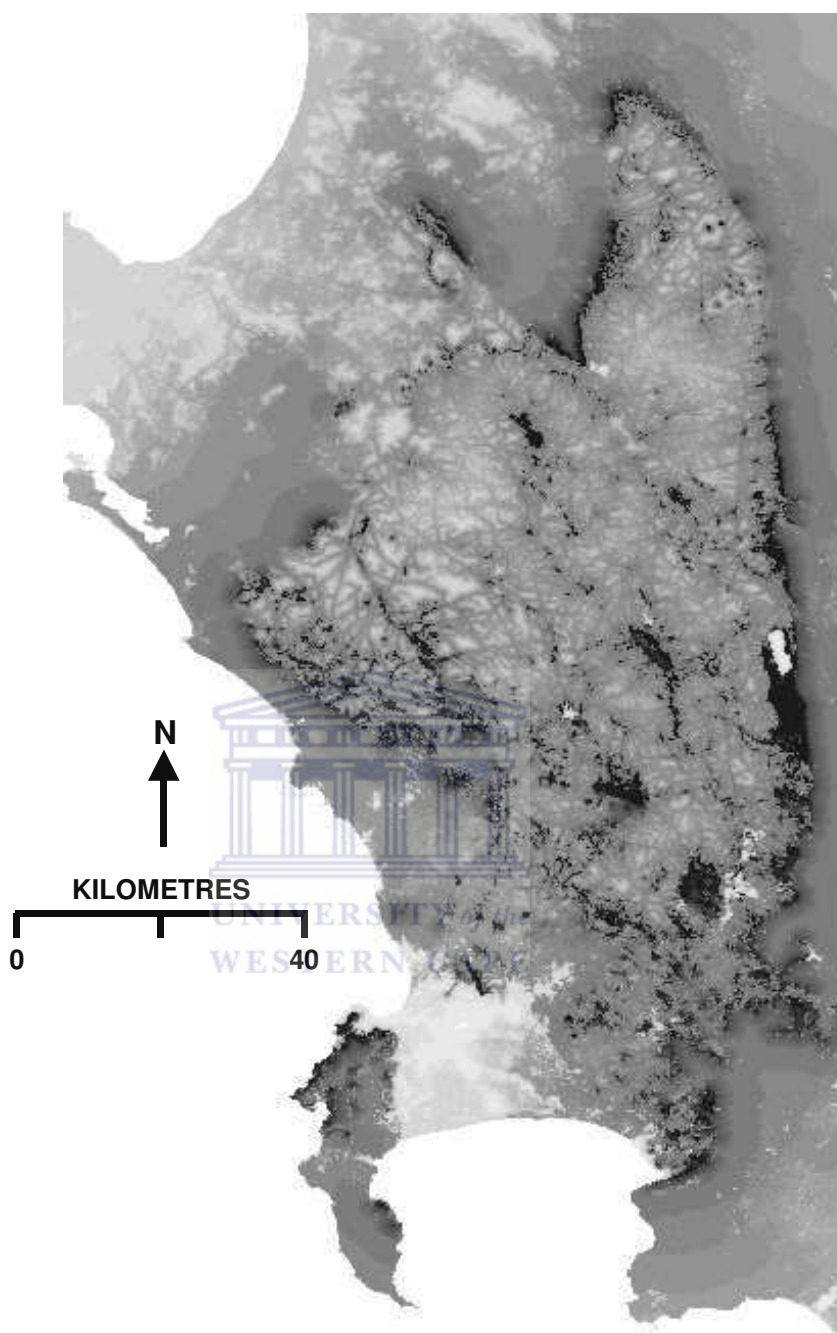


Figure 7. Friction image of the western lowlands, as developed for the dispersal of Renosterveld plant species. Shading is approximately logarithmically related to dispersal cost, with black equating to the base dispersal cost of one (*i.e.* Renosterveld fragments), and white (the ocean) being a total barrier.

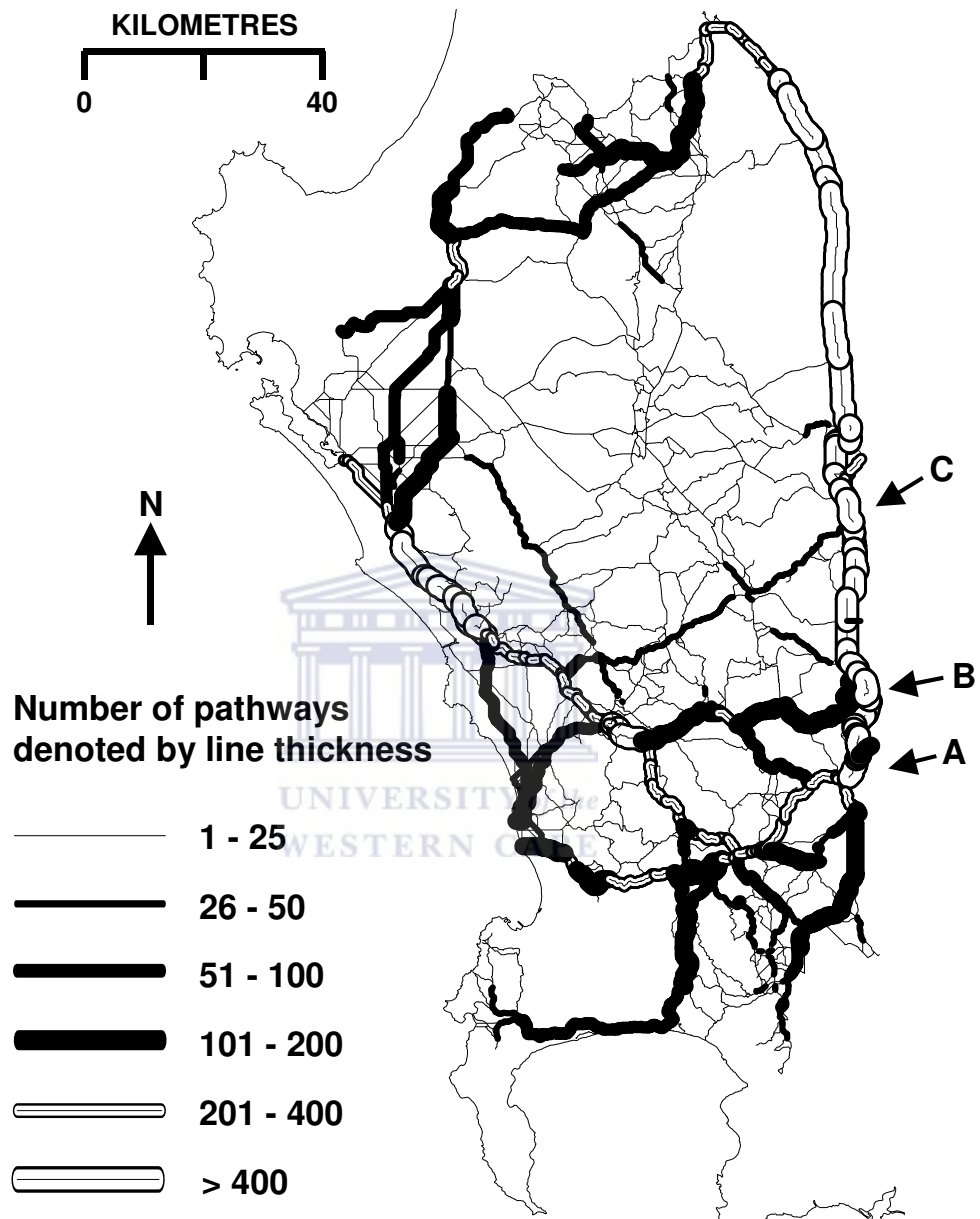


Figure 8. Corridor analysis of 202 source fragments, based upon the cost image shown in Figure 7. A, B and C point to the eastern ends of the three east-west pathways referred to in the discussion section.

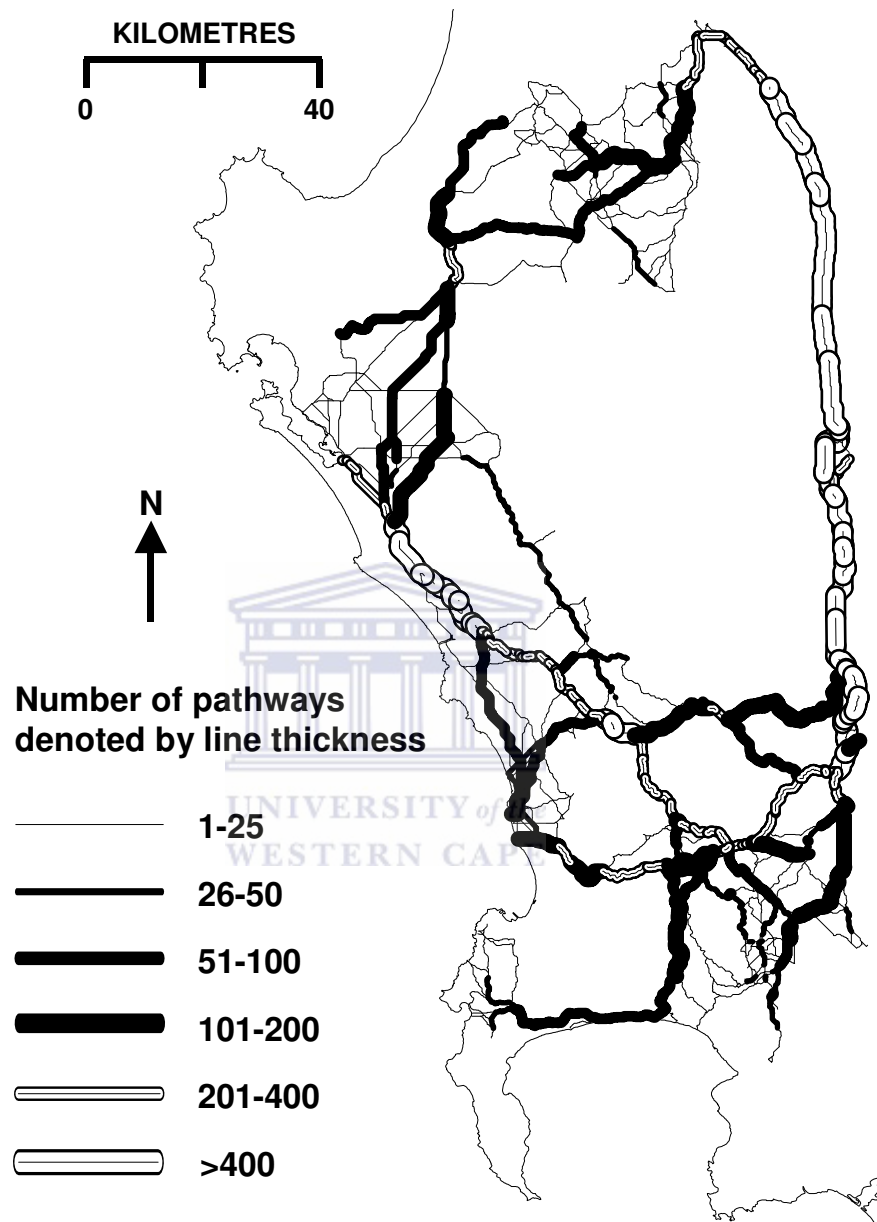


Figure 9. Corridor analysis using only those source fragments lying within 500 m of the “Compound” Renosterveld boundary.

weight equivalent to the sum of the lines. The major factor to note is that the corridors preferentially exist around the perimeter of the Renosterveld region, rather than crossing it. When the analysis was repeated excluding source fragments that were more than 500 metres from the border of the “Compound” Renosterveld area, corridors across the agricultural matrix of the Swartland ceased to exist (Figure 9). This was despite the fact that roads and rivers were given relatively low frictional values. Although the frictional values used in this study did not identify any direct connections between the Peninsula fragments and those of the Tygerberg or Blouberg fragments, the study of Anon. (2002) identified a coastal corridor between Groote Schuur and Blouberg.

Autocorrelation

Moran’s I (the measure of autocorrelation) should reach a maximum of one when there is perfect autocorrelation (*e.g.* the Bishop’s case on a chess board), while a complete lack of autocorrelation (such as the first-lag Rook’s case on a chess board) results in a value of -1 (Eastman 1999). In this study the high positive value at the 30 m resolution level indicates that, for any random pixel within the binary image, the probability of the adjacent pixels being of the same type (either zero or one) is extremely high (Figure 10). The level of autocorrelation dropped off in a log-log manner ($r^2 = 0.963$) to the 50th lag (a resolution of 1500 m, Moran’s I of 0.250 and 0.164 for the “Compound” and “Predictive” fragments respectively), after which it flattened out considerably. Both curves showed the same pattern, but the one representing the “Predictive” Renosterveld fragments dropped off more rapidly. Technical factors cause measures of autocorrelation to become less certain as the lag number increases, due to the smaller fragments and partially filled blocks being absorbed into the background (zero) during image contraction, thus affecting the distance relationships between the remaining fragments (Lorup 1999).

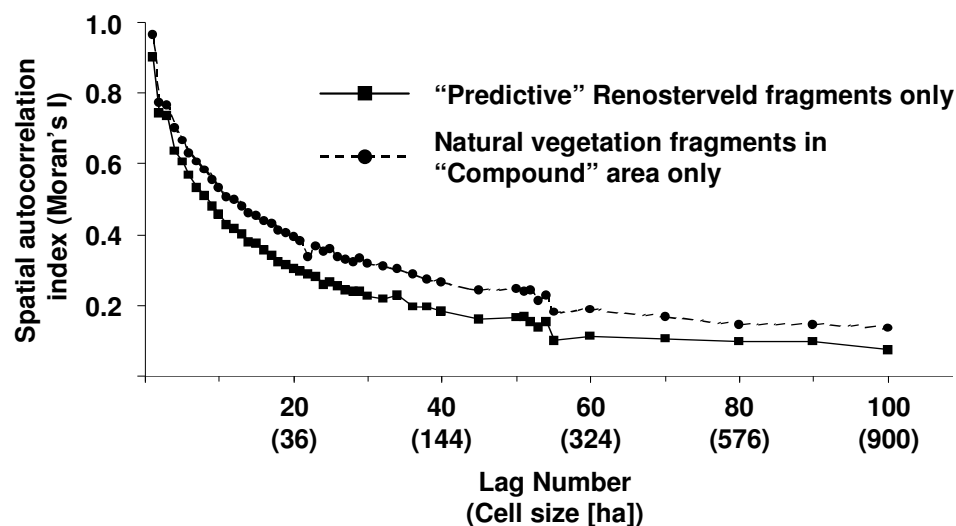


Figure 10. Plot of the spatial autocorrelation analysis for West-Coast Renosterveld.

Cluster analyses

Based upon analyses of the published data, Table 3 suggests that there is a very high level of local endemism within each of the sites analysed. In the all-areas analysis, no species were common to all ten sites, while almost 55% of the species were confined to single sites. Looking at the Southwest region, half the species were again confined to single sites, and only seven were found at all six sites. The Darling region showed a slightly lower proportion of species confined only to one site (44.5%) with eight species common to all ten. This might be because the sites are genuinely more similar than the other groups looked at, or it may just be reflecting a better overall collecting effort.

The cluster tree (Figure 11) shows the relationship of the sites to one-another. In the main grouping (Figure 11A), the two eastern sites (Humansdorp and Riversdale) have come out well separated from the western sites. The Tienie Versveld site (which is in the Darling area) also shows little similarity with any other West-Coast Renosterveld site. It is interesting that Stellenbosch is almost as removed from the other western sites as the Tienie Versveld reserve. This is despite

Table 3. Number and percentage of plant species common to the study sites used for the preliminary assessment of the diversity of coastal Renosterveld.

	All		Southwest		Darling	
	No.	%	No.	%	No.	%
Total number of sites	10		6		10	
Species common to all 10 sites	0	0	-	-	8	1.2
Species common to any 9 sites	5	0.3	-	-	26	4.1
Species common to any 8 sites	16	0.9	-	-	17	2.7
Species common to any 7 sites	26	1.4	-	-	23	3.6
Species common to any 6 sites	47	2.5	7	1.0	31	4.8
Species common to any 5 sites	65	3.5	30	4.4	33	5.1
Species common to any 4 sites	115	6.1	68	10.0	42	6.6
Species common to any 3 sites	194	10.4	96	14.2	58	9.0
Species common to any 2 sites	381	20.3	139	20.5	118	18.4
Species found at only 1 site	1025	54.7	338	49.9	285	44.5
Total number of species	1874		678		641	

the fact that only species recorded from the “grey-bush” community of Duthie (1930) and the Renosterveld site of Levyns (1929) were used. In the Southwest region (Figure 11B), the two features to note are that Signal Hill is more closely clustered with the Tygerberg than are Meerendal and Hoogekraal, and the distant positioning of Blouberg. In the Darling region (Figure 11C), the similarities between the hills were generally higher than elsewhere. The three sites showing the greatest similarity (Bokkop, Renosterkop and Kapokberg) lie adjacent to each other. The Dassenberg and Klein Dassenberg form a separate group, probably because of their mixed-geological origins, and hence floristic community possibilities. The cophenetic correlation coefficients (r) for the three groups ranged

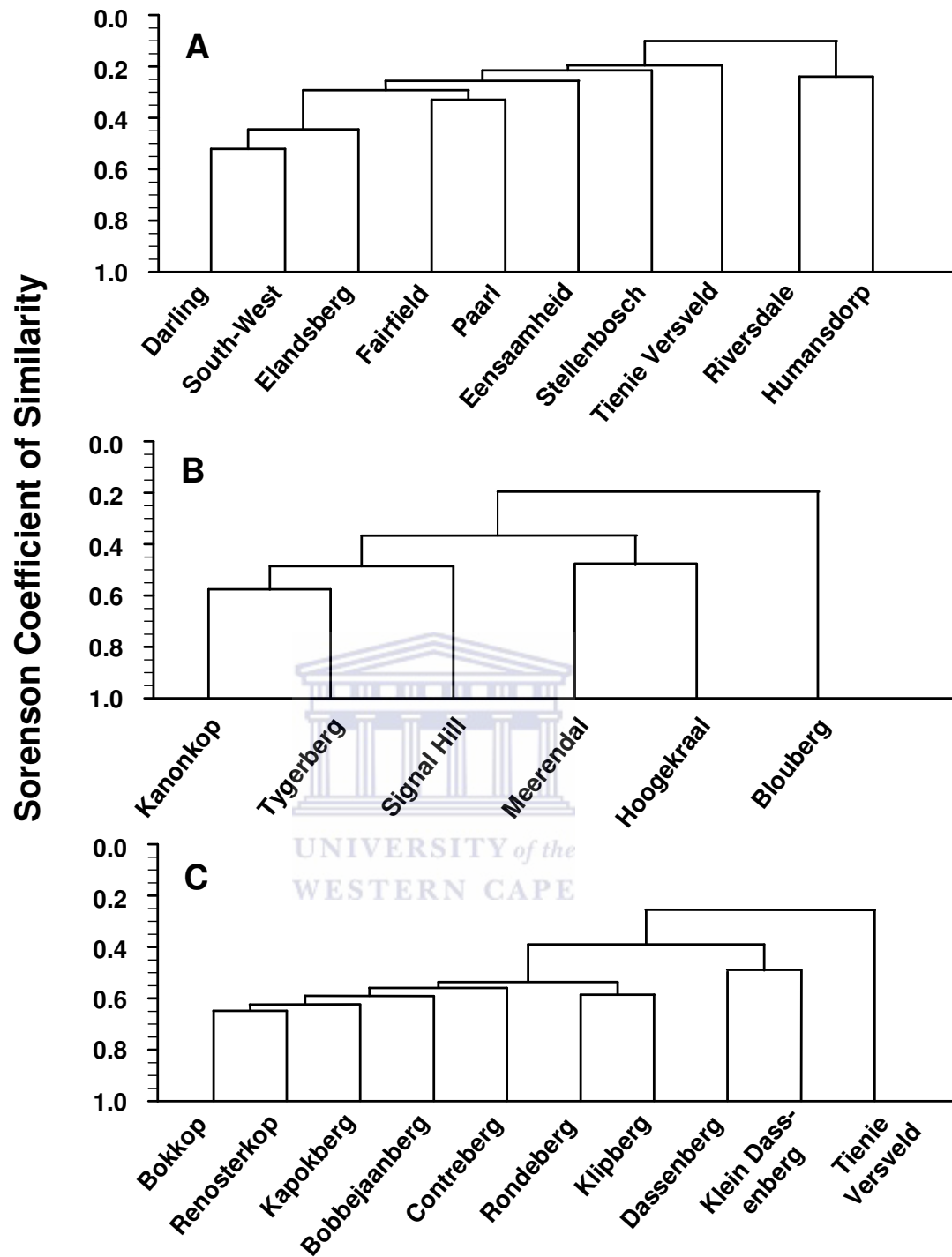


Figure 11. Cluster analyses showing the species community relationships between the sites for which species lists were available.

A = Major sites

B = Sites from the Southwest region

C = Sites from the Darling region

between 0.94 and 0.97, indicating that there was very little distortion introduced during the clustering process (Romesburg 1984). Cluster analyses of the RDB and geophyte subsets (from the published data) showed patterns that were similar to those using all the species. For this reason they have not been displayed. The only items of note were that in the Southwest group, Meerendal was the most isolated site in both the RDB and geophyte analyses, while in the Darling area, it was the Klein Dassenberg and the Tienie Versveld reserve that were the most isolated (Sorenson similarity index < 0.285) in both the RDB and geophyte analyses.

With respect to the lowlands Renosterveld data collected by the Botanical Society, the results supported the findings described above. Of the 135 unique sites, 114 were described as Renosterveld, and the analyses were confined to these. Two hundred and fifty four indigenous species were listed, 109 of which (42.9%) were found only at one site. Two hundred and nine species (82.3%) were found at five or less sites. Only five species were found at more than twenty sites, these being *Eriocephalus africanus* (72 sites), *Elytropappus rhinocerotis* (69 sites), two species of *Ehrharta* (*thunbergii* and *calycina*) at 41 and 36 sites respectively, and *Cotula turbinata* at 26 sites.

The CREW endangered species data list, showed similar trends, although these were not as extreme as for the other data. One thousand four hundred and forty eight records of 184 species distributed over 1037 unique sites were identified. Thirty-two species were recorded from one site only, and 102 species (55.4%) were found at five or less localities. However, 18 species were found at twenty or more sites, and one species was found at 51 localities. When species distributions were examined, it was noted that they were generally well distributed across the whole West-Coast Renosterveld region. Only in the case of those species for which there were only two or three records was there a trend towards local clumping.

Discussion

1. Fragment size and its potential effect upon species conservation within West-Coast Renosterveld

Using island-biogeographical terminology on West-Coast Renosterveld, the “continent” has been fragmented (or degraded) into remnants, covering between five and ten percent of its original area. It is now an “island with no continental source” case. Furthermore, the land-cover classification showed that more than half (58.2%) of the remaining fragments of natural vegetation of greater than three hectares, within the “Compound” area were less than 10 ha in extent.

What are the implications of this as far as the conservation of Renosterveld biodiversity is concerned? Of possible relevance are five published and three unpublished studies, and one in preparation, which examine local species : area relationships. Bond *et al.* (1988) examined Fynbos fragments within Afro-temperate evergreen forest and reached two main conclusions. The first was that the most important factor affecting species diversity within these fragments was the fire (*i.e.* disturbance) regime. Fragments that had experienced fewer fires had a lower species diversity. The second observation was that insular effects were restricted to fragments of smaller than about 590 ha. Cowling and Bond (1991) looked at limestone “islands” in a “sea” of acid sands on the Agulhas plain. These fragments experienced the same level of disturbance as the surrounding acid-sand vegetation, in terms of fire frequencies *etc.* Their conclusion was that reserves of four to 15 ha were adequate to prevent insularization. However, many of the species occurring on the fragments were acid sand generalists, thus reducing the limestone characteristics of the fragments. An important difference between the limestone “islands” and the limestone “mainland”, was that only one ant-dispersed limestone specialist was found on the “islands”, compared to 12 on the “mainland”. These two studies might better be considered in terms of one “fragment” and one “landscape” analysis. The study of Bond *et al.* (1988) was looking at fragments of a generally distinct vegetation type (Fynbos) within a contrasting vegetation type (forest). That of Cowling and Bond (1991) was leaning towards a landscape analysis, in that the surrounding matrix had much in common (species, structure, life-form, pollinators,

seed dispersers *etc.*) with that of the limestone islands. The warning by Bender *et al.* (1998) about generalist and edge species masking the effects of fragmentation might be relevant here. Although the limestone fragments had apparently reached a maximum level of species diversity within a fragment size of 4 ha to 15 ha, the species involved were mainly generalist species from the surrounding matrix, rather than limestone specialists and endemics. Cowling and Bond (1991) have acknowledged this and suggested that their findings would probably not apply to fragments surrounded by transformed habitat.

