PALAEOECOLOGY AND VEGETATION DYNAMICS IN THE CEDERBERG WILDERNESS AREA

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ABSTRACT

The Cederberg Wilderness Area, in the Cape Floristic Region, South Africa, contains over 2000 plant species, 280 of which are endemic. The area has been subject to various forms of land use for millennia ranging from hunter-gatherers, herders, and farmers to visitors today. This study used palaeoecological techniques to investigate the impacts of past land use, specifically the transition from hunter-gathering to farming and herding in order to provide a baseline for current wilderness management. A sediment core was extracted from a wetland adjacent to the De Rif farmstead, analysed for fossil pollen and charcoal and dated using AMS radiocarbon dating. Historical records were used to link changes with land use history. A vegetation survey of the site focussed on the grass component of the vegetation. The largest impacts on vegetation during the last 2300 years are due to grazing and agriculture during the 1800s to 1940. Fire-sensitive taxa have not declined, apart from possibly Ericaceae, suggesting that changes in fire have not exceeded a threshold that affects the community at a family level. Changes in the fire regime, combined with disturbance by ploughing and grazing have increased the abundance of Poaceae and Cyperaceae, resulting in a decrease in Restionaceae. Ploughing affected the height structure and species composition of the site, and allowed the invasion and persistence of exotic grasses which now make up 43% of total grass cover on the previously ploughed area. Few indigenous fynbos grasses were found suggesting that the grass community is depauperate due to disturbance. The higher grass abundance preceded the largest fire recorded in the charcoal record suggesting a grass fire cycle has started at De Rif. Ploughing, grazing and invasive grasses, rather than changes in fire regime or resource extraction, are the main causes of vegetation change at De Rif and still affect the site today. Wilderness management will need to mitigate the impacts of livestock and agriculture on De Rif and monitor the recovery of this and other previously farmed areas to ensure that they do not become as a source of invasive species in the future under novel disturbances such as anthropogenic climate change.

February 2010

DECLARATION

I declare that Palaeoecology and Vegetation Dynamics in the Cederberg Wilderness Area 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.

Fiona Ballantyne
Name

May 2010
Day Year

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1 GENERAL INTRODUCTION

1.1 BACKGROUND AND RATIONALE

The Cederberg, a mountainous area 200km north of Cape Town, has a long and varied history of human occupation. People have been part of this landscape for at least 10 000 years but possibly as long as the last half a million years (Manhire 1987). Today 71 000 hectares of this area is managed as a wilderness area. Knowledge of the impacts of different forms of past land use on the Cederberg will help direct current management actions. This study focuses on the impacts of people on the vegetation of the Cederberg through their role in changing fire and disturbance regimes, while moving from less intensive forms of land use like hunting and herding to more intensive land use associated with agriculture.

Past land use can broadly be divided up by the use of the environment by several different groups. While the earliest inhabitants of the Cederberg would have been purely involved in hunting, gathering and fishing (Parkington 1977), the introduction of livestock to the Western Cape in the last 2000 years (Boozaier et al. 1996, Henshilwood 1996) represents a novel form of land use, that of herding, which most likely resulted in an increase in the use of fire in order to improve grazing (Botha 1924). These two groups, the hunter-gatherers and the herders would probably have coexisted in the Cederberg (Smith 1986) until they were joined by a new group of herders, European colonialists who first entered the Cederberg in 1661 (Parkington 1977), and in time displaced or absorbed the groups who proceeded them in the next 150 years (Mitchell 2002a).

These early European herders later introduced another form of land use, that of agriculture (Smith 1983). Over time stock posts became more fixed and the claims on land became more formal with the first loan farm being granted in the area in 1725 (Mitchell 2002a). This led to permanent settlement in the Cederberg. Before the introduction of agriculture, all land use in the Cederberg had been temporally limited as hunting and herding were generally migratory in nature (Smith 1983) which precludes permanent settlement. The initiation of agriculture and permanent settlement would have led to changes in land use and hence an intensification of impacts on the environment of the Cederberg. From 1973 the area that is the focus of this study was declared a wilderness area (Government notice 1256 1973). Farmers were moved from the wilderness area and tourism has been the main form of land use in the area since.

Each group of land users would have extracted resources from the environment and would have used fire as a management tool to some extent. This would have had impacts on the environment of the Cederberg. This study aims to investigate if these impacts are visible in the palaeoecological record. Further, this study addresses what the impacts were, how intensive they were, and how current wilderness management address this past land use.

The site of De Rif (see Figure 1) was chosen as the wetland bordering the dismantled farmstead had sufficient sediments for coring and the wetland appeared to be water-logged all year round due to it being seep fed. The source area for pollen for the wetland would encompass the farmstead and thus capture the affects of land use on at De Rif.

The wetland is situated on the Northern Inland Shale Band vegetation while the majority of the surrounding vegetation in the wilderness area (demarcated by the thick black line in Figure 2) consists of Cederberg Sandstone Fynbos ((Rebelo et al. 2006) in (Mucina and Rutherford 2006)).

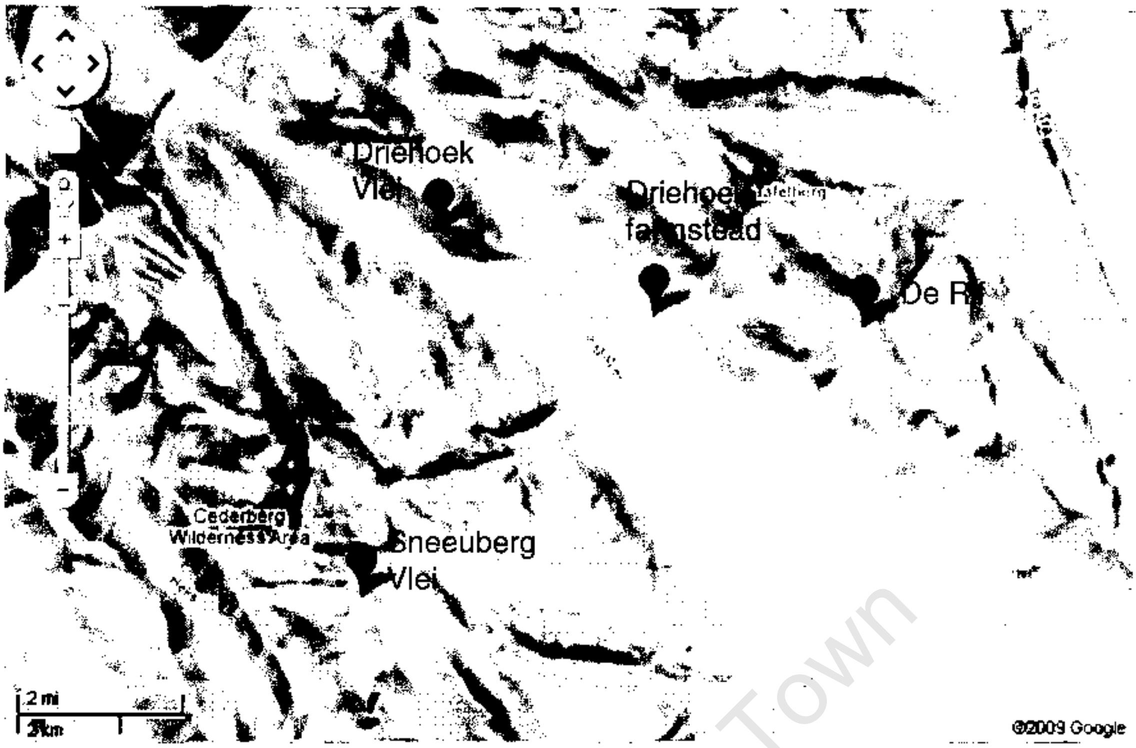


Figure 1 De Rif site in the Cederberg Wilderness Area

The shaded area shows the extent of the Cederberg Wilderness Area. The map was drawn using Google Maps.

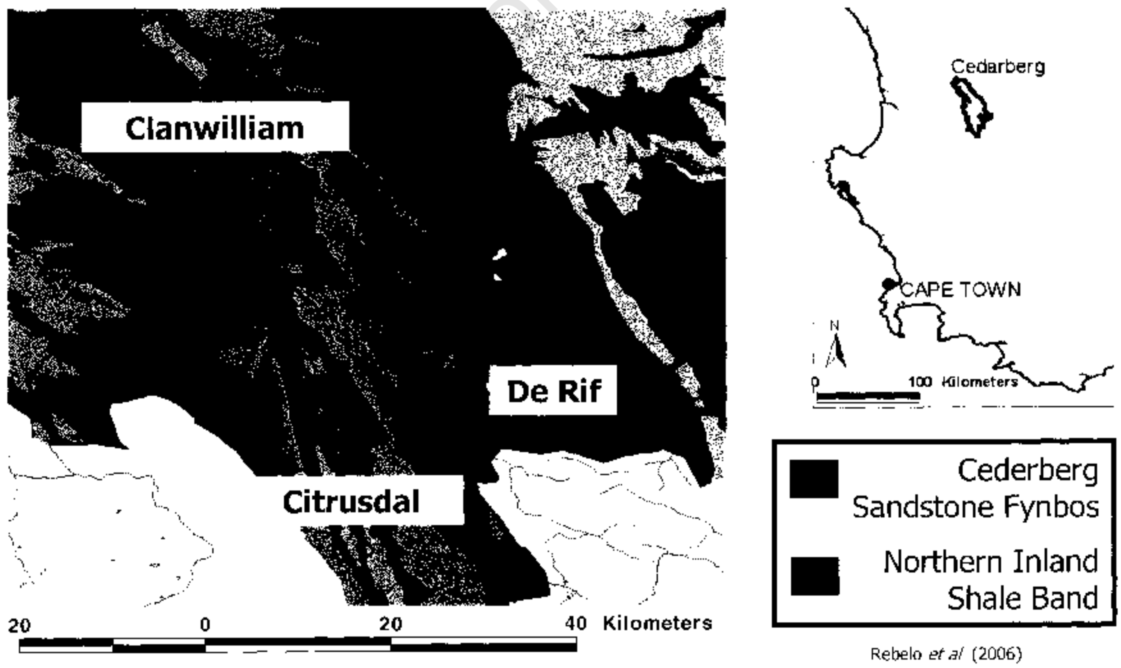


Figure 2 The vegetation types found in the Cederberg Wilderness Area

Vegetation types from Rebelo et al (2006) in Mucina and Rutherford (2006). The position of the Cederberg Wilderness Area in relation to Cape Town is shown in the inset map. The other colours represent vegetation types not found within the Wilderness Area

1.2 PROJECT AIMS

The project considered the effects of different forms of land use on the Cederberg area and had the following aims

- To investigate anthropogenic impacts on fire and vegetation at De Rif
- To determine how the fire history of De Rif changed from the hunter-gatherer period to the present
- To determine the effects of fire on the vegetation of De Rif
- To determine the impacts of disturbance, other than fire, on De Rif
- To investigate the effects of pasture management and livestock on De Rif
- To provide current wilderness management with an undisturbed baseline for areas such as De Rif

1.3 RESEARCH QUESTIONS

The project aims led to the following research questions:

- How has the fire history of De Rif changed from hunter-gatherers to herders and farmers?
- What have been the effects of changes in fire on grasses and how has this affected the grass fire cycle?
- What have been the effects of fire on Cyperaceae, Proteaceae and Ericaceae?
- What have been the effects of disturbance on Cyperaceae, Proteaceae and Restionaceae?
- How has pasture management for livestock affected *Elytropappus spp* and Poaceae abundance, two contrasting indicators of pasture condition?

1.4 THESIS ORGANISATION

Chapter 1 General Introduction

This section contains the study background and rational, the project aims and how these translate into research questions. It also provides the thesis structure.

Chapter 2 Study site and Literature Review

This section introduces the study site and reviews past and present literature relevant to the study. The study site section describes the Cederberg in general and De Rif site in particular. The literature review concerns the prehistory and history of people and fire in the fynbos; the palaeoclimatic history of the Western Cape and the Cederberg and anthropogenic history of the study site.

Chapter 3 Methods

A description of field methods and laboratory methods used in this study are provided in this section.

Chapter 4 Results

This section describes the results of the vegetation survey, the chronology, sediment description and physical proprieties of the core and the results of the pollen and charcoal analyses.

Chapter 5 Discussion

The discussion looks at changes in fire and vegetation in general, and then focuses on the specific impacts of fire, disturbance and pasture management on De Rif. The discussion is then synthesized at the end of the chapter.

Chapter 6 General Conclusion and Conservation Implications

The conclusions drawn from the study including conservation and rehabilitation implications are described here and future research suggested.

Chapter 7 Appendices

Appendices presented here include information on Cederberg plant species and methods used in the pollen analysis.

Chapter 8 References

A complete reference list is provided.

2 STUDY SITE AND LITERATURE REVIEW

2.1 INTRODUCTION

This section aims to provide a context for the current study. It summarises information about the geology, soils, climate and biodiversity of the Cederberg. It also provides a more focused account of De Rif which includes information about the vegetation, setting and fire history of the site. The literature review investigates different forms of land use by different groups of people in the Western Cape and where possible the Cederberg. It focuses specifically on the history of the De Rif site drawing from a range of different types of sources. This information may help interpret the findings of the study and will place such findings within a broader environmental and historical context.

2.2 THE CEDERBERG AND THE DE RIF STUDY SITE

2.2.1 General information about the Cederberg

2.2.1.1 General description of the Cederberg

The Cederberg Wilderness area is situated 200 km north of Cape Town, South Africa. It was declared a wilderness area in 1973 (Government notice 1256 1973). The Cederberg Mountains run in a north westerly direction from around Citrusdal in the south to Clanwilliam in the northwest. It is a mountainous and rocky area; the highest peak is Sneeuberg at 2027m above sea level, while the lowest point in the landscape is Citrusdal at 150m although this falls outside of the wilderness area. The mountains are covered mostly by sandstone fynbos with Karoo type vegetation present in the east, west and northern extremes of the range. The vegetation of the Cederberg Wilderness Area consists of a narrow band of Northern Inland Shale Band vegetation while the rest of the vegetation in classified as Cederberg Sandstone Fynbos ((Rebelo et al. 2006) in (Mucina and Rutherford 2006)). Vegetation is largely structured along rainfall, altitudinal and geological gradients (Taylor 1996). The Cederberg Mountains delimit two catchment areas. To the east lies the Tanqua-Doring River system while the Olifants River lies to the west of the range. The Driehoek River flows through the centre of the mountain chain before turning eastwards and entering the Doring River.

2.2.1.2 Geology of the Cederberg

The description of the geology of the Cederberg that follows is largely summarised from Taylor et al (1996) and Rebelo *et* al (2006). The Cederberg range is made out of sedimentary rocks of the Table Mountain Group that are between 355 and 500 million years old. Four formations of the Table Mountain Group are found in the mountain range: the Nardouw, Cederberg, Pakhuis and Peninsula. The Nardouw Formation consists predominantly of quartzitic sandstone, the Cederberg Formation consists mostly of shale and siltstone interspersed with fine grained sandstone, and is sandwiched between the Nardouw above and the Peninsula below (Taylor 1996) while the Pakhuis formation is composed of a thin layer of glaciogenic material. The Peninsula formation consists of a homogenous quartzite. The Table Mountain Group sediments were not folded as intensively as in other areas (e.g. Montagu) of the Cape Fold Mountains. This resulted in sediment bands that are almost horizontal or gently tipping. These sediment bands were then weathered into blocks that were sculptured by wind and rain, separated by fissures or sandy flats, resulting in the characteristic "Lego" blocks seen in the Cederberg.

2.2.1.3 Soils and nutrient availability

The rocks of the Cederberg weather to form soils of low nutrient status; however soils derived from the narrow band of the Cederberg Formation are a notable exception (Taylor 1996). The higher nutrient status of weathered shale and siltstone (Taylor 1996, Compton 2004) results in a band of greener vegetation on the Cederberg formation or "step" as it is called in the area (Taylor 1996). This is a recognisable and characteristic feature of the Cederberg landscape and has a vegetation type associated with it, the Northern Inland Shale Band vegetation (Rebelo et al. 2006, see section 2.2.2.1). The shale step also influences the hydrology of the area as the higher clay content of the shale makes the soil less permeable to water. Seeps form as water trickles through the cracked and faulted sandstone bands above the step and is forced to the surface when it encounters the impermeable clay. The sandstone bedrock below the clay probably helps maintain the moisture content of the soil in summer as well (Taylor 1996). Thus the step has both better soils and a constant supply of water making it a more important geological feature in the landscape than its geographical extent would suggest.

2.2.1.4 Rainfall and climate

The Mediterranean climate of the Cape results in predominantly winter rainfall in the Cederberg between the months of May and August (Rebelo et al. 2006). These anticyclonic systems from the South Atlantic travel inland causing frontal rain. However, the mountains intercept these systems and influence the rainfall in the following ways; coastal facing slopes receive more rain than east-facing slopes, higher elevations receive more rain than the mountain valleys and the area to the east of the Cederberg range are drier due to the rain shadow effect. These anticlonal systems determine wind direction and magnitude. The prevailing winds are south-easterly in summer and north-easterly in winter with occasional northerly berg winds in early spring; however these winds are generally not as strong as winds further south (Taylor 1996). The average rainfall in Algeria (1994-2004) was 751 mm (February et al. 2007). The average rainfall measured at a site 11 km away from De Rif but on the same mountain range with similar slope, aspect and elevation was 460 mm between 2000-2004 (February et al. 2007). Previous studies in the area (Meadows and Sugden 1991a) suggest that the climate has remained remarkably constant over the last 14 000 years in the Driehoek valley area of the Cederberg while at the northern end of the Cederberg, studies suggest much more variability in rainfall and climate (Scott and Woodborne 2007a, 2007b). For a more in depth discussion of the Palaeoclimate of the Cederberg see section 2.3.4.

2.2.1.5 The biodiversity of the Cederberg Wilderness Area

The Cederberg is florally diverse with over 2000 species and of which about 280 are endemic (van Rooyen and Steyn 1999). These include the snow protea *(Protea cryophila),* the red rocket pincushion *(Leucospermum reflexum* var *reflexum),* the rooibos plant *(Aspalathus linearis)* and the Clanwilliam cedar, *Widdringtonia cedarbergensis.* The Cederberg is named after this species and it is currently the focus of several research projects due to its now endangered status (IUCN 2009). The harvesting of buchu *(Agathosma spp)* and rooibos *(Aspalathus linearis)* are important industries in the area and have been since historical times (Taylor 1978, Taylor 1996).

The Wilderness Reserve is made up of two major vegetation units as determined by Rebelo et al (2006) in Mucina and Rutherford (2006). These are the Cederberg Sandstone Fynbos (FFs 4) and Northern Inland Shale Band Vegetation (FFb 1). The authors state that the classification may be an interim one as they are based on our current understanding of centres of endemism, and acknowledge that a new high-altitude shale fynbos type may be warranted which may include the vegetation of De Rif. This classification is also at a large geographical scale. The intensive phytosociological study of (Taylor 1996) conducted in the Northern Cederberg and including the wilderness area, recognised 26 different communities, and was conducted at a much more local and intensive scale.

2.2.2 The De Rif study site

2.2.2.1 The vegetation of De Rif

The De Rif site is classified as Northern Inland Shale Band Vegetation (FFb 1) by Rebelo et al (2006) in Mucina and Rutherford (2006). Using Taylor's phytosociological study (Taylor 1996), the De Rif study site could contain elements of seven different plant communities which are listed in the appendix (for full details of the classification see Taylor 1996 for details), but the majority of the site was made up by Community 17, with large contributions from community 18 and 24. Table 1 lists the dominant plants found in these communities from Taylor (1996). In the community column the identifying species, various habitat descriptions and the species richness of the community is also given as determined by Taylor (1996).

Table 1 The main plant communities that contribute flora to De Rif

Adapted from Taylor (1996) with family information from Trinder-Smith (2003). The dominant species in each community, the plant families from which they come and general habitat descriptions are provided. Species richness is given as an average with the maximum and minimum values in brackets,

Community	Dominants	Family
17	*Elytropappus adpressus*	Asteraceae
Fynbos of well-drained	*Protea acuminata*	Proteaceae
habitats	*Leucadendron glaberrimum*	Proteaceae
Sandy habitats	*Aspalathus triquetra*	Fabaceae
Silt	*Metalasia densa*	Asteraceae
Elytropappus adpressus - -	*Ischyrolepis unispicata*	Restionaceae
Leucadendron glaberrimum	*Cannomois parvi flora*	Restionaceae
community of the	*Ischyrolepis virgea*	Restionaceae

Welbedacht shale band	*Willdenowia arescens*	Restionaceae
Species richness: 24 (12-36)	*Calopsis viminea*	Restionaceae
	Also	
	Leucadendron pubescens	Proteaceae
	Leucadendron dubium	Proteaceae
	Cannomois virgata	Restionaceae
	Athanasia microphylla	Asteraceae
	Cannomois aristata	Restionaceae
18	*Ischyrolepis monanthos*	Restionaceae
	Thamnochortus platypteris	Restionaceae
Fynbos of well-drained	*Willdenowia arescens*	Restionaceae
habitats	*Willdenowia incurvata*	Restionaceae
Sandy habitats	*Ischyrolepis sieberi*	Restionaceae
Sand	*Cannomois parviflora*	Restionaceae
Willdenowia acrescens -	*Hypodiscus neesi*	Restionaceae
Thamnochortus platypteris	*Rafnia diffusa*	Fabaceae
community of local sandy	*Metalasia agathosmoides*	Asteraceae
flats	*Cliffortia ruscifolia*	Rosaceae
Species richness: 22 (16-37)	*Diosma meyeriana*	Rutaceae
	Also	
	Tetraria compar	Cyperaceae
	Tetraria nigrovaginata	Cyperaceae
	Ficinia bulbosa	Cyperaceae
	Cymbopogon marginatus	Poaceae
	Merxmuellera stricta	Poaceae
	Stipagrostis zeyherei	Poaceae
	Stoebe leucocephala	Asteraceae
	Macrostylis tenuis/decipiens	Rutaceae
	Lampranthus laetus	Aizoaceae
	Protea acaulos	Proteaceae
	Pelargonium coronopifolium	Geraniaceae
	Anthospermum aethiopicum	Rubiaceae
	Athanasia oligophylla	Asteraceae
	Leucadendron salignum	Proteaceae
	Leucadendron loranthifolium	Proteaceae
	Othonna parviflora	Asteraceae
24	*Tetraria spp*	Cyperaceae
Fynbos of poorly-drained	*Elegia asperiflora*	Restionaceae
habitats	*Restio occultus*	Restionaceae
Mid-altitude plateaux and	*Macrochaetium ecklonii*	Cyperaceae
terraces	*Also*	
Permanently moist habitats	*Utricularia capensis*	Lentibulariaceae
Tetraria sp nov (T 11230) -	*Fuirena hirsute*	Cyperaceae
Elegia asperiflora	*Chrysithrix junciformis*	Cyperaceae
community on seepages	*Epischoenus gracilis*	Cyperaceae
Species richness: 14 (10-19)	*Juncus capensis*	Juncaceae
	Andropogon appendiculatus	Poaceae

2.2.2.2 The setting of De Rif

In the middle of the Cederberg range is a valley about 2km at its widest through which the Driehoek River runs at an elevation of 880m and forms the Driehoek vlei (see Figure 1) cored in previous studies (Sugden and Meadows 1990, Meadows and Sugden 1991a). The De Rif site is about 3.5 km from the middle of this valley as the crow flies and 1200m above sea level. A seep emerges a few hundred metres above the site. Below the site the seep joins other tributaries and forms the Groot-Hartbeeskloof stream that flows into the Driehoek vlei. The site can be accessed from the Jeep Track marked on the Cederberg map (1981) or by hiking up from behind the Driehoek farmhouse and following the Welbedacht Wolfberg arch route which is also called the Gabrielspas on the map. The co-ordinates of where the core was removed are S32°26'32.3880 – and E 19°13'55.1280 –.

2.2.2.3 The fire history of De Rif

Using the fire data for the Cederberg under the curatorship of Cape Nature, the fire history for the site can be determined. From the records (considered reliable from 1973 onwards after the area was declared a wilderness area (Government notice 1256 1973) the only fires that burnt the area surrounding De Rif were in 1979 and 1982, both in August. As the site is visible from the road, it would be assumed that records for the date of the fire are quite accurate. However, according to these records the age of the vegetation at the time of coring in 2006 was about 24 years old. From visual inspection the vegetation appeared to be much less mature than this. The site burnt again in January 2008.

2.3 LITERATURE REVIEW

2.3.1 Introduction

This review aims to summarise the literature about different types of land use in the Cederberg wilderness area. It investigates the role of fire in structuring vegetation in fynbos and how different groups of land users may have used fire. It focuses on archaeological and historical records pertaining to land use and the use of fire in general and in the Cederberg area where these records exist, so as to be able to interpret charcoal records from the study site and see if these can be related to specific forms of land use. Palaeoclimatic data for the region is evaluated and related to the Cederberg in order to determine if these trends are apparent in the data for this study, and whether climate is more important in structuring vegetation than changes in land use and fire. Previous palaeoecological studies in the Cederberg are summarised so as to be able to contrast and compare these findings with the current study. Specific records and sources relating to De Rif are also explored as these provide useful information as to the introduction of various pollen markers that can be used to relative dating, and provide insight into the fanning practises that took place at De Rif and if the impacts of these are discernable in the pollen record.

2.3.2 People and fire in fynbos

2.3.2.1 People and fire in the Western Cape

People have used fire to manipulate vegetation in southern Africa for over 150 000 years (Hall 1984) and there is evidence that people have managed to alter the fire regime on the African continent on a large scale since the Holocene (Bird and Cali 1998). There is no reason to believe this has not been the case in the fynbos biome as well. Deacon et al (1992) believe that fire has been used by people in order to increase the abundance of food plants since the Late Pleistocene and resulted in a large increase in fire frequency although admitting that no quantitative measures of this have yet been presented.

2.3.2.2 People and fire in the Cederberg

2.3.2.2.1 Archaeological sources

There is extensive archaeological evidence that people inhabited the Cederberg for thousands of years before the first European explorers viewed the Olifants river valley in 1660 (Parkington 1977, Smith et al. 1991). Archaeological cave deposits exist at numerous sites in the general Cederberg area. Eland's Bay (only 66km from Clanwilliam) has a history of occupation since at least 11 000 years ago (Parkington 1987). Other deposits in the Cederberg have been found at Diepkloof (Parkington and Poggenpoel 1987), Andriesgrond, Renbaan (Kaplan 1987), De Hangen, and Klipfonteinrand although not all studies have been published.

At Renbaan cave (4km south of Clanwilliam) a charcoal sample from the basal level had a date of 5 430 +70 B.P. (Pta-3766) while the majority of remains recovered were dated to the last 2 000 years (Kaplan 1987). The remains found in the cave suggest that the cave users primarily subsisted on plants and small prey items such as rock hyrax and tortoises (Kaplan 1987). This is consistent with other Cederberg cave sites such as De Hangen and Andriesgrond (Kaplan 1987). Renbaan is exceptional due to the high proportion of plant food waste recovered, (Liengme 1987). In one food waste dump area over 60% of the remains excavated were corm material (Liengme 1987). From these remains it can be concluded that the sites were occupied in late spring and summer (Liengme 1987). This abundance hints at the high importance of corms in the diet and suggests that people may have been actively managing the vegetation using fire in order to increase the abundance of these plant types. Historical accounts presented in section 2.3.2.2.2 suggest how this may have been achieved (Parkington 1977).

One of the main reasons early people would have used fire in the fynbos was in order to increase the abundance of food plants. In an analysis of botanical remains found at archaeological sites all within 60km or less of the Cederberg area, Liengme (1987) found that plant remains were a regular feature of cave sites. The iridaceous species identified from cave deposits that date from the last 2 000 years in the study include the genera *Babiana, Watsonia, Gladiolus,* and *Hexaglottis.* A chemical analysis of *Babiana* and *Watsonia* corms showed they contain 83.78% and 78.01% starch respectively, while *Watsonia* and *Chasmanthe* corms, the most evident corm bearing plants in the mountains of the Cederberg (Parkington 1977), have similar calorific values to maize (Liengme 1987). This shows that geophyte corms were an important component of the early inhabitants of the Cederbergs' diet. Many geophytic species in the Cape are most abundant during the early stages of post fire succession (Kruger 1977, Kruger and Bigalke 1984, Kruger 1987). In regularly burnt areas especially when the underlying substrate is shale, corm bearing plants are conspicuous and abundant as can be seen on the slopes of Devil's peak and Lion's head in Cape Town.