Reviewing the effects of disturbance within natural communities, Sousa (1984), and Hobbs and Huenneke (1992), noted that several studies had shown that species diversity in a region peaks at an intermediate level of disturbance. Hobbs and Huenneke (1992) said it was difficult to define the term “intermediate”, but quoted Hobbs *et al.* as suggesting that it was approximately half the lifespan of the dominant species. The structural, life-form and life-span similarities between the two edaphic populations on the Agulhas Plain would suggest that both would benefit from similar disturbance (fire) regimes. Within the forest situation, the greater longevity of the dominant species (forest trees) would suggest that the Fynbos patches would not be receiving regular enough disturbance events (again usually fires) to maintain themselves at optimal levels of diversity. In the latter case, there would be a gradual loss of species that develop early on in the succession, leading to a final lower species : area ratio. Developing this further, Miller (quoted by Sousa 1984) expressed the opinion that where the frequency of disturbance was high, regional diversity would be greater when the areas disturbed were small. That is, where disturbances are frequent, less of the total area must be disturbed at any one time in order to conserve those species occurring later in the succession. Where the frequency of disturbance was low, larger areas should be disturbed in order to maintain high levels of diversity, as the early successional (colonizing species) would otherwise become rare or extinct. These disturbance theories are relevant to the two studies just mentioned, and by extrapolation, to the conservation of West-Coast Renosterveld fragments.

Kemper *et al.* (1999) looked at fragmentation in South-Coast Renosterveld and its effect on plant species composition on Fairfield Farm (34°25'S 19°46'E), near

Napier, Western Cape. They looked at fragments between 0.06 ha and 153 ha in extent, with inter-fragment distances of between 0.03 km and 1.1 km. These were all situated within an area of 9000 ha. They found no relationship between fragment size and community composition, although there was a greater *variability* in species composition, richness and diversity between the smaller fragments. They ascribed this to a greater susceptibility to disturbance, which lead to more local extinctions and colonizations. Smaller fragments also had a higher number of annual and alien species, which was assumed to be a function of the edge effect. Only the percentage cover of perennial graminoid species showed a positive increase with fragment size, the other groups they examined all showing negative relationships.

Kemper *et al.* (1999) ascribed the weak fragmentation effect to three factors. The first was to the large component of species that resprout after fire, and to the high component of Renosterveld species that have wind-dispersed seeds. They did not give figures, but several comparisons exist in the literature. Michell (1922) reported 24 shrub species resprouting after a fire on Signal hill, compared with 26 shrub species that had developed from seeds. Of 181 perennial coastal Renosterveld species sampled by Boucher (1983) 27% were shrubs that resprouted, while 31% were shrubs that survived disturbance by reseedling. Acocks (1979) said that a large number of shrubs in Renosterveld resprouted after fire. Cowling *et al.* (1999), discussing climate change as deduced from charcoal remains at Elands Bay cave, warned that a false picture of change (or lack of change to be more precise) might occur because of the “persistence” of certain long-lived Thicket species that resprouted after fire. A similar *caveat* could be applied to the effects of agriculture on the diversity of Renosterveld fragments. Disturbance, in the form of farming activities may not have prevailed long enough to significantly affect the survival of those “persistor” species in areas where they have not been physically ploughed up. It also needs to be kept in mind that many of the dominant shrub species within Renosterveld respond positively to disturbance (*e.g.* Duthie 1930, Levyns 1956). Only under extreme disturbance levels would these pioneer species be seriously affected *e.g.* very frequent fires could potentially remove Renosterbos (*Elytropappus rhinocerotis*) from an area, as the seeds rarely germinate within the first 12 months of their being dispersed (Levyns 1956). Many annuals are very similar to the typically invasive shrub species, in having small wind dispersed

seeds. They are also able to take advantage of much shorter temporal periods for growth and flowering and should therefore be minimally affected by fragmentation.

The relatively high number of geophytes that remained in the Fairfield fragments may similarly be explained in terms of the disturbance not having continued long enough for widespread extinction to occur. Geophytes, within the Fynbos and other fire-prone regions, are adapted to an intermittent disturbance regime (Le Maitre and Brown 1992), and could also be termed “persistors”. The larger fragments on Fairfield farm were periodically burnt to encourage the growth of grass for grazing (Donaldson *et al.* 2002). McDowell (1995) noted that at Eensaamheid, grazing of domestic stock benefited a number of geophytes, while at Waylands (near Darling), a combination of regular burning, grazing and phosphate fertilization had led to a high diversity of geophytes. It is likely that at Fairfield Farm, the management practices are benefiting the geophytic life-form. Therefore, many of the perennial species recorded are species pre-adapted for disturbed, or cyclically disturbed, situations. Kemper *et al.*'s (1999) first suggestion therefore appears valid.

Kemper *et al.*'s (1999) second suggestion for the lack of a fragmentation effect was that Renosterveld has had a long history of grazing by livestock. Their assumption was that the species present today were the result of disturbance, and were thus not affected by a reduction in the total area available. That the vegetation structure and the relative composition of species has been affected by *recent* farming practices is not denied. It is questionable however, whether their findings can be attributed to 2000 years of grazing by livestock. Early reports (*e.g.* Thom 1952, 1954, 1958) suggested that Renosterveld was predominantly grassy and supported a substantial number of indigenous and domestic herbivores. Similarly, reports from the late 1700's (Rebelo 1992) indicated that the region was undergoing a substantial change in structure and species dominance from a grassland to a shrubland. The large herbivores were being exterminated, and grazing regimes changed from wandering herders to sedentary pastoralists. The conversion of habitat as defined by Kemper *et al.* (1999) has thus persisted for barely 200 years. The changes occurred because the disturbance, which initially developed in fragments around the landscape, benefited pioneer species able to take advantage of long-distance dispersal and disturbed habitat. Livestock grazing has not made Renosterveld predisposed towards

fragmentation. Inappropriate management has resulted in a landscape that has been invaded by “weeds”, which by definition flourish in disturbed situations. The findings thus show how the improvement of habitat for generalist and disturbance-benefiting species can mask the effects of fragmentation by their over-representation in smaller fragments. Combining this with their first suggestion (of persister species) has resulted in a situation whereby two unrelated phenomena have resulted in the same effect, *i.e.* the apparent lack of any effect of fragmentation upon overall species richness.

Kemper *et al.*'s (1999) final suggestion was that Renosterveld has a number of localized endemics which, being genetically confined to a small area anyway, are not unduly affected by fragmentation. One argument that can be levelled against this suggestion is that, since only a small percentage of the original area remains, one would expect only a similar percentage of localized endemics to remain. That is, if 80% of an area containing localized endemics is transformed, then 80% of the localized endemic population should have been affected by the loss of habitat, resulting in an extinction level of probably greater than 50% (one assumes that there is overlap between some species). There are no records of plant species in West-Coast Renosterveld, which is more fragmented and has a greater number of local endemics than Overberg Renosterveld, having gone extinct when species lists compiled in the sixteenth and seventeenth centuries are compared with recent ones (Rebelo 1992). However, the evidence (although very basic) from the analysis of published plant species lists from coastal Renosterveld performed in this study, seems to support the high levels of local endemism theory. Of the almost two-thousand species used in this study, just over half were recorded only from single sites. Von Hase *et al.* (2003) identified 132 West-Coast endemic and 113 Overberg endemic species. It is probable that there are differences in the perception of scale when one uses the term “local”; this is something that will need to be defined in order that studies can be more directly compared. Kemper *et al.*'s (1999) final suggestion therefore appears to be valid, but it raises some questions of logic and the quality of old (and modern) species lists.

A major detrimental effect of the change in vegetation structure from a grassland to a shrubland (*e.g.* Muir 1929, Smit 1943, Acocks 1979, Cowling 1984, Appendix A)

might be on the pollinators of certain species. Donaldson *et al.* (2002), also working on Fairfield farm, found that the insect pollinators were apparently more sensitive to the vegetation structure (percent cover, grassiness, rock cover) than to fragment size, although the degree of isolation of the fragment was also important. Most of the pollinators recorded were not species-specific, and therefore, to increase their diversity (and hence increase the probability of pollination) they suggested that fragments should be managed to increase habitat heterogeneity.

Isolation of a fragment is important in that small, isolated fragments may not attract pollinators, due the energy required to get to them out-weighing the rewards obtained from *e.g.* the nectar (Lamont *et al.* 1993, Pauw 2004). Donaldson *et al.* (2002) noted that, while many pollinator species *were* present on isolated fragments, pollination failure was still more common than in the well-connected fragments. Hand-pollinating individuals of four geophyte species improved the average seed-set in two species. One of these, *Babiana armata*, had shown a greater natural seed-set in larger populations, irrespective of fragment size. The other (*Pterygodium catholicum*) showed natural seed-set only on the largest (> 30 ha) fragments. This species is dependant upon a single genus of the oil-collecting bee, *Rediviva* (Donaldson *et al.* 2002) for pollination, although it also reproduces asexually by means of daughter tubers (Pauw *et al.* 2004). In a more widespread study, Pauw *et al.* (2004) noted that pollination levels of species dependant upon *Rediviva peringueyi* (such as *P. catholicum*), were apparently unaffected by fragment size, provided the fragments were situated within a rural matrix. They did, however note that other factors (soil type, stage of succession, surrounding matrix *etc.*) were of importance in determining pollination levels. Johnson and Bond (1997) found a median pollination level of 30% for 41 populations of 33 orchid species in the Fynbos. In the same study, they found that the median 32.3% natural fruit set for 12 populations of Orchidaceae and Amaryllidaceae was increased to 70% with hand pollination, suggesting that, irrespective of the effects of fragmentation, pollination levels in the Fynbos Biome are sub-optimal.

Cameron (1999), working within South-Coast Renosterveld found that, with the exception of a small fragment in close proximity to a stream and a large fragment, the correlation between fragment area and the number of birds present followed a

pattern that could be predicted from classical island theory. She also noted the positive correlation between fragment size and habitat structural diversity. Randrianasolo (2003) did a similar study in West-Coast Renosterveld and also found that size was the primary determinant of bird species diversity within a fragment, while distance from other fragments was not important. He also observed that fragment structure (vegetation, rocks *etc.*) was important. It should be noted however, that these were “point-in-time” studies, and tell us nothing about turnover, breeding success, dispersal *etc.*

A closer study of the work of Cameron (1999) and Randrianasolo (2003) suggests that they would be better described as studies of how an increase in the heterogeneity of the landscape leads to an increase in the number of bird species, rather than being studies into the effects of fragmentation. A number of authors (Loyn 1987, Lynch 1987, Soulé *et al.* 1988, Saunders and de Rebeira 1991) have noted positive relationships between the number of remnant-vegetation “specialists” and fragment area in California (Chaparral), Western Australia (mixed vegetation types), Victoria (forest) and Maryland, USA (forest) respectively. However, Lynch (1987) discussed other studies that had shown that, with the exception of a few specialist species, habitat variables tended to be more important in determining species number than fragment size alone. Donaldson *et al.* (2002) noted that the level of heterogeneity within fragments on Fairfield Farm tended to increase with fragment size. Cameron’s (1999) data showed that most of the species recorded were also encountered in non-Renosterveld habitats, and along the road verge. She did not identify Renosterveld obligate species, and many of the species she recorded are known to inhabit other vegetation types (McLachlan and Liversidge 1980). While the work of Cameron (1999) and Randrianasolo (2003) both showed a relationship between fragment size and the number of bird species recorded, these observations may be a function of increased habitat heterogeneity in larger fragments, rather than a true species : area relationship.

How can we relate the previous studies to the West-Coast situation? West-Coast Renosterveld differs from South-Coast Renosterveld in a number of ways. The soils are generally less nutrient-rich (Schulze 1997). There is a greater variation in rainfall, and there is a general increase in rainfall from the north-west to the south-

east (Schulze 1997). There are also two main geological formations incorporated into West-Coast Renosterveld, namely the Malmesbury Shales and the Cape Granites (Anon. 1973, 1990, 1997). Many of the remaining fragments are located around the perimeter of the Renosterveld area, or around the isolated hills, which may be derived from the Table Mountain Group of sandstones and thus support Fynbos. The species composition and ecological processes of the Renosterveld fragments situated adjacent to substantial areas of Fynbos are probably different to those of the fragments surrounded by agricultural activities. The situation in the perimeter fragments probably more closely resembles that found on the Agulhas plain (Cowling and Bond 1991), while the isolated fragments are more likely to resemble the Fynbos in forest situation (Bond *et al.* 1988), and would be analogous to the study of Kemper *et al.* (1999). Since many of the dominant shrub genera in West-Coast and South-Coast Renosterveld are the same, and are pioneer species, it is likely that fragmentation effects in West-Coast and South-Coast Renosterveld would be similar, within those fragments surrounded by agricultural activities. Around the perimeter of the Renosterveld extents, there is likely to be a greater input from the adjacent Fynbos, although this may not always be the case. Pauw (2004) noted that the presence of the extensive Table Mountain chain, which is predominantly derived from sandstone, was unable to provide suitable nesting habitat for the oil-collecting bee, *Rediviva peringueyi*. The result of this was that *Pterygodium catholicum* for which *R. peringueyi* is the sole pollinator, had very low levels of seed set on the adjoining clay-derived Signal Hill (385 ha; average = 1.6% seed set). On the other hand, small reserves in rural settings with a diverse matrix (and clay soils) had much higher levels of seed set (*e.g.* Malmesbury; 29 ha; average = 41.2% seed set). Linder (1976) noted that on the Piketberg, there were abrupt changes in plant communities along edaphic boundaries, with Renosterveld occurring upon shale soils and Fynbos upon sandstone soils. This was also commented upon by Pressey *et al.* (2003) in their discussion of upland-lowland gradients. This may suggest that for some ecological processes, these boundary fragments may be more isolated than their proximity to natural Fynbos suggests. They may also have been influenced by Fynbos (generalist) species that are physiologically tolerant of clay soils (*c.f.* Cowling and Bond 1991). Nevertheless, these Renosterveld-Fynbos boundaries are the result of around three million years

of evolution (Deacon *et al.* 1992), and should therefore maintain natural processes that would not be found along Renosterveld-wheat boundaries. It is therefore likely that smaller Renosterveld fragments around the perimeter would be better able to support the ecological processes that occurred in the pre-agricultural system. The fragments scattered among the wheat fields however, would need to be “self-contained” and therefore substantially larger, in order to maintain a functioning ecosystem. They would also have a relatively greater edge : interior ratio, further reducing the effective area of “Renosterveld proper”.

With respect to the animal studies, it is likely that insect guilds within West-Coast Renosterveld would be influenced by the same habitat characteristics as on the south coast. Pollinator efficiency, relative to fragment size is likely to be similar to that described by Donaldson *et al.* (2002) and is probably also influenced by factors other than absolute size. Differences are likely to be species specific and can only be determined by autecological studies. The conclusions of Cameron (1999) and Randrianasolo (2003) were generally similar, suggesting that at this taxonomic level, one can reasonably predict habitat responses from one area to the other.

2. Area : Perimeter relationships

When comparing fragments of different sizes for their richness of species, the number of species that benefit from edge effects (usually weedy species of low conservation value) should be determined (Hobbs and Huenneke 1992). A long disturbed edge (small-area : large-perimeter ratio) may indicate a small fragmentation effect due to a large number of opportunistic species (as was indicated by the work of Kemper *et al.* 1999). One would expect that the effects of fragmentation upon West-Coast Renosterveld patches scattered among the cereal fields would be similar to that found by Kemper *et al.* (1999) on the south coast. One would therefore expect that in small fragments, a greater proportion of the species composition would be made up of annuals, in particular alien annual graminoids and weeds of cultivation. Perennial grasses should also decline in importance in the smaller fragments, due to more intense grazing pressures (attributed to Cowling *et al.*, by Kemper *et al.* 1999). Although there is no directly equivalent study in West-Coast Renosterveld, van Rooyen (2003) looked at the

encroachment of alien grasses into established Renosterveld along old-land – Renosterveld boundaries in the Elandsberg and Jan Briers Louw (Eensaamheid) Nature Reserves. She noted that the cover of these grasses significantly decreased 15 m into the Renosterveld and that edge effects along undisturbed (ungrazed- unburned) Renosterveld were about 20 m. Laurance and Yensen (1991) developed a model for estimating the core area of fragments of different shapes, based upon a known edge-effect distance. Their use of various test shapes gave a maximum error of 3.5%, and a typical error of < 1% when compared with field trials. Their formula was used on all the fragments (1350) of > 3 ha occurring within the “Compound” area. This suggested that, of the 69 799.8 ha of natural vegetation remaining within these fragments, 58 118.9 ha (83.3%) exists as core area. Three points need to be kept in mind with these calculations. The first is that the 20 m edge-effect applied to *undisturbed* Renosterveld; once disturbance (grazing, burning, soil disturbance) was factored in, this edge effect distance became wider. Secondly, van Rooyen (2003) was specifically looking at alien grasses, and finally, many of these fragments abut natural Fynbos vegetation, thereby reducing the length of their affected perimeters. As such, they actually have a shorter effective perimeter (relative to man-induced transformations) than would be implied from the figures. The largest fragment (the VEK fragment) had an area : perimeter ratio of 323.1:1. By shortening the effective perimeter to that bordering non-natural vegetation (a figure of 0.67 the full perimeter length was used), this ratio was increased to 482.3:1 and core area increased by 1.6% (117.6 ha). In cases such as the Kasteelberg, the opposite case could be considered to occur. The perimeter distance excludes the “island” of Fynbos occurring inside the Renosterveld strip around the lower slopes of this mountain. The effective Renosterveld perimeter is therefore longer. Using an estimated value of 1.33 times the full perimeter decreased the ratio at the Kasteelberg from 145.9:1 to 109.7:1 and decreased the effective area of “good” Renosterveld by 4.5% (30 ha). Similar calculations could be done with the Paarlberg and Perdeberg. However, the argument used to increase the ratio in the VEK complex (that Fynbos-Renosterveld boundaries are natural) could also be used here to keep the original ratios. The probable importance of these abutting vegetation types for the continuation of natural ecological processes was mentioned earlier. Similarly, species benefiting from the disturbance found along natural-

agricultural boundaries (such as alien species and weeds of cultivation) are less likely to establish themselves. Nevertheless, van Rooyen (2003) noted that small-scale soil disturbances (animal diggings, trampling, browsing and termite nests) in Renosterveld were strongly correlated with alien grass establishment, even when these occurred a substantial distance from the boundary.

3. Fragment distribution across the landscape and the implications for conservation

The distribution of West-Coast Renosterveld fragments across the landscape might be described as scattered, mainly around the perimeter. Chapter 5 discussed the use of the Korcak exponent (B) to estimate the level of patchiness of the remaining fragments, and showed that the figure obtained ($B = 0.949$) predicted a low probability of persistence of many of these fragments (Hastings and Sugihara 1993). Although it was argued in the previous chapter that the cause of this high value of B was due to processes that had essentially reached their conclusion (*i.e.* all the suitable areas have now been transformed to agriculture), it does indicate that few large fragments remain.

Soulé (1984) was of the opinion that reserves should not be in close proximity to one another. His argument was that the clustering effect was only of benefit to a small minority of birds and some bats and it was therefore unlikely to be compact enough to benefit gene flow for most other species. Fragment distribution therefore needs to be related to the size and dispersability of the organism being considered. Localized endemic plants, and small animals may have had restricted distributions even when the landscape was unfragmented. Mobile organisms, such as birds, may utilize more than one fragment within their “home-range”. This may be because they are incorporating several patches into their territory, because they are non-breeders, or because they are generalist species that can utilize the surrounding matrix (Andren 1994, referring to several studies). The research of Bond and Slingsby (1983) indicated that a distance of two to three metres was a typical dispersal distance for myrmecochorous species, while hundreds of metres was possible for wind-dispersed seeds (Bond 1988, Johnson 1992). Knight *et al.* (MS) have recently provided evidence that, in at least one instance, a myrmecochorous

species had apparently been dispersed by baboons, possibly as far as one kilometre within 30 years. Cowling *et al.* (1992) noted that short-range (< 10 m) dispersal was proportionally more common in local than in regional endemics, while local endemics with long-range (> 50 m) dispersal were almost non-existent in their study areas. Shiponeni (2003) measured the seed dispersal of Renosterveld species by wind and in the dung of indigenous large herbivores and concluded that, within the limits of her study, seed dispersal by these methods was generally not a limiting factor for distances up to 100 m. She did note however that some wind-dispersed seeds (particularly those of geophytes) were unable to move through established vegetation (Shiponeni 2003a). Since the larger herbivores no longer occur outside of reserves, plants relying upon these for seed dispersal will be disadvantaged. However, McDowell (1995) noted that certain Iridaceae and Asteraceae species responded positively to grazing by domestic stock at Eensaamheid and at Waylands, suggesting that the loss of the large herbivores may be partially compensated for by the judicious use of livestock.

When the published seed dispersal distances are compared with the typical inter-fragmentary distances encountered in this study, it can be seen that they mostly fall well short of that required to migrate between fragments. Estimating the distances between the 202 source fragments (the major fragments) used for the corridor analysis, showed that of the 20301 inter-fragmentary options available, only 48 (0.2%) were less than 2.5 km. Seven hundred and fifty-five (3.7%) were less than 10 km, while the number less than 50 km and 100 km were 8930 and 17784 respectively. The median and mean inter-fragmentary distances of 55.2 km and 59.5 km respectively are three or more orders of magnitude greater than most published seed dispersal distances. However, Figure 6 showed that most fragments were within 1 km of their nearest neighbour, and only the Peninsula fragments were more than 5 km from the major cluster. Nevertheless, even 1 km is beyond the normal dispersal range of most local endemics.

Von Hase *et al.* (2003) used a system of priority clusters to identify groups of fragments with less than 500 m separating them (Layer 4 metadata, downloaded with the Renosterveld layers). Eighty-eight of these occurred within the west coast region, many of them coinciding with sections of the corridor lines identified in this

thesis. Their method does not take into account the matrix existing between the fragments and included fragments of less than 3 ha in extent, which resulted in seventeen clusters being independent of the corridor analysis. Like the distance and corridor analyses, this is another useful tool for determining groups of fragments suitable for conservation.

In order to assess the landscape from the perspective of animals with limited vagility, or plants with short-range dispersal mechanisms, autocorrelation studies can be used. Autocorrelation is performed at progressively increasing scales (lags), so that one can assess the landscape pattern at a scale relevant to the organism being considered. The plot (Figure 10) showed how the level of autocorrelation (clumping) changed with scale. It showed that the distribution of the remaining fragments was extremely highly autocorrelated at short ranges (< 60 m). Relating these results to dispersing organisms (*e.g.* a plant seed) it means that, knowing the dispersal distance of the propagule, we can estimate the probability of that propagule arriving in an area of Renosterveld. For an organism currently living within Renosterveld and which disperses a distance of 60 m, the probability of that organism arriving in an area that is also Renosterveld is very high (around 90%), irrespective of the direction of its dispersal (the King's case method was used to allow for multi-directional dispersal). However, if the organism travels 1500 m then the probability of it landing in an area that is also Renosterveld is much lower (around 60%). Note that Moran's I is not directly translatable into a percentage probability value, but for the purposes of this exercise it provides a close enough estimate provided one remembers that zero probability is represented by $I = -1$.

The conclusion to be drawn from this is that, based upon published information about the seed dispersal distances of local endemics (< 100 m), the *probability* that a propagule produced by such a plant will disperse into an area that is also Renosterveld is very good. As the distance dispersed increases, the probability of a propagule dispersing into an area that is also Renosterveld drops off in a manner described by the curves in Figure 10. This implies that, for a species living in a small fragment of Renosterveld, it may be better to have a propagule that only disperses a short distance than one that disperses a long distance. Relating this to the level of local endemism found within the region (and the observation that they

have short-range seed dispersal - Cowling *et al.* 1992), it suggests that many of the local endemics are not threatened by the loss of habitat *per se* (*e.g.* see Lynch's [1987] comments that plants were generally unresponsive to reserve [fragment] size). Of more importance would be competition from aliens, changes to the nutrient status (by fertilization *etc.*), loss of pollinator or dispersal species (by crop spraying, absence of large herbivores), transformation of the land to agriculture *etc.* Donaldson *et al.* (2002) noted that with some geophyte species, seed set was improved when there was a large local population. In cases such as these, clumping of individuals (*i.e.* short range dispersal) may improve overall seed-set, and enhance long-term survival.