The introduction of herding to the Cape was a relatively recent event with most sources agreeing that it occurred around 2000 years ago (Klein 1986b, Boozaier et al. 1996, Henshilwood 1996) while cattle were introduced between 1600 and 1500 BP (Klein 1986b). There is still debate in the archaeological record as to whether hunter-gatherers were a completely different group of people to the herders and whether they can be told apart in the archaeological record e.g. see Klein (1986b), Smith (1986, 1990), Smith et al (1991) and most recently Sadr (2008) and Smith (2008) . However, what is certain is that herders would have used fire in order to improve grazing for their stock. In the Cederberg we have evidence of herding people in the area due to several rock art sites that depict fat tailed sheep (Manhire et al. 1986) with over 20 sheep in a panel found at Boskloof near Clanwilliam. However, we do not know to what extent either spatially or temporally that herders would have used the landscape of the Cederberg.

2.3.2.2.2 Historical sources

2.3.2.2.2.1 Before permanent settlement of the Cederberg

In addition to the archaeological evidence, there is also historical evidence showing that people harvested geophytes and may have used fire to encourage their growth. Parkington (1977) in his analysis of the historical records of the people encountered in the Olifants River Valley by early explorers states on p156,

> *"Certainly by the later part of the dry season Soaqua groups' burnt the veld in the valley, but whether to attract small browsing herbivores to new shoots or to encourage the growth of geophytes for future seasons is not clear. It is tempting to conclude that the burning was part of a management system which recognized that geophyte abundance could be improved by removing the woody shrub competition and increasing the incidence offlowering".*

Since people were practising burning within the Olifants River Valley in 1661 (Parkington 1977), it is very likely that similar burning would be taking place in the Cederberg valley, situated only 10km east as the crow flies. Such burning would have predated any burning by colonial/European settlers as this was one of their first forays into the area.

2.3.2.2.2.2 After permanent settlement of the Cederberg

The first official documents relating to the ownership of land in the greater Cederberg area date from 1725 when the area recognised as Lange Valleij was granted to Johannes Ras for hunting and grazing rights (Mitchell 2002a). Although land tenure in the Cederberg area was originally tenuous, from the period from the 1720s until the 1830s the area became increasingly settled as conflict with indigenous people ended and the

[1] Parkington uses this term to denote people who did not have stock, were highly mobile and travelled in small bands and were most probably hunter-gatherers

number and extent of loan farms increased (Mitchell 2008). By the **1770s** farmsteads in the Cederberg were often year round ranching properties with several hundred sheep and cattle, slaves and various farming implements such as ploughs as well as a whole range of household goods (Mitchell 2008). These early settlers would have used fire as a tool to modify their environment both for grazing for livestock and for plant harvesting (Bands 1977, Taylor 1978, Taylor 1996), and several historical accounts document this process in the Cederberg and are explored below:

The majority of the early records relating to land use and fire in the Cederberg are due to the interest in the Clanwilliam cedar (*Widdringtonia cedarbergensis),* a fire sensitive tree which is found in the mountains of the Cederberg area above 900m.a.s.l. (February et al. 2007), which was considered a valuable source of timber (Hutchins 1897). The main focus of the records was often on how the combination of over exploitation and uncontrolled fire had decimated the cedar population. To quote Hubbard (1937) on p573,

> *"Calamitous as was this excessive and unregulated exploitation of the large timber, throughout the piece the major destruction has been wrought by fire for which the grazing requirements of a number of sheep and goats has been advanced as justification".*

This quote reveals several beliefs held at the time; that cedars were more numerous in the past and had declined due to human exploitation, that fire was now much more common due to burning to improve grazing, and that fire was destructive and hence a negative occurrence rather than being part of a natural cycle in the Cederberg.

Although it is thought that the cedars were first exploited from about 1750 onwards (Smith 1955, Luckhoff 1971), the first official account of the cedars appears in the Livestock Commission's Diary in 1805. The account describes the Cederberg forest as it was called, lists some of the threats to it and some of the uses of the wood. As translated and summarised by Smith (1955) on p 63,

> *"The Bastaards[2] had always lived among the Cederberg and made their living from cutting the timber from the forest...The method of exploitation was wasteful and could not fail to destroy the forest within a relatively short space of time".*

The next historical account, also related by Smith (1955) on p64 is by Sir James Alexander who visited the area in 1836. He commented that,

> *"No care has hitherto been taken of these valuable trees: the fanners, Bastaards[2] and Hottentots[3] living in the neighbourhood, cut them down without leave or licence, and burn the grass to improve the pasture, by which many old trees, and thousands of young plants, are annually consumed".*

These sources together reveal that from as early as the 1725 onwards and certainly by 1805 people were present in the Cederberg area and utilizing the vegetation, for resources such as timber and for livestock grazing. It is also interesting that the account by Sir James Alexander in 1836 recognises that three different groups of people were all involved in these activities (the farmers, Bastaards and Hottentots). Sadly the historical record does not allow insight into these three different groups and how their use of resources may have differed and all three groups would probably have been involved in hunting, herding and agriculture at that time in the Cederberg (Mitchell 2002a).

Patch burning was also used to encourage the production of *Agathosma betulina,* or buchu and well as the rooibos plant, *Aspalathus linearis* (Bands 1977, Taylor 1978, Taylor 1996). A photo in van Sittert (2005) shows several hundred people who harvested buchu within the Cederberg Forest Reserve. The Reports of the Conservators of Forests listed this as a regular source of income for the Cederberg Forestry area (Hutchins 1897, 1904, 1905). Both of these products were harvested and the vegetation burnt on a three year cycle in the Cederberg (Bands 1977) which would have contributed to an increase in the use of fire in the area at that time.

[2] People of mixed race living in the Cape, now considered derogatory but part of the language of the time
[3] Indigenous people living in the Cape, but there is debate as to whether it is possible to categorise them as hunter-gatherers or herders. Now considered by some to be an offensive word, but was commonly used at that time

The Reports of the Conservators of Forests are also an important source of information on fires from around 1896 until the early 1900s and also show some of the prevailing attitudes to fire during this period. In the reports, fire patrolling and the construction of fire breaks is a regular feature of the expense sheet (Hutchins 1897, 1904, 1905). The reports suggests that one of the forestry ranger's main and most important duties in the Cederberg mountains was to protect the whole area from fire (Hutchins 1901, 1906). The 1900 report goes on the describe how, with the co-operation of the farmers, fire breaks were burned above and below the cedars in order to protect them and provide better grazing for the farmers (Hutchins 1901). All fires in areas where cedars occurred were subsequently banned in that year (Bands 1977). According to the report, over 60 miles of fire belts were burnt in 1900 and when fires did break out they were extinguished, sometimes by back burning (Hutchins 1901). In the 1905 report, three fires occurred and were rapidly extinguished, and fire breaks were burnt around all plantations (Hutchins 1906).

From these records it is clear that the prevailing attitude towards fire was one of fire prevention, although its role in improving grazing for local farmers was acknowledged (Hutchins 1901). Both time and money were expended in order to prevent fires. When fires did break out they were actively fought. All of these actions are consistent with a fire suppression mind set where fires are considered wasteful and dangerous and policy was focused on preventing them.

2.3.2.2.2.3 Management as a wilderness area

From 1970 there was a switch from a policy of fire suppression to one of regular proscribed bums in state forest land and other conservation areas (Kruger and Bigalke 1984). Fire was now to be used in these areas in order to achieve the following aims: to maintain yields of silt free water, to maintain species diversity, to manage alien invasions, and to control wildfires (Kruger and Bigalke 1984). This led to a change in fire management in the Cederberg in 1972 from a fire suppression policy to a policy of regular, prescribed bums on a 12 year cycle (Bands 1977). According to Bands (1977) the main reason this policy was adopted was to limit large wildfires.

A further change in the management aims of the Cederberg is due to the increasing understanding of the ecology of fynbos and especially the link between fires and biodiversity in the fynbos region, largely as part of work conducted under the auspices of the Fynbos Biome Project (Kruger 1978) e.g. see (Bands 1977, Kruger 1977, Bond et al. 1984, Kruger and Bigalke 1984, Le Maitre 1987, Midgley 1989, Cowling 1992, Le Maitre and Brown 1992, Richardson and van Wilgen 1992, van Wilgen et al. 1994). Fire management now aims to achieve a fire regime that maintains biodiversity. In order to achieve this, species which rely on fire for their recruitment have been studied in order to determine what fire regime would be most favourable. As such, fire management in fynbos is generally based on the understanding of the life cycle of the Proteaceae (Richardson and van Wilgen 1992).

Ideally one would want to understand the life cycle and ideal fire return interval for all plants in the area being burnt in order to bum fires at an interval that is suitable for the majority of species in the area, or those that are most threatened. However this is an impossible task in the fynbos due to high species diversity and endemism. The south western Cape alone has about 4651 species of which 32% of them endemic to that region (Goldblatt and Manning 2000). Managers usually burn areas once the Proteaceae are large enough to produce seeds and have done so for several years (Richardson and van Wilgen 1992). As these are usually the slowest maturing species this is thought to have allowed all species sufficient time to have reproduced and replenished underground seed banks. This method has been modified in the Cederberg as management also focuses on ways to reduce fuel loads where *Widdringtonia cedarbergensis* grows in order to limit wildfires that would kill the fire sensitive and endangered tree (Brown et al. 1991). This may result in fire return intervals that are less than those proscribed using Proteaceae alone as a guide.

2.3.3 The effects of fire on fynbos

2.3.3.1 Succession

Fynbos is considered a fire type vegetation (Taylor 1978) as the component species are adapted to survive regular fires. After fire a regular repeating sequence of plant communities is seen and this is termed succession (Connell and Slatyer 1977). Succession in fynbos has been poorly studied (Rebelo et al. 2006) but general patterns have been observed. These have probably best been described by Kruger (1987).

Kruger (1987) described five general successional stages. The immediate post fire stage is characterised by flowering of geophytes such as *Cyrtanthus* and *Watsonia* and most annuals reproduce during this phase as well. During the youth phase (1-4 years) graminoids and sprouting shrubs dominate and canopy cover approaches that of pre-bum levels. The exception is that in some communities reseeding Restionaceae and Cyperaceae can become dominant (Rebelo et al. 2006). In the transitional phase (4-10 years) all plants reach maturity and tall shrubs start to emerge from the canopy. During the mature phase (10-30 years) tall shrubs reach their maximum height and shorter shrubs and herbs start to die back. During the senescent stage (30-60 years) mortality of seeding shrubs increase and tall shrubs start to collapse and die.

All the species present in the community establish in the first two years after fire (Rebelo et al. 2006) although their relative cover varies between different stages of succession. Fire ephemerals and many reseeding species are dominant during the first three to five years after a fire but then the plants die and only survive as seeds until the next fire (Rebelo et al. 2006). Resprouters may survive for longer but the flowering of most peak within the first two to three years after fire (Rebelo et al. 2006). Ericoid species start to become dominant between 4 and 5 years, while proteas emerge between 4 and 7 years after fire to reach their maximum canopy cover between 8 and 15 years (Rebelo et al. 2006). It is when Proteas are dominant that they have the biggest effect of the community as they shade out other species (Bond et al. 1984, Richardson and van Wilgen 1992). Succession after fire also results in an increase in structural complexity. Low graminoid fynbos is replaced by restiod, asteraceous or ericaceous fynbos until proteiod fynbos is dominant (Rebelo et al. 2006) which has the greatest structural diversity.

2.3.3.2 Fire regime

2.3.3.2.1 The fire regime of the Cederberg

In fire prone ecosystems, fires often recur in a landscape at regular intervals. This pattern of fire in a landscape is called a fire regime and can be described in terms of the following parameters: fire intensity, fire frequency, fire season and fire type (Gill 1975). Additionally Bond and Keeley (2005) describe the following parameters: the patterns of fuel consumption and fire spread, intensity, severity, frequency and seasonality. The fire regime for the Cederberg from 1956-1986 can thus be described using data from previous studies in the Cederberg (Brown et al. 1991) see Table 2.

Table 2 Parameters of the Cederberg fire regime for the period 1956-1986
Parameters according to Brown et al (1991)

Aspects of fire regime	Average parameters in Cederberg
Frequency	11-15 years, 50% probability of a fire occurring in 12 years old fynbos
Season	Most in November to February Few in March and April
Type	Surface fires
Severity/ Intensity	Not documented
Extent	2000-2600 ha/year, 1000-2000 ha/fire

More recently Seydack et al (2007) proposed that fynbos ecosystems are subject to two different kinds of fire regime depending on the productivity of the environment. In productive areas, sufficient fuel would accumulate relatively quickly and hence these systems have a stable and high frequency of fire. In less productive areas, fire frequencies would be more variable, as the probability of a fire starting was dependant on whether the vegetation had accumulated sufficient biomass in order to carry a fire. In this second case the age of the vegetation was the limiting factor, while in productive environments, fires are limited by sources of ignition and the occurrence of suitable fire weather.

In a recent study Southey (2009) analysed the fire records of the Cederberg and found that the fire regime in the reserve was that of a productive type ecosystem as the area had a high and regular frequency of fires. As a result, fires in the Cederberg are limited by suitable weather conditions and rates of ignition (Southey 2009). This suggests under natural conditions the Cederberg should have a stable and high frequency of fire, but with increased ignition sources and suitable weather conditions, fire frequency could increase even more. Fire frequencies could probably increase with human ignitions and extreme weather conditions until the age of the vegetation became the limiting factor again. This is because it takes between four and six years for the post fire vegetation to accumulate enough fuel to carry a fire (Richardson and van Wilgen 1992) depending on plant growing conditions. A four year return interval is a very short interval for most fynbos systems and has been shown to decrease species richness in mountain fynbos (Richardson and van Wilgen 1992).

The Cederberg fire frequency was not severely impacted by human ignitions as when these did occur they did not significantly influence the fire return interval for the area (Southey 2009). However, fire return intervals are decreasing in the Cederberg. Southey's study (2009) attributed this to changing weather conditions. Climatic states associated with hot summer conditions and thunderstorms were becoming more common in the Cederberg area and resulted in more frequent fires. This has important management implications as it suggests that fuel control strategies will not prevent fires from occurring in the Cederberg as fire will occur when the weather conditions are appropriate as most vegetation in the Cederberg is ready to burn at any period in time. This suggests that management interventions in order to protect the endangered Clanwilliam cedar will need to focus on strategies other than fuel reduction, unless fire belts are burnt as soon as the vegetation is able to carry a fire, and hence prevent other uncontrolled fires during the summer when thunderstorms are increasing more common (Southey 2009). These frequent management fires of relatively young vegetation would have negative biodiversity implications on the vegetation of the wilderness area.

2.3.4 The Palaeoclimate of the Western Cape and the Cederberg

In order to evaluate and link change in vegetation in the Cederberg with changes in land use, the underlying climate of the area needs to be understood. Climate is constantly changing, and consists both of a natural component and an increasing human component (global warming due to an increase in green house gasses) since the onset of the industrial revolution. Various studies both in South Africa and in the Cederberg have attempted to document climate during the last Holocene and to see if global climate events such as the Little Ice Age (LIA) and the Medieval Warm Period (MWP) were experienced in the southern hemisphere and whether this affected local sites such as those found in the Cederberg. Where information pertaining directly to the Cederberg is available it is presented, otherwise information for the Western Cape or South Africa as a whole as presented depending on the scale of the study used.

2.3.4.1 Current climate of the Cederberg

The Mediterranean climate of the Cape results in the Cederberg receiving the majority of its rainfall in winter between the months of June and August. Anticlonal systems from the South Atlantic move inland causing frontal rain. The Cederberg also experiences orographic rainfall. The mountains influence the amount of rain that falls in the following ways: coastal facing slopes receive more rain than east-facing slopes; higher elevations receive more rain than the mountain valleys and the area to the east of the Cederberg range are drier due to the rain shadow effect of the mountains. These anticlonal systems affect wind direction and magnitude. The prevailing winds are south-easterly in summer and north-easterly in winter with occasional northerly berg winds in early spring; however these winds are generally not as strong as winds further south (Taylor 1996). The average rainfall in Algeria, (see Figure 3) was 751 mm (February et al. 2007) between 1994-2004. The average rainfall measured at a site 11 km away from De Rif but on the same range with similar slope, aspect and elevation was 460 mm between 2000-2004 (February et al. 2007). Taylor (1996) measured 923 mm of rainfall on average on sites on the Welbedacht shale band, on which De Rif is situated, between 1986 and 1987.

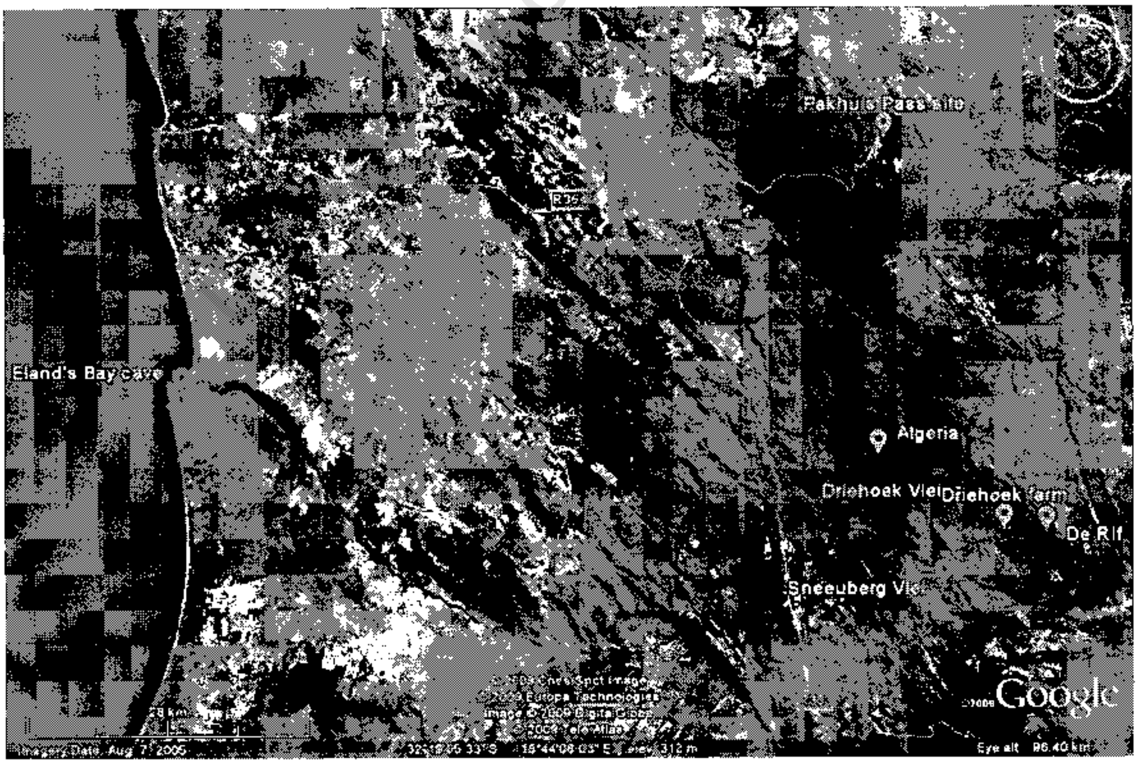


Figure 3 Position of palaeoecological sites in the greater Cederberg Area

2.3.4.2 Past climate of southern Africa and the Cederberg

Southern Africa has very few high resolution palaeoclimatic records (Holmgren et al. 1999, Chase and Meadows 2007) and even fewer that focus on the Holocene in any detail. Southern Africa is situated at the interface between tropical, subtropical and temperate climate systems, and is thus of importance when studying environmental change (Chase and Meadows 2007). However due to this heterogeneity, local or regional studies may not be applicable across other parts of southern Africa but are often used anyway when making climatic reconstructions for the country e.g. Tyson et al (2000). This may be less crucial for large scale global climatic changes which have been shown to occur at the same time in northern and southern South Africa (Scott 1993, Tyson et al. 2001) but may be inappropriate for local studies such as this one.

Recent high resolution palaeoclimatic reconstructions have been made for the Northern Province of South Africa (Holmgren et al. 1999, Repinski et al. 1999, Stevenson et al. 1999) but their contribution to the understanding of the climate of the Western Cape is uncertain. Several studies have investigated the palaeoclimate of the Western Cape, but the records are not as continuous as those from Makapansgat studies, where detailed high resolution temperature records were derived from isotopes recovered from speleothems, as suitable material has not been found in the South Western Cape. Instead, palaeoclimatic studies have focussed on other climate proxies such as those derived from fossil mussel shells (Cohen 1992, Cohen et al. 1992, Cohen and Tyson 1995) and hyrax middens (Scott and Vogel 2000, Scott and Woodborne 2007b) as well as traditional palynological studies (Meadows and Sugden 1991b, 1993, Meadows et al. 1996, Dupont et al. 2007).

2.3.4.3 Last Glacial Maximum

The last glacial maximum, where glaciers formed on every continent due to global cooling associated with Milankovitch cycles (Hays et al. 1976), was most intensely experienced between 25 000 and 15 000 BP in Southern Africa (Lindesay 1998, Tyson 1999, Tyson et al. 2001). There is general agreement that the LGM was accompanied by cooler temperatures in the south western Cape (Deacon and Lancaster 1988, Meadows and Baxter 1999). The best evidence derived from a variety of palaeoenvironmental proxies such as bone analysis of macro and micromammal assemblages, charcoal and pollen from Boomplaas in the southern Cape suggests that the Last glacial maximum was about 5°C cooler than present and drier as well (Deacon and Lancaster 1988) but whether this coincides with drier conditions in the western Cape is subject to debate. Often palaeoclimate interpretations from this study are extrapolated to cover the whole of the Western Cape but this is not appropriate as different rainfall patterns are found in the two areas. Whereas the Western Cape experiences winter rainfall, the southern Cape experiences a tailing off of winter rainfall as you progress eastwards with an increasing amount of precipitation falling in summer, leading to a year round rainfall regime. Thus climatic records derived from Boomplaas, a southern Cape site may not be appropriate to when trying to determine the rainfall of the Cederberg during the same time period. A comparable study situated purely within the winter rainfall area is not yet forthcoming although a study of charcoal fragments at Elands Bay suggests an increase in moisture availability at this site during the LGM (Cowling et al. 1999).

Thus whether the LGM was wetter or drier in the winter rainfall area is up for debate. Meadows and Baxter (1999) attribute this to the difficulty of reconstructing rainfall data from proxy evidence, most often pollen. Indeed, a search for an independent proxy for rainfall over the last few hundred years in the area using dendrochronolgy and isotopes has proved fruitless (February and Stock 1998b, 1998a, 1999, February and Gagen 2003, February et al. 2007). However, the most recent synthesis involving several coastal and inland sites within the fynbos area of the western Cape concluded that the LGM was characterised by higher moisture availability (Meadows and Baxter 1999).

When examining the palaeorecord for the LGM in the Western Cape, Chase and Meadows (2007) suggest that it was generally wetter. At a more local scale, there are discrepancies between the proxy records for the Cederberg (Scott and Woodborne 2007b, 2007a) and those from Eland's Bay Cave (Cowling et al. 1999) see Figure 3, suggesting that the Cederberg area may not have experienced the same changes in temperature and rainfall during this period as coastal areas, but instead suggests local variation in climate (Barrable et al. 2002). Furthermore, the records for the Pakhuis site in the Cederberg (Figure 3) show large variation during this period, suggesting that we shouldn't assume that climatic conditions during the LGM were uniform throughout the whole period even at a single site (Chase and Meadows 2007, Scott and Woodborne 2007a). However, a recent study bordering De Rif suggests that the LGM was wetter as $6^{13}C$ and $6^{15}N$ isotope records for this period are relatively less enriched than during later drier periods (Quick 2009) suggesting greater moisture availability. In general model simulations suggest that the region was around 1 °C cooler than present at 21 000 BP with stronger south easterlies causing increased upwelling and associated summer aridity (Barrable et al. 2002).

2.3.4.4 From the Last Glacial Maximum to the late Holocene

After the end of the LGM, temperatures increased and sea levels rose as glaciers melted between 16 000 and 14 000 BP in the southern hemisphere (Lindesay 1998). However a cooling in sea surface temperatures is recorded off Elands Bay betweenl 1 000 BP to 10 000 BP (Cohen et al. 1992) suggesting that changes in temperature may not have been consistent across South Africa or that the climate during this time in the Cape was more variable than suggested by isotope records from the Makapansgat caves in the north of Southern Africa (Holmgren et al. 1999). In addition, mole rat sizes found at Elands Bay cave suggest wetter conditions between 11 000 and 9 600 BP (Klein 1984, 1986a) so at times the climate may have been wetter and cooler during this global period of generally increasing temperatures. Micromammal assemblages again suggest wetter conditions around 3 000BP at Elands Bay (Avery 1983).

Although local variation between sites in the Cederberg do exist (see section 2.3.4.7), it can be assumed that if a climatic event was powerful enough, it would influence broad regions, but when the influence of such large scale events decline, smaller localised factors could result in differences between sites. Comparisons between the Cederberg studies and Elands Bay studies have been made (Cowling et al. 1999) but suffer due to the poor temporal resolution of the Cederberg studies, and the use of different climate proxies, making direct comparisons difficult.

Mostly on the basis of isotope evidence, namely 6 ^{13}C and 6 ^{15}N derived from fossil hyrax middens, Quick (2009) suggests that the Cederberg generally experienced little environmental change during the Holocene but specific episodes are examined. The period from 12 700 to 11 500 cal yr BP was thought to be drier, possibly indicating a Younger Dryas event, followed by a wetter period from 11 000 to 10 000 cal yr BP. Moisture availability then decreases into the mid Holocene. Another wetter period was experienced from 3500 to 2300 cal yr BP followed by a drier period from 2300 to 950 cal BP. Charcoal evidence from the same study also points to a drier period around 1500 BP although pollen evidence for the climatic fluctuations described above was generally less clear.

2.3.4.5 Medieval warm period

There is evidence of a global warming period between 800 AD and 1300 AD know as the medieval warm period. This is recorded in South Africa by the isotope record from Makapansgat, in the Northern Province, from 900AD and 1300 AD, peaking at 1250AD with temperatures between 3-4°C hotter than at present (Holmgren et al. 1999, Repinski et al. 1999, Tyson et al. 2000). Although high resolution vegetation records for the Western Cape exist (Scott and Vogel 2000, Scott and Woodborne 2007a, 2007b), Chase and Meadows' (2007) review of the dynamics of the winter rainfall zone does not include any study with the resolution to provide insight into this time period and thus inferences on how this global event affected the Western Cape are based on extrapolations from how it affected the Northern Province. A previous palaeoecological study in the Cederberg did not yield any evidence of this event (Meadows and Sugden 1991b).

2.3.4.6 Little Ice Age

The Medieval Warm Period was followed by the "Little Ice Age" from about 1300-1800 AD. This event has been documented extensively around the globe (Hays et al. 1976). In South Africa, both of these events have been found in palaeo proxy climate data from Cold Air Cave in the Northern Province of South Africa (Holmgren et al. 1999, Repinski et al. 1999, Tyson et al. 2000) where they estimate that maximum cooling in South Africa occurred at about 1700 when it was 1 °C colder than today in South Africa.

Cohen and Branch (1992) showed that limpet shells could be used to determine palaeotemperatures off the coast of southern Africa. They found that the shells, dating from between 750 and 400yr BP were isotopically enriched. Using this method Cohen et al (1992) suggest that during the Little Ice age annual inshore sea surface temperatures were between 1 and 2°C colder than they are today. Records from the Limpopo province suggest that the maximum cooling during the Little Ice Age in the interior was about 1°C less than today (Tyson et al. 2000) but the cooling period is not manifest in the Cederberg tree ring record derived by Dunwiddie and La Marche (1980) as some authors suggest (Tyson et al. 2001). A previous palaeoecological study in the Cederberg did not yield any evidence of this event (Meadows and Sugden 1991b). Whether the Little Ice Age commenced at the same time and with the same intensity across the whole of South Africa remains to be demonstrated.

2.3.4.7 Palaeoclimate of the Cederberg

The most extensive attempts at Palaeoclimate reconstruction in the Western Cape Area have centred on the Clanwilliam cedar *(Widdringtonia cedarbergensis).* The potential of this species for climate reconstruction was first explored by Dunwiddie and La Marche (1980). This species has annual rings that are useful for relative dating and allow for high temporal resolution. Their chronology was the first dated annual ring width index for southern Africa. However, cross-dating between trees at the same site is difficult because of poor termination of latewood growth and anomalous rings, and only 29% of total sample variance was retained by the site chronology (Dunwiddie and LaMarche 1980). This shows that individual trees at the same site had a high degree of variation in ring widths even though they were laid down under the same environmental conditions. February and Stock (1998b) reinvestigated this species at two sites that were close to rain gauges in order to see if they could find a better correlation between ring width and rainfall. Their findings show even poorer correlations between ring width and rainfall (23% at Krakadouw and 0.004% at Algeria) suggesting that ring width indices derived from *Widdringtonia cedarbergensis* are not accurate enough to allow for rainfall reconstructions through time.