Turning to those species with long-distance dispersal mechanisms, there are two options. The first is (pseudo) random dispersal (*e.g.* wind), where the propagule is dependant upon non-sentient dispersal. Propagules are statistically less likely to arrive in another fragment of Renosterveld as their dispersal distance increases. It is pseudo random in that winds in this area are predominantly from the north-west in winter and the south-east in summer (Deacon *et al.* 1992). For this option, a very large number of propagules are required. Fragmentation can affect the dispersal and deposition of wind-blown propagules, due to the effect different vegetation structures have upon wind profiles. Changes in wind speeds and characteristics over different vegetation types has been shown to affect deposition rates of wind-blown seeds and inorganic particulate matter, with deposition tending to be greater in fragments of natural vegetation (which is "rougher"), compared with annual crops and pastures (Saunders *et al.* 1991, Hobbs 1993).

A second option is sentient dispersal – a bird eating a fruit is more likely to disperse to areas where other resources are available, which probably means another patch of relatively natural habitat. Fewer propagules are required for this mechanism.

4. Dispersal and corridors

Other authors (*e.g.* Bridgewater 1987, Anon. 2002) have used a system whereby nodes (points where corridor lines overlap) have been created, and a weight, based upon the number of dispersal paths intersecting that node has been assigned to that

node. Nodes with high scores indicate locations that are of importance for dispersal and need to be conserved. Due to the large number of intersections identified in this study, a system of weighting the corridor lines themselves was used instead. The analysis presented here (Figure 8) is a general illustration of connectivity across the landscape. The thick lines indicate a high potential for organisms to step across the landscape. The benefit of corridor analyses, which can take into account hundreds of options, over a subjective viewing of the region, can be seen when the results of this analysis are compared with that of von Hase *et al.* (2003). They identified a “corridor” (their coastal gradient line), which approximates the southern-most (A) east-west pathway shown in Figures 8 and 9. While that link is of importance, particularly for linking up with the Peninsula fragments, the more northerly (B) of the two thick corridor lines is probably more important for the Swartland species, and also supplies an alternative to the southern-most corridor, which is increasingly coming under threat from urban expansion. A further disadvantage of the southern-most corridor (A) is that more of it is situated on Quaternary sands than is the case with the northern corridor. In fact, the thinner corridor line (C) has the most likelihood of providing a dispersal route for those species confined to shale soils.

Of major concern is the lack of connections across the central Swartland area. The corridors identified in this region are little more than indicators of the road system. While some roads, such as that along the eastern foot of the Piketberg (Figure 12) have verges that are maintaining some natural vegetation and its related animal communities, the minor road just to the north of the Koeberg (Figure 13) is clearly little better than the wheat field it bisects, in terms of conservation. This picture becomes bleaker when those source fragments lying greater than 500 m from the border (Figure 9) are excluded from the picture. Even the low frictional value of five, given to roads failed to allow cross-Renosterveld links to develop. Pathways are mostly confined to the perimeter, although both major (A and B) east-west corridors in the south continue to exist. As was mentioned in Chapter 5, many of these perimeter sites are actually situated on low-nutrient sands. Note that the smaller east-west corridor (C) has disappeared.



Figure 12. Road verge along the eastern foot of the Piketberg. Alien grasses and Renosterbos (*Elytropappus rhinocerotis*) are the main constituents.

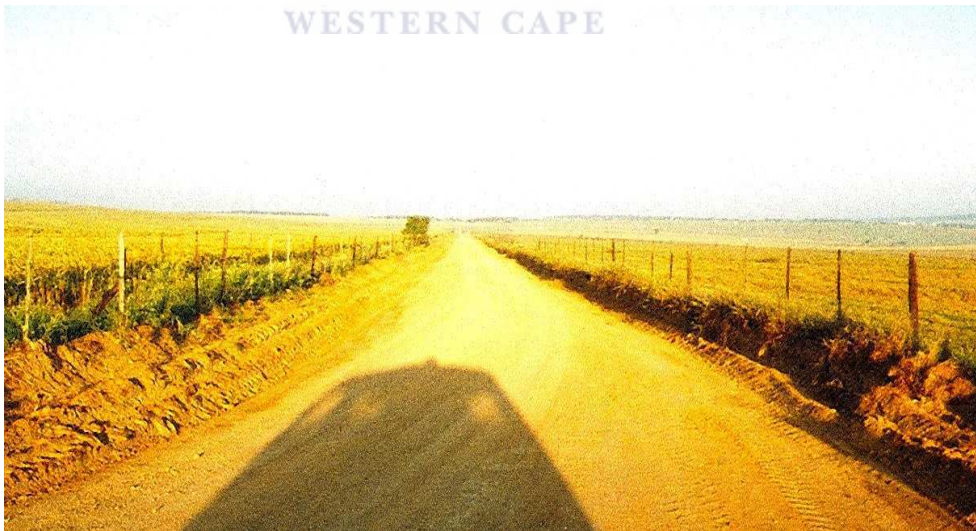


Figure 13. Road just north of the Koeberg showing the absence of any verge. Vegetation along fence-line is mostly alien grasses and wheat

Although the procedure used indicates the “cost” of travelling across areas of different land-cover components, it does not take into account other factors that act independently of land-cover. Such factors include wind, for wind-dispersed propagules and slope for the more terrestrially bound vectors. The western Cape lowlands are predominantly subjected to winds from the south-east in summer, and from the north-west in winter (Deacon *et al.* 1992). Although local winds and eddies exist, the *predominant* dispersal of wind-borne seeds (or pollen) would be in a north-west or south-east direction. In addition, neither the image, nor human investigators can perceive these corridors in terms of how animals perceive them. What may appear to be a suitable dispersal corridor from a human point of view, may have many disadvantages for some animals *e.g.* burrowing animals may find the soil compacted too hard, insects may not be able to find suitable food plants *etc.* Due to the frictional values assigned to the different land-cover classes, the corridor analysis suggests that Renosterveld dispersal benefits from Fynbos habitat. Once again, this is arguable. It has already been mentioned that abrupt edaphic boundaries between shale and sandstone communities exists (*e.g.* Linder 1976, Pressey *et al.* 2003). It may be that these Fynbos corridors are as closed to many Renosterveld plant species as are the wheat fields. These factors cannot be incorporated into a generalized frictional image, due to differences in habitat tolerance of different species, and to a lack of detailed information about conditions along the corridors themselves.

The following discussion has been divided into three units – roads, rivers and agricultural land. In many cases, discussions about road effects can be transferred to rivers or agricultural land as well (and *vice versa*). They were separated because there are certain aspects that relate specifically to the three corridor units discussed.

4-A. The value of road verges as corridors for conservation and the transfer of genetic material

Tansley (1982) estimated that nearly one-third of all the remaining West-Coast Renosterveld was in the form of road verges or isolated patches too small to be considered as viable conservation units. Reyers *et al.* (2001) looking at the effect roads in South Africa had on the natural environment estimated that about 8.1% of

all remaining West-Coast Renosterveld was in one of their “road-effect zone” categories (the equivalent figure for South and South-West Coast Renosterveld [*sensu* Low and Rebelo 1996] combined was 8.8%). The use of road verges as corridors for biotic dispersal and processes within the CFR has received very little attention. None of the plans for the CFR (*e.g.* Cowling *et al.* 2003; Pressey *et al.* 2003) considered road verges, nor did von Hase *et al.* (2003) consider them in their assessment of connectivity and corridors within coastal Renosterveld. A subjective corridor/connectivity study based upon land-cover parameters (including road verges) within the Greater Cape Town area exists (Anon. 2002, Low *et al.* 2004). These corridors identify passages that, based upon current knowledge, are the least transformed, and which may possibly be “restored” for natural connectivity purposes. Although not encompassing a great deal of coastal Renosterveld, the Cape Town study is important as the finer detail used helped identify shorter corridors linking the Peninsula fragments with the main group of fragments than was found in this study.

The only study that touched on roadside habitat/diversity was that of Cameron (1999). Her study included a road verge (3 km in length, verge width 3 m to 10 m, both verges censused). Of the 46 bird species she recorded in her study (other than flying over while transects were being walked), 30 occurred along this verge. Only in three other fragments were more species than this recorded, suggesting that the disturbance levels typically encountered along roads have benefited at least one taxon of organisms. It also supports the general findings of the literature review by Kremsater and Bunnell (quoted by Fahrig 2002), that many species show a positive response to edge effects. It also supports the argument presented earlier that her study was of the landscape, rather than of the effects of fragmentation.

In the absence of any other roadside habitat/diversity studies within coastal Renosterveld, a brief look at other areas may provide some guidelines as to the importance of road verges in conservation. Forman and Alexander (1998) reviewed the literature on the relationship between roads and wildlife. They showed how roads as narrow as 2.5 m could be total barriers for some invertebrates. Even lightly travelled roads of six to 15 m in width significantly reduced the probability of small mammals crossing them. For those animals that do venture across roadways, death

is an ever-present threat. Estimates of the number of animals killed by traffic included twenty million butterflies killed in a single week in the state of Illinois; four-hundred million vertebrates killed annually in the USA; fifty-million vertebrates (including ten-million birds) killed annually in Britain (several reports quoted by Williams 2003). It has also been noted that birds are affected by road noise (Forman and Alexander 1998, quoting several authors), possibly with detrimental consequences to the dispersal of avian-dispersed seeds.

Le Maitre and Midgley (1992) estimated that 17% to 21% of Renosterveld species were wind dispersed, although they added that, in terms of cover abundance these species made up 40% to 53% of the flora. Eddies of wind produced by moving vehicles, and the lack of obstacles to capture the seeds, may increase the distances travelled by such seeds along a road. Against this should be seen the background of extensive wheat fields with few barriers (such as lines of trees) to impede the natural dispersal of wind-borne propagules. A number of wind-dispersed species do so by the breaking-off of the seed head, which is then blown along the ground, scattering the seeds as they go (*e.g. Brunsvigia*, Shiponeni 2003a) and it could be suggested that roads may be beneficial for the dispersal of such species. Forman and Alexander (1998) found few documented studies (world-wide) of species that had spread more than 1 km due to vehicle movements. Bennett (1991) on the other hand, noted some translocations of animal species within Australia in commercially packed fruit crates and in mobile homes. He also referred to a study by Wace, who germinated the seeds from the sludge washed from cars in a commercial car-wash establishment in Canberra. At least 259 species were identified, some only occurring more than 100 km from Canberra. Bennett (1991) also referred to a paper of Weste's suggesting that the spread of *Phytophthora cinnamomi* in the forests of southern Australia could be blamed upon spores carried on motor vehicles. Along the roadsides of the southern Cape, Muir (1929) noted the presence of Renosterbos, which was often used as packaging material by transport riders in the past.

The next aspect to consider is the conditions that a dispersed seed can expect to find when it comes to rest on the verge of the road. What is the probability that a diverse flora will develop and rare species be conserved? Once again there are no data from within Renosterveld areas, and so findings from other areas must be considered.

Forman and Alexander (1998) concluded that, while roadside verges generally had a relatively high species richness, very few rare species were found there. On the other hand, a review of the conservation value of roadside verges in Britain (Way 1977) found that they were important habitats for a variety of wildlife. Field surveys showed that 43.5% of all British plant species were found there, including 13.6% of the nationally rare species. Forty percent of Britain's mammalian species were found to breed along roadsides, as well as 20% of the bird species, all six reptiles species, 42% of the butterfly species and five of the six amphibian species. Having said that, it was found that there was a *usual* roadside community, rather than many diverse communities. The figures quoted here may be an example of the benefits of edge habitats, as referred to in Fahrig (2002).

On the negative side, there is the importation of substrates (and seeds from other vegetation types) into the area during road maintenance, and the apparent benefit that roadside disturbances have for the spread of alien species. For example, Parendes and Jones (2000) noted that road verges (even those that had been unused for 20 to 40 years) were home to many exotic species in the HJ Andrews experimental forest in Oregon. They found that this contrasted with areas of natural disturbance (such as landslides), where few exotics were found (suggesting that these alien roadside species were introduced by human activities, probably related to road construction/maintenance). They also noted that, with one exception, the species most frequently occurring in these corridors had adaptations for wind dispersal, or by adhesion to passing animals. Although it is known that wind-dispersal is common in Renosterveld (Le Maitre and Midgley 1992), no data related to seed dispersal by means of seed adhesion to passing animals was found. Two aspects that need to be determined are, first, how beneficial are roadsides for the conservation of rare plants, and second, how beneficial are they as habitats for animal species that are either rare themselves, or are required for the pollination/seed dispersal of the rarer Renosterveld plants? Neither of these questions can be answered without specific data from coastal Renosterveld.

It could therefore be suggested that road verges are of use in the conservation of some species, but that the communities found there would not necessarily be representative of the original natural communities, nor would they necessarily assist

in the transfer of genetic material between fragments. Additionally, the study of van Rooyen (2003) suggests that corridors of less than 40 m in width would typically be supporting many alien and pioneer species (due to edge effects), rather than the rarer indigenous species. On the other hand, the work of Cameron (1999) and the review of Kremsater and Bunnell (quoted by Fahrig 2002), suggests that certain organisms (*e.g.* birds) may benefit from verge management.

Boucher (1995) suggested that road verges should be “restored” as an integral part of connecting isolated reserves. The evidence presented here seems to suggest that, while road verges could be managed for the limited conservation of natural vegetation (and related fauna), they are likely to be of limited use for a substantial flow of indigenous genetic material between Renosterveld fragments. Although these corridors may act as intermediary habitats for species associated with the pollination or seed dispersal of Renosterveld species, the widespread distribution of the fragments within the landscape makes it questionable as to how effective they would be in real terms. We would also need to know the dispersal range of pollinators, how effectively intermediate (corridor) micro-populations of species can establish and similar factors related to the reproductive biology of Renosterveld species. The CREW data does suggest however, that many of the rare species have small populations that are widely distributed, possibly due to some micro-habitat requirement. Such species probably only need small areas, such as could be set aside along most rural roads, in which to persist.

A further question is to what the verges should be restored, and how should they be managed – shrub or grass? Burnt or mowed? How frequently and at what time of year should the management action be taken? Way (1977) suggested that verges would probably benefit ecologically from a variation in management. For example, close to the road the verge could be maintained at a safe height (*i.e.* so that it does not block the motorists view), while further from the road less management would lead to a different, taller habitat. While this is ideal in theory, it was based upon the assumption that the verge is of substantial width, something that is rarely the case within the areas of intense agriculture being looked at here (*e.g.* Figure 13).

4-B. The value of riverine corridors for conservation and the transfer of genetic material

Much of what has been said about road verges may apply to riverine corridors. Disturbance factors will be present, although of a generally different type to those found along roadsides. Soulé (1984) considered riverine corridors as being of a habitat different to that of the fragments they were connecting, resulting in their being of limited use in the dispersal of fragment species. Simberloff *et al.* (1992) condemned outright the inclusion of riparian habitats in any discussion of movement corridors. They believed that riparian strips should be viewed in terms of their unique characteristics (compared to the surrounding areas), rather than as corridors for dispersal.

The only substantial river system within West-Coast Renosterveld is that of the Berg River and some of its side branches. Von Hase *et al.* (2003), following the guidelines set for the CAPE system (Pressey *et al.* 2003) identified 52 853 ha of riverine corridor within West-Coast Renosterveld, 7691.6 ha (14.6%) of which, they considered natural. Von Hase *et al.* (2003) defined an area to be natural if a block of land of at least 5 ha, and extending 250 m either side of the river (along inter-basin rivers), had > 80% of its area untransformed by urban development, agriculture or high densities of alien plants. For other perennial rivers, the corresponding parameters were 2 ha and 100 m respectively. There are no community studies comparing riverine with non-riverine habitat within coastal Renosterveld, therefore an assessment of its use as a corridor for the dispersal of Renosterveld species cannot be made. One might also refer to Simberloff *et al.* (1992) and suggest that a “corridor” as wide as 200 m (or 500 m), ceases to be a “corridor” and becomes habitat in its own right.

4-C. Fragmentation and dispersal across agricultural transformations

Unlike road verges, where disturbance is random, usually only occurs at extended intervals and is rarely total, the production of cereals is associated with annual and intense disturbance events. Only species that can complete their life cycle within the few dry summer months between harvesting and ploughing (or within fallow

periods) can survive in these areas. McIntyre and Hobbs (1999) tabulated the number of species found by Scougall in woodland fragments and the surrounding croplands in the Western Australian wheatbelt. No native herbs, shrubs or trees were found in the cropland matrix, while exotic herbs were slightly more common in the cropland matrix than in the woodland fragments. Kemper's (1997) study identified a 21% component of indigenous plant species within the wheat fields, but in terms of life form these were either forbs or grasses. In addition, those species found in the wheat fields had a greater proportion of abiotically pollinated species, and their dispersal ranges also tended to be greater than for species found within the fragments.

In the context of coastal Renosterveld as it is now, the dispersal of seeds across the agricultural matrix would be largely restricted to wind or bird vectors. Le Maitre and Midgley (1992) estimated that 17% to 21% of Renosterveld species were wind dispersed, while 13% to 17% were bird dispersed. The studies of Cameron (1999) and Randrianasolo (2003) also showed that birds appear minimally affected by the isolation of a fragment. One might therefore surmise that wind and bird dispersed species are not significantly affected by fragment size or the level of isolation. As mentioned earlier, Donaldson *et al.* (2002) noted that there was some effect on pollinator diversity when fragment isolation was considered. Although interfragmentary distances were not given, Kemper *et al.* (1999) reported distances of between 300 m and 1100 m for the farm. Relating these distances to those at a landscape scale on the west coast lowlands, it is likely that isolation effects on pollinator (and other invertebrate species?) would be much greater than that measured by Donaldson *et al.* (2002). Pauw (2004) suggested that the diversity of the surrounding matrix was also important in determining the degree of isolation of a fragment.

A study by Bowie and Donaldson (in prep) showed that the Cupreous Blue (*Eicochrysops messapus*), a habitat specialist butterfly, actively avoided wheat fields. No individuals of this species were seen crossing wheat fields, and only one was noted in fallow lands. The conclusion from this might be that fragmentary populations are isolated, and without high quality Renosterveld corridors they will remain so. Beier and Noss (1998) referred to a study by Sutcliffe and Thomas

showing that 98% of a butterfly species used corridor strips to travel from one fragment to another. Nevertheless, it was not proven that without those strips, the 2% flying across the agricultural matrix were not enough to maintain the population within the fragments, nor that more of the population would not have used the matrix in the absence of corridors. With this in mind it should be noted that *E. messapus* is found from the Cape Peninsula to Ethiopia (Carcasson 1981), its major requirement being the presence of *Thesium* spp. on which to lay its eggs (Clark and Dickson 1971). It may therefore be that the findings of Bowie and Donaldson, while suggesting that corridors are important for this species, do not prove that their dispersal is impossible without them.

5. Community composition of coastal Renosterveld fragments – How homogeneous is West-Coast Renosterveld?

Rebelo (1995) asserted that one of the reasons that there were no extinctions reported from West-Coast Renosterveld (when lists from the 1700's and today were compared), was because Renosterveld was homogeneous, and so isolated endemic species were rare or absent. Bond and Goldblatt (1984), and Kemper *et al.* (1999), have both suggested that coastal Renosterveld is home to many localized endemics, von Hase *et al.* (2003) recording 132 such species. This problem can only be fully resolved once a significant set of detailed species (and habitat) lists have been collected from a variety of areas, each being censused over several seasons. From the discussion of the definition of Renosterveld in the Historical Review (Chapter 1), we should expect all mature sites to have representatives of the pioneering shrub species, and poorly sampled sites to be sub-sets of nearby, better-sampled sites.

Analyzing the published data, as well as that collected by the Botanical Society, showed high levels of both beta and gamma diversity. This apparently contradicts Rebelo's (1995) assertion. However, one should keep in mind that many of the species occurring in Renosterveld also occur in the surrounding vegetation types (Boucher 1983). One also needs to realize that, for the published data, most of the fragments sampled were adjacent to, or incorporated (*e.g.* Paarlberg) Fynbos, and many are not edaphically homogeneous. Most published collections have been "of the fragment" rather than "of the vegetation type", leaving the headaches to the

analyst. It is therefore difficult to establish to what extent the results are due to genuine local endemism, and how much is due to the heterogeneity of the fragment sampled. How many of the species recorded are genuine Renosterveld endemics, and how many are generalist species present due to physiographic and management factors?

5-A. Heydenrych and Littlewort's study

The nearest published West-Coast Renosterveld approach to the fragmentation study of Kemper *et al.* (1999) was that of Heydenrych and Littlewort (1995), who looked at the flora of seven hills in the Darling district. They also compared their results with those of surveys done at seven other West-Coast Renosterveld sites. Their first observation was that the larger hills tended to have more species, but there was no direct hill-size : species-number correlation (*c.f.* Kemper *et al.*'s [1999] similar conclusion). The smallest hill (Bokkop; area approximately 50 ha) had almost 150 species, whereas the Contreberg (the largest at approximately 475 ha) had a little over 200. When monocots only (mostly geophytes) were looked at, the second largest hill (Kapokberg at 350 ha) was the richest with 70 species. This was followed by the Renosterkop (area about 100 ha) with 66 species.

Their comparison between the Darling flora (as a whole) and that of seven other areas showed that the species overlap was small. About 55% of the species occurring on the Darling hills were also found on the Tygerberg, and it was suggested that this was because the Tygerberg had been intensively sampled over a long period of time. None of the other areas (Dassenberg, Klein Dassenberg, Blouberg, Signal Hill, Joostenberg Hill, Eensaamheid) had more than a 40% overlap. The proportion of overlap of the same sites using only the monocotyledonous species showed almost identical percentages to those using all the species.

Based on their data, the west coast fragmentation effect therefore appears to be much greater than that found by Kemper *et al.* (1999) on the south coast. Having said that, it needs to be remembered that the west coast sites mentioned here were generally larger and more scattered than was the case with the south coast study. In

Kemper *et al.*'s (1999) study the 23 fragments examined occurred within an area of *circa* 9000 ha. The maximum distance between fragments was 1.1 km and only two fragments were larger than 100 ha. Four of the seven Darling fragments were larger than 100 ha, with the maximum distance between any two hills being about 5 km. The three closest Darling hills (Kapokberg, Bokkop and Renosterkop) are separated from each other by about one kilometre. On average, Kemper *et al.* (1999) found between 60 and 90 species in most of their fragments (range about 30 to about 120 – their Figure 3). On the Darling hills, 150 to 200 species were found on each hill. In total 420 indigenous species were recorded from Darling, compared with 366 species (283 of them indigenous) on Fairfield farm.

5-B. This Study

1. Published data

Faith and Walker (1996) have suggested that a combination of UPGMA and Bray-Curtis *dissimilarities* are likely to produce clusters that correctly represent the relationship between sites, based upon species differences. The Sorenson coefficient (which measures *similarities*) is a special case of the Bray-Curtis method that is used when data are restricted to 0 and 1 (Romesburg 1984). The cluster analyses performed are therefore likely to be methodologically robust. Looking at the regional groupings (Figure 11A, Table 3), the most striking feature was that over half the species were found only at one site, and none were common to all ten. Less than 15% of the species were found at more than three sites. It was not unexpected to find that the Humansdorp and Riversdale sites were distinct, as they are subject to rainfall conditions that differ substantially from most of the other sites (South African Weather Services data). Humansdorp and Riversdale receive rainfall all year round, although in both cases, the three summer months (December to February) are drier than the rest. These two sites each had more than 40% of their species found at none of the other sites analysed. About one-third of the species found at the Paarlberg and at Voelvllei-Elandsberg were not found at any of the other sites. This is likely to be due to both of these sites (and hence their species lists) incorporating a substantial number of Fynbos species. The species list of Paarlberg does not differentiate between the lower slopes (considered to be

Renosterveld), and the higher regions, considered to be Fynbos (Low and Rebelo 1996) or Fynbos/Renosterveld mosaic (Cowling and Heijnis 2001). The mosaic of vegetation types at Elandsberg was discussed in Chapter 3. Although Tansley's (1982) Voelvlei species list was included in the Voelvlei-Elandsberg site, (Voelvlei is geologically more likely to be Renosterveld, Anon. 1997), only eight of the 741 species were restricted to Voelvlei. One would have expected Fairfield Farm to be the third most distinctive site, as it is also situated within the south coast region. However, its westerly situation probably results in it receiving a predominantly winter rainfall. The study site was also "true" Renosterveld (in the edaphic sense), and therefore did not have the additional typical Fynbos element (Taylor 1978) found at the Paarl and Elandsberg sites (only two Proteaceae and no Ericaceae or Restionaceae were recorded from Fairfield Farm by Kemper 1997). The remaining sites each had 12% to 20% of their species component restricted to that site. Two of the single-site samples (Eensaamheid and Tienie Versveld Reserve) have had their Renosterveld connections disputed. Tansley (1982) and Savory (1986) have both suggested that Eensaamheid was partially or completely coastal Fynbos. The Tienie Versveld reserve has been insultingly described as being little more than a field with some poor examples of Strandveld and coastal Fynbos (Tansley [1982], referring to personal communications to her by Chris Burgers and Liz Ashton).

Two regions had enough well-sampled sites to do regional analyses. These were the Southwest region and the Darling region. In both regions, local endemism was again high, with close on half the species in each area being confined to one site. In the Southwest region, 85% of the species were restricted to three or less sites. In the Darling area this was lower, with only 72% of the species confined to three or less sites. This may suggest a greater level of connectivity between the Darling hills than between the Southwest sites, although it may also be that the physiographic parameters of the hills are more similar to each other than those of the Southwest region.

In the Southwest region (Figure 11B) the low sampling intensity of Blouberg (51 species) leaves its associations with the other hills in doubt. Like the Klein Dassenberg, this hill not only supports Renosterveld, but also Thicket and Fynbos species (Jarman 1986), and it is not known where the species list was made. The

cluster analysis showed the Tygerberg and Kanonkop to be the most closely related sites. Kanonkop is situated close to the Tygerberg, and appears, from the number of species recorded, to have been well sampled. Signal Hill and Tygerberg have been well sampled, suggesting that their high (one-third) levels of local endemism are probably genuine. However, one should note that Tygerberg is entirely a shale formation, while Signal Hill has shales, granites and some TMS. Both Meerendal and Hoogekraal showed quite high levels of local endemism despite relatively small (111 and 131 respectively) species lists. The high level of endemism at these two small sites is interesting in view of the fact that these hills are in an area that has been cultivated for three hundred or more years. It suggests that the species present are relatively immune to disturbance.

In the Darling region (Figure 11C), it has already been noted how different the Tienie Versveld reserve was from the other areas. The Klein Dassenberg also had a high level of local endemism, with 38% of its species not found elsewhere. However, its character is diverse, with rocky outcrops providing habitats for succulent and Thicket species (Kilian 1995). In addition, its lower slopes blend into Sand Plain Fynbos and it may be the inclusion of those species that is giving it its distinct character (Kilian 1995). Although only the size of the Kapokberg, Kilian (1995) has suggested that its characteristics make it a prime site for conservation. Except for the Dassenberg, with 15% endemic species, all the remaining hills had less than 7% of their species confined to one site. The Dassenberg is considered the largest existing unified area of coastal Renosterveld with almost 2000 ha remaining (Kilian 1995). The similarity between the Rondeberg and the Klipberg is interesting as Heydenrych and Littlewort (1995) commented upon the karroid affinities of the Klipberg and the Strandveld affinities of the Rondeberg.

As mentioned in the results section, the trend in the number of geophytic and red-data species (in the published literature) generally followed that of the total number of species. As the total number of species falling into each of these two groups was lower, sampling errors would be magnified. Some items of note were the very high number of geophytes in the Voelvlei-Elandsberg complex. How much this has to do with collecting effort, and how much to the diverse geology would require detailed local area studies. The Paarlberg had remarkably few endemic geophytes present (in

terms of the total number of species). However, in terms of the percentage component of geophytes, it was, with the exception of the Voelvlei-Elandsberg complex, similar to the other sites in the West-Coast Renosterveld region. Fairfield Farm also had about one third of its species represented by geophytes. Donaldson *et al.* (2002) commented on the paucity of geophytes in the fragments on Fairfield farm that had a dense shrub structure. This could be a combination of the difficulty in seeing them, and the tendency of some geophytes to cease flowering when densely overshadowed by shrubs (Le Maitre and Brown 1992). The south coast sites had more locally unique geophytes, but this can probably be attributed to the relative isolation of these, compared to the west coast sites.

Looking at the Southwest region, there was a remarkably similar proportion of geophytes on all six hills. There was however a big difference in the number of unique geophyte species found on each hill, with the two largest having nearly one-third of their geophyte species locally endemic. In the Darling area, with the exception of the Klein Dassenberg (which it has already been noted, includes Sand Plain Fynbos species), the proportion of geophytes was generally higher than in the other regions. The Tienie Versveld Reserve had nearly twice as many unique geophytes as any of the other sites, reflecting its questionable Renosterveld affinities. It also throws doubt upon the disparaging remarks made about it, as reported by Tansley (1982). Duthie (1930) noted that, while there was a greater *proportion* of geophytes within her “grey-bush” community, her Fynbos community actually had more species in total.

In terms of red-data species (from the published data), the number of these was again largely related to the total number of species recorded from each site. The Klein Dassenberg and the Tienie Versveld reserve had the largest number and percentage of unique red-data species, again probably reflecting their more diverse (Klein Dassenberg) or non-Renosterveld (Tienie Versveld) characteristics.

2. Botanical Society lowlands project and CREW data

Plant lists made during the Renosterveld lowlands project were confined to the dominant and rare species (Von Hase *et al.* 2003). Therefore, the observation that

only five of the species identified occurred at more than 20 of the sites is of great interest. Despite the general assumption that coastal Renosterveld is a vegetation type dominated by one or two species, we find that the most common species (*Eriocephalus africanus*) only occurred at 72 (63.2%) of the 114 sites. Most of the sites had not been burnt for 15 or more years, so sufficient time had elapsed for the dominant shrub species to regenerate. The sample sites were more widespread than was the case with the published data, and included small patches. A bonus was that some of the larger fragments had been sampled at more than one spot, thus allowing one to get an idea of the within-fragment diversity. Taking nine such fragments, it was found that the number of species confined to only one sample site within the fragment ranged between 52.6% and 87.5% of the species recorded (Table 4). One needs to take into account that the sampling effort was low, but again, it does suggest that there is a very high level of beta diversity within West-Coast Renosterveld.

Unfortunately, the CREW rare and endangered species data appeared to contradict all the other analyses. Although by definition uncommon (and one thus assumes locally endemic), most species with five or more records were distributed across the entire West-Coast Renosterveld landscape. In some instances, even those species for which there were only two or three records, their localities were widely separated.

How can we explain the apparent contradiction between the CREW data and the other analyses? The sub-sample data of the lowlands project (Table 4) showed that even within a single large fragment, there was a high level of beta diversity. It is possible that the diversity of the habitat is much greater, as perceived by the plants, than is perceived by humans. Therefore, although from a gross overview the landscape is dominated by a few shrubs, within which are interspersed a variety of grasses and geophytes, there is great variation in how these are distributed, and micro-habitat and disturbance play a much greater role than is thought. Cowling and Lombard (2002) have suggested that plants of the CFR respond to measures of heterogeneity that are more subtle than the coarse variables used in most studies.

Table 4. The number of species common to each (sub-) sample site within fragments that were sampled at two or more localities.

Fragment	No. of species records per fragment	No. of unique species per fragment	No. of unique species occurring in each sub-sample				% occurring in 1 sub-sample only
			Occurring in 1 sub-sample only	Occurring in 2 sub-samples only	Occurring in 3 sub-samples only	Occurring in 4 sub-samples	
Kapokberg	28	23	19	3	1	-	82.6
Swartberg	28	20	14	4	2	0	70.0
Elandsberg	22	14	8	4	2	-	57.1
Voelvllei	16	13	10	3	-	-	76.9
S Kasteelberg	24	21	18	3	-	-	85.7
N Kasteelberg	28	19	10	9	-	-	52.6
E Piketberg Sth	27	24	21	3	0	-	87.5
E Piketberg Nth	15	12	9	3	-	-	75.0
Saronberg	29	24	20	3	1	0	83.3

The comment about the distinct characteristics of the north-east and south-west facing slopes of the Koringberg-Swartberg (Chapter 3, page 172) could be quoted here. In addition, there may be generalist species, as well as local “invasions” of species from adjoining Fynbos and Thicket communities, thus adding to the unique character of each site. It is likely that the rare and endangered species were, like most other “true” West-Coast Renosterveld species, once more common than now, but still confined to particular niches. Due to fragmentation and a breakdown in ecological processes such as pollination, and the spread of seeds by large herbivores, they remain as isolated populations. It would be interesting to examine the micro-habitat conditions of the remaining populations to see to what extent their distribution was limited, even before widespread fragmentation. The vegetation map of Mucina and Rutherford (2004) might be a good starting point, seeing that it has developed the vegetation communities in this area largely on a geological basis.

One might therefore conclude that, rather than West-Coast Renosterveld being home to many *local* endemics, it is home to many widespread *micro-habitat* endemics. The implications of this for conservation is that small isolated patches may contain unique species, and the opinion of von Hase *et al.* (2003) that small fragments are merely sub-populations of the remaining larger extents is probably incorrect. The larger fragments need to be sub-sampled at a suitable time of year, to see to what extent the species distribution is dependent upon such micro-habitats. If this hypothesis is valid, it is going to lead to an even greater level of extinction due to climate change than might otherwise be assumed, since corridors proposed for movements across the landscape are likely to be missing many of these micro-habitats.

A second point to be made here is the identification of a relatively *low* proportion of geophytes. Duthie (1930) identified 45% of her “grey-bush” species as being geophytes (compared with 36.5% in her Fynbos site). Kemper (1997) identified 32.5% of her species as geophytes. Ruiters (2001) reported 40.7% of the species at his Tygerberg study as being geophytes. The average percentage of geophytes identified in this study was 25.6%. Three points should be kept in mind; the first is that geophytes here were determined by family, which suggests an underestimate of up to 10% (so an overall geophyte component of ~ 28% is likely). It can be pointed out in mitigation of the use of this method to identify geophytes, that Proches and Cowling (2004) discussed the difficulty of defining what exactly constitutes a geophyte. The second is that geophytes are the life-form most likely to be missed or misidentified, due to their very short flowering period, which is usually the only time they can be positively identified. Finally, one may also include the fact that several of the sites sampled were not pure Renosterveld, therefore (theoretically) lowering the proportion of geophytes. However, it should also be kept in mind that Fynbos and Thicket are also well represented in terms of the geophytic life-form. As mentioned above, Duthie (1930) found that 36.5% of her Fynbos species were geophytes, and since there were far more Fynbos than Renosterveld species in total, the total *number* of geophytes in her Fynbos site was greater. Ruiters (2001) recorded a 31.5%, 31.1% and 31.4% component of geophytes in his Strandveld (*sensu* Acocks 1953), Mountain Fynbos and Coastal Fynbos study sites respectively. Finally, Boucher (1983) estimated that only 22% of the species in

West-Coast Renosterveld were geophytes. Although this supposition would need more detailed research, it may be that the proportion of geophytes is high at the local level (α diversity), but less so at broader scales (β diversity). This would imply that a large proportion of coastal Renosterveld geophytes are more widespread than this study suggests.

6. Management and conservation

In the wheat belt of Western Australia, approximately 6.7% of the almost 14 million hectares is formally conserved (Wallace and Moore 1987). This compares with the little more than half a percent of the three-quarters of a million hectares of West-Coast Renosterveld (von Hase *et al.* 2003). The conservation status of these protected areas varies from national park (*e.g.* Signal Hill), through local authority (*e.g.* Tygerberg), national monument (*e.g.* Blouberg) and natural heritage site (*e.g.* Klipheuwel radio station) to private nature reserve (*e.g.* Elandsberg). However, the majority of the fragments are privately owned, mostly by farmers who generally make use of them for grazing (McDowell 1988), although apparently not to the same extent as in the past (Pagel Dippenaar *pers. comm.*, Charles Duckitt *pers. comm.*). Some have been modified by the sowing of dry leguminous crops such as clover (McDowell 1988, John Duckitt *pers. comm.*). In some areas, the farmers manage these fragments not only to support livestock, but also to provide a good show of wild flowers, from which further revenue can be obtained in the form of tourism (*e.g.* the Darling area).

Rebello (1995) published four pages of discussion about potential coastal Renosterveld management methods, which can best be summed up in the phrase “we are ignorant of what the correct management method is”.

Numerous factors need to be considered in the context of such management. These include burning, grazing, mowing/bush-clearing, alien clearing, the maintenance of ecological processes *etc.* The Fynbos Biome has been subjected to burning, both natural and man-made, ever since the forests of the mid-Pliocene started retreating with the onset of the Mediterranean climate (Deacon *et al.* 1992). Present-day lightning strikes within the Fynbos Biome are relatively low, (0.74 ± 0.81 per km²

per year [Manry and Knight 1986]). Sousa (1984) quotes Taylor as suggesting that only about 0.03% of lightning strikes within vegetated areas results in fires. Van Wilgen and van Hensbergen (1992) considered rockfall events (which could start a fire) in this area as also being very rare. Shiponeni (2003a) quoted reserve managers at Voelvllei as saying that Renosterveld was very difficult to burn, unless it was very dry, and the ignition fire very hot. In contrast, Levyns (1929) reported that, due to flammable substances in the twigs of the Renoster bush, it burnt very rapidly, even when green. Downing (1978) considered the effect of burning by the pre-herder population of the Cape to be insignificant. Fire therefore has probably only played a significant role in the development of Renosterveld over the past 2000 years. Although this period has had some quite substantial variations in climate, these were of a generally short duration (decades rather than millenia), and were projected onto a trend of gradually decreasing average annual temperatures (Tyson *et al.* 2001). During the same period, nomadic herding (and the associated increase in burning frequency) increased up to the 1700's, at which stage European farming practices became a major factor in the shaping of the landscape. It is therefore difficult to say to what extent the Renosterveld of the pre-herding period was shaped by fire. It is suggested in Appendix A that the dry mid-Holocene period had led to a great deal of shrub (mainly Asteraceae) encroachment into much of the West-Coast Renosterveld region, although progressively wetter conditions towards the south-east encouraged the development of grassier areas.

Despite our current lack of knowledge of Renosterveld processes, evidence is amassing that an important component, in the form of large herbivores, is now missing from the system (Hendey 1983, McDowell 1995, Shiponeni 2003, Krug *et al.* 2004). Hendey (1983) suggested that the extinction of large herbivores in Renosterveld had inhibited the spread of the seeds of many species, especially grasses. Interestingly, Shiponeni (2003) found that, while the seeds of certain geophytes were being successfully dispersed in the dung of large herbivores in the Elandsberg PNR, she found only a small component of seeds from indigenous perennial tussock grasses within the dung and the soil. This may have been because perennial species have more options for survival, and are therefore under less pressure to produce a large number of seeds. Of greater concern was the substantial component of alien species (35%) and alien grass species in particular (44% of all

grass seedlings germinating under experimental conditions), being transported in the dung (Shiponeni and Milton 2006). Concerns were expressed by these authors that these alien grasses, along with the high component of *Cynodon dactylon* (54% of all germinating grass seedlings), might be compromising the establishment of indigenous shrubs. McDowell (1995) suggested that in the grazed area of Eensaamheid, and at Waylands farm near Darling, the presence of stock assisted in the seed dispersal of certain geophytes, especially the Iridaceae. It may be significant that the dominant plant family in West-Coast Renosterveld, in terms of the number of rare and/or endemic species was the Iridaceae, with 51 species (von Hase *et al.* 2003). On the other hand, McDowell (1995) noted that palatable grasses (such as *Themeda triandra*) were less common (and often absent) in the grazed extension. An exception was *Cynodon dactylon*, which survives sustained and intensive grazing due to its underground stolons.

Despite Kemper *et al.* (1999) concluding that fragmentation had very little effect upon species diversity within small fragments, the pollination studies of Donaldson *et al.* (2002) and Pauw (2004) suggest that in the long term, this is not true. The subject of “persistor” species was mentioned in section one. It was suggested that many Renosterveld plant species (the resprouters, including geophytes) could be considered as examples of such species. It appears likely that, given enough time, the diversity of typical Renosterveld species in small fragments *will* drop, due to reduced pollination and seed set at each generation. The lifespan of a typical geophyte is unknown, but even assuming a span of twenty years (almost certainly a gross underestimate) and a seed-set decline of 5% per generation, one doubts whether the fragmentation of the landscape into small (< 10 ha) fragments has persisted long enough for there to be any noticeable effect on species diversity. Although the work of Johnson and Bond (1997) and Pauw (2004) has shown that some species have always persisted at very low levels of pollination and that others can also reproduce asexually, anthropogenic effects upon pollinator abundance is likely to lead to the extinction of those species that rely solely upon pollinators that are affected by fragmentation processes.

Management suggestions have been put forward by Duckitt (1995) and Rebelo (1995), both of which would lead to the maintenance of West-Coast Renosterveld in

a much grassier condition than it currently is. However, it is necessary to examine each situation individually. The Koringberg, which is very dry and has a karroid component to its vegetation (Tansley 1982, *pers. obs.*), has not been completely burnt in living memory (Pagel Dippenaar *pers. comm.*). An area of 150 to 200 ha was burnt about 15 years ago, yet the vegetation has apparently recovered, and neither aerial photographs nor general viewing gives any indication of where this burn occurred. A personal visit showed the general community to be diverse. Renosterbos was present, but did not dominate the vegetation. The Kapokberg was burnt in the late 1850's. It became infested with a tall dense cover of Renosterbos. It was dragged in the late 1940's and now has a diverse community (Charles Duckitt, *pers. comm.*). It has therefore not been disturbed for 50 years. Boucher (1995) suggested that a decline in diversity was concomitant with the practice of mowing. He also argued that land that is left unmanaged similarly suffers a reduction in diversity (this is an observation that is generally true of all ecosystems: Hobbs and Huenneke 1992). John Duckitt and John Donaldson were also both of the opinion that Renosterveld diversity benefited from disturbance (4th Renosterveld Information Sharing Session, Darling, 2003). In the absence of detailed species lists (before and after), only a general observation can be made. That is, the diversity on the Kapokberg has *apparently* increased from a Renosterbos monoculture since dragging. Whether it resembles the vegetation of the 1850's is unknown. There may however be some bias in these conclusions. Firstly, while the Kapokberg may not have been "managed" or "disturbed" in terms of fire or mowing, the level of disturbance that may be ascribed to stock grazing or other natural processes is unknown. Secondly, it is not clear to what extent the "Kapokberg" as defined by Tansley (1982), McDowell (1988) or Heydenrych and Littlewort (1995), compares with that described by Charles Duckitt (*pers. comm.*). There may be areas that have been dragged or burnt in the intervening period, and these are the cause of the high species diversity, while the area that has remained "untouched" has a low diversity. It may also be that, as suggested in the species diversity analysis, there are many habitats on the Kapokberg, and this is what has encouraged a wide diversity of species. Below the Kapokberg, some of the land is managed for grazing and wild flower production. It is burnt every five to seven years (Duckitt 1995), and probably resembles the pre-European herder condition.

Taking into account the items discussed above, some aspects relating to the practical conservation of the remaining fragments of West-Coast Renosterveld can be considered.

The first question to be resolved is *what* do we want to conserve? Renosterveld is currently defined in terms of shrubby pioneer species that are relatively widespread. Their widespread distribution is due to their unpalatability to most browsing species (*e.g.* Levyns 1936), to their ability to take advantage of disturbed areas (such as burns or over-grazing [*e.g.* Duthie 1930, Levyns 1956]) and to their use of wind as a seed dispersal mechanism (*e.g.* Shiponeni 2003a). Furthermore, there are mosaics and interfaces of coastal Renosterveld with other vegetation types. Do we want to concentrate on Renosterveld proper, or on all natural areas within certain boundaries? Should we be looking at Renosterveld as a discrete entity, or as part of a system of integrated ecological processes both within itself, and with adjoining vegetation types?

The first observation is that isolated fragments smaller than about 25 ha probably cannot maintain the ecological processes required for long-term conservation of species. Due to the persistence of geophytes and some of the shrubs, and the relatively high proportion of wind-dispersed pioneer type shrubs (*e.g.* the Renosterbos), the loss of endemic species will probably be very slow. With unlimited funds, these small fragments might be worth maintaining and managing. Under real-world conditions, the limited resources available could be better directed towards the larger fragments. Nevertheless, the distribution of the rare and endangered species collected by CREW, suggests that many of these small fragments probably maintain one or more of the rarer species. Translocation to larger fragments, or nursery propagation may be viable options to conserve these species.

In order both to learn more about the processes occurring within Renosterveld, and to improve the probability of survival of as many species and processes as possible, it is suggested that where the fragment is large enough, a mosaic of different management patterns should be followed. Pauw (2004) noted that the pollination of different guilds of species changed according to the stage of succession of the

vegetation after a fire. Hobbs and Huenneke (1992) noted two important points about maintaining a conservation region in the form of a matrix of disturbance regimes. The first was that it can often lead to an increase in community diversity. The second was that the diversity of indigenous organisms was usually highest when the disturbance regime was maintained at its historical pattern. A change in the frequency or type of disturbance often resulted in native species being less well adapted for recruitment or establishment. In view of the suspected influence of large herbivores in the maintenance of coastal Renosterveld in the past, experimental grazing regimes using domestic stock, combined with mowing or burning (at least initially) should be considered where fragments are large enough. As a basis, we have the experience of farmers like John Duckitt, (4th Renosterveld information sharing session, Darling, 2003; Duckitt 1995) and historical records such as the Journals of van Riebeeck (Thom 1952, 1954, 1958). Cowling *et al.* (1986) have also suggested that grazing is not incompatible with Renosterveld conservation on the south coast, and management suggestions were made. Neil MacGregor, a farmer from Niewoudtville (Mountain Renosterveld), similarly noted that geophyte flowering was more abundant in camps that were regularly grazed (Fynbos Forum, 2001). Donaldson (2002) drew attention to Acocks' pronouncement that many Karoo farms were understocked but overgrazed. Before the arrival of Europeans, indigenous herbivores would heavily graze an area before moving on to new areas. The Khoekhoen herders emulated this process. Such a system of heavy grazing by domestic stock, followed by two or three years of rest may lead to an increase in the local biodiversity. Where possible, indigenous browsers and grazers could also be reintroduced. Species such as the Grey Rhebok *Pelea capreolus*, Grysbok *Raphicerus melanotis* and Steenbok *Raphicerus campestris* could be introduced into quite small fragments, while Eland *Taurotragus oryx* and Red Hartebeest *Alcelaphus buselaphus* may be suitable for the larger fragments.

Should corridors be developed and/or maintained? Australia is one of the leading countries in road verge management. In many of the agricultural areas, natural vegetation strips up to 200 m wide border the roads (Hussey 1991). These strips are ecologically managed, and their width (as compared to the few metres typically found along the roads of South Africa) means that they can even function as reserves in themselves (Forman and Alexander 1998). The possibility of



Figure 14. Rill vegetation in the Piketberg region.

introducing such a scheme into the Renosterveld areas is unlikely to be an option, due to the smaller area available for agriculture, compared to that of Australia. It is also suggested that if purchases of agricultural land were to be made for transformation to natural vegetation, it might be better to enlarge the remaining fragments, both to enhance local ecological processes, and because of the apparent rehabilitation problems (*e.g.* McDowell 1988). On the other hand, allowing narrow strips of natural vegetation to grow up between fields (*e.g.* along rills – Figure 14), or between fields and the road may help to enhance conservation (and countryside aesthetics) in general.

The corridor pattern developed in this study, while highly subjective, gave one an indication of the connectivity of the remaining fragments. The two most striking points were that most fragments were located around the perimeter of the area, and connectivity within the agricultural matrix was poor. The first factor is probably a function of these fragments being at the boundary between the fertile clay soils and the infertile sandstone soils (or between flat lands and steep slopes). As such, their agricultural potential would be low, and they remain because of mapping errors and “squaring-off” during agricultural activities. This is also true in the case of the larger fragments present within the agricultural matrix (*e.g.* Kasteelberg, Paarlberg

etc.). In terms of what can be observed, we should perhaps be promoting linear reserves along these interfaces. Although these have all sorts of disadvantages under normal circumstances, we need to consider that, in this case there would only be one Renosterveld – agricultural boundary, as the external boundary would generally be with Fynbos, where a natural situation would prevail. This is essentially what has been proposed by von Hase *et al.* (2003) in their five-year conservation plan. The development of such linear reserves around natural vegetation interfaces would automatically lead to the development of dispersal paths. However, unlike road-verge corridors, these linear reserves could act as substantial refuges while promoting the movement of genetic matter between the major fragments. A further benefit might be that, with the adjacent Fynbos, these linear reserves may be able to maintain a nucleus of large herbivores, thus reintroducing some of the processes lost with their extermination. The study of Donaldson *et al.* (2002) suggested that many of the insect-pollinated species were pollinated by generalist species whose presence was primarily (> 90%) determined by vegetation cover. To what extent these pollinators differentiate Fynbos and Renosterveld is not known, but structurally these two vegetation types often have much in common. A further benefit would be the presence of a variety of soil types, as certain pollinators appear to have problems nesting in loose sandy ground (Pauw 2004).