February and Stock (1999) investigated stable carbon isotopes from cedars used in the Dunwiddie and La March (1980) chronology to see if these could be used to reconstruct past rainfall. They found a declining trend in the ratio of ^{13}C to ^{12}C due to the modern burning of fossil fuels but were not able correlate the isotopic record with known rainfall even after anthropogenic CO2 contribution was removed. Thus February (2000) concluded that *Widdringtonia* was not suitable for rainfall and climate reconstructions. As a result we currently lack a palaeo rainfall reconstruction for the Western Cape area in general. Such a record, had it existed, would have been very useful for interpreting palynological evidence from the Cederberg as well as allowing the examination of potential feedback between rainfall and fire through the examination of fossil charcoal. Thus there has been little successful work in southern Africa that furthers our understanding of past climate even for the last 2 000 years.

Although there are relatively few palaeoecological studies in South Africa, the Cederberg has had several palynological studies (Meadows and Sugden 1991b, Scott and Woodborne 2007a, 2007b). The Meadows and Sugden sites were situated on either side of the Driehoek valley while the site of the Scott and Woodborne study is further north in the Pakhuis Pass area (see Figure 3) of the Cederberg. Several comparisons have been made between these two sites in papers that have attempted a regional synthesis of palaeoecological work in the Cape (Meadows and Baxter 1999, Chase and Meadows 2007, Scott and Woodborne 2007b).

Although these two sites, Driehoek and Pakhuis, are quite close to each other, the vegetation of the two areas appears to have responded very differently to changes in climate over the period of overlap in the studies. Meadows and Sugden took cores from the Driehoek wetland and from a high lying seep near the Sneeuberg hut in the Cederberg (see Figure 3). Their publications (Meadows and Sugden 1989, Sugden and Meadows 1990, Meadows and Sugden 1991b) show very little change in the vegetation of the area over the last 14 000 years. In contrast, Scott's work (Scott 1994, Scott and Woodborne 2007b, 2007a) conducted at the Pakhuis Pass Shelter (see Figure 3) shows marked fluctuation in vegetation composition from *Elytropappus/Stoebe* type pollen (from here on referred to as Elytro/Stoebe as these pollen grains are not distinguishable from each other), typical of renosterveld and fynbos elements during the LGM to mosaic of fynbos and thicket vegetation during the Holocene at the Pakhuis Pass shelter.

Both of Meadows and Sugden's sites (1991b) at Driehoek and Sneeuberg wetlands show very small changes in vegetation composition through time and are quite similar to each other. The predominant vegetation for Sneeuberg pollen diagram is Restionaceae (10-20%) while Poaceae and Asteraceae make up around 10 to 15%, and Cyperaceae, Ericaceae, Fabaceae, and Proteaceae contribute around 10% and less. Fluctuations in composition over time are very small and often not detectable in the pollen diagram. The Driehoek pollen diagram is similar, except Restionaceae make up around 10% of all pollen while Cyperaceae makes up around 15% and Asteraceae fluctuates between 10 and 20%. In the most recent sediments for both cores (no dates were determined for these layers) several changes in pollen types are interpreted as indicators of human disturbance (Oxalidaceae, Montinaceae, Plantaginaceae for Sneeuberg and Fumariaceae, Liliaceae, Oxalidaceae, Ranucaluaceae and Campanulaceae for Driehoek) but all of these fluctuations are around 2% or less and are not visually detectable in the published pollen diagrams. The general conclusion from this study is that there has been little environmental change in the area for the last 14 000 years apart from a steady, gradual decline in *Widdringtonia cedarbergensis* pollen from around 8% to about 1-2%. As several global climate events occurred during this period (the MWP and LIA see above) it would seem that vegetation in this part of the Cederberg appears to be very stable despite variations in climate, or that the geographical position of these sites in some way buffered them from changes in climate.

In contrast, the Pakhuis study (Scott and Woodbome 2007a, 2007b) suggest much greater changes in vegetation in the Cederberg. The study covers a longer time period (the last 23 000 years to 180 BP), and has much better temporal resolution than the Meadows and Sugden (1991b) study, but if sections of the same age are compared, the Pakhuis record shows major changes from post glacial conditions into the Holocene. The Pakhuis study site today is also in a much drier area of the Cederberg than Driehoek. Around 16 000 BP there is an increase in *Dodonea* scrub vegetation (a type not found today at De Rif or Driehoek) which may be related to the end of the LGM. Around 9 000 BP succulent and scrub vegetation dominate interspersed with peaks of *Olea* and Cyperaceae, which may be indicative of alternating wet and dry periods as suggested by the wetter conditions at Elands Bay between 11 000 and 9 600 BP (Klein 1984, 1986a). Asteraceae rich shrubland were established by 8 000 BP with a decline in succulents (Azioaceae type (Scott and Woodbome 2007a)). By 4 900BP succulents had increased suggesting an increase in aridity. There is a gap in the record between 4 900 and 2 800 BP, then Cyperaceae peaks around 2 800, 2 000 BP and 500 BP, while fynbos elements increased slightly up until 1 000BP. Increases in Cyperaceae are interpreted as wetter periods while succulents are seen to indicate drier periods.

Many of the Pakhuis vegetation types (Scott and Woodbome 2007b) have no analogues in either the current study or in the Driehoek study (Meadows and Sugden 1991b), but the comparison is informative as it highlights the large differences in vegetation through time and at sites that are about 35 km from each other. It would appear that the vegetation of the Pakhuis site is less stable and rapidly changes in response to climate changes that are reflected at other sites such as Elands Bay while the Driehoek vegetation appears to be very stable and does not alter when there are regional changes in climate.

2.3.5 Historical information about the De Rif site

2.3.5.1 Introduction

The following section summarises the information available about the study site, De Rif, and how it may have changed through time. Archival sources were used as well as repeat photographs for the site from 1934 and 2007 and information from an interview conducted by Daniela Bonora as part of her masters thesis (Bonora 2009). With all sources an attempt is made to link the information back to land use, changes in vegetation and potential pollen indicators that can be used to provide a timeframe for the core used in the palaeoecological section of this study.

2.3.5.2 Archival sources

There is currently a plantation of cedars above the De Rif site and this was used in order to search for historical references about this site that may have been included in the Department of Forestry and government records. A 1937 map of the Cederberg Forest reserve showed the distribution of cedar plantations (Hubbard 1937) at that time. Three Cedar plantations were established around De Rif and these were the "Gabriel", "De Rif' and "Hartbeeskloof' plantations. These names are still in use today as they are found in the official Cederberg map (1981). The most likely interpretation is that the De Rif plantation is the current plantation visible above the old farmstead, while the Gabriel and Hartbeeskloof plantations burnt down at some stage in the past. These names were used when searching through archival sources. The following table is a summary of the data found pertaining to the establishment of Clanwilliam Cedar plantations from 1896 to 1919 (Hubbard 1937) that were in the general vicinity of De Rif, or whose exact location were not recorded but may have been De Rif. Sections which provided useful information on the growth a cedars, which is helpful when trying to establish a relative age for pollen recovered as part of the study, were also included.

Table 3 Potential dates for the establishment of the Cedar plantation above De Rif
All reports by D.E. Hutchins as part of the annual Conservator report (Hutchins 1897, 1901, 1904, 1905, 1906), spelling and measurements as they were in the original sources.

Year	Action taken	Comment	Importance
1896	25 acres ploughed and sown with Cedar seed at the Plantation on the Cederberg Mountains	Cederberg Mountains: "A small trial sowing made in Oct 1895 continues to look well... now average 9 inches high... further 25 acres ploughed and shown with 1000 lbs of Cedar seed" and "50 lbs of Cedar seed were also dibbled in on various selected places on the mountain, amongst rocks, where there is little soil, and where, for this very reason, destruction from fire is little to be feared"	First attempt to establish Clanwilliam cedars in the Cederberg
1900		Trees sown in 1896 at Honigvlei are 11 foot high.	Rapid growth of cedars possible, 11 feet in 4 years
1903	Plantations of Cedar extended by sowing 29.1 acres with 900 lbs of Cedar seed.	Oldest trees of Cedars planted at Hoenig Vley in 1896 are now 16 feet high. Those from sowing are 7 feet high.	Growth of 7 feet in 7 years recorded from seeds
1904		"459 lbs of cedar seed have been sown in the existing plantations on the mountain"	
1905	17 040 cedar transplants planted **125** lbs seed shown over 3 acres	Mention of 5 established small plantations, Algeria slopes, Kiel Vlei I and II, Jurysburg Plateau and Moeder Seels Hoek II (at Hoenningvlei)	

The De Rif plantation may have been planted relatively early due to its comparatively easy access and level ground and its proximity to a permanent spring and nearby natural cedar population. From the table (Table 3) it can deduced that the earliest date a plantation could have been established at De Riff may have been 1895 (Hutchins 1897) although the exact location of the Cederberg Mountains Plantation mentioned is unknown. It is possible that these plants may even have reached a height of 11 feet in 1900 if they grew at the same rate as those grown at the Honigvlei site (1900 report). Even if the De Rif trees did not reach such great heights, if they were planted at the same time it is likely that these trees were producing pollen by 1900. However, as the specific sites "Gabriel", "De Rif' and "Hartbeeskloof' were not found in these records, it is still not possible to limit the age range for the establishment of the plantation from the general age of establishment given by Hubbard as 1896 to 1919 (Hubbard 1937). It is possible that the name of the area had changed from the 1900s to when Hubbard produced his map in 1937.

A database of loan farm records produced by Leonard Guelke was also searched using the names listed above. This had been complied from the Receiver of Land Revenue archival records (also called *oude wildschutte boeke)* housed at the South African Archives, Cape Archives Depot. This covers the period from 1687 to 1793. It did not have any mention of a farm called De Rif, Drie Hoek or Gabrielpas. Although there were several loan farms registered under the name of Gabriel found in the vicinity of the greater Oliphants River area as it was then called, from the description it was not possible to determine where in the landscape these loan farms were. It is possible that the farm post dates these early records or that it was known under a different name during that period.

2.3.6 Repeat photographs

The two photos in this section are repeat photographs of the De Rif site. The first was taken in 1934 by Ken Howes-Howell, a mountaineer, and forms part of a series he took documenting the Cederberg. The collection is held by the library at the University of Cape Town. The second was taken by Timm Hoffman in 2007, as part of a larger project to re-photograph the areas that Howes-Howell and other photographers had photographed in order to evaluate changes in vegetation and land use in the last century. The core for this study was extracted from the light green area in the 2007 photo which is the De Rif wetland.

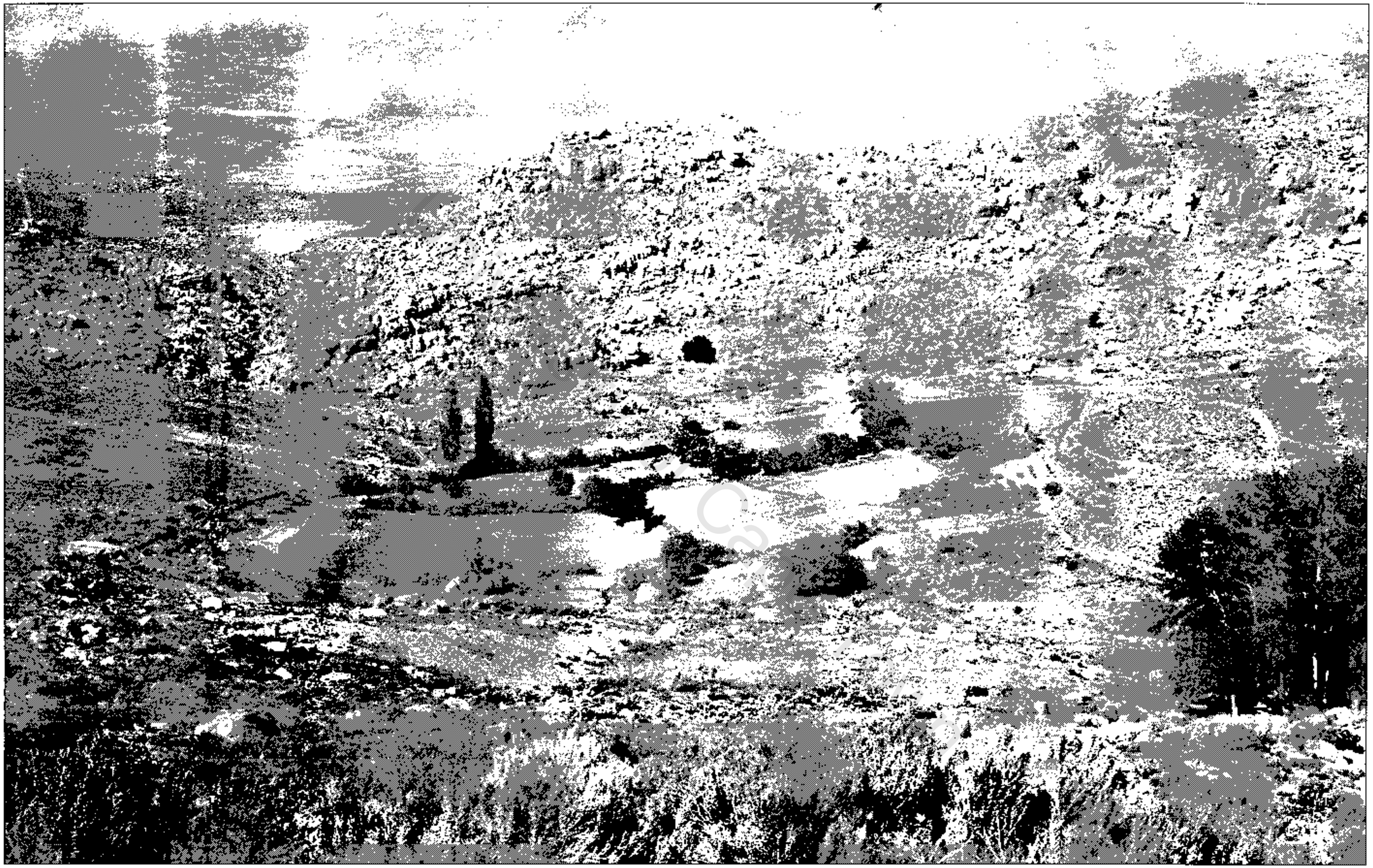


Figure 4 De Rif and the Vissers' Farm 1934

Figure 5 De Rif and the Vissers' Farm 2007

2.3.6.1 Disturbance visible from 1934 photo

The 1934 photo shows several forms of disturbance at De Rif. The terraced fields, which were ploughed in order to grow wheat and possibly other cereals, show the extent to which people modified the landscape. The terraces are still visible today, especially after the vegetation has burnt, but are not obvious in the 2007 photo. They are made up of rocks, stacked into walls, and back-filled in order to create level fields with a deeper soil layer. This probably involved a lot of disturbance both to the donor site and to the area where the fields were created. The farmhouse is visible to the right of the farmstead and would have been built from local stone. Wood for beams and furniture would also have been sourced locally, most probably from Cedar trees and restios (a common name for members of the Restionaceae family) for thatching the roof would have been harvested from the vegetation around the farmstead.

Although livestock are not present in the photo, the numerous tracks visible in the photo show their presence in the landscape and are suggestive of the trampling and vegetation transformation that livestock are capable of. It is uncertain where the livestock were kept at night as no such structure is visible in the 1934 photo, but about 150m below De Rif on the donkey track, several round walled structures are present and these may have been the kraals for this farmstead. The vegetation of this area also has a disturbed nature as grasses are dominant in the landscape.

The 2007 photo shows the extent to which the area has been transformed since its inclusion in the Cederberg Wilderness Area. The exotic trees have all been removed. The farmhouse has been broken down (although the foundations are still present on the site). Although not visible in the 2007 photos, the terraced fields are still present on the site today. The light green in the photo marks the edge of the wetland which was not visible in the 1934 photo. Either the wetland has shifted position, or was ploughed over or it was obscured by the trees in the 1934 photo. The silvery grey vegetation in the 2007 photo is *Stoebe plumosa* (now known as *Seriphium plumosum).*

2.3.6.2 Tree species in the 1934 photo

The tree species were identified with the help of Duncan Ballantyne (forestry diploma, Saasveld). The two tall trees look like cypresses but on closer examination have a branching structure more like that of Lombardy Poplars *(Populus nigra).* The tees in the foreground look like poplars *(Populus deltoids)* while the other big trees are most probably oaks *(Quercus* spp) as these were commonly planted around farmsteads in the Cederberg. It was not possible to identify what the hedges were while the smaller trees in the photo were most probably deciduous fruit trees.

2. 3. 6. 3 Oral history about De Rif farmstead

Several families have lived in the Cederberg for generations and hence interviews with people can be an important source of historical information. Irene Spamer, who lives at Drie Hoek farm and whose family has lived in the area for several generations, was interviewed by Daniela Bonora on the 23 August 2007 (Bonora 2009). According to this interview, the Visser family lived at De Rif They were "bywoners" or tenant farmers. When trying to find a date for when the occupation of the farmstead began, Mrs. Visser suggested that many of the bywoners occupied farms after World War II. However, the Howes-Howell photo taken in 1934 (Figure 4) obviously predates this, and in the same interview Mrs. Visser talks about a woman who was born in 1939 at De Rif, who said that her father had lived there for a long time before she was born. The house and fields were well established when the photo was taken in 1934 so this suggests that the latest date for the establishment of the farmhouse was around the beginning of the 1930s but the farmstead is probably several decades older than this. The Visser family left the farm in 1947 in order for the children to attend school, but whether the whole family left the farm, or only the children, is not clear from the interview. The farmhouse was broken down and exotic trees felled most probably after the declaration of the Cederberg Wilderness Reserve in 1973 (Government notice 1256 1973).

According to the Spamer interview, the Vissers mainly grew wheat, which was sown and harvested by hand and threshed on clay threshing floors, probably constructed from mud from the wetland. They also planted fruit trees including peaches, pears, quinces, and grapes. As for livestock they kept pigs, goats, sheep, cows and donkeys. Transport was by wagon using donkeys. As part of a bywoner lifestyle the Visser family probably grew crops in excess of their own needs and gave these to the family who owned their land (probably the Drie Hoek farm) but whether they engaged in commercial agriculture is debatable. Most probably all crops and food grown was for subsistence purposes or traded for goods with neighbouring farmers or in Citrusdal or Wupperthal.

2.4 CONCLUSION

From this literature review it is clear that people have been part of the landscape of the Western Cape and the Cederberg for thousands of years. Archaeological and historical records provide tantalising glimpses as to what people were doing in the landscape, but these records are often shaped by the people who recorded them and still leave large gaps in our knowledge as they very seldom capture why people were doing what they were doing in the landscape. They do suggest that people have been using fire in the fynbos region for thousands of years (Hall 1984, Deacon 1992). During this time there have been several changes in climate although this does not seem to have affected the vegetation of the mountainous areas of the Cederberg in the last 14 000 years (Meadows and Sugden 1991b). Historical records about De Rif are fragmentary despite an extensive search through various archival sources but have provided information about the establishment of the cedar plantation above the site which is a useful pollen indicator. The repeat photographs of De Rif are an invaluable resource as well as the oral history of the farm. They indicate the kinds of disturbance that were taking place at De Rif such as wheat farming and livestock herding, and the tree species visible in the 1934 photographs provide useful information about potential pollen indicators and will help provide a timeframe for the farmer period of the core. This information will place the current study in context and help interpret the data collected.

3 METHODS

3.1 FIELD METHODS

3.1.1 Collection of core

For this study a core that captured the transition from hunter-gatherers and herding to farming and wilderness management was needed. As a result, a wetland situated within an abandoned farmstead was chosen within the Cederberg Wilderness Area. Core DH5 was extracted from S 32°26' 32.3880" and E19°13' 55.1280", 1200m above sea level from a small wetland. The wetland is visible as the light green area in Figure 5. The core was 1.6m long and used for all laboratory and palynological analyses for this study. A rocky layer at 1.6m prevented further coring and probably marked the depth of the accumulated sediment at this site.

To core the site, an irrigation pipe of 7.5cm in diameter cut into 2m lengths was used. A handle attached to the pipe enabled the corers to hold onto the pipe and push it down into the sediment. To retrieve the core a rubber bung was inserted into the top of the pipe creating a seal that kept the sediments in place while the core was removed from the sediment. Once the core was horizontal, surplus piping was sawn off and the ends were packed with plastic and sealed. The core was labelled and measured. The cores were kept horizontal and transported back to Cape Town. At the University of Cape Town the pipe was split in half using an angle grinder and a thin wire that split the core into separate halves with little or no displacement of the sediment. One half was placed in a plastic sleeve for storage. The other half was described using the Troels-Smith notation (1955) . Both halves were stored in a 1°C fridge to inhibit the growth of mould.

3.1.2 Vegetation survey

In order to determine the abundance and diversity of grasses on De Rif a rapid vegetation survey was carried out in February 2009. The site was examined in August 2008 but very little vegetation was present on the site due to a fire in January 2008. The survey was divided into two adjacent areas. Both were situated above the jeep track at the De Rif site and had been completely burnt. The first area was on the previously ploughed fields of the De Rif farm. The extent of the fields was recognisable from the stone walls demarcating the different terraces and from the photographs taken of the site in 1934. The ground had been cleared and the stones piled in heaps next to the fields. The unploughed area started about 200m to the north of the old farmstead but on the same elevation and substrate. The two sites were distinguishable during the survey as in the unploughed site rocks were scattered throughout the area, not piled into heaps and there was no evidence of terracing while in the ploughed site there was.

Two transects of 200m were surveyed in the previously ploughed and unploughed area each. Every 2m along a transect a point was dropped and whatever the point landed on was recorded leading to a total of 200 points surveyed for each area. Categories consisted of small shrubs (<30cm), medium shrubs (> 30cm) bare ground, rock, dead rooted plants, herbs (non woody plants), sedges and grasses.

Grasses were identified to a species level in the Bolus Herbarium, Botany Department UCT, from a shortlist compiled from the Cape Nature species list for the Cederberg and with comparison with species listed in Goldblatt and Manning (2000) for the north western region of the Western Cape. The "Guide to Grasses of southern Africa (van Wyk and van Oudtshoorn 2004), "Grasses of southern Africa" (Gibbs Russell et al. 1990) and "A revision of Pentaschistis" (Linder and Ellis 1990a) were also used to provide extra information on distribution and photosynthetic pathways. Grass identification was verified by Dr Tony Verboom (UCT) and Terry Trinder-Smith from the Bolus herbarium. The sedges were identified by Dr Muthama Muasya (UCT).

Some species of grass and sedges were not identifiable to a species level as they did not have inflorescences at the time of collection and were identified to genus level only. In total 13 species of grass were collected of which 12 were identified to a species level. Two species were found adjacent to the site near the wetland and were identified but were not included in the grass proportions. In order to analyse the grass community of the ploughed and unploughed sites, grasses were put into categories according to their general distribution patterns. Grasses in the "Fynbos" category only occurred in the fynbos biome, "Generalist" grasses were species that were found throughout South Africa, while "Weed" denoted declared weed species, information from Gibbs Russell (1990) and Linder and Ellis (1990a).

3.2 LABORATORY METHODS

3.2.1 Chronology

To establish a chronology for the core a combination of dating techniques were used. Firstly AMS dating was used to determine the age of the base and the middle of the core. After an initial pollen analysis was completed it was suspected that the top of the core contained sediments from the last 100 years and hence was sampled for Pb-210 dating (Appleby et al. 1979). The dates for the introduction of various crops in South Africa were also used in order to provide relative age horizons as well.

3.2.1.1 Radiocarbon Dating

Accelerator Mass Spectrometry (AMS) measures the number of ^{14}C atoms in a sample, which differs from conventional radiocarbon dating, which measures the radioactivity of a sample as it decays over time. With AMS dating a much smaller sample is required, enabling higher chronological resolution. Smaller samples are stratigraphically and therefore temporally more constrained because fewer sedimentary levels of different ages are combined in a sample. As this results in a more accurate determination of the age of the sample, AMS dating is the preferred technique for high resolution palynology, such as in this study.

14c is formed when cosmic rays enter the atmosphere and collide with nitrogen atoms, knocking a proton off the nitrogen atom, and donating a neutron. This creates a carbon atom with six neutrons and eight protons called ^{14}C, a radioactive atom with a half-life of 5 730±40 years. ^{14}C combines with oxygen to form carbon dioxide that is then incorporated into the terrestrial carbon cycle through photosynthesis. Organic mater containing ^{14}C is later incorporated into the soil when the organism dies. This organic matter is then incorporated into the soil where the ^{14}C decays over time and its concentration can later be measured and the age since burial determined.

Analysing a sample for ^{14}C involves determining how many ^{14}C atoms have decayed since the sediment was buried. Results are presented as the age of the sample in years BP (before present) where "present" is defined as 1950. This method is based on the assumption that the amount of ^{14}C in the atmosphere has remained constant over time and that the ^{14}C in living plants and tissues is in equilibrium with that in the atmosphere.

This assumption is not correct, as ^{14}C concentrations in the atmosphere have varied over time. To mitigate for this, calibration curves of past ^{14}C concentrations have been determined by measuring the ^{14}C that was incorporated into living things in thepast and preserved such as in tree rings. In the Southern Hemisphere the ShCa104 curve developed by McCormac et al (2004) is used to calibrate dates. AMS radiocarbon ages can be converted into calibrated age in calendar years, reported as BC or AD, using a calibration programme such as OxCal (Bronk Ramsey 1995, 2001, 2008).

Samples were taken from core DH5 at depths of 80cm and 160cm using a parallel pair of razor blades in order to remove as small a stratigraphic, and therefore chronological, slice of sediment as possible. Care was taken to avoid contaminating the samples with sources of carbon. The samples were wrapped in aluminium foil before being packaged and sent to the Poznan Radiocarbon Laboratory at the Adam Mickiewicz University. Pre-treatment to remove possible contamination from bicarbonate in the water, humic acids from decaying plants, dissolved carbon dioxide from the atmosphere, and carbon from humus leaching or adsorbing into the sediments or down the sediment profile was by a three step acid-alkali-acid process.

The samples were run on a 1.5 SDH-Pelletron model "compact carbon AMS" series 3 manufactured in 2001 by the National Electrostatics Corporation, Middleton USA. The sediment is combusted and carbon dioxide is evolved. The gas is then ionised by bombarding it with caesium ions and focused into a fast moving beam of negative charges. This beam is accelerated and broken up into smaller ions then filtered so that only ^{14}C ions travel onwards. The detector at the end of the accelerator then counts the number of ^{14}C isotopes that reach it. The reading obtained is recorded and then analysed. The mass of the sample is taken into consideration and standard error for the technique and the laboratory is included with the age estimation. Ages can then be calibrated to give a date in calendar years using standard calibration programmes such as OxCal (see section 3.3) or left as ^{14}C years.

3.2.1.2 Pb-210 Dating

A naturally occurring isotope of lead, Pb-210 is part of the uranium radioactive decay series. Uranium is present in all soils and since it has a half-life of 4.468 x 10^9 years, is considered to be present at an unchanging concentration through time. One of the products of the uranium decay series is radium (Ra-226). When it decays it forms the inert gas radon (Rn-222), which escapes into the atmosphere from the soil surface and decays into polonium (Po-218). Po-218 falls back down to earth with dust and rain and decays to form Pb-210. Pb-210 becomes incorporated in the sediments of water bodies and buried under accumulating layers where it decays with a half-life of 22.3 years. As this half-life is relatively short, this technique is used to date soils that are younger than150 years old. Pb-210 is also present in the soil due to the in situ decay of uranium. This means that two rates of radioactive decay; that of Pb-210 from the sediments (supported Pb-210) and that of Pb-210 from the air (unsupported) have to be measured. A model is used to calculate the inputs of supported and unsupported Pb-210 to the sediment called the constant rate of supply (CRS) model (Oldfield et al. 1978). This model assumes that unsupported Pb-210 is being supplied to the sediments at a constant rate. This model is convenient, as the rate of sediment accumulation does not have to be constant over time in order to accurately calculate the age of the sediment. This is useful as recent sediments often have an increasing rate of accumulation due to erosion caused by modem land use. This provides a more accurate calculation than earlier constant initial concentration models (Appleby et al. 1979).

The measurement of Pb-210 requires between 1-2g of dried sediment and 10-20 samples from sediments that are 150 years old and younger. Where the depth of this horizon is not known, samples are systematically taken from the top of the core downwards at predetermined intervals. For core DH5, an AMS date of the 80cm level had an age of 400±30 years BP. Therefore sediments above this level are assumed to be less than 400 years old and sampling would concentrate on the upper end of the core.

Samples of between 1 and 2g dry weight were taken every 3 cm for the first 58cm of the core and then every 4 cm for the remaining five levels resulting in 24 samples spanning the top 78cm of the core. The first round of the analysis is conducted on an initial batch of 4-5 samples that are used to give a preliminary idea as to the nature and extent of the Pb-210 horizon. Thereafter two further rounds are usually processed to fill in the intermediate levels and fill in the detail. Samples were removed from the core using an isotope spatula after carefully cleaning the surface in order to remove any contaminating sediments. This sampling strategy was adopted with the aim of including several levels of sediments that have no measurable quantities of unsupported Pb-210 left, as required by the CRS model described above.