Turning to those fragments scattered within the agricultural matrix, we need to note that few fragments of substantial size remain upon flat, fertile soils (McDowell and Moll 1992, this study). There are fewer options for the rehabilitation and maintenance of these fragments. Edge-effects will reduce the amount of core habitat. Distances from other major fragments are generally of a magnitude that precludes frequent immigration of small organisms, such as those involved in pollination. Similarly, the introduction of large herbivores to maintain processes is likely to be impractical in most cases. As mentioned above, although small fragments may currently appear unaffected by the fragmentation process, it is likely that in the long term (centuries), this is going to change. Although corridors (even those that mainly support exotic plant species) may be of benefit to birds and small animals, the distances involved would suggest that their use in the conservation of endemic plant species is doubtful.

In view of the matters that have been discussed, it may be advisable to specify a fragment size, below which the limited resources available for conservation should not be allocated. Donaldson *et al.* (2002) took “large” fragments (in which pollination processes appeared to be minimally affected) to be those greater than 30 ha. Kemper *et al.* (1999) did not categorize their fragments, but did note a strong presence of “edge” (mainly alien) annuals in the smaller fragments. The work of Van Rooyen (2004) provides further support for this. Therefore, one might feel justified in determining a minimum fragment size where formal (public) conservation programmes are to be implemented. This study identified 280 fragments of greater than 25 ha. This is probably greater than could be maintained with the budget available to conservation agencies in this area. *All other things being equal* (which is rare) fragment conservation should be planned on the basis of conserving the larger fragments first. However, this study, and that of CREW have shown that there are a large number of local endemic plant species present, probably on many of the smaller fragments. One may begin by regionalizing the area (*e.g.* as *per* Mucina and Rutherford 2004), but one would also need to know the conservation worth of each of those regions. Are they in fact Renosterveld, or are they Fynbos/Thicket that has been incorporated into the Renosterveld region due to generalizations present in the layers used to define the extent? How distinct are they in terms of unique species or ecological processes? What is the quality of the vegetation – is it badly transformed by alien plants or agricultural activities?

This suggests that detailed conservation analyses should be done on the major fragments, as well as those smaller ones that have been identified as supporting rare species or special habitats (*e.g.* wetlands). C-Plan (Ferrier *et al.* 2000) or similar could be used, taking into account, not only the broad-scale factors, but also slopes, aspects, macro-climate, seeps, rivers, the presence of rare and endangered species, micro-habitats *etc.* Although the ultimate effect of climate change on these western lowlands is debatable, it must also be considered that, while the Fynbos species, which are adapted to sandy soils, have the “option” of using altitude as an ameliorating factor for increased temperature, Renosterveld endemics are essentially confined to a highly fragmented lowland area. In addition, should rainfall decrease (particularly the small amount that falls in summer) drought-

stresses are going to be far greater than would be the case on sandy soils, due to the lower water-potential of clay soils (Bidwell 1974).

The autocorrelation study suggested that if a local endemic plant is located in a block of Renosterveld, the probability that the reproductive propagules it produces (short dispersal distance) will land in Renosterveld is very good. It might therefore be suggested that it would be more beneficial to spend money on maintaining fragments in a good condition (remove aliens, limit influences from surrounding farmlands *e.g.* with drainage ditches, incorporating a buffer) than on the purchase of land for dispersal corridors. If one of the reasons for “abandoning” small fragments as a conservation option is pollination failure, it may be of interest to examine the pollination efficiency of the honeybee *Apis mellifera*, thus providing an incentive (honey) for landowners to maintain small fragments of Renosterveld in good condition. In Argentina, fragmentation of dry thorn forest led to declines in pollination and fruit and seed set for most of 16 species examined. However, visitations by introduced Africanized bees helped compensate for the lack of native pollinators in the smaller fragments (Aizen and Feinsinger quoted by Kearns *et al.* 1998). Various studies have been done on the effect of introduced honeybees in different parts of the world (see Kearns *et al.* 1998 for a review). Their effect upon native pollinators, the pollination of indigenous plants and the spread of alien plant species appears to be complex, with positive and negative effects emerging. In the light of an apparent breakdown in pollination processes on small fragments, and the large inter-fragmentary distances described in this chapter, one may be justified in experimenting on a small scale.

The few observations available from Renosterveld suggest that, as would be expected, fragmentation affects different species in different ways. However, it does appear that, while large, structurally diverse fragments are better, the small fragments still support many Renosterveld species, even if this is only relatively temporary. Additionally, small fragments may help the small, but vagile species (*e.g.* butterflies) step across the landscape. What must be faced however is that one of the major forces shaping Renosterveld ecology, namely the large herbivore, is gone, and in most cases cannot be returned. Research within the Elandsberg PNR and Bontebok National Park may help us to understand how processes occur under

conditions that are more “natural”. These could then be mimicked as far as possible, using domestic stock and/or other manual processes.

Finally, we need to tackle the question of what Renosterveld is, and how this interpretation may impact upon management strategies. Boucher (1995) talked of the vegetation on Bottelary Hills (mainly granite) reverting to *Fynbos* under the right management regime. The SANBI Vegetation Map of South Africa (Mucina and Rutherford 2004) has classified much of the Elandsberg PNR as Fynbos. In all previous studies, both of these areas were assumed to be Renosterveld. Tansley (1982) rejected both the Eensaamheid and Kalbaskraal nature reserves as being Renosterveld. She classified them as coastal Fynbos that had been invaded by *E. rhinocerotis* in stress areas. It was mentioned that Tansley (1982) referred to disparaging comments about the Tienie Versfeld reserve. If these observations are correct, how much relevance should be given to the findings of McDowell (1988) and van Rooyen (2003) at Eensaamheid and Shiponeni (2003, 2003a), van Rooyen (2003) and others at Elandsberg? How much West-Coast “Renosterveld” is the conservation plan of von Hase *et al.* (2003) actually conserving? How many “types” of West-Coast Renosterveld are there – is the “Granite Bulb Veld” as defined by Mucina and Rutherford (2004) still Renosterveld, or do other rules apply? As one sub-divides the region, how does this affect the status of each region in terms of its endangered status? Table 5 shows how regionalization has affected the relative area of the “Predictive” class of fragments within each particular classification. Regionalization, without sufficient field studies, may result in conservation efforts being directed to the wrong area. If this SANBI map is identifying genuine vegetation types within “West Coast Renosterveld”, it would imply that the conservation analyses of Pressey *et al.* (2003) are outdated, as three of the five Renosterveld types have more than 9% of their original area remaining.

It does appear, even from casual observations, that West-Coast Renosterveld, as originally defined (*e.g.* Boucher 1981) is relatively heterogeneous. Examining physiographic factors (climate, geology *etc.*) enhances those observations. Cowling and Heijnis (2001) recognized three areas, based on physiographic factors and peer-review. Mucina and Rutherford (2004) went a step further, subdividing the region still further. While this may be another step towards the “correct” *mapping* of

Table 5. The total area of fragments of natural vegetation of > 3 ha predicted to be Renosterveld (see Chapter 5 for details), falling within the West-Coast Renosterveld class(es), of the three most recently published vegetation maps.

Author of extent used	Fragment area (ha)	% of original extent remaining	Proposed original extent (ha)
“Predictive” extent (this study)	74765	9.4	798228
Low & Rebelo (1996)	33121	5.4	613589
Cowling & Heijnis (2001)			
Boland	22102	9.2	241456
Swartland	13927	3.4	410946
Combined	36028	5.5	652402
Combined: Low & Rebelo (1996) and Cowling & Heijnis (2001)	40402	6.0	678053
Mucina & Rutherford (2004)			
Peninsula Shale Renosterveld	325	10.9	2968
Swartland Alluvium Renosterveld	1125	18.0	6244
Swartland Granite Bulb Veld	8933	9.4	94655
Swartland Shale Renosterveld	21971	4.4	493944
Swartland Silcrete Renosterveld	393	3.9	9977.3
Combined	32748	5.4	607788
Swartland Alluvium Fynbos ^a	4935	10.9	45447

^a Included as the much of the Voelvlei-Elandsberg-Krantzkop fragment is represented by this unit.

ecological entities, it has two major shortcomings. The first is that boundaries have often been developed upon generalized data (*e.g.* geology), which means that they are no better defined than those in Boucher's (1981) map. The second point is that conservationists desperately need rules to conserve the few remaining fragments of Renosterveld. If we are uncertain of the correct management procedures for "West-Coast Renosterveld", how more uncertain are we of how processes in "Swartland Alluvial Fynbos" (Elandsberg) can be related to processes in "Swartland Granite Bulb Veld"? The most important next step with respect to the conservation of coastal Renosterveld (or indeed the CFR as a whole) is to identify the basic missing data. While GIS and statistical packages are useful tools, they cannot deliver more than is already known. Even without the threat of climate change, land transformations have reached the point where putting up a fence and leaving the rest to nature is inadequate. The establishment of SANBI opens up the possibility of long-term studies being instituted. While studies such as that of Midgley *et al.* (2003) are esoterically interesting, we simply do not know enough about current ecological parameters, or even species distributions, to begin projecting the effects of an indeterminate amount of climate change.



Conclusion

More than half the fragments remaining within West-Coast Renosterveld are less than ten hectares in extent. It is also certain that less than 10% of the original extent of West-Coast Renosterveld remains in any sort of natural condition, which effectively makes all fragments irreplaceable. It may also suggest that, as an ecosystem, West-Coast Renosterveld is beyond redemption and it is only inertia that has prevented the system from entirely collapsing. While there has been considerable success with the "stewardship" projects (*e.g.* Winter 2006, 2006a), it seems unlikely that substantial blocks of agricultural land will be returned to their natural state, and studies have shown that Renosterveld does not readily re-invade previously cultivated lands. Conservation efforts will therefore have to be directed at the areas remaining. Preliminary studies are suggesting that a mosaic of different vegetation structures would probably enhance the conservation value of the remaining fragments. It also seems likely that the reintroduction of indigenous

ungulates where the fragment is large enough, would be of benefit to the maintenance of natural processes. Failing this, the judicious use of domestic stock may ameliorate for the lack of these.

One facet that is clearly under debate, and is apparently area and species specific, is the use of road and river verges as corridors for dispersal. For every reference to the benefit of verges in this matter, there is one arguing against their importance. It is clear that without further research, we can only guess at the importance of such corridors to Renosterveld species in general, and endangered Renosterveld species in particular. However, the general opinion is that road and river corridors can play an important role in conservation *per se*, although edge effects may be significant in the narrow verges found along the roads in this region.

There is quite a lot of evidence emerging from the amalgamation of various studies, as well as results presented here, that West-Coast Renosterveld is not a homogeneous entity. The agricultural potential of this area within the generally nutrient-poor Fynbos Biome has resulted in it being lumped as a single vegetation type. At a very basic level, five different habitat types probably exist – wet and dry granites, wet and dry shales, and alluvial/colluvial communities along the foot of the western Fold Mountains. As with all natural communities, these will grade into each other. The absence of accurately mapped soil/geological boundaries makes the zoning of these habitat types difficult to define. Areas will have to be examined individually, and a suitable management plan for the conservation of the area in a scientifically designed manner will have to be made. It is likely that the optimum management plan for this area is unknown, which means long-term experimental plots need to be established.

FINAL CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH.

West-Coast Renosterveld has been shown to be, arguably, the most transformed vegetation type in South Africa (Reyers *et al.* 2001). Its close proximity to Cape Town, the hub from where European colonization began, coupled with its occurrence on mostly flat, relatively nutrient-rich soils receiving adequate rainfall, made it an ideal candidate for agricultural transformation. Before the arrival of Europeans, wandering Khoekhoen herders had been regularly burning the vegetation to encourage the growth of grass for their stock for almost 1500 years (Deacon 1992). It is likely that species that were not adapted to frequent fires either became extinct, or lingered on in sheltered refugia. Grasses and geophytes probably thrived under those conditions. The change from the peripatetic herding system of the Khoekhoen to the sedentary husbanding and crop-growing practices of the Europeans led to a change in environmental pressures upon the vegetation. Large browsing ungulates were destroyed, reducing competitive pressures upon the shrubs (*c.f.* Midoko-Iponga *et al.* 2005). Burning was immediately followed by the grazing of one or two domestic species. Selective grazing led to a few unpalatable shrub species becoming more common, and finally to complete dominance by one or two species adapted to heavy disturbance (*e.g.* the Renosterbos, *Elytropappus rhinocerotis*). With the development of an efficient transport system, and later mechanization, large-scale cereal production became economical (Talbot 1947). Eventually only marginal areas (too rocky or too steep to plough), and areas conserved by a few enlightened farmers remained in a natural, if not pristine, condition. The “true” vegetation of West-Coast Renosterveld will never be known. It is likely that it was not a monotypic vegetation type, but underwent local and large-scale cycles, according to changing climatic regimes and the effect these had upon the movements and composition of the large herbivore communities.

It is also probable that South-Coast and West-Coast Renosterveld are only related in terms of their occurring on relatively nutrient rich, fine-grained soils in a region that receives more rainfall in winter than in summer. Their similarity, in terms of how they have both been invaded by Renosterbos and other pioneer species, is due to the similar (mis-) management of both regions by European farming practices. Palaeoenvironmental data, although still patchy, and annoyingly absent from actual

coastal Renosterveld areas, suggests that the south coast area should have a much higher grass content than the west coast (Appendix A), and experimental data indicates that pioneer shrub species have more difficulty establishing themselves in South-Coast Renosterveld than in the west (Levyns 1929, 1936).

Analyses of the coarse resolution NDVI imagery identified two major vegetation patterns. The first suggested that there were five major classes, predominantly determined by their annual sum of NDVI, which in turn was determined by the rainfall received. The second pattern identified regions based upon their seasonal cycles, which in its turn was largely determined by the major vegetation type occurring within each class. This second pattern confirmed the fact that most of the coastal lowlands had been taken over by agriculture, especially wheat. In the wetter areas, the soil type that previously supported Renosterveld had been largely transformed to vineyards or orchards. Of interest was that, contrary to other studies, there was very little correlation between NDVI and cereal production in the wheat growing areas. Changes over the twenty-year period were generally small, and mainly restricted to local housing developments, or the development of vineyards.

The use of aerial photography to determine changes in the amount of natural vegetation occurring at three sites since 1938, showed that this had been reduced by as much as 49% in one case. Most transformations had occurred on slopes of less than 12° but slopes as steep as 20° were sometimes affected. Only the Elandsberg Private Nature Reserve showed an overall increase in conserved land. Although the resolution of aerial photographs is high (a metre or two), this did not always translate into a correct interpretation. Although uncultivated for about 10 years (at the time of the 1997 photograph), the “old fields” at Elandsberg still had the appearance of cultivated land.

From problems encountered personally, and from information received from other people involved in satellite imagery interpretation, it appears that the west coast lowlands are difficult to classify using Landsat imagery. This resulted in an extended amount of time trying to develop a reasonable classification upon which landscape analyses could be performed. A map of the remaining Renosterveld fragments was developed, and field checks suggested that this had an accuracy of

about 80%. It has been suggested in the literature that this is the general upper limit that can be reached using single-image classifications (Wilkinson quoted by Mather 1999).

Using the fragment map developed, landscape analyses were performed, relating the fragments to slope, aspect and farming activities. As expected there was a relatively higher proportion of Renosterveld remaining on steep slopes than on the flatter lands. Aspect analyses showed that there was about 8% more natural vegetation found on west facing slopes than on east facing slopes, relative to aspect availability. Fractal analyses suggested that fragments of all sizes were subjected to a mixture of natural and anthropogenic pressures. In addition the fragments were assessed both in terms of spectral response, and their edaphic profiles, to assess which of the fragments might be genuine Renosterveld, and which were more likely to be Fynbos or Thicket that had been incorporated into the Renosterveld region due to generalizations of boundaries or spectral misclassification. These helped identify fragments outside of the currently recognized Renosterveld boundaries that were likely to support Renosterveld. Probability ratings were assigned to these fragments. The use in the recent literature of two original extents (those of Low and Rebelo 1996, and of Cowling and Heijnis 2001) have made comparisons between estimates of the amount of West-Coast Renosterveld remaining difficult, but this was partially overcome by developing a “Compound” coverage (the sum of both of these extents, as well as that of McDowell 1988). It would appear that the amount of *natural* vegetation within the general extent of West-Coast Renosterveld is between eight and ten percent (Reyers *et al.* 2001, this project), while the actual amount that is “genuine” Renosterveld (as edaphically defined) is between five and seven percent (von Hase *et al.* 2003, this project).

The final chapter looked at conservation and management options, mainly from a temporal and spatial viewpoint. Due to the development of a practical conservation plan by the Botanical Society of South Africa (von Hase *et al.* 2003), it was decided to concentrate on complementary matters, and to discuss aspects of the published plan considered in need of further development. Fragment connectivity studies were performed and conservation matters were discussed both in general terms, and in terms of comparisons with work carried out, mainly on the south coast (Kemper

1997, Cameron 1999, Kemper *et al.* 1999, Donaldson *et al.* 2002, Randrianasolo 2003). The main factor to emerge was that there was a distinct lack of information on natural processes occurring within coastal Renosterveld (and Fynbos in general). However, compiling the available data led to a number of important findings. The first was that fragmentation *per se* is probably not of great importance to the local endemic plant species that typically have a dispersal distance of only a few metres. Nor does it greatly affect those which produce thousands of small wind-borne seeds or to those that are bird dispersed. Of more importance is the effect that fragmentation and the subsequent reduction in habitat heterogeneity has on pollinator species diversity (Donaldson *et al.* 2002), which will eventually lead to the extinction of those plants that rely upon them for pollination. Currently, the longevity of many of these threatened species has masked the consequences of reduced pollination. Thus, studies such as that of Kemper *et al.* (1999) showed only minor fragmentation effects. However, the biggest impact upon small populations is the invasion of alien species, either due to natural dispersal, or as a means to improve the forage quality of the veld. The addition of fertilizers and pesticides are further cause for concern. It also seems likely that the extermination of the large herbivores has reduced seed dispersal in certain species, although domestic stock may be able to compensate for this to some extent (McDowell 1995). Some observations that are emerging from research is that biodiversity in coastal Renosterveld appears to benefit from disturbance (John Duckitt and John Donaldson, Fourth Renosterveld information sharing session at Darling). Cluster analyses of species lists from major Renosterveld sites suggested that local endemism levels might be as high as 50%, which means that without a widespread network of reserves, a large number of species are going to go extinct. However, data collected by CREW (Custodians of Rare and Endangered Wildflowers) suggests that the distribution of the rare species (and probably others as well) is being defined by micro-habitat considerations, rather than gross environmental parameters. This would suggest that reserves should be chosen for habitat heterogeneity, and managed to maintain this.

Suggested projects

1. The use of the honeybee *Apis mellifera* to increase pollination levels on small fragments, and their interaction with indigenous pollinators. This may provide a monetary incentive for landowners to maintain small patches of Renosterveld in good condition.

The next six suggestions may help determine what the natural vegetation was like in the past (*i.e.* pre-herder).

2. Why does Renosterbos form open-canopy communities on the south coast, and closed-canopy communities on the west coast – is it soil nutrients, rainfall seasonality or competition from C4 grasses?

3. What are the micro-nutrient levels of the soils, streams and springs of the western lowlands?

4. What is the age of the Heuweltjies within West-Coast Renosterveld, especially those in the extreme south?

5. Sample soils for $\delta^{13}\text{C}$ signatures across South-Coast Renosterveld, to see if C4 grasses were common during the last glacial (*e.g.* see Stock *et al.* 1993).

6. What is the grass component of the diet of the Red Hartebeest at Cape Point.

7. How close (genetically) are the endemic Iridaceae or other endemic groups?

The next six suggestions may help determine conservation priorities.

8. A comparison of plant community development of Renosterveld on the clay and on the alluvial soils within the new sector added to the north-western corner of the Elandsberg PNR. This will help determine the effect of the soil component on species development.

9. Along boundaries between coastal sands (Qg formation) and clay or granite soils, how does the depth of the wind-blown sands affect community composition?

10. Are road-side verges conserving any Renosterveld species other than the common pioneers like Renosterbos?

11. How do vegetation communities (riparian) along major rivers in this region compare with “typical” Renosterveld communities situated away from rivers?

12. Are the rare species that are widely dispersed limited by micro-habitat conditions?

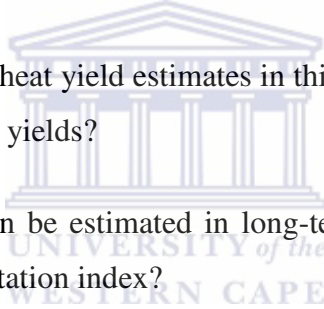
13. How does Renosterveld vegetation respond to heavy overgrazing followed by a rest of two or three years?

This next project may help to identify growth patterns in the Fynbos Biome

14. Can Fynbos productivity be estimated by NOAA-NDVI imagery?

Finally – why were the wheat yield estimates in this project so poor when compared with other studies of crop yields?

15. Can cereal production be estimated in long-term, coarse scale imagery, using the simple NIR/Red vegetation index?



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APPENDIX A.

USING ARCHAEOLOGICAL AND PALAEOCLIMATIC PROXIES TO RECONSTRUCT THE ORIGINAL VEGETATION OF COASTAL RENOSTERVELD.

A popular article summarizing the findings of this appendix has been published as:

Newton IP and Knight R 2004. The Matrix: The evolutionary development of coastal renosterveld. *Veld & Flora*, December 2004: 162-165.

In addition, extracts from this chapter were used in a presentation by Rainer Krug, at the 10th MEDECOS conference at Rhodes in Greece:

Krug RM, Krug CB, Midoko Iponga D, Walton BA, Milton SJ, Newton IP, Farley N and Shiponeni NN 2004. Reconstructing West Coast Renosterveld: past and present ecological processes in a Mediterranean shrubland of South Africa. In: Arianoutsou M and Papanastasis V (eds). *Proceedings 10th MEDECOS Conference, April 25 – May 1, 2004, Rhodes, Greece*. Millpress: Rotterdam. CD file: “101.pdf”.

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Introduction

The debate about what “pristine” coastal Renosterveld should consist of will no doubt continue indefinitely. It is not possible to definitively state what the vegetation of coastal Renosterveld should be. It is likely that it was never a homogeneous vegetation, as it encompasses a wide range of environmental parameters. It also borders on (and blends into) other vegetation types as different as semi-desert (in the north), and forest (in the east). Changes in the climatic regime would allow species from these adjoining vegetation types to move into the coastal Renosterveld areas, where they might persist in enclaves after the climate had reverted. For example, typical karroid (semi-desert) species occur on the north facing slopes of the Koringberg (Tansley 1982, *pers. obs.*). Understanding some of the processes that occurred in the past might help to explain some of the recent patterns and processes. What follows is an attempt at synthesizing the knowledge

gained from archaeological, palaeoclimatological, palaeobotanical and palaeontological studies to help explain the origin of coastal Renosterveld.

A major problem when trying to reconstruct the palaeovegetation (or palaeoclimate) of coastal Renosterveld is the lack of archaeological sites actually occurring within this vegetation unit. However, from sites in the general area, one may deduce the conditions that may have existed within coastal Renosterveld during the same period. Care needs to be taken in this, as one assumes that the climatic relationships between the Renosterveld region and the regions where the archaeological evidence was found are the same as today, which may not always be the case. For example, during the Last Glacial Maximum (LGM), frontal winter rainfall continued along the west coast (Cowling *et al.* 1999), but along the south coast it was probably much drier, due to a cooler, weaker (or even seasonally absent) Agulhas current (Prell and Hutson 1979, Hutson 1980). Deacon and Lancaster (1988) also pointed out that plants and animals do not react to climate change as an integrated community, but rather as individuals. As one delves further back in time, short-term changes become more difficult to discern. Although it is the more recent past (the last 2000 years) that is of interest in the context of this project, an idea of the changes that have occurred in the past 100 000 years may help to explain the current vegetation patterns.