Sediments were dried in a drying oven at 60°C until they reached a constant weight, were weighed to determine soil water content and then placed in sample bags and sent to the Liverpool University Environmental Radioactivity Research Centre. Here they were allowed to equilibrate for three weeks before being measured using an Ortec HPGe GWL-80210-S well-type coaxial low background intrinsic germanium detector. Lead, copper and sodium iodide shields screen out background radiation enabling the detector to pick up single gamma rays emitted during radioactive decay. Both Pb-210 and 226Ra are measured

3.2.2 Sediment description

Core lithology was described in the laboratory using the scheme devised by Troels-Smith (1955). Sediments were described in terms of five main components: Tufa, Detritus, Limus, Argilla and Grana. Tufa consists of plant remains that are visible to the naked eye. Tufa herbacea consists of roots, intertwined rootlets and rhizomes of herbaceous plants. The Tufa category also has a term for the humicity of the component in it. This is described using a five-point scale with 0 representing the absence of humic matter and 4 being the complete dominance of humic matter. Detritus consists of the above ground parts of plants. Limus consist of mud made up from <0.1 mm fragments of plants and animals and also has a humicity term included using the five point scale described previously. Argilla and Grana record the mineral components of the sediments. Argilla consists of clay and silt while Grana consists of the sand and gravel components of the sediment. After description, the results of the Troels-Smith analysis were described in an MS-DOS file, compatible with the Psimpoll Programme so that sediment description could be plotted alongside the pollen diagram (see section 3.3).

The Munsell colour of each Troels-Smith section was also recorded and presented in the pollen diagram.

3.2.3 Physical Properties Analysis

Loss on ignition (LoI) is a commonly used method to estimate the organic material and carbonate content of sediments but can also be used to determine the bulk density and water content of the sediments. The LoI determination requires three steps. In the first step, weighed samples are dried to constant weight at a temperature of around 100°C and the dry weight recorded. The second step involves exposure to temperature of over 500°C for several hours, in order to oxidise organic matter into carbon dioxide and ash. The new weight is then recorded. In the final step involving further heating at higher temperatures (usually between 900 and 1000°C) carbon dioxide escapes from carbonates in the sediment, enabling carbonate content to be calculated from the final weight of the sample (Dean 1974).

For the analysis of LoI the protocol of Heiri et al (2001) was followed unless otherwise stated. Samples were removed from the core at 4 cm intervals using a 3 ml syringe with the tip removed. Sediments were removed every 4 cm from the top of the core to the base. Two samples of 1ml each were removed from each level. The sediment was then extruded into dry, pre-weighed crucibles. The syringe was washed, rinsed with distilled water and dried between each sample. The crucible and wet sample were then weighed. Samples were placed in an oven at 100°C until they reached a constant dry weight (DW) and were reweighed. For the LoI step, crucibles were placed in the oven in batches of 9 (Heiri et al. 2001).

To determine the LoI at 550°C (LoI550 or the carbon content) the Muffle Furnace was preheated to 550°C and the samples placed in the oven for six hours and then left to cool overnight before weighing. Testing revealed that samples had not reabsorbed moisture during this step as they were adequately sealed in the oven. Crucibles were placed in a desiccator when they were removed from the oven and between weighing.

For LoI at 950°C (LoI950 or the carbonate content) the oven was heated to 900°C. The Muffle furnace used could not reach temperatures of 950°C so there may be some underestimation of carbonate content although probably minimal. Crucibles were placed in the muffle furnace at room temperature and then heated up to avoid cracking the crucibles. Samples were exposed to temperatures of 850°C and above for 2 hours (the oven temperature dropped when the samples were added). The oven was then switched off and the samples left to cool overnight to be reweighed in the morning.

The following equations from Heiri et al (2001) were used.

$$\text{LOI550} = \frac{\text{DW105} - \text{DW550}}{\text{DW105}} \times 100$$

$$\text{LOI950} = \frac{\text{DW550} - \text{DW950}}{\text{DW105}} \times 100$$

$$\text{Bulk density} = \frac{\text{DW105}}{x\ \text{cm}^3}$$

x being the volume of sample, in this case 2cm^3

3.2.4 Pollen Analysis

Samples were removed from the core using a pair of razor blades that were inserted in parallel into the sediment 5 mm apart. The volume of sediment removed for analysis was 1 cm^3 as determined by the volumetric displacement of water in a 10m1 measuring cylinder. The sample together with 5 ml of water was washed into sample vials and stored in a refrigerator. Samples were initially taken every 8 cm down the length of the core. This was increased to 2 cm for the first 66 cm of the core and thereafter 4-8 cm until the base of the core.

Pollen was extracted from the sediment samples using standard procedures outlined in Bennet and Willis (2001) see (Figure 6). Two *Lycopodium* tablets were added to each 1 cm^3 of sediment (step 1). The use of *Lycopodium* tablets allows for pollen concentration to be calculated and to allow for comparison between levels where these concentration may differ due to changes in sedimentation rate (Stockman 1971, Bennet and Willis 2001). The *Lycopodium* tablets were obtained from the Quaternary Sciences research group in the Department of Geology at the University of Lund, batch number 483216. Batch details are listed in Appendix 1 or can be obtained from http://www.geol.lu.se/personal/tsp/Ly483216Eur.pdf .

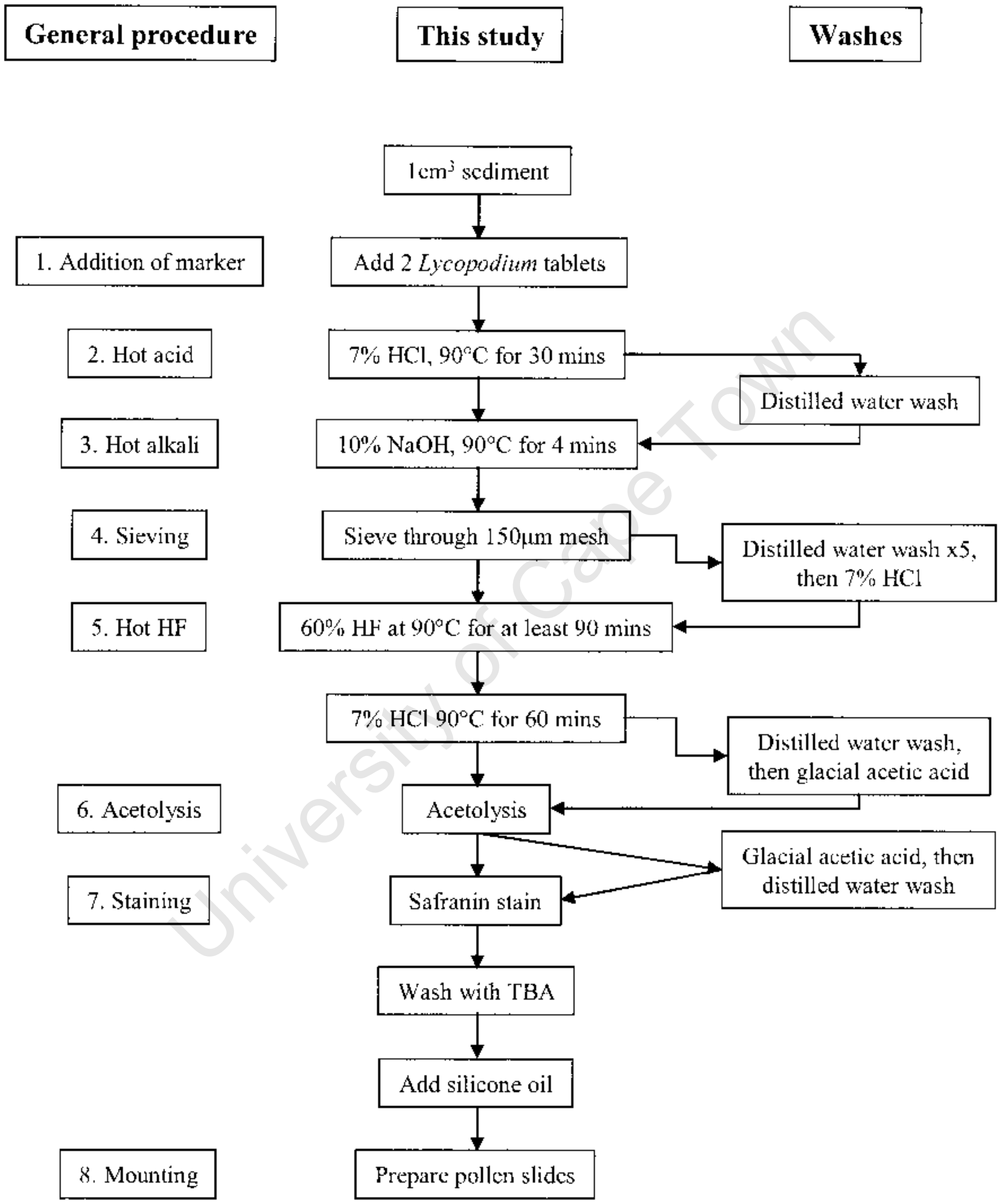


Figure 6 The pollen preparation process.
Adapted from Bennet and Willis (2001). TBA stands for tertiary butyl alcohol

The pollen concentration is then calculated as follows:

$$\text{Fossil pollen concentration} = \frac{(\text{Lycopodium added} \times \text{fossil pollen counted})}{\text{Lycopodium counted}}$$

Equation modified from Bennet and Willis (2001)

Samples were transferred into 30 ml Nalgene® Centrifuge tubes with sealable caps. Samples were mixed using a "whirlimix" during each step. To remove carbonates from the sediments and break up the *Lycopodium* tablets 7% HC1 was added to the samples (second step Figure 6), and they were heated at 90°C for 30 minutes, followed by a distilled water wash. To remove humic acids (step 3, Figure 6), samples were treated with 10% NaOH solution and then heated at 90°C for 4 minutes. The process was halted with the addition of distilled water and the samples are sieved into another set of tubes in order to separate out macrofossils and large silica and rock particles (step 4, Figure 6). The samples generally had little clay in them and thus no specialised chemical treatments or further fine sieving was required. Samples were then rinsed a minimum of five times but generally over 10 times until the supernatant was clear. Samples were then washed again with 7% HC1 to acidify the sediments.

Concentrated Hydrofluoric acid (HF) was used in order to dissolve silica and silicates from the sediments (Bennet and Willis 2001). HF was added (step 5, Figure 6) and the tubes placed in a water bath at 90°C for at least 90 minutes and were often left overnight to cool. Sometimes a second treatment of HF was required in order to remove all silica. Another wash with 7% HC1 helps remove colloidal silica and silicofluorides created during the HF step (Bennet and Willis 2001).

In a process called acetolysis (step 6, Figure 6) polysaccharides which may otherwise obscure the pollen grains are digested (Erdtman 1960, Bennet and Willis 2001) using a mixture of acetic anhydride and concentrated sulphuric acid. The sediment was transferred into 15m1 tubes in the previous step. After the acetolysis mixture was added the samples were placed in a water bath at 100°C. Glacial acetic acid was added after 2 minutes to stop the reaction. The samples were washed with distilled water for several washes until the pH of the samples tested neutral.

The samples were then stained using 2 drops of undiluted Safranin solution (step 7, Figure 6) which makes the sculptural elements on the grains are more visible (Bennet and Willis 2001) and then washed with distilled water. The samples were transferred into 5m1 sample bottles using tertiary butyl alcohol (TBA), Silicone oil was then mixed into the samples and the tubes left uncovered in order for the TBA to evaporate. The remaining mixture consisted of silicone oil, charcoal pieces and stained pollen and spores. This suspension was stirred before slides are prepared in order to ensure that the pollen grains are equally distributed throughout the mixture. Pollen slides were prepared (step 8, Figure 6) using glass slides and cover slips sealed with clear nail polish. A toothpick was used to depress the cover slip during pollen identification in order to move the silicone oil which turns the grains and allows for more accurate identification. The advantage of using a liquid such as silicone oil as a mounting medium is the three-dimensional structure of the pollen grain can be studied unlike glycerol-jelly mounts that are solid.

Slides were analysed using a Leitz Labourlux K microscope with 10x, 20x, 40x and 100x objectives, although most identification took place at 400x magnification. An oil immersion objective was used when a higher magnification of grain elements was needed. The calibrated stage of the microscope was used to systematically traverse the slide at 1 mm intervals. For each slide a minimum of 400 grains were counted to allow for the calculation of 95% confidence intervals (Maher 1972). Counting continued until at least 200 grains other than Cyperaceae were counted. Pollen was identified using reference slide collections (housed in the Department of Environmental and Geographical Sciences and the Botany Department, UCT), general reference books on pollen (Bonnefille and Riollet 1980) (Moore et al. 1997) and the African Pollen Database (http://medias.obs-mip.fr/pollen/). Reference slides were made for *Widdringtonia cedarbergensis* from a specimen housed in the Bolus Herbarium at UCT, as well as of several Restionaceae and Cyperaceae species found on the site. Using previous palynological work completed in the Cederberg (Sugden and Meadows 1990, Meadows and Sugden 1991b) a reference poster was drawn up using photographs of the fifty most common pollen grains encountered in Cederberg studies.

Using various references on the vegetation of the area and in the Western Cape (Taylor 1996, van Rooyen and Steyn 1999, Trinder-Smith 2003) and the plant species list developed by Cape Nature, grains could sometimes be identified to a genus or even species level. Where pollen was not identifiable it was classified as either unknown, concealed or degraded. Concealed and degraded grains were not included in the pollen sum. Pollen grains were counted whilst scanning the microscope slides and were tallied up in workbooks and the data was later entered into Excel spreadsheets for further analysis. Unknown grains were sketched or photographed and also tallied up and later identified using reference collections or the help of Dr L Gillson (UCT).

3.2.5 Charcoal Analysis

Charcoal abundance was estimated using the point count estimation of Clark (1982) on the same slides that were used for pollen analysis. This method is considered quick and accurate (Clark 1982) and can be easily adapted to any microscope that has a calibrated stage. A sampling grid was devised so as to transverse the slide to sample all areas of the slide equally. The eyepiece micrometer is used to sample the field of view (f.o.v.) at certain pre-determined points. These points are the ends of the lines of 12 eyepiece units forming a total of 22 sampling points, as there is a top and bottom to the lines. At each point on the transect the f.o.v. of the microscope is inspected. If the end of the line falls on a piece of charcoal then this is recorded. The stage is advanced step by step along the transect and each f.o.v. is investigated. The total number of f.o.v. that were investigated per slide is recorded and multiplied by 22 to get the total number of points sampled for the slide. The total number of Lycopodium encountered in all f.o.v. for the slide is also recorded. This allows for comparison between samples which may have different concentrations of pollen by using a calculation based on how many marker spores were originally added to each sample (see equation in section 3.2.4).

In this study the method developed by Clark (1982) was used and adapted so that for each slide at least 30 Lycopodium were counted and at least 50 field of views investigated at 400 x magnification. Only slides that had an evenly spread pollen suspension were used. Charcoal was identifiable by its dark colour and its characteristic sharp edges when compared to pieces of organic matter. Ambiguous small fragments were excluded. Charcoal abundance is expressed as a surface area of charcoal per unit volume of sediment (cm^2cm^{-3}) calculated using the following equation:

$$\text{Charcoal concentration} = \frac{\text{f.o.v.} \times \#\,\text{charcoal hits}}{\#\,\text{points}} \times \frac{\dfrac{\text{Lycopodium added}}{\text{Lycopodium counted}}}{\text{Sediment volume}}$$

Where f.o.v. is field of view

\# is number

These charcoal concentrations were then used to compare charcoal abundances between different levels as the concentration of pollen and charcoal in each layer had now been standardised.

3.3 STATISTICAL TECHNIQUES AND SOFTWARE

Pollen data were plotted and analysed using the Psimpoll programme version 4.27 found at http://www.chrono.qub.ac.uk/psimpoll/psimpoll.html. An online manual was used, see http://www.chrono.qub.ac.uk/psimpoll/psimpoll_manual/4.27/psimpoll.htm. Zonation was carried out within the Psimpoll program using optimal splitting by information content into six zones. Binary splitting (Bennett et al. 1992) was tested as well, and resulted in the same number of zones and in the same places in the pollen diagram. The zonation was run using decreasing number of zones until the smallest number of zones that were statistically significant when compared to a broken stick model of variance were found (Bennet 1996).

Radiocarbon dates were calibrated online using the OxCal program version 4.1, see https://c14.arch.ox.ac.uk/oxcalhelp/hlp_contents.html, (Bronk Ramsey 1995, 2001). The calibration curve for the southern hemisphere was used (McCormac et al. 2004).

Phase diagrams were constructed using the chart builder option found in SPSS version 17.0 released on 23 August 2008 (See http://www.spss.com/). Values were then linked up consecutively in temporal order. SPSS was also used for the construction for box and whisker plots for the analysis of Charcoal. Chi squared and Fishers exact tests were performed using SigmaStat 2.03 (SPSS Inc, Chicago, USA) and a Yates correction for continuity was used when there was only one degree of freedom. Fisher's exact tests were used when over 20% of the values in the contingency table were less than 5. Pollen data was prepared and analysed in Microsoft® Office Excel 2003 student edition. Excel was also used for constructing pie charts and bar charts for loss on ignition diagrams. Flowcharts and timelines were created in Microsoft® Office PowerPoint 2003 student edition, while some figures were also edited using this program.

4 RESULTS

4.1 VEGETATION SURVEY

The results of the vegetation survey, conducted a year after the site had burnt, are presented below. The previously ploughed (hereafter referred to as the ploughed site) and unploughed areas are presented separately in all the results. Table 4 presents the differences between the ploughed and unploughed sites in terms of vegetation cover and vegetation structure. Figure 7 focuses only on the grass component of the survey and shows the general species distribution of the grasses found in the two areas. Table 5 also focuses on the grass component and lists the individual species found in each area and the proportion each species makes up of the total grass cover in each area.

Table 4 The effects of past ploughing on vegetation cover and structure
Significant differences between treatments are marked with * (P < 0.01) or a # (P < 0.05)

		Ploughed	***n* =**	**Unploughed**	***n* =**
Cover					
	Substrate	42.5%	*85*	36.5%	*73*
	Vegetation	57.5%	*115*	63.5%	*127*
	Total		**200**		**200**
Structure					
	Shrub, small	13.1%	*14*	32.2%*	*37*
	Shrub, medium	18.7%	*20*	6.1%*	*7*
	Grasses	33.6%	*36*	30.4%	*35*
	Sedges	15.0%	*16*	19.1%	*22*
	Herbs	12.1%	*13*	7.0%	*8*
	Restios	0.0%	*0*	5.2%#	*6*
	Other	7.5%	*8*	0.0%#	*0*
	Total		**107**		**115**

There was no significant difference in vegetation cover between the ploughed and unploughed sites although the ploughed site had less vegetation cover. There were highly significant differences within the shrub component of the two areas as determined using a chi squared test (Table 4; $x^2 > 7.1$, $P < 0.01$). Small shrubs were more abundant in the unploughed area while medium shrubs were less abundant. Restios were more common on the unploughed site (chi squared test result Table 4; $x_1^2 > 3.9$, $P < 0.05$, power 0.5). Vegetation falling into the "other" category, such as soil crusts and mosses, was more common on the unploughed site (chi squared test result Table 4; $x_1^2 > 3.9$, $P < 0.05$, power 0.8) but the analysis lacked statistical power. Herbs were more abundant on the ploughed site, but not significantly so. There were no significant differences in the grass and sedge component between the two areas. Dead vegetation which mostly consisted of protea skeletons was not included in the structural analysis.

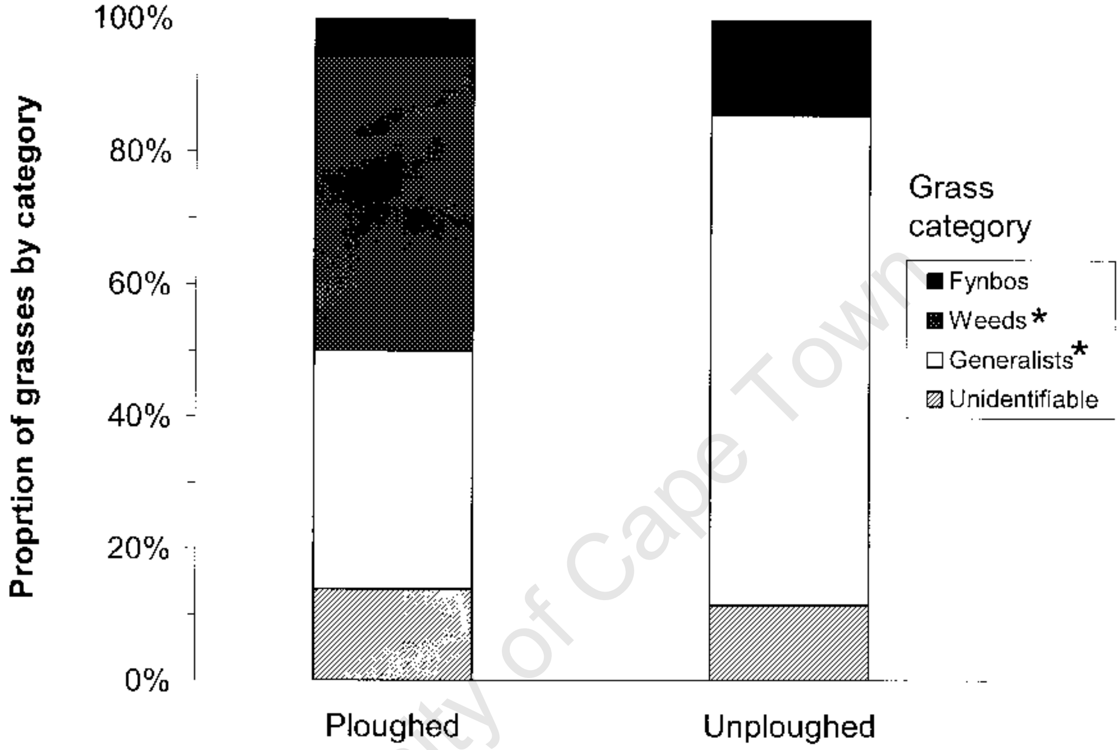


Figure 7 The effects of past ploughing on the grass community of De Rif
Significant differences between the treatments are marked with an * (chi squared and Fishers exact test **P** l.005). See methods for statistical treatments and grass categories

The most abundant grass category in the ploughed area was the weedy grass category, and no weedy grasses were on the unploughed area, making it highly significantly different from the unploughed area ($x_1^2 > 17.6$, $P < 0.0001$; Figure 7). Generalist grass species were significantly less common on the ploughed area than on the unploughed area ($x_1^2 > 8.9$, $P < 0.005$, Figure 7). The proportion of the grass component made up of fynbos endemics and unidentifiable species was not significantly different between the two areas (Figure 7).

Table 5 Proportion (%) of identified grass species found in the ploughed and unploughed area at De Rif of the total grass component

Distribution and habitat information from Gibbs Russell (1990) and Linder and Ellis (1990a), see methods

Grass species	% ploughed	% un-ploughed	Distribution and habitat preferences
Bromus diandrus	11.1%	0%	Naturalised weed
Ehrharta calycina	5.6%	5.7%	South Africa
Ehrharta capensis	2.8%	0%	Fynbos, generalist
Ehrharta ramosa	0%	14.3%	Fynbos
Ehrharta sp	13.9%	11.4%	unknown
Hainardia cylindrica	33.3%	0%	Naturalised weed
Tribolium hispidum	0%	20%	South Africa
Tribolium uniolae	2.8%	0%	Fynbos, disturbed areas
Merxmuellera stricta	16.7%	45.7%	South Africa
Pentaschistis pallida	8.3%	0%	Fynbos and Succulent Karoo
Pentaschistis glandulosa	5.6%	2.9%	Fynbos and Savannah
Pentaschistis ampla *	n/a	n/a	Fynbos and Succulent Karoo
Pennisetum macrourum *	n/a	n/a	Africa, wet places

A large proportion of grasses in the unploughed area were ubiquitous South African species of fynbos species (see 3.1.2 for categories) while weedy grasses made up the largest percentage of grass cover on the ploughed site.

All of the grass species identified on the site, apart from the two weedy species *(Bromus diandrus* and *Hainardia cylindrical)* follow the C3 photosynthetic pathway (Gibbs Russell et al. 1990, Linder and Ellis 1990a). The two weedy species follow the C4 pathway (Gibbs Russell et al. 1990).

4.2 CHRONOLOGY

4.2.1 AMS dating

AMS radiocarbon dating showed that the base of the sequence began accumulating at around 2300 BP (400-200 cal yr BC, see Table 6). The date for DH5.800 (core De Rif 5, sample taken at a depth of 800mm, see Table 6) of 1450-1630 cal AD suggests that the top half of the core captures the transition from hunting and herding land use to farming land use in the Cederberg as settlers and farmers would only have moved into the area after the 1720s (Mitchell 2002a). In order to pinpoint when changes in pollen abundance occurred, particularly the large increase in grass pollen, further AMS dating above DH5.800 was conducted. These results are also presented in Table 6. The results were not as expected as the two overlying samples DH5.720 and DH5.500 appear to be older than those below. The age for DH5.720 may be anomalous because of the small amount of carbon recovered from the sample which may have introduced greater error to the dating process and hence this date was discarded from further analyses. The age for DH5.500 still fits within the chronology proposed by DH5.800; the sediments between the two dates are probably of a similar age, representing a period of rapid sediment accumulation.

Table 6 The results of AMS dates obtained for core DH5.

Sample name	Sample depth	Radiocarbon age	Calibrated age	Probability
DH5.500	50cm	545 ± 30BP	1400- 1448 cal AD	95.4%
DH5.720	72cm	1310 ± 30BP*	650-899 cal AD	92.3%
DH5.800	80cm	400 ± 30BP	1450-1630 cal AD	95.4%
DH5.1600	160cm	2320 ±30BP	400-200 cal BC	95.4%

* The sample only contained 0.19mgC and hence the dates should be interpreted cautiously

4.2.2 Pb-210 Dating and pollen indicators

No measurable quantities of Pb-210 were found in the sediments analysed. This would imply that the top of the core is older than 100-120 years old, because this is the usual time horizon for Pb-210 dating (Appleby et al. 1979), but the pollen evidence does not support this interpretation. The top of the core has a large peak in *Widdringtonia cedarbergensis* pollen due to the establishment of a cedar plantation above De Rif about 100 years ago (see section 2.3.5.2 and Table 3) which should be within the time constraints that this technique can detect. It is possible that the age of the sediments was on the cusp of the age that this technique can accurately detect and hence no age determination was made. The lack of published data using Pb-210 dating in South Africa suggests possibly further studies are required in order to successfully apply this technique.

Other pollen indicators include maize pollen which is identifiable because of its large size (Van Zinderen Bakker 1953). A single grain was recovered from 64cm while it is more consistently recovered from 48cm and above. We know that maize was not grown in the Western Cape by indigenous peoples (Mitchell 2002b) prior to the introduction of it by Jan van Riebeeck in the Company Gardens in 1653 (Thom 1952, Smith 1983). It was probably only introduced in the Cederberg after the 1720s (Mitchell 2002a, 2007) along with exotic trees (van Sittert 2000) whose pollen from was initially found in the 46cm level of core DH5.

4.3 SEDIMENT DESCRIPTION

The majority of the sediment which made up core DH5 consisted of a greyish brown matrix of fine sand with clay and humic limus (Troels-Smith 1955) with some small rootlets and occasional charcoal pieces visible while the top 23.5cm of the core differed from this with greater variation in composition and colour with several different layers of material present. The top 4cm of the core consisted of fine sand and densely packed vegetative matter, most probably rootlets. This was followed by a band of fine sand from 4cm to 11.5cm with several visible rootlets. The next layer of sediments consisted of clay with fine plant limus. Between 18.4cm and 23.5cm two rocks were recovered (approximately 5 x 2.5cm and 2 x .5cm respectively). The deepest sediments (from 123.5cm to the base of the core) did not contain small pieces of gravel but were otherwise the same as the majority of the sediment above it. The bottom of the core was deformed when the corer struck the base of the sediments indicating that the wetland probably had a rocky base and if so, the maximum length of sediments possible had been recovered.

4.4 PHYSICAL PROPERTIES ANALYSIS

Figure 8 The organic and carbonate content of core DH5
The solid bars shows the percentage of carbonate present in each sample while the shaded bars show the percentage of organic carbon per dry weight of sample. The bulk density of the sediments is shown on the right of the figure.

The sediments found in core DH5 generally contained low amounts of organic matter and carbonates. Amounts of organic matter and carbonate were lowest in the upper levels of the core. The very low carbonate and organic values obtained from in the first 8cm of the core correspond with sandy layers (see section 4.3 and Figure 9 and Figure 10). The high organic content of samples from 12cm and 16cm correspond with a layer of clay which contained fine plant limus consisting predominantly of small rootlets (see section 4.3 and see Figure 9 and Figure 10). The bulk density of the sediments is relatively uniform throughout the core apart from the top 16cm when the density drops. This is due to the high proportion of sand found in these layers (see section 4.3) and this is less dense than the rest of the sediments making up the core.

4.5 POLLEN RESULTS

The pollen results are presented in two pollen diagrams showing pollen expressed as a proportion of the total pollen sum (Figure 9) and the actual pollen concentrations per cm^3 of sediment (Figure 10) found in different levels of core DH5. The results of the zonation of the two different figures are presented in section 4.5.2 and section 4.5.4 respectively.

4.5.1 Percentage pollen diagram

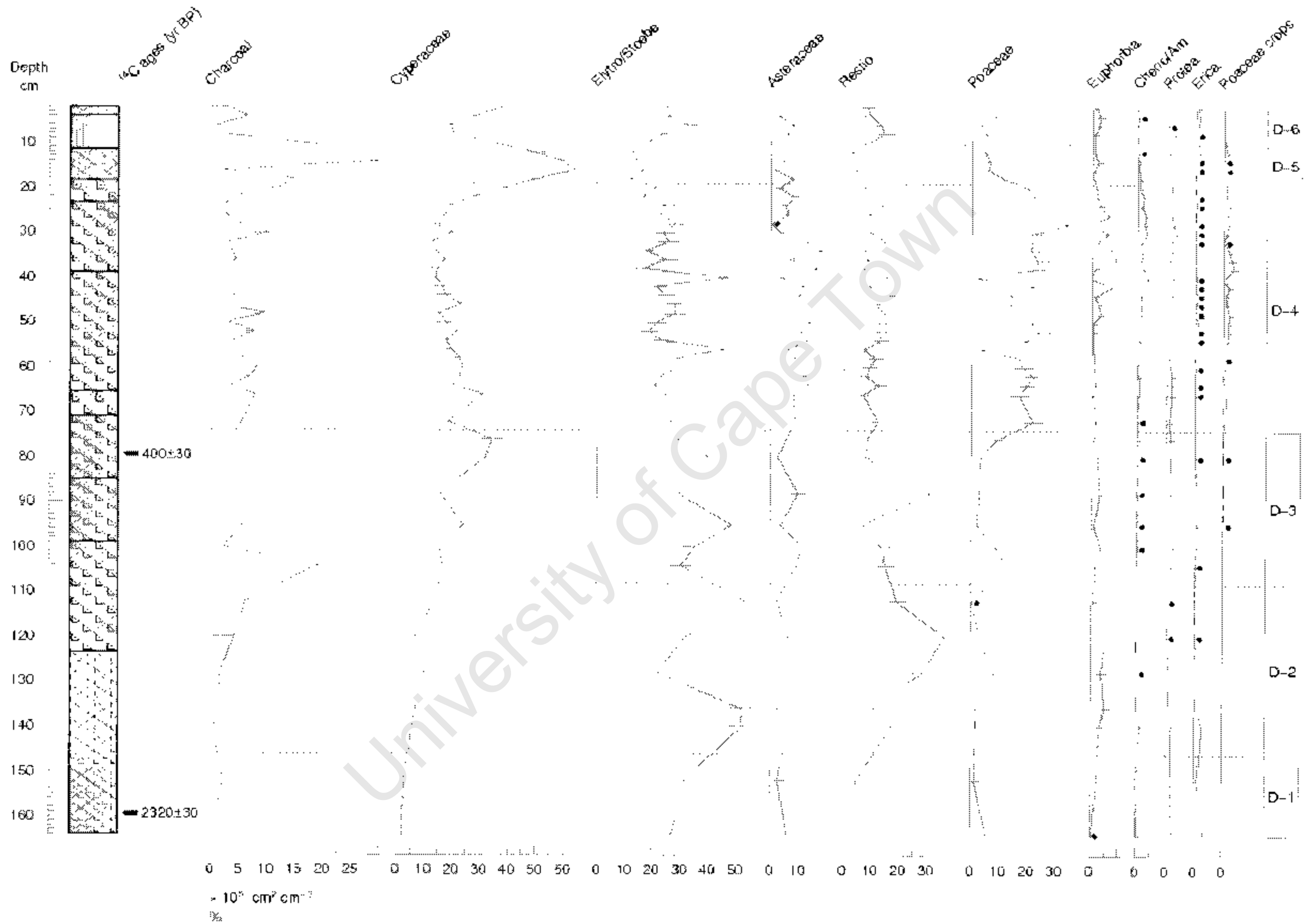


Figure 9 The percentage pollen diagram for core DH5

Pollen is measured as a proportion (%) of the total pollen sum while charcoal is measured in cm^2cm^{-3}. Dots indicate values of 2% or less. The summary diagram (far right) shows the contribution of the most common pollen types to the total pollen sum. Numbers to the left of the summary diagram indicate the total pollen grains counted per level excluding spores. The stratigraphy and chronology of the core are shown on the far left of the diagram while pollen zone labels (D-1 to D-6) are on the far right.

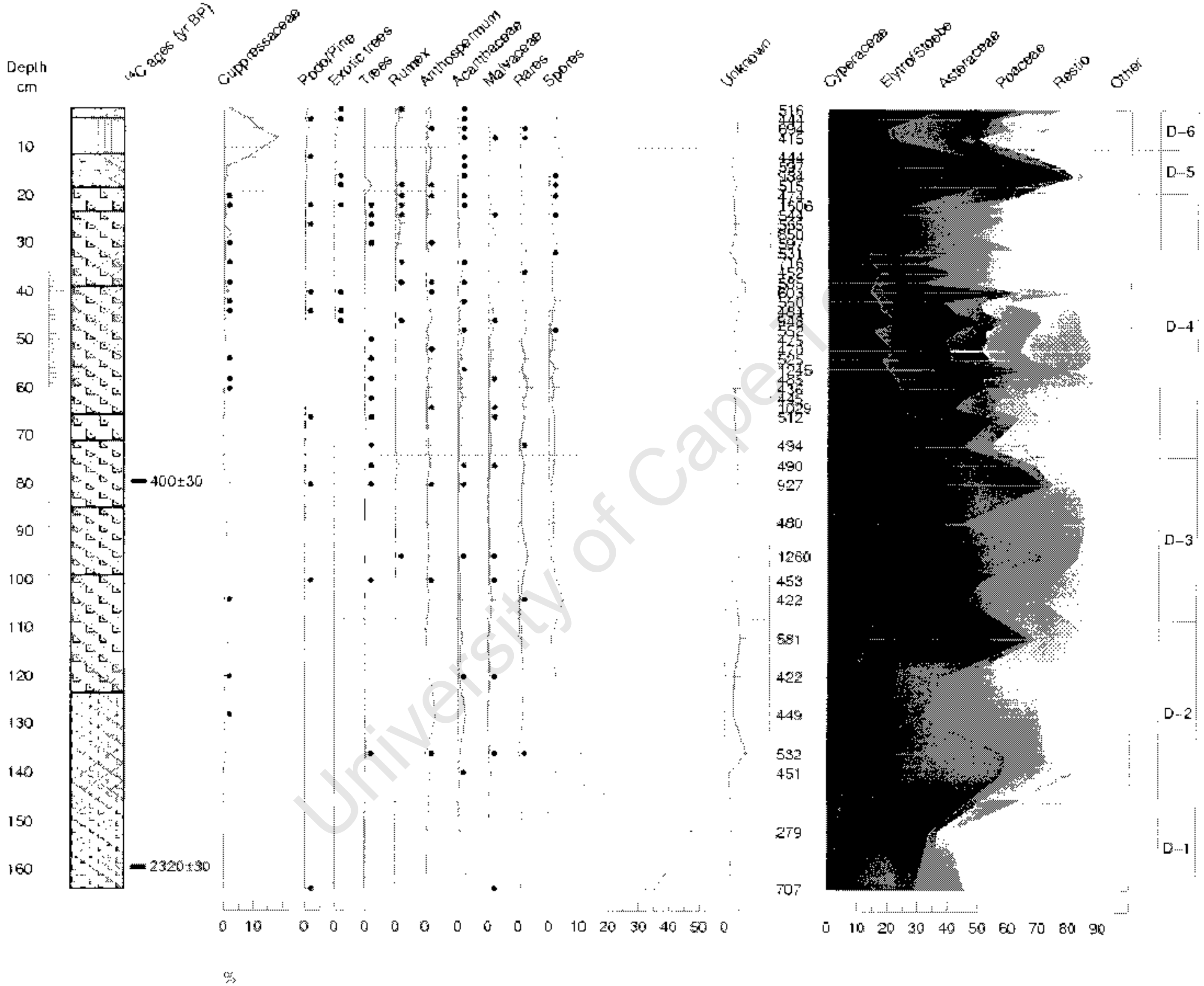


Figure 9 Continued. The percentage pollen diagram for core DH5

4.5.2 Percentage pollen diagram zonation

The results of the Psimpoll pollen zonation programme showed that the pollen data could be divided into six statistically different zones when compared to a broken stick model of variance (Bennet 1996). Each zone represents a section of the core that was similar in terms of the percentage composition of the pollen found within it. The zones are described in terms of their average pollen composition, their charcoal composition and where relevant, pollen grains of interest such as exotic tree pollen.

Zone D-1 146-164cm (2 levels) "the spore zone"

This zone consisted of only two levels; however, these two levels are markedly different when compared to the overlying levels, as spores make up over 42% of the pollen sum. This makes all other grains less common by comparison as pollen was expressed as a proportion in this section. Cyperaceae and charcoal were at their lowest levels in this zone, 2% and 1.4 $x10^{5}\ cm^{2}cm^{-3}$ respectively. Poaceae abundance was low in this zone contributing only 3%.

Zone D2 108-146cm (5 levels) "the Restio zone"

The most common grains in this zone were Elytro/Stoebe (42%) and Restio (22%) which is a generic name for members of the Restionaceae family. Cyperaceae were found at lower concentrations (8%) than in the overlying zones and charcoal concentrations were low at 2.8 $x10^{5}\ cm^{2}cm^{-3}$. Poaceae makes up on average only 3% of the pollen sum. Spores were still common in this zone reaching a high of 10% but an average of 4%. Restio pollen proportions peaked in this zone at 36%.

Zone D-3 74-108cm (6 levels) "the Elytro/Stoebe zone"

Moderate amounts of Cyperaceae pollen and higher amounts of Elytro/Stoebe and Restio pollen characterised this zone. They made up an average of 23%, 35% and 13% of the pollen sum respectively. Charcoal has one peak of 20 $x10^{5}\ cm^{2}cm^{-3}$ but was otherwise found at slightly higher concentrations to those in zone D-2, around 7.7 $x10^{5}\ cm^{2}cm^{-3}$. Poaceae was found at a lower concentration in this zone of 6% but did peak at that same time that charcoal did reaching 12% of the pollen sum at its maximum. The isolated grains of exotic trees found in this zone were probably rare long distance dispersed *Podocarpus* grains that were not distinguishable from the more common *Pinus* grains. The first grains of *Rumex* and wheat were found in this zone.

Zone D-4 19-74cm (25 levels) "the Poaceae zone"

The zone can be defined by a high proportion of Poaceae, a small but constant presence of Chenopodiaceae/Amaranthaceae pollen type (hence know as Cheno/Am) and lower, fluctuating amounts of Cyperaceae and charcoal. Charcoal concentration averaged 5.2 $x10^{5}$ $cm^{2}cm^{-3}$. The most common grains were Elytro/Stoebe at 25%, Cyperaceae at 20% and Poaceae at 19%. Restio pollen makes up around 11% of all pollen. Crop pollen was most common in this zone but still contributes less than 4% at its peak to the pollen sum. Euphorbia peaks in the zone reaching a high of 8% with an average of 2.5%. Grass grains over 90 microns in length, most probably maize, were exclusive to this zone.

Zone D-5 10-19cm (4 levels) "the Cyperaceae zone"

Cyperaceae pollen dominated this zone at around 56% on the pollen sum. The next most common grain was Elytro/Stoebe at 14%. Charcoal peaks in this zone with it highest value in any zone of 30.5 $x10^{5}$ $cm^{2}cm^{-3}$. Cyperaceae and charcoal peaked synchronously in this section with charcoal reaching its peak one level after Cyperaceae did. Cupressaceae pollen, hereafter referred to as *Widdringtonia* (cedar pollen) was also elevated in this zone reaching a high of 8% of the total but declining with depth to the low amounts that were found throughout the other zones (1 % or less). Restio pollen was at its lowest percentage in this section averaging only 4% of the pollen sum. Poaceae makes up the same low proportion of the pollen sum as it did in the zone D-4. Small amounts of what was most probably wheat pollen were found in this zone.

Zone D-6 0 -10cm (4 levels) "the cedar zone"

This pollen zone was closest to the surface of the core. In this zone there was a decline in most pollen taxa especially Cyperaceae compared to the peaks it reached in zone D-5. Cyperaceae and Elytro/Stoebe grains both make up 26% of the pollen on average. Poaceae pollen comprises 5% of the total pollen sum. *Widdringtonia* was more common in this zone than any other zone, making up an average of 10% of all pollen with a maximum of 18%. Charcoal values were on the low side at $3.3x10^{5}$ $cm^{2}cm^{-3}$. This zone contained small amounts of exotic tree pollen.

4.5.3 Concentration pollen diagram

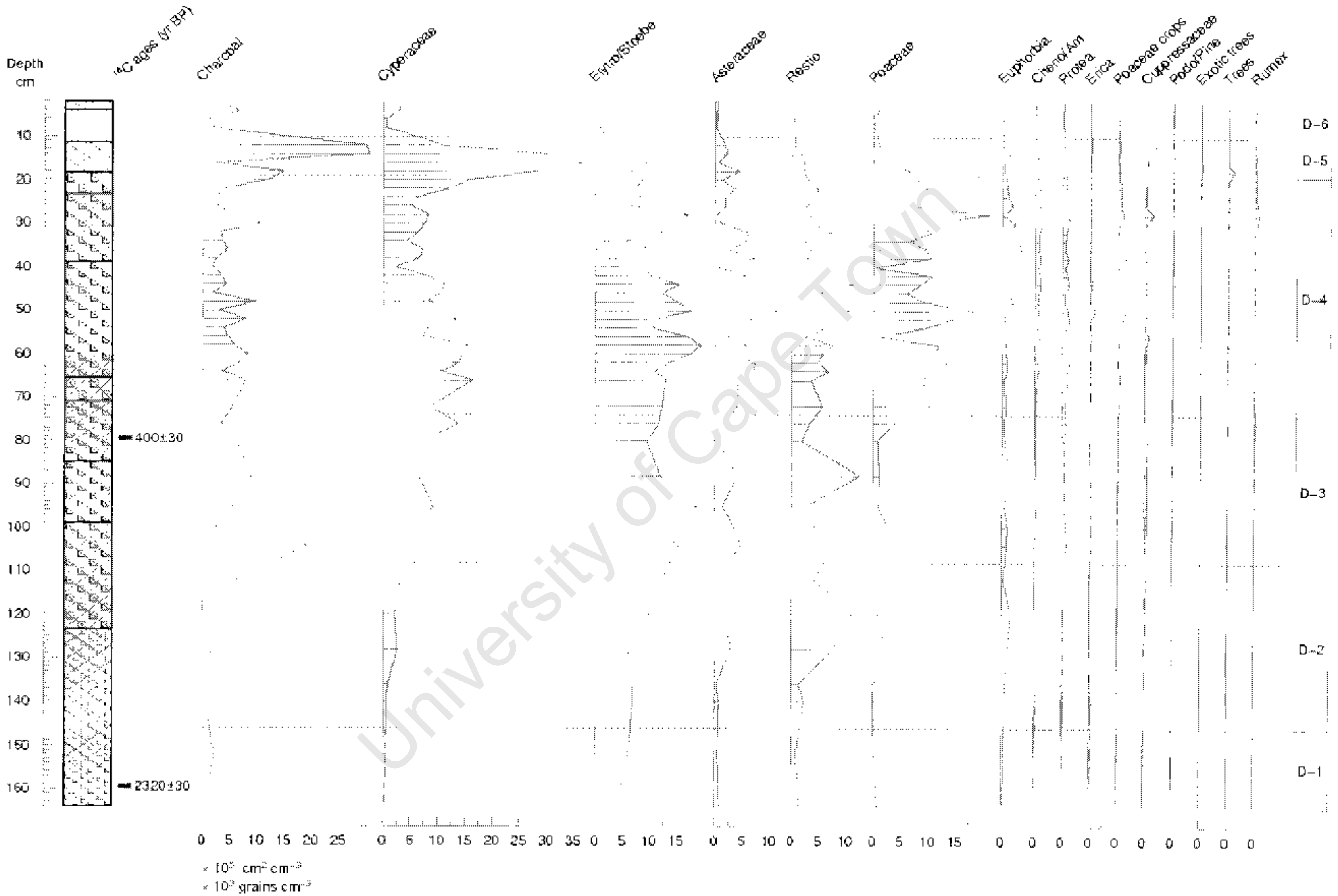


Figure 10 The concentration pollen diagram for core DH5.
Pollen is expressed as the number of 1000 grains per cm^3 of sediment while charcoal is measured in cm^{2}cm^{-3}. The summary diagram shows the contribution of the most common pollen types to the total pollen sum. Numbers to the left of the summary diagram indicate the total pollen grains counted per level excluding spores. The stratigraphy and chronology of the core are shown on the left of the diagram while pollen zone labels (D-1to D-6) are on the far right

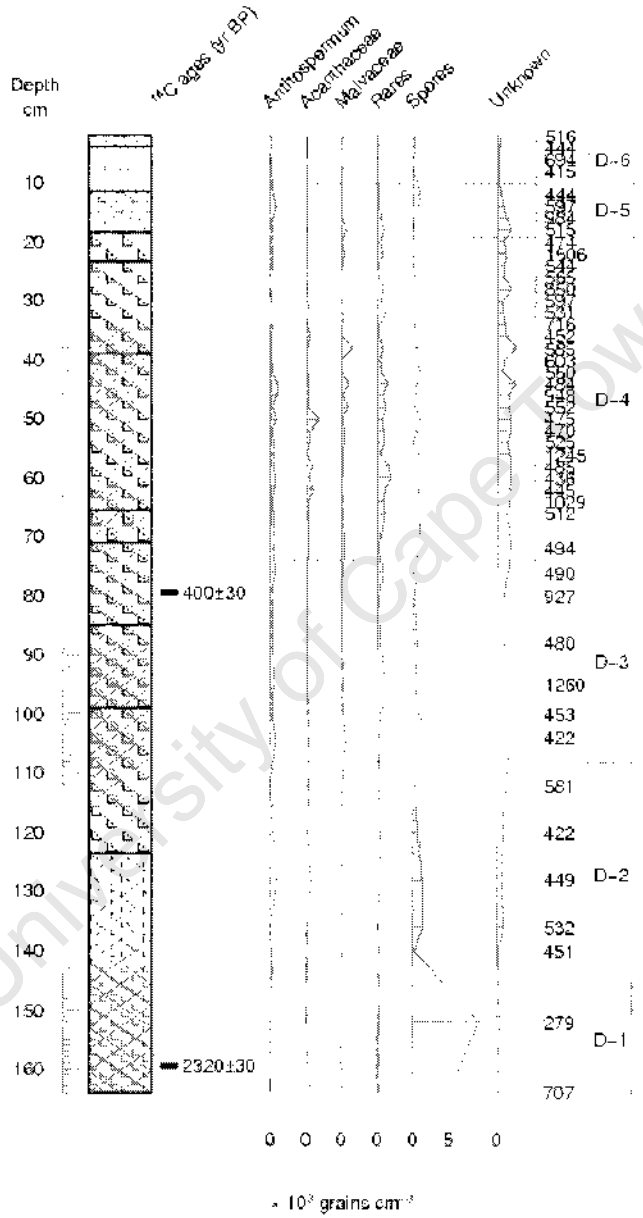


Figure 10 Continued. The concentration pollen diagram for core DH5.

4.5.4 Concentration pollen diagram zonation

The results of the Psimpoll pollen zonation programme divided pollen data into six zones that were statistically different to each other when compared to a broken stick model of variance (Bennet 1996). The pollen within each zone probably accumulated under similar conditions. The number and position of zones was the same whether the concentration or percentage composition data for pollen was used which suggests that the zonation was robust. The zones are described in terms of their average pollen or spore concentration.

Zone D-1 146-164cm (2 levels) "the spore zone"

This zone was singularly dominated by its high concentration of spores (7 000 spores/ cm^3) while having the lowest pollen concentration of any zone (160 000/cm^3). Poaceae crops, *Widdringtonia,* Exotic trees, Trees, and *Rumex* grains are not found in this zone at all. Malvaceae concentrations were at their lowest in this zone

Zone D-2 108-146cm (5 levels) "the Restio zone"

This zone had the second lowest pollen concentration of 300 000 grains/cm^3. Restio pollen was as concentrated in this zone as in zones D-3 and D-4 (between 5 200 and 5 400 grains/ cm^3). Podo/Pine grains were not found in this zone while Poaceae crops, Exotic trees and *Rumex* were not found in this zone.

Zone D-3 74-108cm (6 levels) "the Elytro/Stoebe zone"

Zone D-3 had the second highest pollen grain concentration with about 800 000 grains/cm^3. Both Elytro/Stoebe and Restio pollen were most concentrated in this zone. There were on average 13 000 Elytro/Stoebe grains per cm^3 in this zone. Exotic tree pollen was no longer found in this zone or any deeper zone.

Zone D-4 19-74cm (25 levels) "the Poaceae zone"

In this zone pollen was as concentrated as in all the other zones on average at 570 000 grains per cm^3 of sediment. Elytro/Stoebe and Restio were nearly as abundant in this zone as in zone D-3. Several pollen taxa were most concentrated in this zone such as Asteraceae, Restio, Poaceae, Euphorbia, Cheno/Am, Protea, Poaceae crops, Acanthaceae, Malvaceae, Rare and Unknown grains.

Zone D-5 10-19cm (4 levels) "the Cyperaceae zone"

This zone had the highest pollen concentration of all the zones, on average 2 000 000 grains per cm^3. Cyperaceae pollen was three times more concentrated in this zone than in the next highest zone. *Widdringtonia,* Podo/Pine and Exotic trees were all at their highest concentration in this zone as were Rumex and Anthospermum grains.

Zone D-6 0 -10cm (4 levels) "the cedar zone"

This zone had a low pollen concentration of 340 000 grains per cm^3. Elytro/Stoebe, Asteraceae, Restio, Poaceae, Euphorbia, Cheno/Am, Protea, Erica, Poaceae crops, Trees, Anthospermum, Acanthace, Rares, Spores and Unknown were all at their lowest concentration in this zone. *Widdringtonia* was at its second highest concentration, as was Podo/Pine and Exotic trees.

4.6 CHARCOAL RESULTS

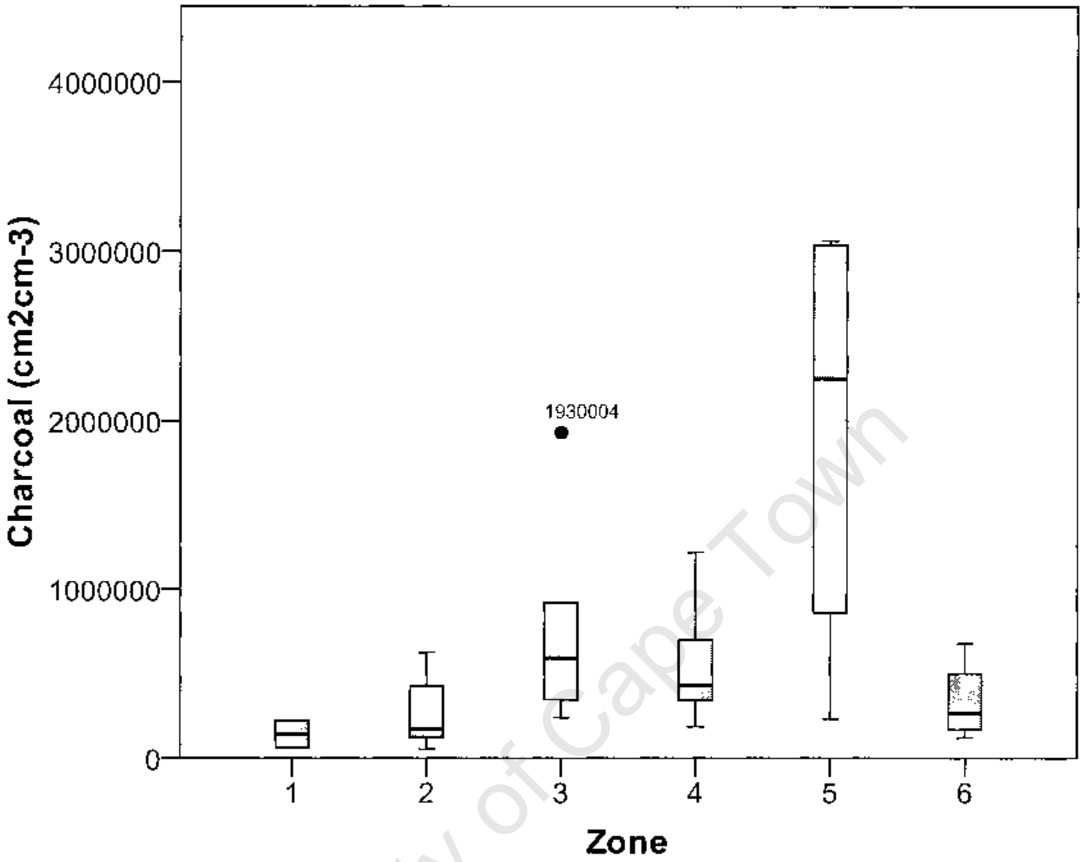


Figure 11 Box and whisker plot of charcoal concentration per pollen zone
The box represents the upper and lower quartiles of the data while the whiskers show the maximum and minimum datum still within 1.5 interquartile ranges (IQR) above and below the box. The solid line in the box indicates the median value. The closed circle represents an outlier of between 1.5 and 3 IQR and the number is the actual amount of charcoal measured as a surface area of charcoal per unit volume of sediment ($cm^2 cm^{-3}$). Zones 1, 2 and 3 (as used in Figure 9 and Figure 10 where they are prefaced by a D) correspond with the hunter/herder period while zones 4, 5 and 6 encompass the farmer period.

When evaluating the charcoal concentration found in each zone of the pollen diagram (Figure 11) charcoal tends to increase from the oldest zones (zone 1, 2 and 3) to the newest zones (zones 4, 5 and 6) with zone 4 and 6 being exceptions. This is visible whether considering the median value or the interquartile range. Zone 5 has the highest charcoal values while zone 3 also has a very high charcoal value that is an outlier in that zone. Although the median for zone 4 and the interquartile range are lower than for zone 3, the upper quartile is higher than that of zone 3. Zone 6, the most recent in time, has charcoal values that are low and equivalent to those found in zone 2.

5 DISCUSSION

5.1 INTRODUCTION

From the 1720s farmers in the Cederberg area started to build and settle on what had been up until then migrant livestock posts (Mitchell 2002a) and started growing wheat for their own consumption (van der Merwe 1937). Many farmers who adopted a sedentary farming strategy had probably been nomadic herders or would still practise a certain degree of nomadism by moving stock to the Karoo in the winter months (van der Merwe 1937, Brown et al. 1991, Taylor 1996) even though they now had legally established tenure of land (Mitchell 2002a, 2007). The major differences between indigenous herders and the farmers were a year-round presence on the land and the building of permanent structures such as farmhouses. This process was well underway in the Cederberg from the 1730s onwards (Mitchell 2002a, 2007, 2008) and intensified throughout the 1800s and 1900s with a large increase in the area under cultivation and the number of livestock in the last century (Bonora 2009) in the greater Cederberg area. This period of land use intensification would have definitely ended in the study site region by 1973 when the area was declared a wilderness area (Government notice 1256 1973). Ploughing and fertilising as well as livestock grazing were intense forms of disturbance on the vegetation of De Rif. The more permanent presence and larger herds of livestock would probably also have resulted in the more intensive use of fire in order to encourage sufficient grazing in this otherwise unsuitable area (Bands 1977, Taylor 1978, Taylor 1996).

To evaluate and understand potential impacts of people on natural systems, an understanding of natural flux in the system is needed. It may then be possible to try and decouple anthropogenic change from natural change and to understand when people have responded to environmental changes. Once the natural trajectory of change in the system is known, then managers can then make decisions based on some understanding of what the natural baseline originally was. In Africa, with our long history of human habitation and use of fire to manipulate the environment (Bird and Cali 1998) it is almost impossible to consider a pre-human baseline. However, for the purposes of this study it is useful to try and determine the impact of human induced change over the last

3 000 years, as this incorporates the period including exclusive hunter-gatherers and the introduction of livestock and herding to the Cape about 2 000 years ago (Klein 1986b, Boozaier et al. 1996, Henshilwood 1996), and in particular the last 350 years when land use changed due to the arrival of agriculture in the Cape (Thom 1952, Smith 1983). This study examines the transition between hunter-gatherer and herder land use and farmer land use, using the pollen diagrams presented in the results chapter, and phase diagrams, presented in this chapter. The study investigates the extent of the disturbance created by this change and how this change affected the vegetation and the fire regime of the De Rif site in the Cederberg, and how such changes may be indicative of areas throughout the winter rainfall region of the fynbos biome.