Palaeoclimates cannot be directly measured. Instead they are inferred from various proxies, including sedimentology (*e.g.* Butzer 1984), oxygen isotope ($\delta^{18}\text{O}$) signatures in ocean cores and stalagmites (*e.g.* Tyson 1986); by the ratio between guilds of herbivore remains, and their carbon isotope ($\delta^{13}\text{C}$) signatures (*e.g.* Sealy 1996, Luyt *et al.* 2000); by the species composition of charcoal remains (*e.g.* February 1992, Cowling *et al.* 1999, Parkington *et al.* 2000); pollen cores (*e.g.* Scholtz 1986, Meadows and Sugden 1991, Baxter 1996) and by dendrochronological studies (*e.g.* Tyson 1986). In the western coastal lowland region, there are several sites of archaeological importance (Figure 1), situated around the present-day coast. These include Elands Bay cave, Melkbosstrand, Swartklip and Die Kelders. Along the south coast, three sites have provided good data. These are Nelson Bay cave (Robberg Peninsula, Plettenberg Bay), which is about 60 km to the east of the South-Coast Renosterveld block (as defined in this

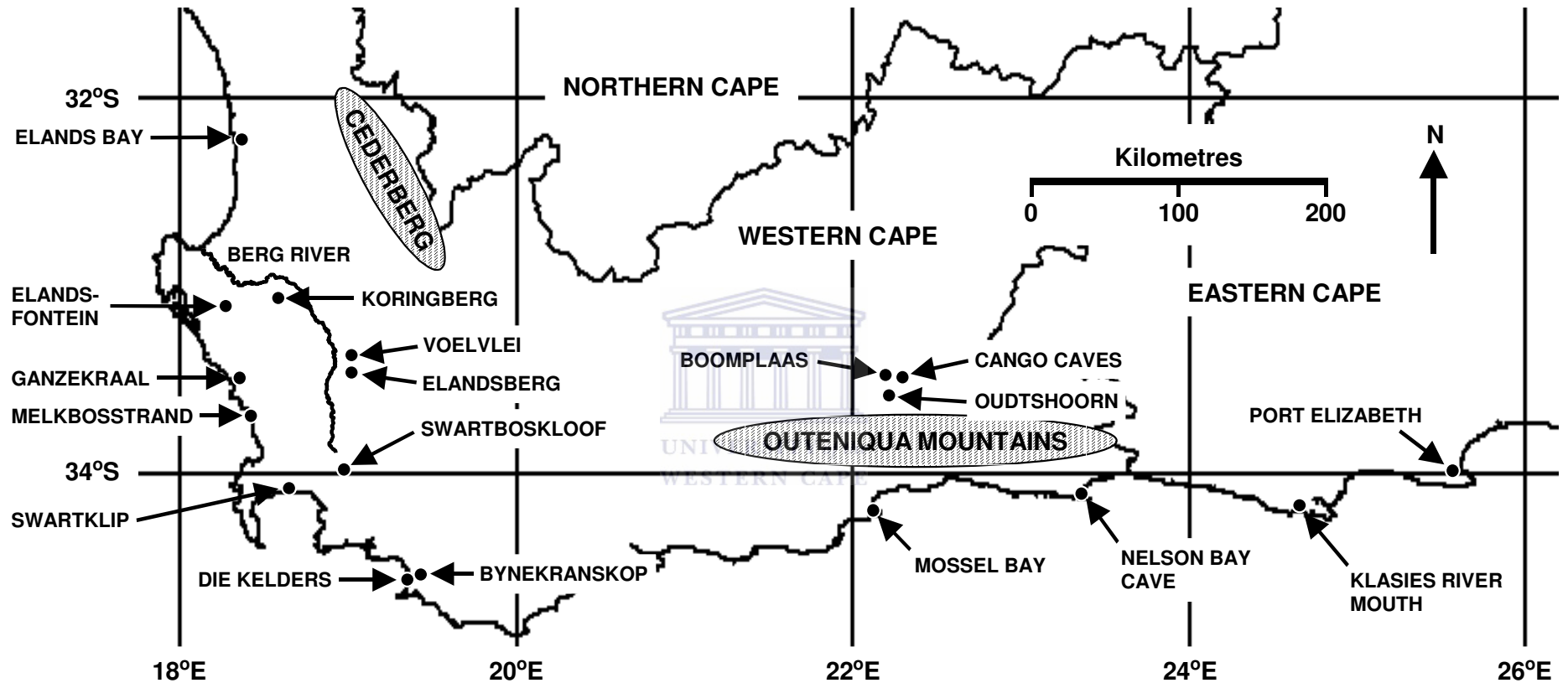


Figure 1. Map of the Western and Eastern Cape Provinces, showing the location of places mentioned in the text. The “southern Cape lowlands”, as referred to in this appendix is essentially that area south of 34°S and east of Swartboskloof; the “south-western Cape lowlands” covers the same area, but only as far east as Mossel Bay. The “western Cape lowlands” is the region west of Swartboskloof.

thesis). Boomplaas cave, situated in the Cango River Valley, about 40 km north of Oudtshoorn is the second. It is separated from the coastal lowlands by the Outeniqua Mountains. The third is at the Klasies River mouth, close to the eastern block of South-Coast Renosterveld region (*sensu* Low and Rebelo 1996), and about 300 km east of the South-Coast Renosterveld block (*sensu* this thesis).

Palaeoecological studies have indicated that much of the Fynbos Biome was forested around three million years ago (ybp) (Coetzee *et al.* 1983). At that time (the mid-Pliocene), a summer drought - winter rainfall (Mediterranean-type) regime developed in the Western Cape region (Deacon *et al.* 1992). The resulting increase in aridity (especially in summer) led to gaps in the forest, which became available for understorey taxa to colonize (Deacon *et al.* 1992, Linder *et al.* 1992). The low nutrient status of the sandstone soils is believed to have led to the dramatic speciation that characterizes the Fynbos Biome today (Cowling *et al.* 1992, Deacon *et al.* 1992). Coastal Renosterveld, unlike the typical Fynbos areas, has soils that are relatively nutrient rich (Schulze 1997). Linder *et al.* (1992) postulated that these soils were primarily colonized by extant, widespread tropical taxa. Over the millennia there were fluctuations in climate and sea levels, which influenced the flora and fauna of the area. During the second half of the Pleistocene (~ 0.5 million to ~ 10 000 ybp) the earth experienced cycles of glaciation, each lasting about 100 000 years; the intervening interglacials never exceeded 12 000 years (Fairbridge, quoted in Deacon and Lancaster 1988). The current interglacial is expected to end within the next 2000 years (Deacon and Lancaster 1988) – assuming human pollutants have not upset the climate cycles too much! This review will begin with the last interglacial (~ 120 000 to ~ 130 000 ybp).

125 000 to 20 000 ybp

Animal remains from the last interglacial at the Klasies River Mouth site, showed a similar grazer : browser (28% grazer; 72% browser) ratio to that of modern times (Deacon and Lancaster 1988), suggesting a predominance of bushy vegetation (as is found today). Oxygen isotope records from deep-sea cores, (as illustrated in Tyson 1986) also suggest a climate regime similar to that of today. However, the $\delta^{18}\text{O}$ signature of the shells of sea-molluscs, and their presence well above the current sea

level, suggests that sea levels were three to six metres higher than today, and that the sea (and by implication the general climate) was warmer (Tyson 1986, Deacon and Lancaster 1988, quoting several authors).

Between 100 000 and 80 000 ybp, the remains of grazing mammals at the Klasies River mouth site increased to 53% of the large faunal component, suggesting an increase in grass, and a concomitant decrease in shrub (Deacon and Lancaster 1988). Evidence from oxygen isotope values from deep-sea cores (Tyson 1986) showed that average temperatures were lower than today. Sea levels thought to be 40 m to 50 m lower than at present also provides evidence for a general global cooling (results from several authors synthesized by Deacon and Lancaster 1988).

Data is available from Boomplaas cave from about 80 000 ybp. This data, derived from pollen, large herbivore, micro-mammal and charcoal remains, also suggests the climate between 80 000 ybp and 17 000 ybp was colder than that currently experienced. Analyses of micro-mammalian remains from Boomplaas, as well as $\delta^{18}\text{O}$ measurements of a speleotherm from the nearby Cango caves (data available from ~ 47 000 ybp, although corrected temperature data was only available from ~ 30 000 ybp) both suggest average annual temperatures around 13°C between ~ 50 000 ybp and ~ 25 000 ybp (Deacon and Lancaster 1988), with occasional dips as low as 10.5°C during the LGM (Talma and Vogel 1992). The average annual temperature for Oudtshoorn between 1926 and 1950 was 17.9°C (Anon. 1954). The $\delta^{13}\text{C}$ values from the Cango speleotherm also indicated that the vegetation of the area predominantly used the C3 photosynthetic pathway during this period (Talma and Vogel 1992).

During the last 125 000 years, the atmospheric CO₂ level has varied between ~ 180 ppm during the LGM, and ~ 280 ppm during the interglacials, excluding recent anthropogenic influences (Barnola *et al.*, quoted by Du Pisani and Partridge 1990, Gray 1999). Ehleringer *et al.* (1997) constructed a temperature-atmospheric CO₂ curve showing where C4 photosynthesis becomes productively more efficient than that of the C3 cycle, and hence, under what temperature conditions C4 plants might have become predominant. Based upon these data, C4 plants would only have become predominant (assuming a suitable rainfall regime) had the average growing

season temperatures been above about 12°C (180 ppm) or 21°C (280 ppm). The general C3 signature found in the Cango cave speleotherm for that period therefore supports the lower-temperature hypothesis. An alternative (or complementary) hypothesis would be an absence of summer rainfall in the region at that time, as C4 species require the combination of high temperatures and sufficient precipitation to predominate. There have been no isotopic analyses undertaken of the remains of the large herbivores from Boomplaas cave to assess the relative proportions of C3 and C4 (or possibly CAM) species (Judith Sealy *pers. comm.*).

From ~ 40 000 ybp comparisons between fossil charcoals and pollens at Boomplaas cave (Scholtz 1986), and at Elands Bay cave (Baxter 1996, Parkington *et al.* 2000) have been possible. Before 40 000 ybp, the most common charcoal at Boomplaas was derived from an *Olea* spp., while at Elands Bay this was the fifth most common species used, with Afromontane forest taxa being the most important contributors. Mesic Thicket species made up the balance of the charcoal remains at Elands Bay, and Cowling *et al.* (1999) pointed out that many of these now occur in areas where the annual rainfall is in the region of 400 mm to 600 mm, although Scholtz (1986) was of the opinion that 800 mm would be a better estimate. It may therefore be that some of the Thicket species were present only as riparian vegetation along the shoreline of the palaeoriver that today constitutes part of the Verlorevlei. Cowling *et al.* (1999) pointed to the presence of *Ficus sur* and *Salix mucronata* as being almost certainly related to this river. Baxter (1996) noted that some of these (usually stunted) Afromontane species remained in refugia among the south facing ravines of the Verlorevlei krantzline.

By 20 500 ybp, evidence suggests that six of the ten Afromontane species present in the Elands Bay area twenty thousand years earlier no longer occurred there, and those that remained were considerably less common. Charcoal identified at this time (20 500 ybp) was predominantly derived from Mesic and general Thicket species, and pollen counts showed a high frequency of grasses (about 45%) and scrub forest taxa. Asteraceae made up about 3% of the total pollen count. Pollen counts from sample DMS120 at Elands Bay (date not established, but older than 20 500 ybp - Baxter 1996) gave grasses and Asteraceae 49.4% and 31.3% respectively (Parkington *et al.* 2000) suggesting a rapid decline in the presence of Asteraceous

species between the two sample periods. This apparent reduction in the presence of the Asteraceae appears to be in conflict with the change to the tree component to species better able to tolerate drier conditions. However, these data may be misleading, as Baxter (1996) pointed out that much of the grass pollen may have been derived from vlei-related species, such as *Phragmites* and so assumptions as to the abundance of dry-land grasses should be treated with caution. Similarly, absolute pollen counts were low and extremely variable (Baxter 1996); the difference between 11 and 97 pollen grains (the Asteraceous pollen counts from which the 31.3% and 3% figures respectively were obtained) should not be considered significant.

Between 40 000 ybp and 20 000 ybp, the rainfall at Boomplaas apparently decreased. By 20 000 ybp, most charcoals (~ 67%) were derived from Asteraceous species, and these (especially *Elytropappus*) contributed more than 60% to the measured pollen load (Deacon *et al.* 1983). The contribution of the Proteaceae to the charcoal remains dropped over this period from 12.1% to 2.58%, while that of the Ericaceae increased from 6.3% to 34.5%, before dropping to ~ 15.7% by 20 000 ybp (Deacon *et al.* 1983). At Elands Bay, charcoals derived from Proteaceae (or other typical Fynbos taxa) did not appear until after the LGM (Cowling *et al.* 1999, Parkington *et al.* 2000).

These results suggest that Elands Bay was wetter than Boomplaas throughout the entire period, but that both areas became drier towards 20 000 ybp. This trend would have been more severe in the Boomplaas region, thus increasing the climatic differences between the west and the south coast situations. The weakening (and cooling) of the Agulhas current (Prell and Hutson 1979, Hutson 1980) would have led to reduced rainfall along the south coast, while the winter frontal rainfall would probably have continued along the west coast (Cowling *et al.* 1999). However, it is probable that some of this frontal rainfall spilled over onto the south-western coastal plains exposed by the lowering of the sea level (Figure 2).

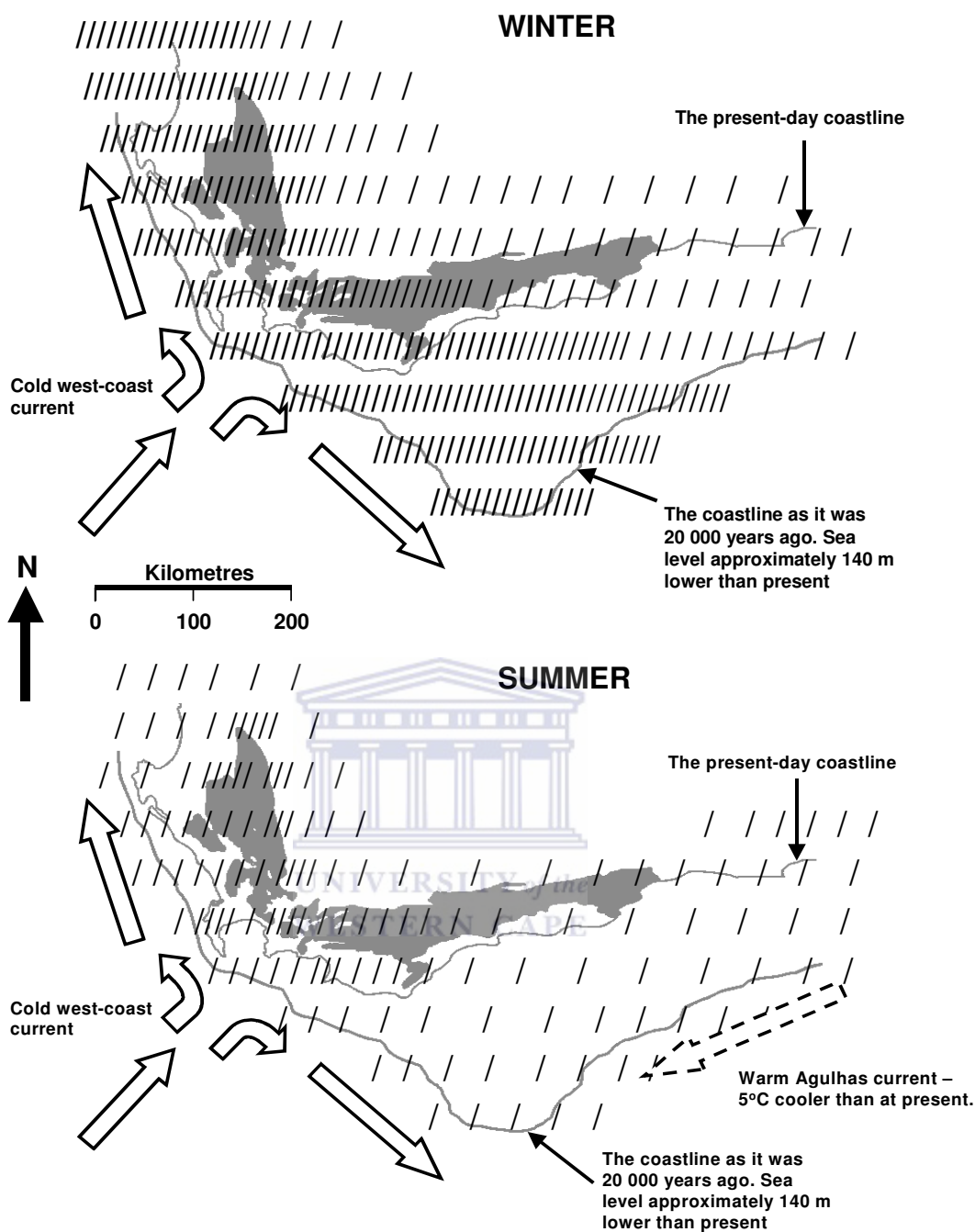
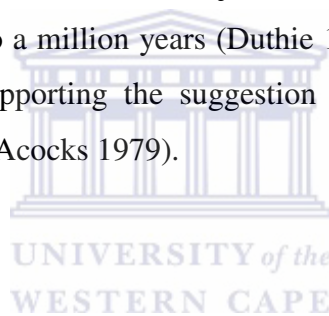


Figure 2. Hypothetical rainfall regime over the Western Cape coastal regions during the Last Glacial Maximum. Rainfall levels (diagonal slashes) are indicated by the density and boldness of slashes. Current Coastal Renosterveld areas are shown in grey. Palaeo-coastline adapted from Inskeep (1978).

Using ^{14}C measurements, Midgley *et al.* (2002) provided evidence to suggest that the heuweltjies existing near Elands Bay, and in the Cederberg were formed between 25 000 and 30 000 ybp. They argued that the termite species that made these structures no longer exist in this area (*c.f.* Moore and Picker 1991). They suggested that, at that time the area was wetter and grassier than it is now and that the structures were made by a termite species that was displaced as the climate became warmer and drier during the Holocene. The grass pollen count at Elands Bay showed that grass had undergone a steady decline in importance in the vegetation of the area since before 20 500 ybp (Parkington *et al.* 2000). It could be suggested that if reduced rainfall and a reduction in grassland was the cause of the termite's extinction, then heuweltjies from more southerly locations should show more recent dates, due to the wetter conditions expected to persist further south. There have been suggestions that heuweltjies in West-Coast Renosterveld could be much older, maybe up to a million years (Duthie 1930, Lambrechts *pers. comm.* to Boucher 1987), thus supporting the suggestion that the southern areas tend to support more grass (*e.g.* Acocks 1979).

20 000 to 10 000 ybp



The onset of the Last Glacial Maximum occurred around 25 000 ybp. It reached its peak (*i.e.* coldest temperatures) between 20 000 and 16 000 ybp, although there appears to have been regional differences relating to the actual time when the climate was most severe (Deacon and Lancaster 1988). The evidence from all the available data indicates that this was the coldest interval of the last 130 000 years. Most data also suggest that, overall it was drier as well (Deacon and Lancaster 1988). From the south coast, the micro-mammalian component (Avery, quoted by Deacon and Lancaster 1988), the mean individual size of herbivores (Klein, quoted by Deacon and Lancaster 1988), and an impoverished diversity of plant and animal remains at Nelson Bay cave, supports this hypothesis. All aspects of the Boomplaas cave sequence also points to colder and drier conditions, with average temperatures around 5°C less than they are now (Vogel 1983, Deacon and Lancaster 1988), while $\delta^{18}\text{O}$ measurements from the Cango cave speleotherm suggests that temperatures could have been as much as 7°C lower at times (Talma and Vogel 1992). At Nelson

Bay cave, frost generated rubble has been found from around 18 000 ybp (Butzer, quoted by Deacon and Lancaster 1988). Tyson (1986) compiled the data from numerous authors to produce maps of southern Africa showing moisture and temperature conditions between 25 000 and 15 000 ybp. These showed that, while the south coast was drier, the west coast appeared to be wetter than now. Recent research supports this, suggesting that during the LGM, the west coast climate was probably wetter, colder and cloudier than it is at present (Cowling *et al.* 1999, Parkington *et al.* 2000). This probably resulted in the area being grassier, a situation that persisted until the end of the Pleistocene (~ 10 000 ybp).

Hutson (1980) has suggested that, during the LGM, the Agulhas current only flowed along the South African coast in summer, and its temperature was approximately similar to that presently occurring in winter. It should be kept in mind that his conclusions were drawn from an ocean core collected off the Kwazulu-Natal coast, and so the actual events occurring along the south coast can only be surmised. Sealy (1996) noted a strong C4 signature in the remains of grazers from Nelson Bay cave during this period, which she ascribed to a year-round rainfall regime. Although the lower average temperatures would suggest that C4 species would have been at a competitive disadvantage against C3 species, it should be remembered that the atmospheric CO₂ level around the time of the LGM would have been about 180 ppm, thus reducing the growth-period temperature required for a C4 advantage to around 12°C (Ehleringer *et al.* 1997). The finding of a strong C4 signature, may however also be ascribed to the presence of a large local vlei supporting C4 grasses all year round. Should regular summer-drought conditions have been common, there would have been heavy grazing pressure upon these grasses, particularly in summer. Deacon and Lancaster (1988) noted that there was an influx into that region of generally migratory herbivores (Wildebeest *Connochaetes gnou*, Springbok *Antidorcas marsupialis*, Quagga *Equus quagga*, Bontebok *Damaliscus dorcas dorcas* and Warthog *Phacochoerus aethiopicus*) during the period between 18 000 and 12 000 ybp. It is unknown whether these species were only present seasonally, or all year round, but it does supply evidence for, at least seasonally substantial grazing.

In terms of average temperatures being about 5°C lower than at present, and with a possible source of warmer water off the south-east coast in summer, it is quite feasible that this area received year-round precipitation. The compression of the climatic belts, due to the enlarged polar ice sheets implies that the south coast (and the southern part of the Cape west coast) would have received year-round frontal rainfall, although with a winter maximum (Tyson 1986, several authors discussed by Deacon and Lancaster 1988). The degree of compression and the actual climatic effects have been argued by a number of authors and are discussed in Deacon and Lancaster (1988).

Between 16 000 and 11 000 ybp, most evidence points to increasing temperatures in the Cape ecozone, with markedly increased rainfall in most areas, (Deacon and Lancaster 1988, Partridge *et al.* 1990). However, at Elands Bay cave, this is neither reflected in the charcoal nor in the pollen records, suggesting either a climatic stasis, or a slightly more arid situation (Parkington *et al.* 2000). It is likely that this apparently static condition on the west coast, compared to the south coast would have been due to the drier conditions experienced on the south coast during the LGM. The resumption of a year-round flow of the Agulhas current after the LGM (Hutson 1980) would probably have been the major cause of the greater climatic changes along the south coast. In addition, the decreasing width of the wide coastal plain (due to rising sea levels), which existed along the south-western coast, would have had a greater effect on the climate than the relatively narrow one along the west (and south-east) coasts. However, the permutations of inter-relationships between the effects of less actual rainfall, more seasonal rainfall, or an increase in moisture stress caused by higher temperatures need to be kept in mind. One must also keep in mind the presence of inertia to change, and Cowling *et al.* (1999) warned of the problems of persistent species, especially long-lived resprouting species. Other ecological factors are also of importance in the fire-prone vegetation of the Cape, and some anomalous data of Scott (described by Cowling *et al.* 1999) is discussed in these terms by Cowling *et al.* (1999).

It was during the period between 12 000 and 9500 ybp that the last appearance of several, now extinct, grazing ungulates occurred in the fossil record of the Cape ecozone (Klein 1984). Outside of the Cape, the same species became extinct

somewhere within the 25 000 to 5000 ybp period, but an absence of fossil sites between these two dates makes a more accurate dating impossible. Klein (1984) suggested that the extinctions were a combination climate change and an improvement in the hunting practices of the indigenous peoples at that time.

10 000 ybp to 1652

The Cape ecozone was the only southern African ecozone to show marked differences between the glacial and interglacial faunas (Deacon and Lancaster 1988). Generally, it is thought that during the glacial period grassy conditions predominated along the southern and western coastal lowlands of the Cape. However, to reconstruct the vegetation of 2000 years ago in the coastal Renosterveld areas, it is necessary to consider a regional approach. The increasing amount of archaeological data for the southern and western Cape from about 10 000 ybp, suggests that regional variation was high, a factor that would have implications for the present day vegetation. The general trend has been that the area became drier and warmer than at present towards the mid-Holocene, but that it then became less xeric towards 2000 ybp (Partridge *et al.* 1990).