5.1.1 Dates and timelines

In this study two major time periods are considered as identified using radiocarbon dating and pollen markers. These are the hunter/herder period, levels 160 cm (400-200 cal BC) to 80cm (1450-1630 cal AD) and the farmer period, levels 76cm to the surface (estimated due to the consistent presence of crop pollen and exotic tree pollen, see section 4.5.2 and 4.5.4, as radiocarbon and Pb-210 dating did not produce consistent dates). It was not possible to distinguish between hunter-gatherer land use and pastoralist land use with the chronology that was obtained for the core used in this study (section 4.2), and as these forms of land use probably had considerable overlap, the term hunter/herder is used throughout this study. This also includes a brief period of overlap with European herders who originally also followed a herding pattern similar to that of the indigenous herders (Sparrman 1786, Botha 1924). The main separation is between hunter/herders and farmers from the 1720s onwards after the initiation of permanent land ownership and settlement in the Cederberg area (Mitchell 2002a). Farmers would still have had considerable herds of livestock, but were engaged in agriculture which resulted in permanent settlement and the intensification of land use impacts on De Rif. Thus for ease of reference the hunter herder period for this study ranges from 2300 BP to ±1750 while the farmer period at De Rif is from ±1750 to ±1900. The terminal date of ±1900 is used due to the presence of the cedar plantation detectable in the pollen diagram and the lack of detectable Pb-210. However these dates are not very accurate as they are based on a combination of different age indicators. The timeline below (Figure

12) shows how the dates from the core relate to dates for land use in the Cederberg and general changes in climate.

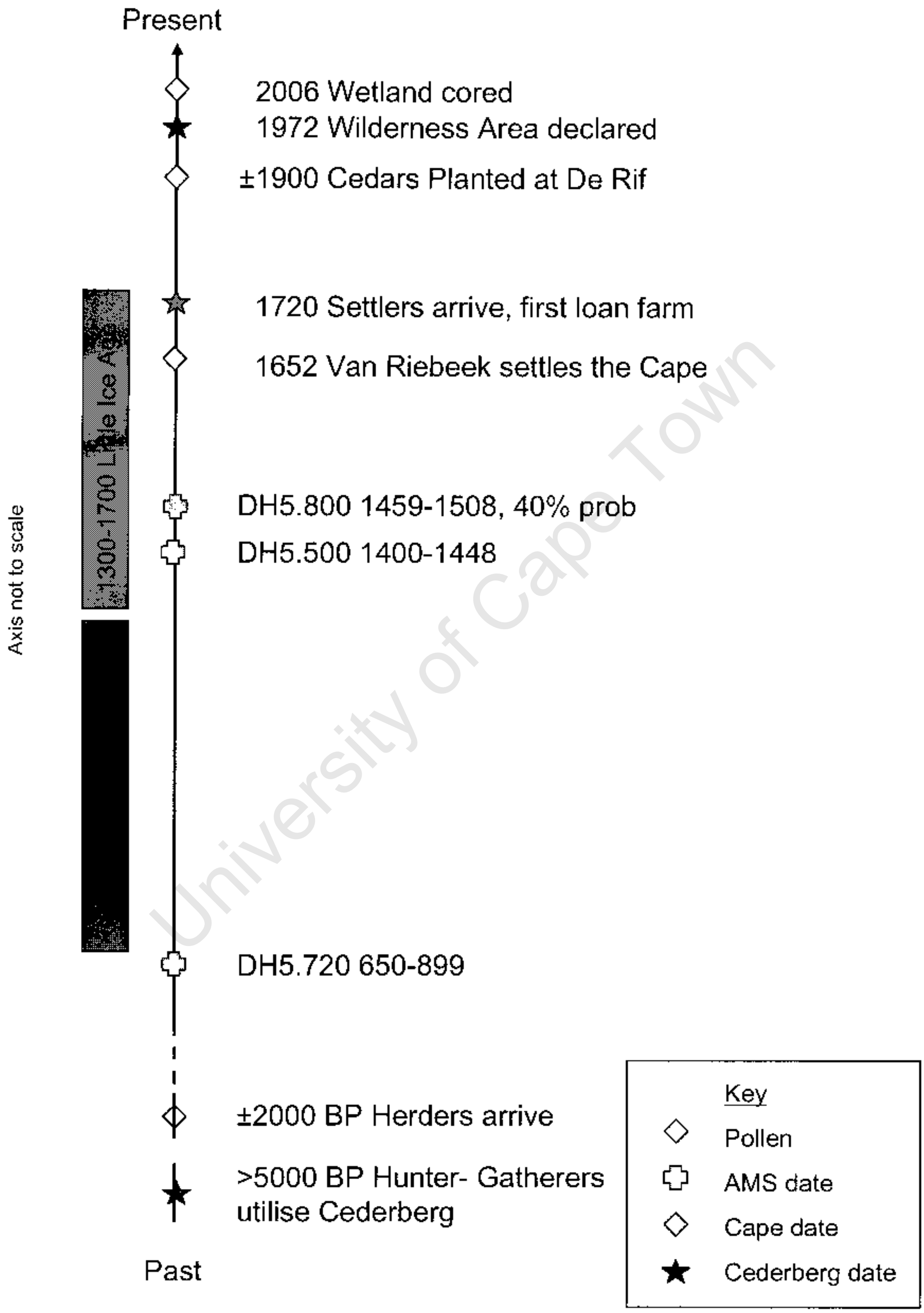


Figure 12 Timeline for the Cederberg Wilderness Area

5.2 GENERAL CHANGES IN FIRE WITH CHANGES IN LAND USE

People have used fire to manipulate vegetation in southern Africa for over 150 000 years (Hall 1984) and there is evidence that people have managed to alter the fire regime on the continent on a large scale since the early Holocene (Bird and Cali 1998). Deacon et al (1992) believe that fire has been used to increase food production (both food plants and as part of hunting strategies) in the fynbos biome since the Late Pleistocene and that this would have resulted in a large increase in fire frequency. However no quantitative measures of this have yet been presented. After the introduction of herding to the Western Cape about 2000 years ago (Klein 1986b, Boozaier et al. 1996, Henshilwood 1996) the use of fire would have increased in order to improve grazing (Botha 1924, Bands 1977, Taylor 1978). A further increase would be expected when agriculture was introduced to the Cape by European settlers (Thom 1952, Smith 1983) as fire would also have been used to clear vegetation and accidental fires may have started more frequently. The introduction of agriculture led to the more intensive use of the land in the Cederberg (Bonora 2009) thus an increase in the use of fire would expected. Although other studies have investigated whether fossil charcoal is informative about changes in land use and fire in South Africa (Scott 2002, Gillson and Ekblom 2009), this is the first investigation of this within the fynbos region of the Western Cape.

Whether considering the charcoal concentration values for hunter/herders (2300 BP to ±1800s) and the farmers (±1720s to ±1970) both Figure 13, or the different pollen zones (Figure 11), from the deepest levels to the youngest levels there is clear trend of increasing charcoal concentration. This shows a general increase in fire as land use in the Cederberg becomes more intensive after the introduction of agriculture (Bonora 2009).

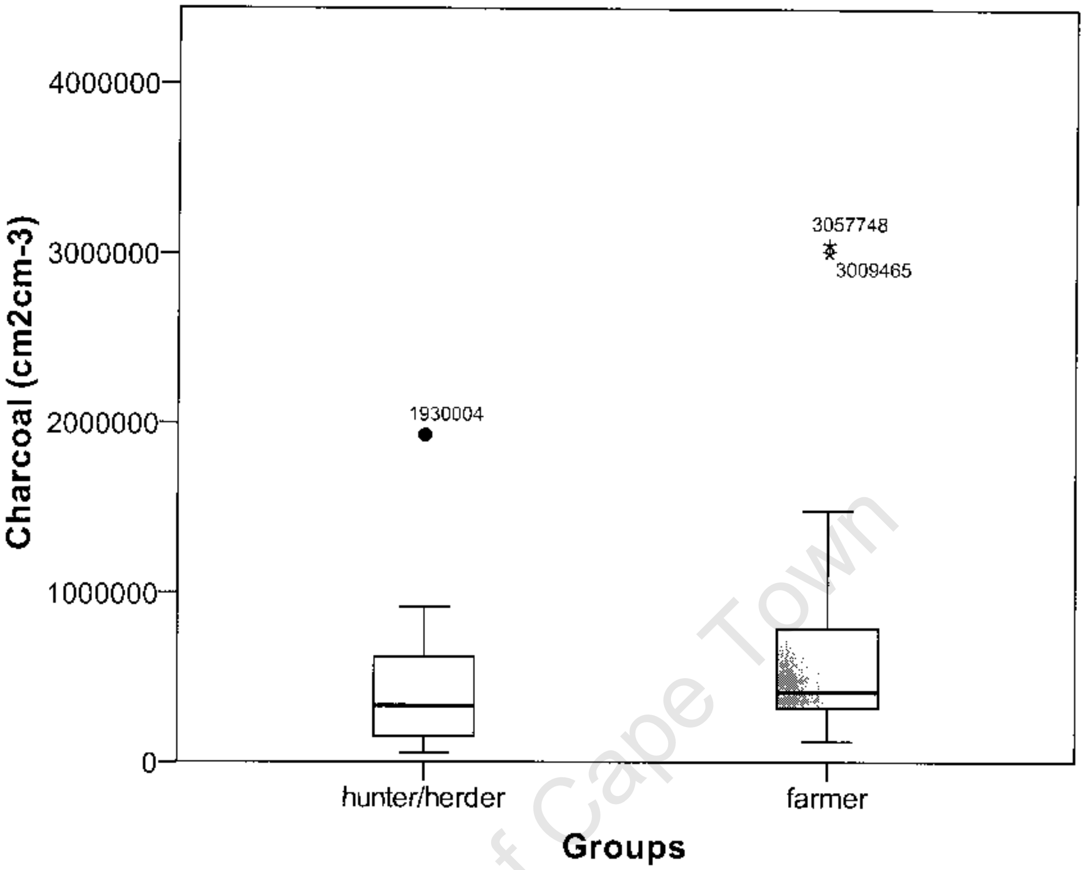


Figure 13 Box and whisker plot of charcoal concentration for the hunter/herder period (2300BP to ±1750 AD) and the farmer period (±1750 AD to ±1900 AD)
The box represents the upper and lower quartiles of the data while the whiskers show the maximum and minimum datum still within 1.5 interquartile ranges (IQR) above and below the box. The middle line in the box indicates the median value. The closed circle represents an outlier of between 1.5 and 3 IQR while the stars represent extreme values greater than 3 IQR. The numbers for the outliers are the actual value of charcoal recovered where charcoal abundance is measured as a surface area of charcoal per unit volume of sediment (cm^2cm^{-3}).

There would be several ways in which the use of fire by farmers would have differed from that of hunter/herders resulting in the increase in charcoal concentration seen in Figure 11 and Figure 13. One of the main differences in land use between the hunter/herders and the farmers is the introduction of permanent settlement due to the initiation of agriculture in the Cederberg. Before agriculture, both hunter-gatherers and herders would have moved though the Cederberg on a migratory route (Parkington 1977, Smith 1983, Parkington 1987) especially the herders who used the Strandveld for winter grazing and only moved into the mountains or beyond them in summer (Taylor 1996). Indeed the early colonial herders followed a similar route as they learnt many of their herding practises from the indigenous herders who worked for them (Sparrman

1786, Botha 1924). This pattern continued up until the 20 th century with many Cederberg landowners moving their flocks into the Karoo in winter (van der Merwe 1937, Brown et al. 1991, Taylor 1996) in order to avoid the cold mountains during the lambing season (Irene Spamer pers com).

Permanent settlement became necessary after the introduction of agriculture by European settlers (Smith 1983) in order to ensure that the crop was adequately cared for and was not destroyed by grazers or wildfire. The year round presence of people at the site may have resulted in an increase in charcoal concentration. This may have been due to the higher incidence of accidental fires, or as farmers and foresters regularly burned fire breaks (Hutchins 1901) in order to protect crops, plantations and Cedar populations from wild fire (Hutchins 1901, 1906).

Another source of charcoal would have been from fires lit to encourage grazing e.g. see Hutchins (1901). Even though the farmers were engaged in agriculture, they did not give up their livestock. The animal paths visible in Figure 4 demonstrate that livestock were in the area. An oral history of the farm by a neighbouring farmer shows that pigs, goats, sheep, cows and donkeys were all kept at De Rif (Irene Spamer pers com, see section 2.3.6.3).

In order to encourage the growth of palatable grazing the farmers in the Cederberg used a patch burning system which involves the regular burning of small blocks of vegetation (Taylor 1996). Although the indigenous herders may have also used such a system, the agriculturists were permanently settled in the landscape, thereby concentrating the effects of patch burning around a farmstead, rather than spread more uniformly throughout the landscape. This would explain the increase in charcoal values found at De Rif (Figure 11 and Figure 13), as burning would have been concentrated around the farmstead and the evidence of it, charcoal, would have been directly captured in the De Rif wetland.

There are numerous accounts that testify to the use of fire in the Cederberg by the early settled farmers (Hubbard 1937, Smith 1955, Taylor 1996) and these are explored in more detail in the Literature review (see section 2.3.2.2.2). The general focus of these accounts is how the use of fire threatened the Clanwilliam Cedar and was carried out in order to improve grazing for domestic livestock. As the tree was seen as a valuable timber resource at the time (Hutchins 1897), its destruction by fire was viewed in a negative light. This focus on the negative effects of fire on the Clanwilliam Cedar does not mean that fire did not affect the composition of the rest of the fynbos vegetation, but the historical records do not show what the effects of fire on other vegetation types was other than that it improved grazing.

Further evidence of the farmers' use of fire and the authorities' attitude towards it are revealed in the Reports of the Conservators of Forests, the first of which was written when parts of the Cederberg was declared a demarcated forest in 1897 in government notice 491 (Hutchins 1897). The reports state that one of the forestry ranger's most important duties in the Cederberg was to protect the whole area from fire (Hutchins 1901, 1906). In the reports, fire patrolling and the construction of fire breaks is a regular feature on the expense sheet (Hutchins 1897, 1904, 1905). The 1900 report describes how, with the co-operation of the farmers, fire breaks were burned above and below the cedars in order to protect them and interestingly in order to provide better grazing for the farmers (Hutchins 1901). All fires in areas where cedars occurred were subsequently banned in that year (Bands 1977).

From these records it is clear that the prevailing attitude towards fire was one of fire prevention, although its role in improving grazing for local farmers was acknowledged (Hutchins 1901). Both time and money were expended in order to achieve this aim (Hutchins 1901) and when fires did break out they were actively fought. All of these actions are consistent with a fire suppression mind set where fires are considered wasteful and dangerous and policy was focused on preventing them. Even though the dominant mindset of the time was one of fire suppression (Hutchins 1897, 1901, 1904, 1905, 1906), it is clear that farmers were still using a patch burning system in order to improve grazing during this time, and continued to do this around their farmsteads regardless of official policy.

Patch burning was also used to encourage the production an of *Agathosma betulina,* or buchu and well as the rooibos plant, *Aspalathus linearis* (Bands 1977, Taylor 1978, Taylor 1996). A photo in van Sittert (2005) shows several hundred people who harvested buchu within the Cederberg Forest Reserve. The Reports of the Conservators of Forests listed this as a regular source of income for the Cederberg Forestry area (Hutchins 1897, 1904, 1905). Both of these products were harvested and the vegetation burnt on a three year cycle in the Cederberg (Bands 1977) which would also have contributed to an increase in the use of fire in the area.

The large increase in charcoal in zone 5 (Figure 11) within the farmer period occurs directly after a period of high Cyperaceae and Poaceae abundance (Figure 9 and Figure 10) and the link between this change in vegetation and fire is discussed in section 5.4.1. What is interesting is that the highest levels of charcoal were reached over a hundred years ago as they predate the high cedar pollen values which originate from a plantation that was established above De Rif around 1900 (Table 3).This suggests that disturbance related to agriculture and permanent settlement led to a change in the vegetation of De Rif which may in turn have influenced the fire regime. A recent study (Bonora 2009) showed the intensification of land use in the Cederberg during the last 100 years, both for agriculture and livestock. This study shows that on a local scale, farmers were transforming vegetation and fire in the De Rif before this time period.

The large outliers, found in Figure 11 and Figure 13, require further explanation. These may be the result of a large fire which swept through the catchment area or valley (Clark 1990, Clark and Royall 1996) rather than just a fire in the immediate vicinity of the wetland. As such they may be a signal of extreme weather conditions which are often responsible for causing catchment-wide fires (Clark 1990, Mensing et al. 1999). However, there is currently no palaeoclimatic reconstruction for the Cederberg with which to test this hypothesis. There have been several attempts at establishing one using dendrochronological studies of *Widdringtonia cedarbergensis* after the potential of this species for climate reconstruction was first explored by Dunwiddie and La Marche (1980). February and Stock (1998b) reinvestigated this species at two sites that were close to rain gauges and found very poor correlations between ring width and rainfall. In another study February and Stock (1999) were also not able to correlate the stable carbon isotopes from cedars used in the Dunwiddie and La March (1980) study with known rainfall even after anthropogenic CO_2 contribution was removed. Thus February (2000) concluded that *Widdringtonia cedarbergensis* was not suitable for rainfall and climate reconstructions. Thus we do not know how common extreme weather conditions in the Cederberg are or how they have changed through time, but a recent study, focusing on the period from 1970 to 2007 has shown that weather conditions in the Cederberg are changing and causing an increase in fire frequency (Southey 2009), which would provide some support for this interpretation of the data.

Southey (2009) explores the role of weather in the fire regime in the Cederberg for the period 1970 to 2007. Her results suggest that fires in the Cederberg are limited by suitable weather conditions and rates of ignition. This suggests under natural conditions the Cederberg should have a stable and relatively high frequency of fire, but with increased ignition sources and suitable weather conditions, fire frequency could increase even more. Indeed, Southey's (2009) study showed that fire frequencies were increasing in the Cederberg due to changing weather conditions. Climatic states associated with hot summer conditions and thunderstorms were becoming more common in the Cederberg area and resulted in more frequent fires (Southey 2009). The results presented here could suggest that Southey's (2009) study potentially forms part of a much larger trend. This trend started some time after 1450-1630 cal AD years ago, the AMS date marking the transition from zone 3 to zone 4 (Figure 11). It is not yet possible to determine if the increase in fire frequency is purely a result of changing weather conditions or a result of changes in land use. Indeed, such a distinction may be artificial as both processes were probably taking place at the same time in the Cederberg.

The return to low charcoal values seen in Zone 6 (Figure 11) could be the result of the enforcement of the fire suppression policy operating in the Cederberg up until the 1970s (Kruger and Bigalke 1984) in order to protect the fire sensitive (Brown et al. 1991) and endangered *Widdringtonia cedarbergensis* (IUCN 2009). It could also result from the abandonment of patch burning by the farmers or a combination of the two. Farmers may have ceased patch burning as the area fell under increasing control by the managers of the surrounding state forest land, or due to the farmer leaving De Rif in 1947 (Irene Spamer pers com, see section 2.3.6.3) but whether this was the last time the farm was occupied is not clear. All activities on the farm would have definitely ceased by 1973 when the Cederberg was declared a wilderness area (Government notice 1256 1973) and the farmsteads within it were dismantled (Taylor 1996). The amount of charcoal from zone 6 is similar to that before the initiation of farming (zone 2, Figure 11) which supports the theory that higher charcoal levels seen from zone 3 to zone 5 were the result of agriculture and permanent settlement and were above those which would have occurred under a "natural" fire regime.

5.3 GENERAL CHANGES IN VEGETATION

5.3.1 General changes in vegetation as revealed by pollen analysis

The pollen diagrams (Figure 9 and Figure 10) show how the abundance of different types of pollen (and hence vegetation) have fluctuated through time and when combined with a chronology for the site, help link these fluctuations to changes in land use. Starting with the oldest sediments and working up to the surface, zone D-1 (Figure 9 and Figure 10), which is dated to 400-200 cal BP, is distinct because of its high proportion of spores, probably due to wet conditions, which also resulted in the initiation of sediment formation (Meadows 1988). Waterlogged sediments result in anaerobic conditions which are conducive to the preservation of pollen and the accumulation of further sediments. Cyperaceae is also at its lowest proportion in the zone, possibly as the wetland is very small or that Cyperaceae is not very abundant in the surrounding vegetation. This zone also has the lowest pollen concentration of any zone, suggesting that the factors that led to the formation of the wetland also led to quick deposition of sediments, or that preservation from this level is not ideal. On average 43% of all pollen grains were degraded in this zone (data not shown) which does suggest that preservation in this zone was not ideal which may have increased the relative abundance of the thicker walled spores.

Zones D-2 and D-3 (Figure 9 and Figure 10) are both dominated by Restio and Elytro/Stoebe pollen. In the Cederberg *Stoebe* type pollen is not differentiable from *Elytropappus* pollen (Scott and Woodbome 2007a), a common species especially on the shale step (Taylor 1996). *Stoebe* type pollen has traditionally been interpreted as a disturbance indicator (Meadows and Sugden 1991b, Meadows et al. 1996) but as Scott and Woodborne (2007a) explain, this type does not allow insight into vegetation and moisture conditions (or for that matter disturbance) as we cannot identify the species from its pollen. However, a survey Taylor's survey in 1986 (1996) identified *Elytropappus adpressus* as a dominant plant on the Welbedacht shale band, and not *Stoebe* species. Thus in this study Elytro/Stoebe pollen probably consists mostly of *Elytropappus* pollen. This is also suggested by the high abundance of this type in the lower levels of the core where one would assume the vegetation was more intact and less disturbed. The fact that this pollen type is less abundant in the overlying, more recent levels when other disturbance indicators are more prevalent seems to support the interpretation that Elytro/Stoebe consists predominantly of *Elytropappus* pollen and this interpretation is used throughout the rest of the thesis. Cyperaceae pollen is not abundant in zone D-2 but increases in concentration and abundance in zone D-3 possibly as increasing charcoal values result in an increase in Cyperaceae abundance as they are dominant components of the post fire vegetation (Kruger 1987). This zone also has the second highest pollen accumulation rates for the core and thus may represent a long period of time as sedimentation rates appear to be slow.

Zone D-4 is where Poaceae grains of a size considered to be from domesticated crops (Van Zinderen Bakker 1953, Scott 1982, Moore et al. 1997) are first regularly encountered indicating that this zone is associated with agriculture. This is confirmed by the presence of exotic tree pollen and an increasing abundance of Podo/Pine type (assuming the increase in this type is due to the increase in *Pinus* species in the area and not an increase in *Podocarpus* pollen). Poaceae, Euphorbia and Cheno/Am also reach their highest concentration in this zone and these taxa are often considered to increase in response to disturbance (Meadows and Sugden 1991b). The constancy in the charcoal data could result from a period of no fires (fire suppression) or due to a policy of patch burning which would involve small, regular fires around the site resulting in a homogenous input of charcoal to the wetland. The decline in Elytro/ Stoebe could be the result of clearing vegetation in order to create fields for agriculture (see sections 2.3.6.1 and 2.3.6.3) and hence a decrease in the input of *Elytropappus* pollen to the wetland.

The most striking trend in zone D-5 is the large increase in charcoal and Cyperaceae pollen. The increase in Cyperaceae pollen and charcoal is unusual as one would expect a lag between fire and Cyperaceae increase if Cyperaceae were increasing in abundance due to post fire stimulated flowering. However the increase in Cyperaceae seems to precede the increase in charcoal. This is apparent whether considering the concentration data or the proportional data. If this was a signal of increasing aridity, leading to a fire, one would predict that Poaceae would increase at the same time as Cyperaceae. However Poaceae is found in low concentrations and makes up a small proportion of the pollen sum in this level. This may be due to disturbance associated with agriculture and pastoralism resulting in Cyperaceae increasing in disturbed areas (e.g. along paths) while Poaceae are being heavily grazed by livestock. This zone is also associated with a high amount of organic matter in the sediments (see Figure 8) which may be due to ploughing and other farming practises. It is also in this zone that *Widdringtonia* pollen starts to increase dramatically showing that these changes occurred in the last 100 years (see section 2.3.5.2 and Table 3). Restios are also in low abundance during this time which may be the result of harvesting for thatching material as the farmstead that was probably built around this period. Podo/pine also becomes more abundant in this zone and the zone above it, again confirming the timescale suggested as it was during this time the large *Pinus* plantations were established in the Cederberg (Hutchins 1897, 1901, 1904, 1905, 1906).

The top of the core (zone D-6), representing the upper layers of the sediment, is distinctive because to its high abundance of *Widdringtonia* pollen. This is due to the cedars in the plantation maturing and increasing their production of pollen. Almost no Poaceae crop pollen was recovered suggesting that farming activities decreased during this time, possibly as the inhabitants of De Rif switched to buying grain rather than growing it themselves or as the site recovered after being abandoned (see section 2.3.6.3). Restionaceae pollen (from here on referred to as Restio pollen), Protea and Erica pollen also increase in this zone suggesting that vegetation may be recovering from harvesting and disturbance. The increase in Elytro/Stoebe type may be the result of the regrowth of *Elytropappus* on fields left fallow, or the increase in *Stoebe* pollen as this family often colonises disturbed areas (Taylor 1996, van Rooyen and Steyn 1999). The high amount of sand in this level (see section 3.2.3) and low organic matter (Figure 8) may also explain the generally low concentrations of pollen found in this zone as sandy samples tend to retain less pollen.

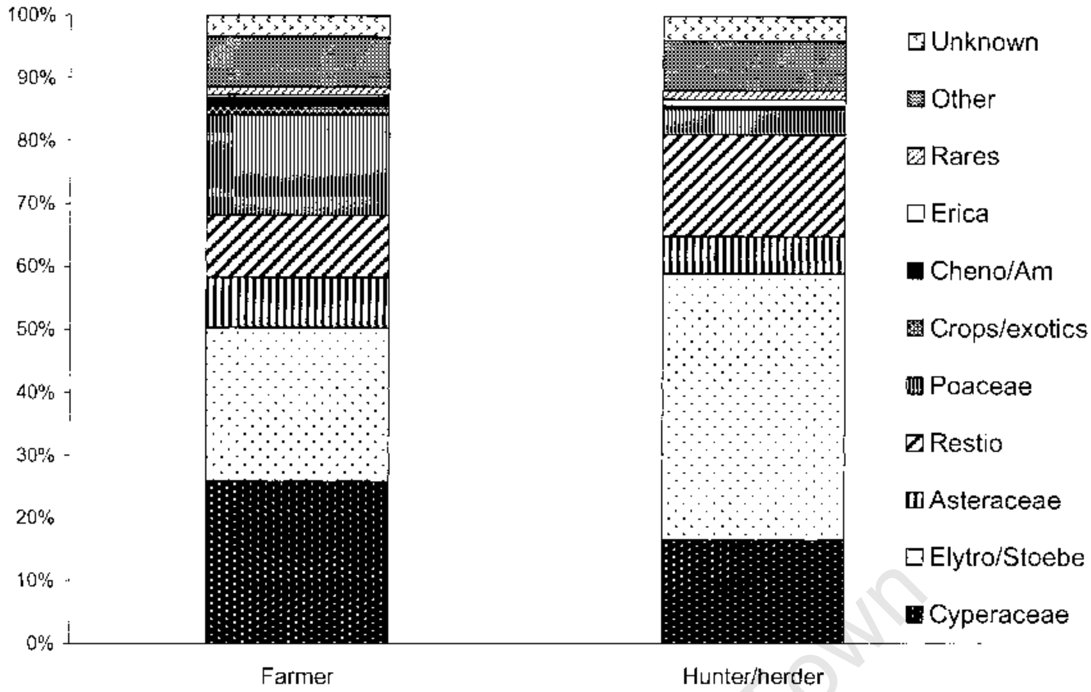


Figure 14 The average vegetation composition during the hunter/herder period (23 00BP to +1750 AD) and the farmer period (+1750 AD to +1900 AD)

Figure 14 reveals the average vegetation composition for the two main periods of land use considered in this study as determined from the pollen data collected in this study. The major changes are seen in the Cyperaceae, Elytro/Stoebe type pollen, Restionaceae and Poaceae categories and these reasons for these changes are explored in more detail in this chapter through the use of phase diagrams.

5.3.2 General changes in vegetation as revealed by phase diagrams

Phase diagrams consist of two variables that are plotted against each other with each point joined by a line and hence showing a temporal succession of points, in this case highlighting the relationship between two variables as the system moves from the hunting and herding time period into farming the farming period. The hunter/herder period includes zones D-1, D-2 and zone D-3, while the farmer period consists of zones D-4, D-5 and D-6. Phase diagrams assist in the interpretation of the complex interactions between human action, climate and landscape change (Dearing 2008). The use of phase diagrams enables the study of changes in the behaviour of the system, including stable states and the effects of the transition between hunting and farming can be elucidated. The fluctuations found in pollen diagrams often make them difficult to analyse statistically, but phase diagrams allow one to visually identify general trends in the system, and evaluate them without the data needing to be normally distributed, and can provide insight into how the two variables may change in their relationship to each other through time.