From pollen frequencies near George, Scholtz (1986) suggested that the coastal region of the southern Cape had undergone considerable climatic variations during the past 10 000 years. He suggested that, in the mid-late Holocene, rainfall and climate were ideal for the spread of forest after a more xeric trend in the early-mid Holocene. His data did not show any indication of the eastern parts of the southwestern coastal lowlands being invaded by Asteraceous shrubs. Micro-mammalian remains from Bynekranskop suggested a dry period during the mid-Holocene (Avery, quoted in Deacon and Lancaster 1988) with an increase in precipitation since about 3000 ybp (Avery, quoted by Deacon and Lancaster 1988). The grazer : browser ratio of the larger herbivores in that area suggested a change towards more shrubby conditions. This data is probably of doubtful quality, due to conditions within the cave (Judith Sealy, *pers. comm.*). However, at Die Kelders cave, close by, there is also evidence for drier conditions prevailing during the mid-Holocene (Butzer and Helgren, quoted by Deacon and Lancaster 1988).

At Elands Bay cave, Cowling *et al.* (1999) suggested that the climate changed from cool and wet conditions around 14 000 ybp to the more xeric conditions typical of today by about 4000 ybp. During this period charcoal remains from Proteoid Fynbos species and Mesic Thicket species gave way to the Asteraceous shrubland and Xeric Thicket taxa commonly found there today. Concurrently, the Asteraceous pollen component increased from about 10.6% to 38.9%, the Mesembryanthemaceous pollen component increased from zero to 10.8%, and the grass component dropped from 37.2% to 12.8% (Parkington *et al.* 2000). However, as mentioned earlier, the pollen percentages are based upon very small sample sizes (< 103 grains). Nevertheless these changes all suggest an increase in water stress levels in the area. Baxter's (1996) study in the same area showed evidence of wide changes in the natural vegetation within the last 10 000 years. His study generally indicated that the mid-Holocene was drier and warmer than either the beginning or end of the Holocene. He also suggested a cooler wetter period around 3000 ybp, with a short warmer drier period around 1500 ybp. However, his overall conclusion was that the climate was roughly the same 10 000 ybp as it is now, with a grassy Strandveld as the local vegetation. His data also shows evidence of a reduction in the grass component, and an increase in the Asteraceous component of the vegetation since the introduction of herding around 2000 ybp. This effect intensified with the arrival of European farmers, but was not insignificant before that.

At Boomplaas cave, *Acacia karoo*, from being a minor component 6000 ybp, suddenly became a significant part of the charcoal component around 2000 ybp, while charcoal from the more Mesic species (*e.g. Olea, Rhus*) became much less common. During the same period, the pollen frequencies of the Asteraceae remained constant, but there was an increase in the pollen frequencies of grasses, Restionaceae, Umbelliferae and *Anthospermum* (Scholtz 1986). These data are somewhat contradictory. The apparent displacement of mesic tree species by *A. karoo* may have been due to the warmer mid-Holocene, but due to an ecological lag, *A. karoo* only became dominant once the climate began ameliorating (possibly an example of the dangers of "persistor" species mentioned by Cowling *et al.*, 1999). The shorter life-span of the grasses and smaller shrubs may have made them able to more rapidly adapt to the changes in climate.

The grazer : browser ratio of the larger herbivores in the southern and western Cape also suggests a general reduction in moisture availability between 10 000 and 5000 ybp (Klein 1984). Klein (1974) published a provisional list of mammalian species present in the western and south-western Cape for the late Pleistocene and the Holocene. Klein's terms "south-western Cape" and "southern Cape" are roughly equivalent to the terms "western Cape lowlands" and "southern Cape lowlands" as used in this appendix (see caption to Figure 1 on page 432). As expected from the discussion about changes to the vegetation, there were more large grazing than large browsing mammal species on the coastal lowlands during the late Pleistocene than during the Holocene. In addition, more large-herbivore species (grazers and browsers) were recorded from the southern Cape than from the western Cape during both periods. The $\delta^{13}\text{C}$ values of the bones of grazers recovered from Nelson Bay cave (Sealy 1996) showed that the proportions of C3 and C4 grasses grazed by these species had remained constant throughout the Holocene. She suggested that there may have been a higher proportion of C4 species between 10 000 and 11 000 ybp with three of the six animals having $\delta^{13}\text{C}$ values of $> -10\text{‰}$. However, the bias towards Hippotragines at that time (4 of 6 samples), compared with the rest of the sequence, which are mostly of Buffalo, *Syncerus caffer* does not allow a true trend to be traced. Indeed, one of the *Syncerus* values from that time-period is the second-most depleted of all those reported (-15.7‰). The slope of the curve, using just the *Syncerus* data, extracted from her Table 1, was 0.0001, with an r^2 of 0.1026, indicating no measurable change or temporal correlation.

A problem that now arises is that there is an apparent conflict between the data from the Congo cave speleotherm, and that reported by Sealy (1996). The Congo speleotherm suggested a rise to prominence of C4 grasses only from about 9000 ybp (Talma and Vogel 1992). There is a hiatus at the actual point where this change begins (possibly suggesting very dry conditions), but the curve derived from the available data suggests it began somewhere between 8000 and 10 000 ybp. The Congo caves are in the rain shadow of the Outeniqua Mountains, whereas Nelson Bay cave is located on the (present-day) coast. It is likely that with the absence of the Agulhas current in summer, and the wider coastal plain, rainfall in the Boomplaas cave region was restricted to overflow from the winter frontal storms, thus reducing any C4 competitive advantage during the glacial period. The anatomy

of charcoal remains from Boomplaas cave during the period from 14 000 to 10 000 ybp showed definite signs of summer drought stress (Scholtz 1986). Such conditions would be detrimental to the growth of C4 species and explain the C3 characteristics of the Cango speleotherm during this period. With the warmer climate developing towards the mid-Holocene and the narrowing of the southern coastal plain, there was probably an increase in summer rainfall derived from the stronger Agulhas current, as well as from convectional thunderstorms in summer.

Over the South-Coast Renosterveld region (*sensu* this thesis), a situation intermediate between that of the Nelson Bay cave and Boomplaas cave probably existed during the period between the LGM and the beginning of the Holocene. Firstly, the conditions were probably cooler than at Nelson Bay cave, as the Agulhas current would have been weakening as it moved westwards. They would however have been warmer and less extreme than at Boomplaas, due to their lower altitude and closer proximity to the ocean (Dent *et al.* [1989] considered that oceanic influences extended up to 300 km inland). Secondly, the Renosterveld region probably received more of a seasonal (winter) rainfall than Nelson Bay cave, thus reducing the competitive advantage of C4 species in the west. Thirdly, the lower sea levels increased the width of the coastal plain along the western portion of the south coast much more than it did along the east. This disproportionate expansion of the south coast plain begins around the longitude of Nelson Bay cave. The increased distance from the ocean would have reduced the amount of summer rainfall proportionately more than at Nelson Bay cave. The increase in average annual temperatures, the resulting rise in sea levels and the all-year resumption of the Agulhas current at the end of the Pleistocene, led to an increased level of summer precipitation, and hence allowed the spread of C4 grasses into South-Coast Renosterveld.

The indications are that by 2000 ybp animal and plant community structures had stabilized, and without the impact of Khoekhoen herders or European farming practices would have been largely unchanged today. In evolutionary terms, two thousand years is very little. However, in terms of the ecological impact of modern man upon the vegetation of the Western Cape, it has assumed great importance, greater probably than the short, but sometimes extreme, climate changes that

occurred during this period (Tyson *et al.* 2001) – see the section on climate change in Chapter 1, pages 64-66. Archaeological evidence indicates that domestic stock first appeared in the Western Cape around 2000 ybp (Schweitzer and Scott 1973, Schweitzer 1979, Klein 1986). It is not known how quickly stock keeping grew, or at what stage it began to have a significant impact upon the natural vegetation in terms of increased grazing pressure or an increased frequency of burns. However, reports from early visitors to the Cape (*e.g.* Thom 1952, Raven-Hart 1967, 1971) indicated that burning was widespread, and that in any one place, it probably occurred with a frequency of about two to four years. Burning helped maintain a high grass component in the vegetation, which was required for the grazing of sheep and cattle. Baxter (1996) noted an increase in Asteraceous pollen in the Verlorevlei area from about 1900 ybp. This was associated with charcoal remains within some of the soil profiles examined, and he suggested that the apparent increase in the Asteraceae might have been due to the management of the veld for grazing purposes.

Palaeoclimate and modern West-Coast Renosterveld

The above discussion about the Palaeoclimate of the Western Cape lowlands has revealed three basic trends. The first was that, during the last glacial there was apparently a great deal more grassland about than is currently found in the Cape ecozone. All the fossil records showed a predominance of grazing ungulates during that period (Klein 1974). There is always a possibility that this may be due to hunting bias, but this seems generally unlikely. The second was that during the LGM there was a general increase in aridity, and temperatures were about five degrees (possibly more) lower than at present over most of southern South Africa (Deacon and Lancaster 1988, Partridge *et al.* 1990). This led to a general decrease in the diversity of the fauna and flora (Deacon and Lancaster 1988). The apparent exception was the western lowlands, which were believed to have been colder, wetter and grassier than at present (Cowling *et al.* 1999). The third trend was an increase in temperatures after the LGM, to levels fluctuating within 1°C (Deacon and Lancaster 1988) or 2°C (Partridge *et al.* 1990) of the present level since about 7000 ybp. This led to the development of new vegetation and animal community

structures, with browsing species becoming predominant in the Cape ecozone (Deacon and Lancaster 1988). Most of the large grazing species in this region became locally or, in a number of cases, globally extinct (Klein 1984).

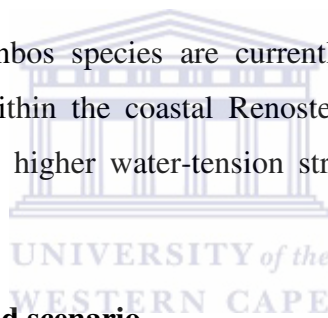
It is not unreasonable to suggest that West-Coast Renosterveld followed ecological trends similar to those occurring at Elands Bay. It would have received more rain than Elands Bay cave (assuming present-day patterns). Cowling *et al.* (1999) suggested that the Mesic Thicket flora that predominated at Elands Bay cave (~ 10 000 to ~ 4000 ybp) has modern analogues on the lower slopes of inland mountain ranges. In these areas about 400 mm to 600 mm of rainfall is received *per annum*. This rainfall range covers most of that usually assigned to coastal Renosterveld (Low and Rebelo 1996). The pollen spectrum at Elands Bay cave for ~ 10 000 ybp identified grasses with a 26.1% frequency and scrub-forest taxa with 24.8% (Parkington *et al.* 2000). Asteraceae contributed only 5.6% to the pollen load. Two items must be taken into consideration here. The first is that a further 25.6% of the pollen was unidentifiable. The second is that much of the input of grass pollen was possibly from aquatic species (Baxter 1996).

The suggestion therefore, is that the “natural” current vegetation composition (at least in terms of guilds) of coastal Renosterveld areas receiving a winter rainfall maximum, should reflect that of the Elands Bay cave area about 8000 to 10 000 years ago. A factor that would need to be considered would be the difference in soil types. Most of the soils around the Elands Bay cave area are either calcareous coastal sands or sands derived from the Table Mountain group (Cowling *et al.* 1999). Clay soils, while potentially holding more water per unit volume (Bidwell 1974), also place a greater water stress upon plants when the water content decreases, as the finer particles adsorb the water more strongly (Bidwell 1974). In effect, this means that, particularly in the western lowland areas, where summer droughts prevail, the species occurring there have to be able to withstand greater water deficits than the species that grow under the same climatic conditions but in sand.

The current West-Coast Renosterveld situation has a similar family component to that of the Elands Bay cave region around 10 000 ybp. Thicket species are common in rills and on heuweltjies (*i.e.* where soils are deeper and often wetter). Asteraceae

are common on the shallower soils, but grass is abundant between the shrubs. There are variations in proportions, probably related to rainfall and disturbance. At Elands Bay, no charcoal remains of Proteoid or Ericoid Fynbos taxa dating after 12 000 ybp have been found. However, consideration must be taken of the fact that, even when present (~ 12 000 to ~ 14 000 ybp), they were generally of secondary importance (for firewood) compared to the Thicket taxa (Cowling *et al.* 1999, Parkington *et al.* 2000). If we take cognizance of the comment of Linder *et al.* (1992) that widespread tropical taxa were able to fill the more nutrient-rich soils of the Western Cape at the onset of the winter rainfall regime, leaving the nutrient-poor soils to the explosive speciation typical of the Fynbos today, then the secondary importance of the Proteoid and Ericoid taxa in the Elands Bay area at that time, might be largely due to the relatively higher nutrient levels of the calcareous sands in the area.

It may be that true Fynbos species are currently mostly restricted to granites, alluviums and sands (within the coastal Renosterveld regions) because they are unable to cope with the higher water-tension stresses found in the clay soils in summer.



The coastal Renosterveld scenario

In West-Coast Renosterveld, I would hypothesize the following situation. Unlike the typical Fynbos areas, the soils were relatively nutrient rich. There were therefore many extant, widespread tropical taxa (Linder *et al.* 1992) capable of taking advantage of them without the need for low-nutrient specializations. Amongst these would be the grass and Thicket species, the last of which would probably have been forest-margin species. The developing Fynbos endemics were mostly unable to gain a foothold in the face of this competition. Archaeological remains from the last glacial has suggested that the cooler conditions promoted grasslands, an assumption based upon the grazer : browser ratio of animal remains in caves and elsewhere (Deacon and Lancaster 1988). Clearly, there would have been competitive interactions between the herbivore guilds and the vegetation, but it is likely that the vegetation had a greater impact upon the herbivore guilds than *vice versa*. The fact that Luyt *et al.* (2000) recorded a predominance of grazers in fossil remains at

Elandsfontein some half a million years ago suggests that the predominance of grazers on the west coast lowlands during the last glacial was not an isolated event. They also demonstrated that these grazers were feeding predominantly upon C3 species, which in the light of the winter rainfall regime experienced, would be expected. Elandsfontein lies about 20 km north of the granites making up the Darling hills.

After the LGM there was a rise in mean annual temperatures of about 5°C over the West-Coast Renosterveld areas. This led to greater water stress, a reduction in grassland, and a spreading of Asteraceous and woodland species. Both the south coast and the west coast lowland areas are cut off from the central grasslands of South Africa, mainly by the Cape Fold Mountains. To the north of the West-Coast Renosterveld areas the present climatic conditions become very xeric, potentially inhibiting the passage of grazing species, except in wet periods. This would probably have been exacerbated by the mid-Holocene dry period. To the east of the South-Coast Renosterveld region, forest forms a barrier to open-country species.

The local extinctions of several grazing species in these coastal lowlands can probably be attributed to a decrease in grassland during the late Pleistocene - early Holocene period. This might be ascribed to (Asteraceous) shrub encroachment caused by the drier conditions, and the rise in sea level due to a general global warming, leading to a narrower coastal plain. Improved hunting methods by late Stone Age peoples (as suggested by Klein 1984), probably contributed to some extinctions in the Cape coastal lowland areas (but does not entirely explain their extinctions in other areas). Some species became permanently extinct (*e.g.* Long-horned Buffalo *Pelorovis antiquus*, Giant Hartebeest *Megalotragus priscus*, Giant Cape Horse *Equus capensis* and Southern Springbok *Antidorcas australis*). Other large grazers became locally extinct, or very rare, although they survived elsewhere (*e.g.* Quagga, Roan antelope *Hippotragus equinus*). Two local grazers (Bontebok, Bluebok *Hippotragus leucophaeus*) became extinct on the western lowlands, but survived on the south-western lowlands (Klein 1974). The two large ungulates surviving in the western lowlands (Red hartebeest *Alcelaphus buselaphus*, Eland *Taurotragus oryx*) are both capable of browsing. Eland are predominantly browsers, while Red hartebeest have been recorded with a 44% browse content in their

stomachs (Smithers 1983). The other common large herbivore species on the western lowlands reported by the early European settlers were predominantly browsers, such as Elephant *Loxodonta africana* and Black Rhinoceros *Diceros bicornis* (Skead 1980). Hippopotamus are a special case as riparian vegetation is not as affected by climatic changes as is dryland vegetation. It is suggested that the survival of a larger variety of grazers on the south-western coastal lowlands was due to the presence of C4 grasses, which slowed and then reversed the mid-Holocene trend towards shrubby conditions.

Most of the fossil data comes from sites outside of the recognized West-Coast Renosterveld area. These areas mainly consist of wind-blown sands, which currently have severe micro-nutrient deficiencies (*e.g.* Zumpt and Heine 1977). John Duckitt (*pers. comm.*) has noted that near Bok Bay (on the west coast, near Ganzekraal), these deficiencies (mainly copper) could have such a debilitating effect upon large herbivores, that they could be approached on foot. Although deficiencies do appear to exist within the West-Coast Renosterveld areas (see Acknowledgements), it is usually not severe enough to affect game animals. It is therefore suggested that many of the animals, whose remains have been found in Sandveld, but close to Renosterveld areas, would have moved between the two soil types, thereby minimizing the effects of micro-nutrient deficiencies. It may also be that plants existing upon sandy soils, being less water stressed in summer, provided a better food source in summer than the clay soils. See Chapter 1, page 49 for the comment of van Reenen (Blommaert and Wiid 1937) about the necessity of moving from the granite hills around Darling to the moors and downs of the coastal plain in summer, which were better supplied with water. Finally, parts of the Sandveld area actually consist of sand overlaying clay (Schloms *et al.* 1983). It is possible that variations in the depth of the overlaying sand, plant species with long roots, water seeping through clay or water remaining in clay pans probably helped alleviate some micro-nutrient deficiencies.

It is likely that the eastern part of the South-Coast Renosterveld area (*sensu* this thesis), receiving more of a year-round rainfall, had remnants of C4 grass species even during the LGM, which rapidly spread as temperatures (and summer precipitation) rose towards the Holocene period. Further west, it took time for the

C4 grasses to become dominant (perhaps only with the resumption of moister conditions from about 3000 ybp), and so more of a shrubland-grassland mosaic existed. The presence of these C4 grasslands (or mosaics of shrubland and grassland) at the eastern extremes of the south-west coastal areas, maintained the grazing species (Blue Antelope, Bontebok, Buffalo, Reedbuck *Redunca arundinum*) that were able to move westwards as the grassland spread. The mountainous boundary of the Western Fold Mountains, bedecked with Fynbos probably acted as a barrier to their moving back into the western lowlands.

On the west coast, the warm dry mid-Holocene exacerbated the summer-drought conditions experienced there, resulting in the disappearance of almost all deciduous grasses (and hence the grazers that depended upon them). C4 grasses gain most of their competitive ability from being more productively efficient under high temperature conditions (Ehleringer and Monson 1993). The inability of these species to grow on the west coast lowlands during the summer period (due to a lack of precipitation) would have restricted their presence there. Some C4 grasses would have been able to survive along the major rivers (*e.g.* the Berg River), and run-off from the western Fold Mountains may have supplied enough moisture for C4 grasses to exist in a balance with the shrublands along these slopes. Concerning this, it is interesting to note that Tansley (1982) mentioned a pure stand of *Themeda triandra* at Voelvlei (at the foot of the Elandskloofberge). However, large obligate grazers would probably have been unable to find enough grass to survive, and would hence have gone extinct. Richardson and Cowling (1992) noted that there was a poor representation of C4 grasses in Mountain Fynbos, with only 28% of the grasses at Swartboskloof (Jonkershoek valley) being C4 species. This was despite the area receiving more than 1500 mm of rainfall per annum, with never less than 50 mm of rainfall being recorded in any one month between 1976 and 1989 (Versfeld *et al.* 1992). This summer precipitation (probably orographic) on the mountains may help to explain the survival of Zebra (probably Mountain Zebra *Equus zebra zebra*), which are predominantly grazers, close to these mountains. It is therefore likely that the seasonality of rainfall is not the only factor limiting the presence of C4 grasses in West-Coast Renosterveld.

When the Europeans arrived at the Cape, it was noted that there was a great deal of grassland about (see Chapter 1). Grassland was even more common along the south-west coastal lowlands, even to recent times (*e.g.* Muir 1929, Smit 1943, Acocks 1979). My suggestion is that the predominance of grasslands in West-Coast Renosterveld at that time was largely the result of the herding and burning practices of the Khoekhoen. The paucity of large grazing species was partly due to hunting by the indigenous peoples, but mainly because these grazers had become locally extinct during the early part of the Holocene. The mountains, desert, forest and Thicket that prevented the migration of the grazers out of the area 8000 years ago, were also responsible for the isolation of the area when the grasslands became more prominent, perhaps 1500 years ago.



APPENDIX B.

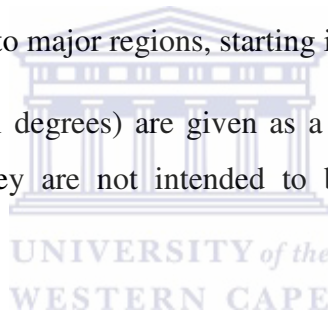
FIELD VERIFICATION NOTES.

This appendix is a tidied-up version of the notes made during the field-verification phase of the project. It should be noted that it was not the aim, nor was it feasible within the time allotted, to give a detailed analysis of the sites visited. The aim was to estimate the accuracy of the classification. A by-product was the sub-division of the Renosterveld class into three sub-classes, which allowed the accuracy to be improved. Data was mostly collected in late November/early December 2001, with some additional data collected in November 2002.

Layout of this appendix

The notes are grouped into major regions, starting in the north.

Co-ordinates (in decimal degrees) are given as a guide to the location of the site being discussed, but they are not intended to be definitive of the actual spot examined.



Definitions

1. Renosterveld structure = single strata of shrubs, usually of a single height with few or no emergents. Species diversity appears low. Where emergents are present, they are Thicket species rather than Proteoid.
2. Proteoid structure = generally a single strata of shrubs, but with emergents such as *Protea*. Species composition appears generally more diverse than “1”.
3. Natural = usually used when the fragment was too far for a definite statement to be made, or a “Fynbos-Renosterveld” mosaiced structure.
4. Dense, medium, low shrub cover = a visual estimate. Boundaries between the terms are at 75% and 25%.
5. Wasteland = mixture of grasses, weeds of cultivation, alien shrubs.

6. Thicket vegetation = Thicket species like *Rhus*, *Euclea*, *Olea* etc. Same as that found on rocky outcrops.

7. Karroid vegetation = strong succulent structure, usually low to very low cover.

Area 1. Piketberg – north-west of the N7 between Piketberg town and Greys Pass

Small hill along the old Moorreesburg road, just south of the SE tip of the Piketberg (18.752002E; 32.943947S). Renosterveld structure; Medium shrub cover. Grass between the shrubs. Renosterveld along road verges. Some succulent components.

On the south-west side of the tip of the Piketberg (18.681389E; 32.875972S). The area classified as Fynbos was a mixture of broad-leaf sclerophyllous shrubs and grass, while the Renosterveld class tended to be a mixture of shrubs and rocks.

The south-east tip of the Piketberg (18.745382E; 32.922269S) had quite a dense Proteoid presence.

Next few comments about the eastern foothills of the Piketberg massif:

Versveld Pass (18.739865E; 32.865648S) (turn-off just north of Piketberg village) at the boundary between agriculture and natural vegetation. The Fynbos class had a greener hue, but with a higher soil/rock cover. Renosterveld class – more small-leaved shrubs, and a higher vegetation cover. Patch of dense Renosterveld within “U” turn just after leaving the agricultural boundary.

In the general region of “Groenvlei” (18.805751E; 32.798709S). Small patches of Renosterveld on the road [R366] running along the eastern foot of the Piketberg. Good verge vegetation (Renosterbos *etc.*) along this road (see Chapter 6, Figure 12, page 350).

In the area of “Waboom” (18.793192E; 32.720247S). Vegetation low and sparse.

In the region of “Winkelshoek” (18.791258E; 32.702852S). Vegetation quite dense with a Proteoid presence.

In the “Keurbos” area (18.774237E; 32.666902S). Grassy, with apparent subsistence-type farming.

South to south-east slopes of Grootkop (18.778493E; 32.646801S). Slopes look like they were burnt a year or two prior to the field trip; wheat fields at the bottom of the slope.