5.4 THE EFFECTS OF FIRE ON THE VEGETATION OF DE RIF

5.4.1 People, fire and fynbos: the grass fire cycle at De Rif

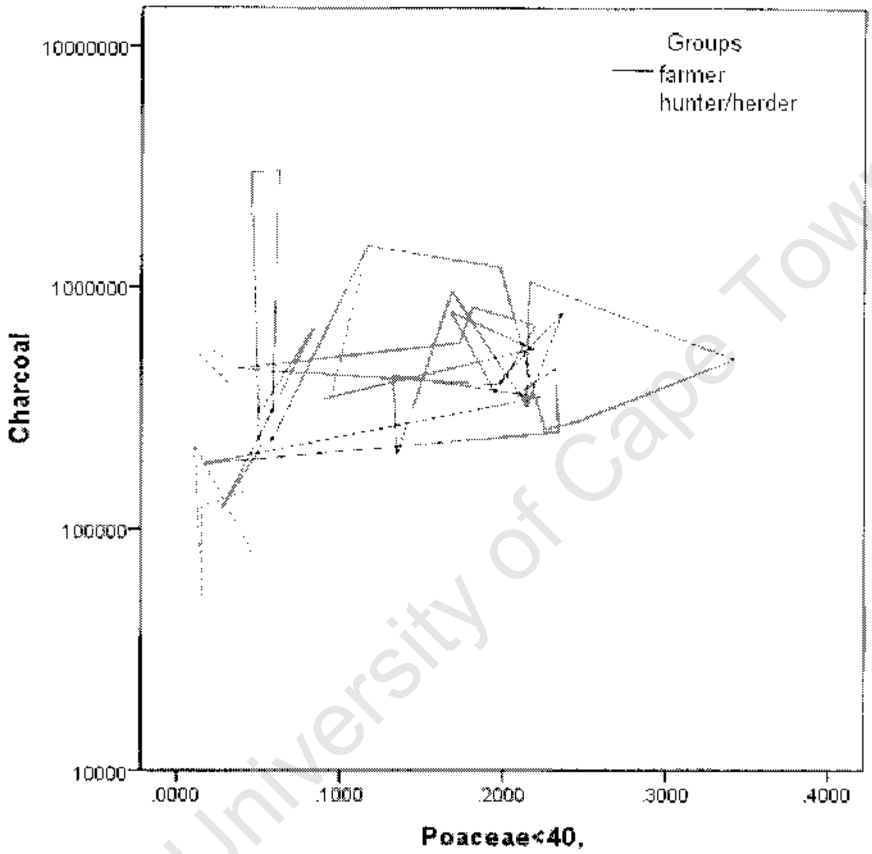


Figure 15 The phase diagram for wild grass abundance and charcoal abundance.

Poaceae <40 are grass pollen grains that are less than 40 microns in length and most likely to be from wild grasses (Van Zinderen Bakker 1953). Grass abundance is measured as a proportion of the total pollen sum of 1. Charcoal abundance is shown using a logarithmic scale and is in $cm^2.cm^{-3}$.

DUring the hunter/herder period there is a positive relationship between the amount of wild grass pollen and charcoal abundance suggesting that increasing grass cover is associated with more frequent fires. Figure 15 also shows that the proportion of grasses in the plant community of the Northern Inland Shale Band Vegetation (Rebelo et al. 2006) around De Rif has increased through time. The increase in grass abundance after fire was expected as previous studies have shown that the proportion of grass in the community can rapidly increase after fire especially on more fertile soils in fynbos (Kruger 1977, 1984, Hoffman et al. 1987, Kruger 1987) and in Renosterveld communities (van Rensburg 1962). This increase is due to a post fire environment that is favourable to grasses; defoliation and higher nutrient levels, both consequences of fire, caused the increased growth and flowering of *Ehrharta capensis* (Verboom et al. 2002), a generalist Cape Grass (Gibbs Russell et al. 1990) which was found on the site (section 4.1, Table 5). Several Cape grass species resprout after fire (Linder and Ellis 1990b) and grasses mature quickly allowing them to reach a high percentage cover in the early post fire community before shrubs and other plant life forms have established (Kruger 1987). Thus when charcoal levels are high, indicating periods of fire, Poaceae levels are high as due to its increased abundance in the post fire community.

Although grasses are present in fynbos, they are seldom dominant (Linder 1989). However, this result suggests that by manipulating the fire regime, a community with a greater abundance of grass could emerge. The patch burning associated with livestock farming in the Cape (Kruger and Bigalke 1984) typically consisted of the setting of small, regular fires, usually every 3 years (Bands 1977) and would have kept the vegetation of the area in an early successional state, which is associated with high grass abundance (van Rensburg 1962, Kruger 1977, 1987). The removal of old woody vegetation through fire can make even unpalatable fynbos components, such as Restionaceae, palatable for a few seasons after fire (Kruger and Bigalke 1984). The increase in grass abundance, the gently fluctuating amounts of charcoal, and changes in other vegetation types like *Elytropappus* (section 5.6.1), all confirm that patch burning was taking place in this area. The resulting high grass abundance decreased the abundance of other vegetation types in the fynbos like the Restionaceae.

The results suggest that it is more likely that the abundance of grass is responding to the amount of fire, rather than both factor responding to some other factor such as climate due to the nature of succession in fynbos. Fynbos communities only reach maturity between 10 and 30 years (Kruger 1987) at which stage the proportion of grasses in the community decreases. A short term drought may reduce the abundance of grass in the youth or transition phase, but the probability of young fynbos burning is low as sufficient biomass takes several years to accumulate (Kruger 1977). Thus during early successional stages a drought may result in the die back of grasses but it would be unlikely to result in a fire in young vegetation. During later successional stages, droughts may lead to fires, but grass abundance is usually low as it is shaded out by taller late successional vegetation (Kruger 1987). The fact the grasses and fire increase together, rather than out of phase, suggests that grasses are increasing post fire, rather than as a result of climatic factors that then affect grasses and fire.

The largest peak in charcoal abundance in the pollen diagram is found directly after a period of novel, high grass abundance and probably represents the largest fire in the last 2300 years in the area. Although the landscape was generally grassier due to patch burning, the peak in grass abundance is probably also due in part to the introduction of weedy grasses to De Rif as these are currently still present in the landscape (Table 5 and Figure 7). Grass invasions can often cause a change in fire regimes (D'Antonio and Vitousek 1992, Hobbs 2001). A change in fire regime due to the invasion of grass species can become a self-sustaining pattern (D'Antonio and Vitousek 1992) and can lead to the transformation of the vegetation in an area. Grass can also increase the horizontal connectivity of the vegetation (Brooks et al. 2004) which may allow it to carry a fire into areas that might otherwise have been isolated from a fire e.g. the Cedar areas below the De Rif site. The results show that a large fire has occurred after the increase in grass abundance and suggests that this grass fire cycle will persist in the area as long as high grass abundance continues.

5.4.2 The effects of fire on Cyperaceae

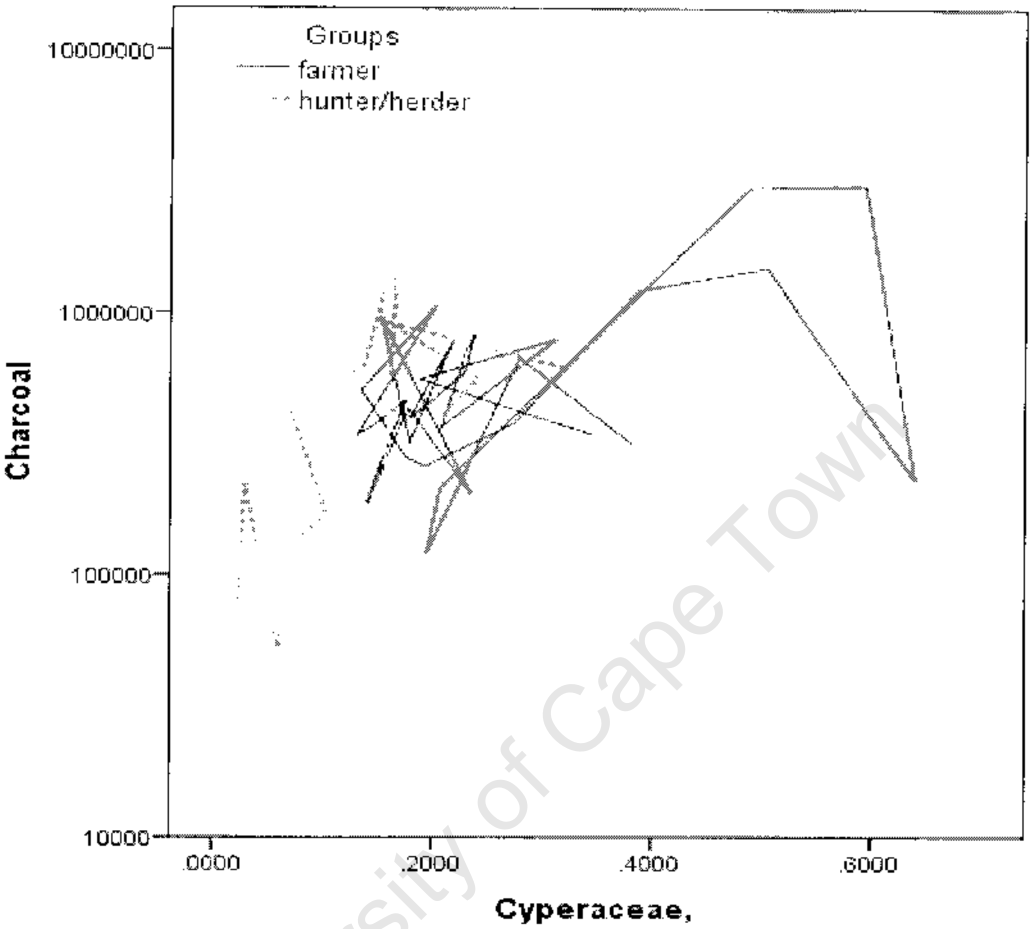


Figure 16 The phase diagram for charcoal abundance and Cyperaceae abundance.

The x axis shows the proportion of the pollen sum made up of Cyperaceae pollen with a maximum of 1 being possible while the y axis is in logarithmic scale and shows the abundance of charcoal as measured in $cm^2.cm^{-3}$.

During the hunter/ herder and the farmer periods the amount of charcoal and the amount of Cyperaceae pollen were generally positively related which suggests that as fire increases in the system, so does the abundance of Cyperaceae. Sedges recover quickly from fire and are often a dominant component of the post fire vegetation for several years after fire (Kruger 1987). The correlation between sedge pollen and charcoal can then be explained; periods of low charcoal abundance are inter-fire periods and Cyperaceae abundance is low as shrubs and woody vegetation are now dominant and shade out the shorter sedges, whilst high charcoal abundance occurs after fires when Cyperaceae abundance increases (Kruger 1987) because the over shadowing vegetation has been removed.

Charcoal levels are generally lower during the hunter/herder period than during the farmer period (Figure 13) suggesting there was a difference in the use of fire between these two periods. However, there is still considerable overlap in phase space between the hunter/herder domain and the farmer domain. This area of overlap could be showing the early farmers, like the herders who preceded them, were first and foremost livestock herders, and hence were using fire in a similar way. Botha (1924) states that farmers learnt the practise of transhumance and burning from Khoi pastoralists. This could explain why in places the phase diagram shows there is little difference between the two. As time progresses the farmer domain in the phase diagram does move away from the hunter/herder domain suggesting that either fire practises changed or other factors started to influence the relationship between fire and Cyperaceae to increase the abundance of both. At the highest abundance of Cyperaceae, charcoal levels are relatively low, which may mean that these high levels of Cyperaceae are caused by another factor such as disturbance and this is discussed in section 5.5.3.

An increase in Cyperaceae pollen is often interpreted as indicating a shift to wetter conditions in the Western Cape (Meadows and Baxter 1999) and in the Cederberg (Scott 1994, Scott and Woodborne 2007a, 2007b). This interpretation is based on the assumption that Cyperaceae are mainly an aquatic family. This is not valid in the Cederberg; of all the Cyperaceae species found the area (Cape Nature 2009), 11 species are wetland specialists while 23 species prefer dry conditions (Goldblatt and Manning 2000). Aquatic Cyperaceae do account for some of the pollen collected in the wetland but pollen traps situated away from wetlands showed that up to 20% of the total pollen sum consisted of Cyperaceae (Meadows and Sugden 1991b), probably all from species adapted to dry conditions. This suggests that any changes in moisture availability would influence the Cyperaceae from wet and dry habitats in opposite ways with an unpredictable effect on the total amount of Cyperaceae pollen entering the deposits. Thus using changes in Cyperaceae abundance as a proxy for changes in moisture availability is not valid unless a method is developed for determining whether Cyperaceae pollen is from wetland sedges or dry habitats, or in combination with other moisture proxies, which as yet have not been developed for the Cederberg (February and Stock 1998b, 1999, February 2000).

5.4.3 The Proteaceae and fire: family resilience to fire and land use?

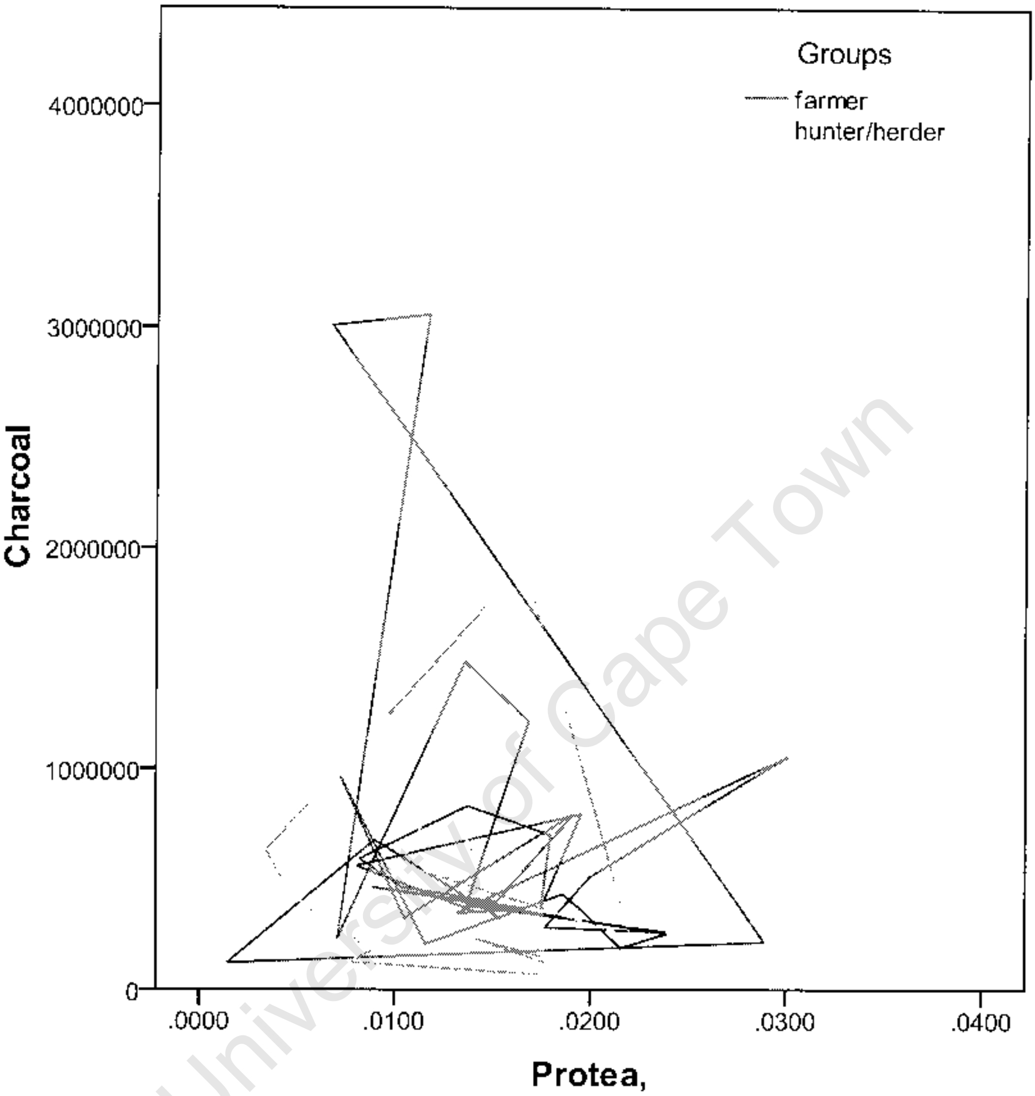


Figure 17 The phase diagram for Proteaceae and charcoal abundance
Protea abundance is measured as a proportion of the total pollen sum, while charcoal abundance is in cm^{2} CM^{-3}.

Proteaceae pollen reaches high abundance at both low and high levels of charcoal, suggesting that the amount of fire in the system does not determine the abundance of Proteaceae in the Cederberg. This is unexpected as Proteas are thought to be one of the species most affected by changes in fire frequency and consequently fire management has often been based around the recruitment requirements of this family (Richardson and van Wilgen 1992). Most mountain fynbos species can survive fire frequencies of between 10 and 15 years but 5 year intervals were enough to eliminate two species of

Protea from Jonkershoek burn experiments (van Wilgen and Forsyth 1992). Managers usually burn areas once the Proteaceae are large enough to produce seeds for several years (Richardson and van Wilgen 1992). The Proteaceae are usually the slowest maturing species in fynbos and this time cycle is thought to then allow all other species sufficient time to reproduce and replenished underground seed banks. If the recruitment of Proteaceae fails due to fires that recur too frequently, dramatic changes in community structure can follow (Richardson and van Wilgen 1992) such as the replacement of a 2-4m high shrubland by a Restionaceae dominated low shrubland after a single fire (Bond et al. 1984).

The Proteaceae family consists of proteas and leucadendrons which are characteristic and charismatic components of the fynbos vegetation (Kruger 1979) and have similar pollen. Proteaceae pollen does not form a large proportion of the pollen sum (less than 4% in this study, Figure 9) as they are not wind dispersed and are pollinated by birds or insects (Collins and Rebelo 1985). They were found in similar abundance in this study as in other studies in the Cederberg (Meadows and Sugden 1991b, Scott and Woodborne 2007a). The phase diagram allows us to investigate the relationship between Proteaceae and fire even though the pollen is not abundant, which is an advantage over traditional pollen diagrams.

At a family level the Proteaceae found in the area of De Rif may be resilient to changes in fire frequency as several reseeding and resprouting species are found in the Cederberg (Cape Nature 2009). The resprouting species include *Protea nitida, Leucadendron salignum*, *Protea glabra,* and *Leucadendron bruniodes var bruniodes* while there are 17 reseeding species (Rebelo 1995). This suggests that while some members of the family may fail to recruit if fire frequencies become too high, other resprouting members may be unaffected or may increase in abundance and thus there appears to be no net change in Proteaceae abundance. The future effects of climate change on the Proteaceae of the Cederberg are expected to be dire (Midgley et al. 2002) which suggests that in future this family may not be as resilient to changes in fire as the results of this study suggest.

Further research into the morphology of Proteaceae pollen grains may help determine if reseeding or resprouting guilds of Proteaceae have different pollen morphology. This would help untangle the interpretation of Proteaceae pollen in future palaeoecological studies. Until such a time, palaeoecological interpretations of changes in protea pollen abundance should not be taken as informative about past fire regimes.

The Proteaceae family also appear to be resilient to changes in land use as there is no clear separation between hunter/herder and farmer phase space, suggesting that as well as fire, the intensification of land use around the site of De Rif has also not affected the Proteaceae. Various protea species were utilised by early settlers (Taylor 1978, Taylor 1996) but either such activities did not occur at De Rif, or if they did it did not affect the abundance of the Proteaceae.

5.4.4 The effects of fire and climate on Ericaceae

Several factors could explain the temporal changes in *Erica* abundance (Figure 18), a very low threshold to increases in fire, or changes in climate from a wetter period to a drier period, or a combination of the two. That the two highest *Erica* values occur at the two lowest charcoal values is suggestive that *Erica* is sensitive to increased fire frequency, and once that threshold is reached, *Erica* abundance is no longer related to the abundance of charcoal. The highest Erica values occur in the oldest sediments of the core, 2320 +30BP (400-200 cal BC), a period also associated with wetter conditions due to the high abundance of spores in that zone (Figure 9 and Figure 10). Wetter conditions are often thought to be cooler in the Cape (Scott and Woodborne 2007b) which would result in fewer fires so these two factors may be interlinked, but will be discussed separately.

Ericas are characteristic components of fynbos vegetation (Kruger 1979) and are usually underrepresented in pollen diagrams as they are predominantly pollinated by insects and birds with only 5% of all species being wind pollinated (Rebelo et al. 1985). A phase diagram allows the investigation of fluctuations in their abundance that might not otherwise be detectable due to their low abundance in the total pollen sum. In this study this was less than 4 % (Figure 9 and Figure 10) which is the same as other studies in the Cederberg (Meadows and Sugden 1991b, Scott and Woodborne 2007a).

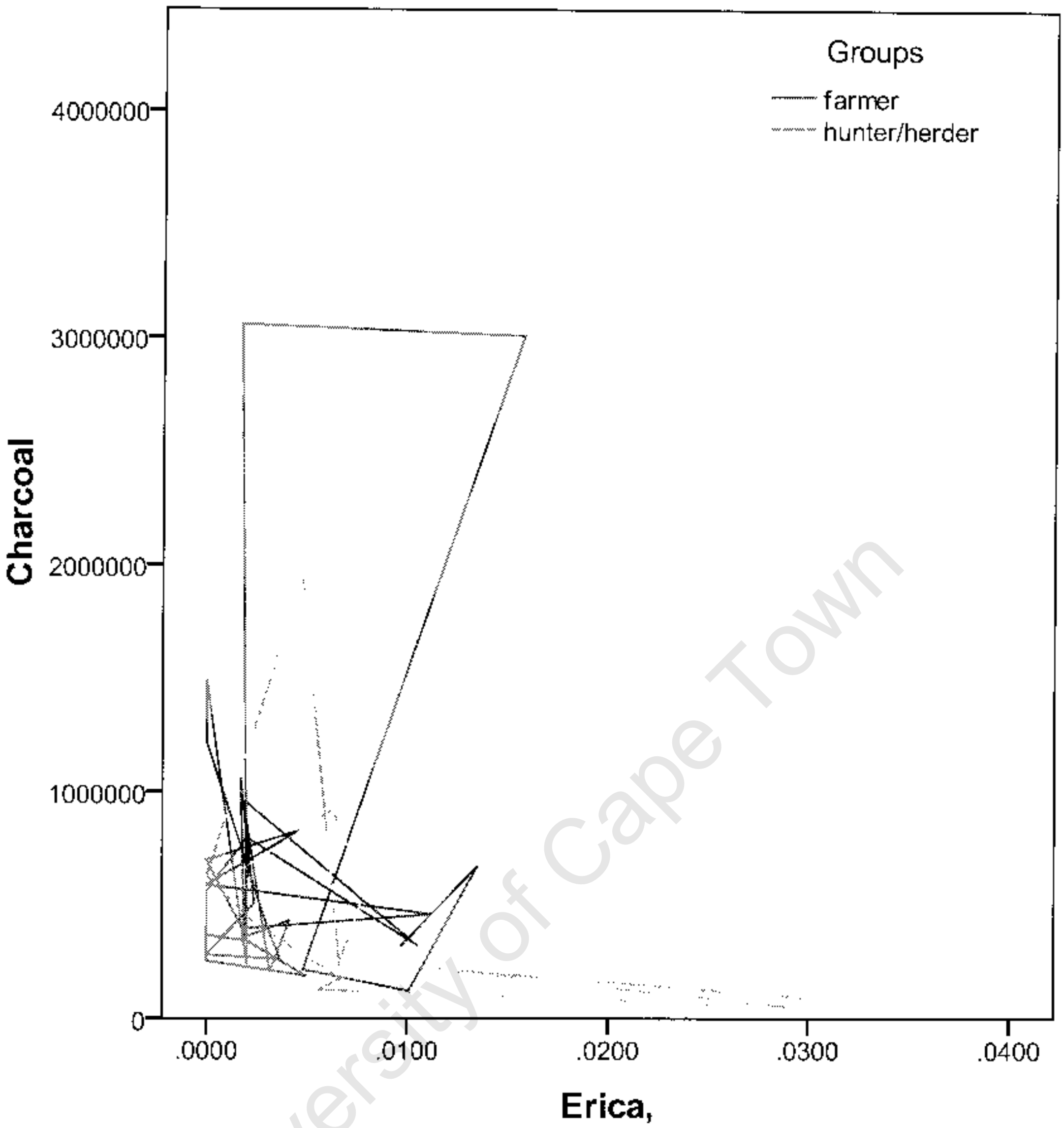


Figure 18 The phase diagram for Erica and charcoal abundance
Erica abundance is measured as a proportion of the total pollen sum while charcoal abundance is measured in $cm^2 cm^{-3}$.

Studies at the Pakhuis Pass 3 5km to the north of Driehoek suggest that wetter conditions were experienced there between 2800 and 2000 years ago, and again in the last 500 years due to the increase in *Erica* pollen (Scott and Woodborne 2007a). Meadows and Sugden (1991b) also found an increase in ericaceous pollen up until 1990 BP for the Sneeuberg core and after 3230 BP for the Driehoek core. These studies have interpreted higher *Erica* abundance as a signal of increased moisture availability due to a fynbos classification system (Campbell 1986, Campbell and Werger 1988) where "ericaceous fynbos" occurs at the highest levels of rainfall within the fynbos biome. The temporal resolution of these two studies is limited, negating any direct comparison with the De Rif core; however periods of higher ericaceous abundance do seem to overlap in these two studies and this one. The high abundance of spores in the pollen diagram (Figure 9 and Figure 10) adds further weight to this argument. On the basis of isotopic evidence, a recent study bordering De Rif (Quick 2009) concluded that the area experienced wetter conditions from 3500 to 2300 cal yr BP. If this was indeed a wetter period, then this may have been what initiated the accumulation of deposits at De Rif (Meadows 1988). If a wetter period did occur it may have been reasonably widespread in the Western Cape as micro-mammal assemblages at Elands Bay also suggest wetter conditions around 3 000BP (Avery 1983).

The two highest values for *Erica* abundance occur at the two lowest values for charcoal abundance, suggesting that this family is responding negatively to fire in the De Rif area and / or both ericas and fire were responding to another factor. Fire has been used as a tool to control *Erica* abundance in the grasslands of the eastern Cape where *Erica brownleeae* is considered a non-desirable species because it interferes with grazing (Trollope 1973). Fire has also been observed to decrease *Erica* abundance in plant communities in the Kamiesberg (Adamson 1938). However, the response of *Erica* species to changes in fire frequency has not been explicitly studied. This is probably due to the high species diversity of this family with over 500 species in the Cape (Goldblatt and Manning 2000).

Of the few *Erica* species to have some aspect of their ecology investigated, several form seed banks with a half life of less than 2 years (Holmes and Newton 2004) with most seeds germinating soon after deposition. If a population of *Erica* failed to produce sufficient seeds due to environmental conditions, and was destroyed by fire, it is likely that it would become locally extinct, as few viable seeds would exist in the soil seed bank. Although resprouting *Erica* species do exist, they make up only 6% of the genus, while 90% rely on a reseeding strategy (Ojeda 1998). Thus it would only take one badly timed fire to result in the loss of this genus from an area.

5.5 THE EFFECTS OF DISTURBANCE ON THE VEGETATION OF DE RIF

5.5.1 The effects of disturbance on the grass community of De Rif

During the farming period the abundance of grass increased to levels not seen during the hunter/herder period (Figure 9, Figure 10 and Figure 15) which suggests that the intensification of land use in this area of the Cederberg led to an increase in the abundance of the Poaceae family. This probably occurred due to a combination of factors. This section will focus on the role of disturbance other than fire, and the role of livestock in changing nitrogen cycling, and how these factors can facilitate the introduction of invasive species which in turn become another form of disturbance. Disturbance alone has been shown to push vegetation to a younger successional state (Debussche et al. 1996) which in the fynbos would result in a higher abundance of grasses (van Rensburg 1962, Kruger 1977, 1987).

From the 1700s onwards farmers in the Cape started to settle on what had been up until then migrant livestock posts and started growing wheat for their own consumption (van der Merwe 1937). When wheat fields were left fallow they would have been colonised by grasses. This has been shown in the Renosterveld, another clay-derived vegetation type, where grasses dominate old fields (Midoko-Iponga et al. 2005) and may have contributed to the large spikes in grass abundance during the farmer period, followed by rapid declines in grass abundance probably when livestock were allowed to graze the wheat fields after being returned from winter grazing in the Karoo (van der Merwe 1937, Brown et al. 1991, Taylor 1996).