North-east corner of Grootkop, sandy area to east of the road [R366] (18.793192 to 18.804798E; 32.642549 to 32.615567S) – strip farming, using natural vegetation as wind breaks. Mixed shrubs – mostly a low Renosterveld structure, with *Rhus* emergents. Some patches are fallow and have “weeds” in them. Area between the strip patches and the road have a Renosterveld structure but with a Proteoid and Restioid presence. West of the road, parts had been burnt, and there were typical rock-outcrop shrubs (*Rhus* etc).

North-west corner of Grootkop (18.779266E; 32.621752S). Low vegetation cover, open Renosterveld/karrooid structure.

Southern slopes of the main hill in “Duikerfontein” (18.782361E; 32.593688S). Typical open Renosterveld structure. At the foot of the slope – bare and very badly eroded.

Notes about the Kapteinskloof road through the Piketberg

The natural vegetation in this kloof is a mixture of Proteoid, Thicket and Kloof (*i.e.* tree species) vegetation. Very little vegetation with a Renosterveld structure was seen, although there was a small patch at the south end of “Banghoek” farm (18.617049E; 32.737938S). The saddle area between Bobbejaanskop and Gryskop had some dense Renosterveld (18.653781E; 32.721381S), but this blended into more of a Proteoid structure on the higher slopes (see Chapter 5, Figure 6 on page 286). The patches to the north, after reaching the bottom of the pass, tended towards a more karrooid structure (like Boglei se Berg [18.617419E; 32.690472S]). Part of Banghoek farm vegetation burnt early 2003.

Comments about the vegetation along the road from Duikerfontein to Eendekuil

Patches of Renosterveld structure around “Middelpos” (18.809440E; 32.601419S); “Kruisriver” (18.842321E; 32.655538S); and just north-west of Eendekuil (18.878538E; 32.679681S). More strip farming with natural vegetation wind breaks between “Arendshof” and “Droeryskloof” station (18.824502 to 18.829308E; 32.618464 to 32.641058S).

Still harvesting in parts near “Renosterhoek”. Some small (unresolvable on Landsat imagery) Renosterveld fragments on slopes along Eendekuil-Renosterhoek road.

The slopes of the Olifantsrivierberge have natural vegetation, which like the Piketberg, appears to have a variable structure and is therefore presumably a mixture of Proteoid and Renosterveld communities.

Area 2. Piketberg-Moorreesburg-Porterville-Greys Pass

Koringberg (18.665402E; 33.026571S). Walked over the north slopes of the Koringberg (hiking path). Low down on the north-east side the vegetation cover was low, but this became thicker higher up. The north-east side had a high succulent component (*Euphorbia*, *Cotyledon* etc. – see Tansley’s 1982 project). Renosterbos was present, but in some places it gave way to *Othonna* sp. (c.f. Peter Linder's 1976 UCT botany honours project on the Piketberg where the same phenomenon was noted). *Eriocephalus* occurred in both the Renosterbos and the *Othonna* communities. On the south-west side the vegetation was predominantly Renosterbos and a broad-leafed grass (species?). The vegetation also appeared denser. Thicket clumps (*Rhus* etc.) occurred on the south-west slopes of the Swartberg section. The “tail” that trails off the north-west tip of the Koringberg (did not show up on the Landsat classification) was about a 50% grass/Renosterbos composition on quite a steep slope. The wheat field situated on the top of the Koringberg is invisible from the surrounding plains.

Tontelberg (18.732463E; 33.179063S). A mixed medium and low-density Renosterveld structure; agricultural activity appears to be taking place wherever feasible.

Goudmyn se Berg (18.67914 and 18.687914E; 33.117247 and 33.130924S). Renosterveld structure.

Neulfontein se Berg (18.667561E; 33.187983S). Renosterveld structure – at the top of the hill around the transmitter station.

Public road to the south-west of the Heuningberg, on the south side of Berg River (18.800235E; 33.106573S). Some small Renosterveld patches in this area – most unresolvable at Landsat scale.

Heuningberg (18.888000E; 33.134687S). Northern section of south-west slope – quite dense Renosterveld structure. A couple of wheat fields on flat spots. Southern section of south-west slopes were more grassy. A number of rocky outcrops to the north-east of the Heuningberg had a dense Renosterveld structure. The patch at the south of Heuningberg which was classified as “urban” had been burnt by a spark from a train, shortly before the satellite image was exposed.

Spitskop (18.762856E; 33.013607S). Renosterveld structure.

Slopes along the southern Olifantsrivierberge – natural vegetation, but again mixed Renosterveld/Fynbos communities. Examined at the Dasklip Pass (~ 360 m. altitude; 19.031384E; 32.888287S); *Proteas*, *Leucadendrons* (so Proteioid structure), but Renosterbos common.

Herculesfontein (18.935918E; 32.840873S). Quaternary sands. Strip farming. Vegetation very mixed - had Renosterbos species, *Rhus*, *Acacia karoo* trees and riverine species.

Area 3. South of Moorreesburg to the Perdeberg; excluding the Darling hills

Kanonberg (18.756225E; 33.273232S). Renosterveld structure on south-eastern slopes.

Malmesbury-Hopefield Road [R45] (18.607699E; 33.263545S). Small patches of vegetation with Renosterveld structure.

Grootvlei area (18.817446E; 33.241873S). Renosterveld structure, but sparse cover.

Skoenmaakersfontein area (18.942641E; 33.244874S). Mixture of grass, dead and live alien *Acacias*, and general wasteland.

Saron region (19.037699E; 33.239594S). Very mixed, difficult to allocate to any one class – open shrub, alien *Acacias*, other trees, Eucalypts and bare soil.

Between Saron and Porterville (19.014861E; 33.210261S). Renosterveld structure.

Excelsior region (18.839498E; 33.289297S). Seen from a distance and largely obscured, but apparent Renosterveld structure with a medium to low shrub cover.

Voelvrei area: some dense Renosterveld cover along the east side of the road [R44] by Voelvrei dam. Similar situation on the west side of the road near the Voelvrei railway station.

Elandsberg PNR: Mixture of Renosterveld (usually quite open) and Fynbos. Very complex mixture – south has quite a lot of trees (mainly alien pines, eucalypts). In the southern half (north of the treed region) – an apparent east-west differentiation. The east has more of a Proteoid (*Leucospermum*, *Serrurias*, grasses, some Renosterbos) structure; the west side has more Renosterveld species (Renosterbos, grasses) but also includes some *Leucadendrons* (tall straggly species), geophytes, aromatic herbs and Restios. Although the cover looks quite good from the road, when you walk in it, it can be as low as 20%. To the north end – much of it burnt in March 1999. The areas classified as a mixture of agricultural and Fynbos classes mostly consisted of low Proteoid species, grasses, Restios *etc.* in October 2002. Unburnt patches had a relatively high cover of the straggly *Leucadendron*. Although the communities were very variable, their actual *structures* were very similar in many cases. The “old lands” are largely short grassland, but also included low forbs.

Kasteelberg: Central part, south-west side (18.849079E; 33.373927S). Mixture of quite dense Renosterveld structure and grass patches. Grass with occasional trees

(*Proteas?*) higher up. Some denser bush in the kloofs. North tip (18.818291E; 33.328407S) and north-east of that (18.828079E; 33.337370S) has dense shrub cover. Mine dump on other side of the Riebeeck West – Moorreesburg road [R311] (18.845144E; 33.327122S) has mixture of trees and grass. East side (October 2002) – whole side very grassy with sparsely scattered *Protea* sp. higher up (estimate 1-2m in height - burnt in 2001?). A few alien tree patches along the foot of the mountain.

North-east slopes of the Swawelberg (18.814868E; 33.359884S). Lower parts recently burnt (2001) – very sparse cover. Higher up a dense shrub cover. Burnt area not obvious in October 2002.

Along Riebeecksrivier in “Smithsfontein” region (18.837308E; 33.402994S). Some fairly dense Renosterveld structure on the slopes. Above the slopes - strip agriculture with natural vegetation to act as wind breaks.

Malmesbury – commonages (18.744333E; 33.450738S; and 18.714154E; 33.450738S). Renosterveld structure, but Eucalypts mixed in with first patch. Scattered Renosterbos bushes along the N7 verge and in the surrounding wasteland to the south of Malmesbury.

“Helderfontein” district (18.719249E; 33.567453S). Medium to high cover Renosterveld structure, cereal fields in flat spots.

Porseleinberg – west side is mostly wheat fields. The “dark” patches on the western slopes tend to be vineyards, and “plantations” of alien trees (around farms?). On the eastern side the patches appear to be mostly of a good Renosterveld structure. Variable shrub cover. The northern patches seem to have a generally more dense shrub cover.

Perdeberg - Western side towards the north (18.762275E; 33.576119S). Many trees - a mixture of indigenous and Eucalypts, with some bad Eucalypt infestations in places. Around the north end a more natural (Fynbos/Renosterveld) vegetation. Grapes being grown quite high up the mountain here. The north-east side has more exposed rock than the south and has a Thicket/Proteoid structure, but some Renosterveld structure in parts. On the eastern side a Proteoid shrub structure, with

some scattered stone pines. Some Renosterveld present at the foot of the Perdeberg, to the east (18.857137E; 33.585082S). Occasional patches of agriculture. South-east slopes – Proteoid/Thicket structure. Pines in the kloofs, “new”(?) vine field high up on the slopes. The south side also had a natural (Fynbos) structure, but towards the south-west more trees were present – and a lot of alien trees present along the lower boundaries of the mountain, as well as in patches higher up. Kloof vegetation in the natural gullies, and the natural shrub areas look quite sparse. To the south-west of the public road to the south of the Perdeberg (18.775928E; 33.641811S) there are quite dense alien *Acacia* infestations. This is one of the “Qg” geological formations – so probably not true Renosterveld.

Area 4. South of the Perdeberg and north of the N1

Slent Road – Klipheuwel-south Perdeberg (18.712362E; 33.679125S). Where the road goes under high tension lines – a few hundred metres to the north (follow the power lines) – a patch of a mixture of Thicket species, (indigenous?) trees, and patches of Renosterveld structure. This is one of the “Qg” geological formations so may not be true Renosterveld.

Graafwater area (18.761441E; 33.656204S). Difficult to see, but appears to be mostly small trees, species unidentifiable (3-4 metres tall).

Klipheuwel (18.692483E; 33.694554S) and Klipheuwel radio mast (18.712836E; 33.680330S). Klipheuwel mostly grassy, some Eucalypts, dead shrubs, but a few patches of quite dense Renosterveld. Klipheuwel radio mast – Renosterveld structure.

Hill south of Philadelphia – wheat fields all over. Diep River bridge (Philadelphia-Klipheuwel road [R304]) quite a lot of Renosterveld species and grass growing along the river banks, but also alien and indigenous tall trees/shrubs present.

Along the N7 at the foot of the Koeberg (18.544698E; 33.714784S). High level of (mostly dead) alien *Acacias*. Some Renosterbos. North side of the Koeberg – Renosterveld structure low down – low cloud so higher slopes not seen. NNE side – mostly grassy with occasional bush clumps (*e.g.* *Rhus*). East side - lower parts - Thicket type vegetation – *Rhus* and other unidentified broad-leaf shrubs. Also areas

of medium density Renosterveld structure. Good grass cover between the shrubs, which have ~ 60% cover. The hill at the NE corner of the Koeberg (De Hoop farm) – vines all over. Road verges, where there are cuttings – Renosterveld/Thicket mix – Renosterbos, *Eriocephalus*, *Rhus*, *Putterlickia*, many grasses, white “hyacinth”.

N7, south of Koeberg (18.551388E; 33.758386S). Some small patches of Renosterveld.

Hoogekraal (Die Plaas) (18.591907E; 33.766847S). East side of hill has a fairly dense Renosterveld structure, a strip to the north is grassier.

Meerendal (Humeklip/ Cotswold-Oatlands) (18.621157E; 33.781699S). East side – mixture of shrub densities – 60% dense Renosterveld structure, grass 20% and the other 20% a gradation.

Rondeboschiesberg (18.661437E; 33.764931E). Quite dense Renosterveld structure on the west side, especially towards the north. Wheat being grown on quite steep slopes on the south and south-west aspects.

Kuyperskraal area (18.630544E; 33.755235S). Patch of mixed grass and Renosterveld structure, with Eucalypts present.

Blouberg (18.487753E; 33.781318S). From the north-east appears to be quite sparse with high alien *Acacia* infestation. From the north and west side, the upper $\frac{3}{4}$ has a fairly dense Renosterveld structure, but grassier lower down. Wheat field on the west side of the north slope – separating *Acacias* from the natural vegetation. On the south-west side, alien *Acacias* form a boundary a couple of hundred metres wide along the road [R27]. The smaller hill to the south is quite grassy – criss-crossed with vehicle tracks. Isolated shrub patches (*Rhus*, *Chrysanthemoides*).

Tygerberg (18.587666E; 33.871795S). Very variable. Pine plantation on south end, and pines scattered about in other parts. Nature reserve and other areas consist of grass, Renosterveld/grass and medium density Renosterveld structures.

Kliprug region (18.750307E; 33.734167S). Not much natural vegetation on the south-east side, but quite dense Renosterveld structure on top – forming erosion protection on the edge of a small quarry [Cotswold Quarry?].

Fisantekraal airfield (18.739605E; 33.768504E). Dense alien *Acacia* infestation around airfield. The airfield mostly very short grass and small Renosterbos type shrubs.

Joostenberg (18.782824E; 33.769281S). East side of the hill – 50% shrub cover; Renosterveld structure.

R312 between Joostenberg and Eensaamheid (18.804671E; 33.747727S). Patches of generally high density Renosterveld (Renosterbos), some scattered aliens (*Acacias*, Pines) in places.

Kuilenberg region – southern patch (18.857882E; 33.726144S). Variable mixture of grass patches and very high cover Renosterbos. North patch (18.852355E; 33.721124S). Mostly high cover (> 70%) Renosterbos monoculture. Grass between bushes. Blends into pine trees in the north-east. Occasional alien *Acacias*.

Matjieskuil region (18.753370E; 33.79541S). Renosterveld structure.

Eensaamheid (18.881497E; 33.767805S). Area surrounded by alien *Acacias*, otherwise dense Renosterveld structure.

Groenberg (19.045639E; 33.583187S). North slopes – some areas with a Renosterveld structure. The north-west arm appears grassier. Other grassy patches on the north side. Alien trees along the base of the mountain (north/east sides). Kloofs have a more Thicket type appearance. Lots of pines and gums (plantation) on the lower slopes with south and south-west aspects.

Paarlberg - western slopes – mostly low, quite dense Renosterveld structure almost down to the Agter-Paarl road [R44] (18.893556E; 33.725642S). Grass along the lower boundary. Higher up the slope – a lot of grass, with some shrubs. Around the south-west side (18.913655E; 33.752245S) is more of a Proteoid slope, although some Renosterveld structural components present. Alien pines spreading from a couple of small plantations on the south slope. Around the north slopes a mixture of Renosterveld structure plus *Proteas* and vines, as well as some pine infestations. Most of the lower east slopes (18.953650E; 33.713093S) are urbanized or given over to vineyards – the higher slopes classified as Renosterveld, but appeared to

have more of a Fynbos structure. The natural vegetation class was Proteoid and had some pine infestation.

Area 5. The Darling area

Darling (18.383840E; 33.386090S). The area on the south-east side of the town (to the west of the side-road to “The Towers” farm – natural vegetation, but quite grassy. There was a lot of grass present in the natural vegetation.

Klipberg (18.364085E; 33.332847S). Very rocky. Moderate grass cover, karroid type shrubs on the rocky outcrops.

Three km north-west of Darling (18.351346E; 33.610320S). Mixed vegetation structure, some high density Renosterveld patches, some open grass and some Thicket (*Rhus* etc).

Bonteberg (18.334028E; 33.350796S). Generally high canopy cover. A mixture of Renosterveld structured patches, Proteoid patches, and karroid looking stuff. North-east side has more of a Renosterveld structure. Looks like Olive groves near the top.

Turksvyberg (18.294998E; 33.332399S). Renosterveld structure

Rheeboksfontein (18.294011E; 33.370539S). Renosterveld structure

Bokkop (18.370814E; 33.416984S). North side has a dense Renosterveld structure. On the south side of the west end a moderately dense Fynbos type structure. Patches of a Renosterbos monoculture interspersed with patches of other shrubs in parts (18.363112E; 33.421530S). The area to the east of the high-tension cables here was very grassy. On the koppie to the north of the farm “Smalpad” there is a triangle of grass (18.360852E; 33.419458S).

Kapokberg – (18.395848E; 33.412270S). Good cover of Renosterveld, some grass patches. The reason for the confusion between natural and agricultural classes here is that there are many “fallow” grassy areas adjoining the natural veld. The higher parts of the slopes with a north-east aspect generally had a better Renosterveld structure, while lower down there was a mixture of grass and the yellow-leaved shrub (*Galenia africana*), or grass and clumps of *Rhus*.

Oranjefontein (18.426991E; 33.422060S). Grassy Renosterveld structure, also some Thicket species (*Olea*, *Rhus*), alien *Acacias* and a lot of *Galenia africana*.

Contreberg (18.449711E; 33.447038S). Where the south-west side was classified as “Fynbos” it was mostly grass with quite a lot of *Galenia africana* mixed in. The rest was mostly a medium to high density Renosterveld structure.

Bobbejaanberg (18.460720E; 33.478081S). The north side was very grassy, a couple of rocky outcrops with typical Thicket associations (*Rhus etc.*). Lot of *Galenia africana*. The saddle was grassy.

Nieuwepos (18.472181E; 33.476533S). Dense Renosterveld structure on the south and south-west side. Areas classified as Fynbos were grassy with much *Galenia africana*.

Dassenberg (18.493059E; 33.486754S). South side was mostly grassy, with some patches which had a Renosterveld structure. The north end (near the Contreberg), on the NE side was largely grassy, but there were some large patches with a Renosterveld structure. The southern $\frac{3}{4}$ mostly covered with a medium-dense Renosterveld structure, but also had patches of grass. On the saddle between Dassenberg (see Nieuwepos, above) and Contreberg – a lot of grass ~ 50/50 mixture of predominantly grass and predominantly Renosterveld patches.

Hill side north of Mamre (18.478368E; 33.502036S). Although classified as mixed Renosterveld and natural, it is mostly alien *Acacias*, with some scattered pines and other wasteland species.

Area 6. South of the N1

Signal Hill/Lions Head (18.401792E; 33.915663S). West side: at higher altitudes, Lions Head had more of a Fynbos composition. Lower down and along to Signal Hill parking lot it was characteristically pock-marked with clumps of Thicket species. Closer up there is a high grass presence, and a lower cover of predominantly different shrubs – Renosterbos, a spiny *Muraltia* species; a *Psoralea* type species, *Cliffortia* sp. The bush clumps were predominantly *Rhus* sp., but *Chrysanthemoides*, *Tarchonanthus* and *Olea* species were quite common. *Acacia*

karoo present near the Signal Hill parking lot. Pines growing along lower north and west slopes. The east and south side has more of a Proteoid structure, the northern slopes tend to be badly invaded with pines. Where spectral analyses suggest Fynbos, this tends to be associated with a higher representation of broad-leaved shrubs.

Table Mountain north face (18.408501E; 33.94730S). Very mixed and patchy structure, burnt areas, sparse cover, Proteoid structure, pines.

Groote Schuur area (18.446714E; 33.944370S). Grassy area where game graze, but also patches of pines, areas of Renosterveld structure, Proteoid presence.

Klein Leeukop (18.342193E; 34.013397S). Upper north slopes – Renosterveld structure.

Skoorsteenberg (18.369768E; 34.027969S). North-west slopes, Renosterveld structure.

Klapmutskop (18.857098E; 33.825354S). Between Klapmutskop and the N1 – a low grassy wasteland, but some Renosterbos scattered about. The north-east and eastern slopes of Klapmutskop, very sparse and stony with scattered pines present.

Skurweberg (18.886118E; 33.843764S). Very low vegetation, probably recently burnt (in the last year or two), next to a pine plantation. South-west slopes appear natural vegetation.

Simonsberg (18.923061E; 33.871306S). North-east slopes – vines on many of the lower areas, blends into natural vegetation higher up, but vegetation very low – probably burnt within previous year or two. The entire south-west slopes appear to be natural vegetation with a couple of small pine plantations at the foot of them.

Middelberg (19.067583E; 33.898017S). Very low sparse vegetation, also appears recently burnt.

Kleinberg (19.012391E; 33.851324S). Difficult to see properly, but some natural vegetation present.

Perdekop (19.043103E; 33.878006S). Lower south-western slopes. Very mixed. Vineyards (some new areas cleared, November 2001); also some vegetation with Renosterveld structure.

Jonkershoek Valley (18.905435E; 33.957874S). Forest on northern (south facing) slopes. Along southern slopes (north facing), Renosterveld structure intermingled with vineyards. Area above (south-east of) Coetzenberg sports stadium (18.882290E; 33.941865S) has Renosterveld species, but also a strong Proteoid and broad leaf shrub presence. Pines and gums in places.

Pappegaiberg (18.844573E; 33.932055S). Eastern slopes have a lot of pine trees, but some cleared areas with Renosterveld structure.

Bottelaryberg (18.777470E; 33.908512S). The south facing slopes are a patchwork of pines and natural vegetation which has a Renosterveld structure. Most of the natural vegetation was on the northern side of the hills. NW slope (“Rosendal”, NNW to NNE of trig beacon 50) – Renosterveld structure, but badly invaded with alien pines and *Acacias*. Dense alien *Acacia* infestation above “Amandelrug”. North side of Kanonkop (the south-westerly hill) – a similar situation. Between “Rosendal” and “Koopmanskloof” – Renosterveld on some north facing slopes but mainly invaded (and degraded) to various degrees. On north and north-west facing slopes of “Koopmanskloof” – looks like some good Renosterveld. On north-east facing slope a bit more good stuff, but quickly blends in with dense alien woodland, especially along the ridge. On the opposite side of road [M23] the Groenland brickfield and Bracken nature reserve (18.711404E; 33.879983S) have a mixture of grassy-wasteland and Renosterveld.

Verblyf Hill – east of the R44, and just south of M23 extension junction, between Klapmuts and Stellenbosch (18.860524E; 33.881609S). Some Renosterveld structured patches on the western and northern facing slopes, but mostly infested with pines, often very dense. Even the “good” patch has many young pines coming up. Some Renosterbos along the R44 road verges between the M23 junction and Stellenbosch.

Faure district (18.747604 to 18.767188E; 34.007502 to 34.029292S). Grassy-wasteland patches, grassy patches and grass with alien *Acacia* invasions at various densities. (Includes “Kahlenberg” – one of Clive McDowell's sites).

Lynedoch (18.782370E; 33.993701S). This patch had mixed agricultural use, with a large orchard. Renosterbos was seen along the railway line south of Lynedoch station.

Annandale Road (18.810129E; 33.985477S). Degraded wasteland and weeds of cultivation.

Junction of the Vlotenburg-Pinewood Road and the R44 (18.824696E; 33.985010S). Stone Pine plantation but had some Renosterbos in it. The Stellenbosch airfield adjoining the pine plantation is mostly open shrub and grassland, with alien *Acacias*, but had a small patch of Renosterveld in south-west corner.

Stellenrust road (“Stellenzicht” farm area) (18.856707E; 33.992664S). Degraded grassy-wasteland, pasture and vines.

Renosterveld patches to the west of the Papegaaiberg (e.g. 18.819228E; 33.910878S) were mostly shady suburbs with exotic woodland (including pines).

Bothmaskop (18.913488E; 33.922119S). Northern slopes were natural vegetation but the structure could not be determined.

Macassar region (18.753917E; 34.045653S). Eucalypts and alien *Acacias*, grass in between.

East of Firgrove on the north side of R102 (18.803201E; 34.063371S). Grass, abounded by gums.

R44/R102 intersection area (18.828143E; 34.078098S). Grass.

Between “Lwandle” and “Weltevreden” (18.850565E; 34.120074S). Mostly grass, a few alien *Acacias* and gums present

Above the dam at “Sweetwater” (18.903430E; 34.147895S). Low, recently burnt vegetation. Lot of *Pelargonium cucullatum*.

Hottentots Holland Nature Reserve (18.918785E; 34.132299S). Low shrub. Ericoid presence, giving it a similar structure to Renosterveld.

South of Schaapenberg (south of the old road between Somerset West and Sir Lowry's village) (18.888980E; 34.103054S). Grass, occasional gums.

Schaapenberg (18.885960E; 34.091449S). Fynbos structure around the trig beacon; North side a mixture of vines and natural vegetation (structure not determined).

Helderberg Nature Reserve (18.868460E; 34.060611S). Medium density of Fynbos structure, Thicket/kloof vegetation in the kloofs.