Animals can increase nitrogen cycling in South African Savannahs through grazing (Craine et al. 2009) while livestock have been shown to add readily available nitrogen to the upper layers of soil by depositing their urine and faeces in an area, (Hobbs 1996) as does run off from fertilised wheat fields (Milton 2004). Both grazing and crop farming were taking place at De Rif and forms of disturbances probably increased the amount of available nitrogen which can result in changes in the composition of plant communities (Hobbs 1996, Bokdam and Gleichman 2000). As many fynbos plants are not able to increase their uptake of nitrogen (Stock and Lewis 1986, Midgley et al.

1995, De Mazancourt et al. 1998) grasses already on the site may instead benefit (Milton 2004), resulting in an overall increase in grass abundance in the area. The wetland at De Rif could also have become eutrophic due to run-off from the nearby wheat fields which would also have influenced the vegetation community of the site.

The effects of disturbance together with changes in fire (discussed in section 5.2) altered the vegetation composition of De Rif. The increase in grass abundance resulted in other vegetation types becoming comparatively less abundant, but changes within the grass community also resulted. Of the current grass species found at De Rif, only around 10% are endemic to fynbos, and on the most disturbed site, the previously ploughed area, invasive grasses make up nearly 45% of the grass abundance, and are discussed in section 5.6.2. The majority of indigenous grasses that are present are generalist grasses that colonise disturbed sites (see section 5.6.2). Alien grasses have also been shown to compete with indigenous grasses in fynbos (Pretorius et al. 2008) and this would in future act as another form of disturbance in the area .The one species of grass endemic to the Northern Inland Shale Band Vegetation (Rebelo et al. 2006) was not encountered at all (see section 5.3 and Table 5). Thus the current grass component of De Rif demonstrates the disturbed nature of the site nearly seventy years after the site was abandoned.

5.5.2 The persistent effects of ploughing on abandoned fields

The vegetation of De Rif has undergone several forms of disturbance. The effects of agriculture, focussing on the consequences of ploughing, will be discussed in this section. Fire and its effects have been covered in section 5.2 and 5.4, while the effects of pasture management and livestock on the vegetation of De Rif are discussed in section 5.6. It was thought a vegetation survey of the post fire vegetation of the site would provide insight into the effects of fire on the vegetation and help link changes in the pollen record with changes in land use and fire. A fire at De Rif in January 2008 provided such an opportunity. The results of the survey provided insight into the role of past ploughing in structuring the vegetation community seen today. The average abundance of different kinds of vegetation during the hunter/herder period and the farmer period are also discussed in this section.

The composition of the grass community on the ploughed and unploughed sites was markedly different (Figure 7 and Table 5). *Bromus diandrus* and *Hainardia cylindrica* formed 43% of the grass cover on the ploughed site, while being completely absent on the unploughed site. That weedy grasses were the most abundant category on the ploughed site (Figure 7) and that this category consisted of two grass species previously not recorded in the Cederberg (Cape Nature 2009) which are both declared weeds (Gibbs Russell et al. 1990) was surprising. These two grasses also are the only C4 grasses found in this survey (Gibbs Russell et al. 1990), although the consequences of this on ecosystem function, if any, are unknown. On the ploughed site, the combination of disturbance, grazing and possibly changes in nitrogen cycling (Knops and Tilman 2000) favoured alien grasses as they tend to have larger seed banks and are better adapted to disturbance which gives them a competitive advantage over local grasses (Milton 2004). That the invasive grasses have not colonised the unploughed areas is remarkable considering that these two areas border each other. This confirms that invasive non native grasses often only colonise an area following severe disturbance (Vlok 1988, D'Antonio and Vitousek 1992, McClaran and Anable 1992, D'Antonio et al. 2000).

Even though the unploughed site does not appear to have been invaded by weedy grasses, it does contain a very high proportion of generalist species (Figure 7) when compared to the species distribution for all the grass species found in the Cederberg Wilderness Area (Figure 19). 47% of the grass species found in the Cederberg are endemic to the fynbos biome, yet only 2 out of 6 grass species on the unploughed site were fynbos endemics, and these only make up only 17.2% of the grass community in this area. This suggests that fynbos endemics are underrepresented on the unploughed site, and to an even greater extent on the ploughed site.

Taylor's 1996 study listed four endemic fynbos grasses found on the Welbedacht shale band community. Only *Ehrharta ramosa* was encountered in this study (Table 5). When examining the combined grass floras of the vegetation units of the Cederberg as determined by Rebelo et al (2006), there are potentially eight fynbos endemics as well as two fynbos and succulent Karoo endemics to be found. However, only *Ehrharta ramosa* and *Tribolium hispidum* (14% and 20% on the unploughed site) were encountered during this survey (Table 5). Significantly, none of the endemics listed in either Taylor's study (1996) or Rebelo et al (1995) were found on the ploughed site. The more generalist grass species and weedy species seem to have outcompeted the Cape endemics at De Rif, especially on the ploughed site. This shows that although ploughing has caused the largest impact on the current grasses of De Rif, other forms of disturbance have also left the community depauperate when compared to the Cederberg as a whole. In section 5.5.1 some of these factors are discussed.

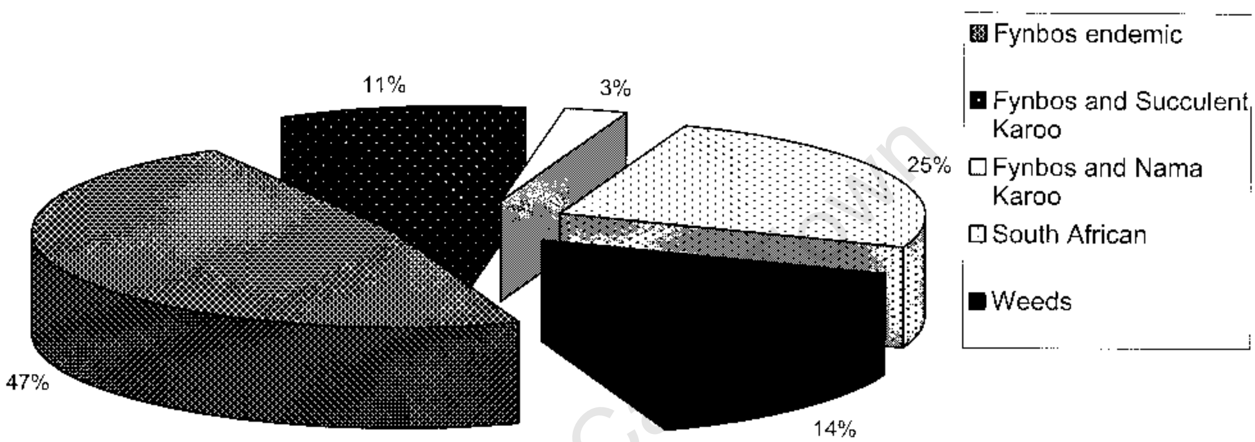


Figure 19 Pie chart showing the provenance of grasses found in the Cederberg

The results of the vegetation survey show that the effects of past ploughing also have also affected the vegetation structure of De Rif. The higher abundance of medium shrubs on the ploughed site (Table 4) may be a result of the altered structure of the soil, the previously ploughed soil allowing roots to grow down quickly and establish. The previously ploughed areas were also probably fertilised when wheat was grown, and this may have altered nitrogen cycling in the soil (Knops and Tilman 2000) and enabled large shrubs to grow. The medium shrubs were predominantly fast growing weedy species (e.g. *Stoebe sp,* data not shown) that probably established due to the past disturbance on the old fields. The change in height structure of the vegetation could influence the species diversity of the site as these medium sized shrubs could shade out smaller species explaining why fewer smaller shrubs were found on the ploughed site (Table 4).

The survey also suggests that Restionaceae are excluded from areas that have been previously ploughed although the analysis lacked statistical power (Table 4). This finding is intriguing, as it may help to explain the decline in restio abundance witnessed during the farmer period (see section 5.5.4). A survey of the literature on the establishment of Restionaceae did not yield an explanation of why ploughing would hamper the recruitment of this family. If it does, then in order to rehabilitate old fields, transplants would probably be necessary, as natural recruitment does not seem to take place.

5.5.3 The effects of disturbance on the Cyperaceae of De Rif

Although Cyperaceae are naturally more abundant in the post fire community (Kruger 1977, 1987), the highest values in Cyperaceae occur at relatively low values of charcoal suggesting that other factors, such as disturbance may have resulted in Cyperaceae reaching a new abundance in the De Rif community. An increase in Cyperaceae pollen abundance has been shown to be an indicator of increased disturbance and trampling associated with livestock farming (Dull 1999). Cyperaceae could also be colonising the disturbed paths and agricultural land around the farmstead as several of the Cyperaceae found in the Cape are weedy, cosmopolitan species (Goldblatt and Manning 2000). Thus there is potential for using Cyperaceae abundance as an indicator of disturbance if the amount of fire in the system can be quantified.

The increase in Cyperaceae abundance may also be related to changes in the total surface area of the wetland (Gillson 2006). The farmers at De Rif may have dammed the wetland in order to store water for the irrigation of the terraced wheat fields; furrows are still visible in the landscape today. A bigger wetland would support a greater abundance of Cyperaceae around the margins of the wetland (Gillson 2006, Duffin 2008) and thus increase the abundance of Cyperaceae pollen compared to the amount of charcoal. This would represent another form of disturbance to the De Rif site.

5.5.4 The effects of disturbance on the Restionaceae of De Rif

During the hunter/herder period Restionaceae were relatively abundant, but changes during the farmer period, led to Restionaceae pollen halving in abundance (Figure 20).

Restionaceae are one of the defining families of fynbos vegetation (Taylor 1978, Kruger 1979) and together with Cyperaceae, they are the dominant graminoid in fynbos (Goldblatt and Manning 2000). The Restionaceae found at De Rif were subject to several different forms of disturbance including changes in nitrogen cycling, grazing, an increase in competition from grasses, and an increase in harvesting, which may all have contributed to the decline in Restionaceae abundance. The increase in grass pollen at the expense of Restionaceae pollen (Figure 20) shows that species that respond well to disturbance are increasing in abundance while those that can't are declining.

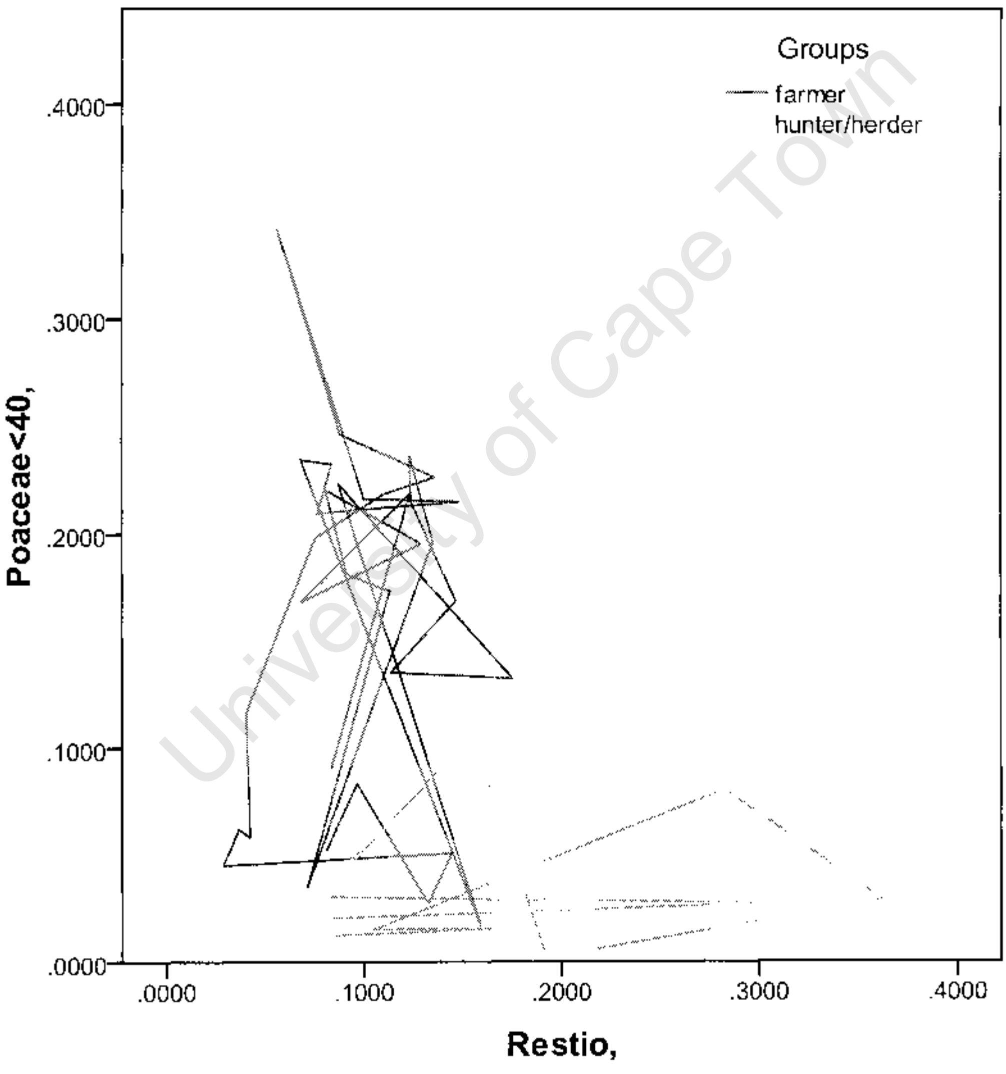


Figure 20 Phase diagram showing changes in the abundance of wild grasses and Restionaceae
Both Restionaceae and Poaceae pollen are expressed as proportions of the total pollen sum.

As Restionaceae are adapted to the nutrient poor soils of fynbos area (Linder 1991), they follow a "stress tolerant" strategy rather than a "competitive" strategy (Grime 1977) However changes in nitrogen cycling caused by the introduction of livestock and agriculture probably resulted in increased competition from grasses, which in turn caused the abundance of the Restionaceae to halve. According to Campbell and Werger (1988) the Restionaceae comprise more than 25% of the graminoid component of fynbos communities, otherwise the vegetation is defined as "non-fynbos". More recently Rebelo et al (2006) suggest that if Restionaceae abundance drops below 5% of the vegetation cover then the vegetation is defined as renosterveld rather than fynbos. Thus, at De Rif anthropogenic disturbance has altered the vegetation from what is considered typical fynbos in the area. This study is not suggesting that the vegetation of De Rif should be re-classified, but it shows that human disturbance alone may be enough to change the vegetation community to such an extent that it could be re-classified.

Although the Restionaceae are considered to be of poor grazing quality, they are frequently grazed (Linder 1991) but unlike most indigenous grasses which are adapted to tolerate this (Milton 2004), there is no evidence that restios can survive regular grazing. The introduction of intensive grazing at De Rif site with the initiation of permanent settlement may have resulted in a threshold in Restionaceae persistence being exceeded. If young, post fire Restionaceae were regularly grazed, it is possible that the plants were not able to accumulate enough biomass to recover and set seed, and hence declined in abundance in the community. This suggests that once a threshold of disturbance in the system was exceeded that plants that followed either a competitor strategy or ruderal strategy were favoured over those that followed a persistence strategy (sensu (Grime 1977)) and grass abundance increased at the expense of the Restionaceae.

Restios were also commonly used for thatching in the Cape (Taylor 1978) and it seems likely that the inhabitants of De Rif would have harvested restios growing in the vicinity of the homestead for this purpose. *Thamnochortus isignis* has been shown to suffer population declines under a combination of harvesting and fire (Campbell 2008) while *T erectus* is robust as long as harvesting occurs only every 3-5 years with fires after every 10 years. This shows that the Restionaceae display a variety of responses to harvesting and fire but it is plausible than an increase in harvesting around De Rif may have contributed to a decline in their abundance.

There seems to be no relationship between Restionaceae abundance and charcoal concentration (Figure 9 and Figure 10) although Restionaceae usually make up an important component of the post fire community (Kruger 1979). Kruger (1987) in his thesis on post fire succession shows that 3 years after fire Restionaceae make up approximately 40%, of the cover, while Cyperaceae makes up 14% and Poaceae 11%. However, Kruger's data suggests that for at least 10 years after fire Restionaceae abundance does not decline as the fynbos matures. This suggests that changes in Restionaceae abundance seen at De Rif are not linked to successional changes but due to other factors. Changes in Restionaceae abundance have been interpreted as support for changes in climate in the Cederberg. Meadows and Sugden (1991b) interpret an increase in the Restionaceae as suggesting moister conditions as does Scott (1994) who later acknowledges the problems associated with using this indicator in this and a later paper (Scott and Woodborne 2007a) due to the family consisting of both mesic and xeric adapted species. Both mesic and xeric members of the Restionaceae are abundant in the Cederberg, creating similar problems with using Restionaceae as a climatic indicator as those associated with Cyperaceae. However, using the charcoal data for this study, at the temporal and spatial scales investigated it is clear that the Restionaceae are responding to disturbance other than fire, rather than changes in climate.

5.6 THE EFFECTS OF PASTURE MANAGEMENT ON THE VEGETATION OF DE RIF

5.6.1 The effects of pasture management on *Elytropappus*

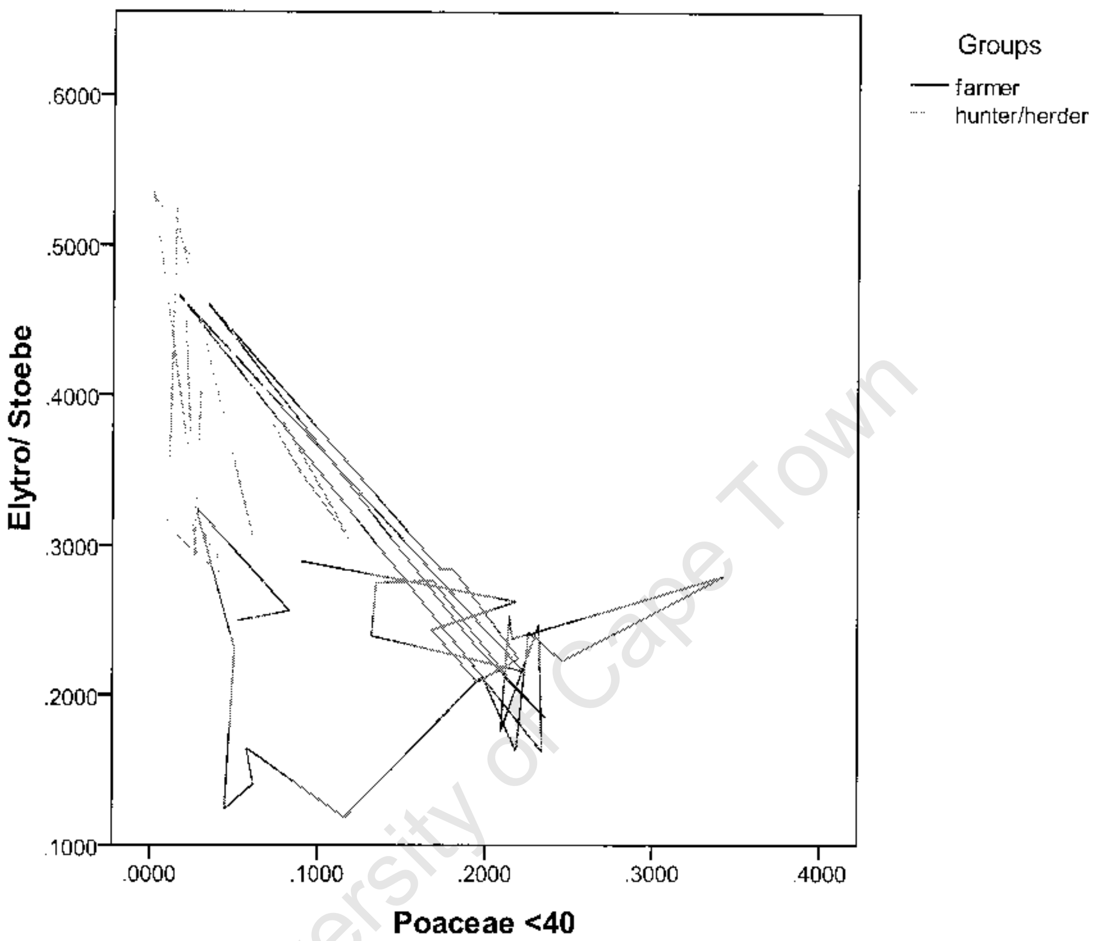


Figure 21 The phase diagram for the abundance of grass and *Elytropappus*
Both pollen types are expressed as proportions of the total pollen sum of 1. Poaceae <40 consists of wild grass pollen grains

This is the first study to show that during the farmer period, which included intensive management in order to improve grazing, there were switches between periods of high *Elytropappus* dominance with periods of high Poaceae dominance, one occurring at the expense of the other. This suggests that farmers were successfully manipulating the vegetation of De Rif in order to improve the quantity and quality of grazing available to livestock. The impacts of grazing are apparent at a family level in Renosterveld (McDowell 1988) which suggests they may be detectable when analysing pollen data as well.

These results suggest that herders and farmers were able to use fynbos for grazing by using fire in order to increase the abundance of grasses at the expense of *Elytropappus*. This form of management has been used in the grassy fynbos of the southern Cape (Cowling et al. 1986), but this is the first study to demonstrate the historical use of this technique and its effectiveness in the winter rainfall area of the fynbos. Although it is not possible to differentiate between *Stoebe* and *Elytropappus* pollen either in the Cederberg (Scott 1994, Scott and Woodbome 2007b, 2007a) or southern Africa in general (Dupont et al. 2007, Neumann et al. 2008), in this study it seems that the Elytro/Stoebe type predominantly consist of *Elytropappus* pollen. *Stoebe* pollen is considered an indicator of disturbance (Meadows and Sugden 1991b, Meadows et al. 1996, Neumann et al. 2008) and is commonly found in disturbed areas in the Cederberg (Taylor 1996). If this Elytro/Stoebe did consist predominantly of *Stoebe* pollen then we would expect higher values during most disturbed period, the farmer period. However, this pollen type dramatically declines at during the farmer period, so it is more likely to be *Elytropappus* than *Stoebe* and in this study is interpreted as such. Luckhoff (1971) saw the presence of *Stoebe* in the landscape as an indicator of too frequent fires resulting from patch burning. The pollen evidence suggests that this is not the case (Figure 9 and Figure 10) as there does not seem to be a direct relationship between the amount of charcoal and the amount of Elytro/Stoebe type pollen.

Elytropappus rhinocerotis (renosterbos) is an unpalatable shrub that forms dense stands, and thus is considered an undesirable species (Cowling et al. 1986) and farmers try to control its abundance in grazing areas (Cowling et al. 1986, McDowell 1988). It is thought to become dominant in an area due to a combination of fire and grazing; the seedlings germinate after fire but are very sensitive to shading (Levyns 1935), thus if grazing removes the competing grasses, *Elytropappus* dominates (Levyns 1956). Once the plant is dominant it is controlled either by physical removal through bush cutting (McDowell 1988) or the judicious use of fire (Cowling et al. 1986) with a break from grazing (Taylor 1978). *Elytropappus adpressus* used to be thought of as conspecific to *E. rhinocerotis* (Taylor 1996) and is one of the dominant, diagnostic plants of the Welbedacht shale band (Taylor 1996). It is not possible to distinguish between the pollen of different *Elytropappus* species so this discussion will refer to *Elytropappus* in general.

To what extent *Elytropappus-dominated* vegetation is a product of disturbance by pasture management is not understood (Cowling and Holmes 1992). No work has been conducted on the shale band vegetation of the Cederberg but there is a generally held belief that renosterveld vegetation was grassier in the past and that people have converted it to an *Elytropappus* dominated shrubland through overgrazing e.g. Deacon (1992). Cowling et al (1988) describe how asteraceous fynbos, subjected to frequent burning and grazing, resulted in either high grass cover or high *Elytropappus* cover. Areas with a high abundance of *Elytropappus* may be an example of the changes in vegetation that result when such a management technique is abandoned or incorrectly applied.

If the grasses are allowed to mature, (i.e. not subjected to early grazing) it is possible that they can compete with the *Elytropappus* and form a grassy community such as was found in areas of the southern Cape (Cowling et al. 1986). *Elytropappus* seedlings are very sensitive to shading (Levyns 1935, 1956) and thus a dense cover of grasses would inhibit the establishment of renosterbos. It is only when this shading influence is removed e.g. after a fire, that *Elytropappus* seedlings can germinate and establish (Levyns 1935, 1956). If livestock were allowed into a burnt area too soon, and grazed all the grass, the *Elytropappus* seedlings would be expected to successfully establish and dominate the area. Most livestock farmers up until this century moved their flocks to the Karoo during the winter months and burnt the fynbos a month before returning their flocks to the Cederberg (van der Merwe 1937, Brown et al. 1991, Taylor 1996). This may have given the grasses enough time to establish before grazing commenced. However, until the relationship between *Elytropappus,* grasses and their responses to fire and grazing are better understood, these ideas remain speculative.

The traditional interpretation of *Elytropappus* dominated landscapes is that they were grassier in the past (Deacon 1992) and are now only dominated by *Elytropappus* due to over grazing (McDowell 1988). This study suggests the opposite, as *Elytropappus* type pollen was more abundant during periods of lower human activity and land use in the Cederberg. Thus the management of the vegetation improved grazing and led to lower *Elytropappus* values. The decrease in *Elytropappus* abundance was probably achieved through a combination of physical removal through bush cutting (McDowell 1988) and the judicious use of fire (Cowling et al. 1986) with a break from grazing (Taylor 1978), although there are few published account of how 18 th and 19 th century farmers managed the landscape in the Cape (Bands 1977).

5.6.2 The effects of pasture management on weedy grasses

Pasture management, together with disturbance probably led to the introduction of weedy species to the De Rif site and these are still present in the landscape today. *Bromus diandrus* and *Hainardia cylindrical,* both exotic grasses, make up nearly 45% of the grass abundance on the formerly ploughed site (Table 5). These species were most likely introduced to the area by livestock (van Sittert 2000) as grass seeds can be transported hundreds of kilometres externally in the fleece of sheep (Manzano and Malo 2006) and internally after being consumed before being deposited in the faeces of animals (Manzano et al. 2005). In the Renosterveld up to 50% of all species that germinate in the faeces of livestock and game are alien grasses (Shiponeni and Milton 2006).The Cederberg farmers regularly moved their flocks to the Karoo in winter months (van der Merwe 1937, Brown et al. 1991, Taylor 1996) and this form of pasture management probably led to the spread of weedy species as well as generalist and succulent Karoo to De Rif.

The introduction of invasive grasses can lead to a decrease in the abundance of annual plants (Vlok 1988), but the impacts of alien grasses on ecosystems in South Africa are generally unknown (Milton 2004). Once alien grasses have established, grazing is generally thought to allow introduced grasses to persist (Hobbs 2001) and even increase in abundance especially if they are unpalatable species (McClaran and Anable 1992). Thus the consequences of past pasture management are still present in the landscape today.

5.7 SYNTHESIS OF THE EFFECTS OF CHANGES IN LAND USE ON DE RIF

This study investigated the effects of different forms of land use in the Cederberg using palaeoecological techniques in order to study vegetation change through time. The study aimed to determine if such changes in land use at De Rif were visible in the palaeoecological record, if they did result in changes in the vegetation and if these changes are still affecting the vegetation of the area today, especially as the area is currently managed as a wilderness area. If these effects have shaped the vegetation of the Cederberg, the context provided by this study would then give management a pre-agricultural baseline for the area from which to develop management plans. This study focuses on the impacts of people on the vegetation of the Cederberg through their role in changing fire and disturbance regimes, while moving from less intensive forms of land use like hunting and herding to more intensive land use associated with agriculture.

The results of the study suggest that the impacts of hunter-gatherers and herders in the De Rif area of the Cederberg were negligible and that this period of land use acts as a baseline with which to contrast the successive effects of permanent settlement and farming in the area. Thus there is a contrast, highlighted by the phase diagrams, between the hunter/herder period and the farmer period. The change in abundance of Poaceae and Cyperaceae could be explained by their relationship with fire before farming started. After farming began at De Rif, the relationship broke down, and other factors became more important in determining their abundance. Ericaceae may also be a family that is negatively affected by changes in fire even before farming started although this family may also be responding to changes in climate, while the Proteaceae seemed to be unaffected by changes in fire or land use during the period covered by this study.

The relationship between people and vegetation is a complex one and is subject to several feedback mechanisms which can make the untangling of cause and effect complicated. Figure 22 shows the relationship between people and vegetation and how factors like fire, invasive species and livestock can all interact. This figure focuses on the negative effects people can have on vegetation and can be used to examine the changes seen at De Rif with the initiation of agriculture and intensification of grazing.

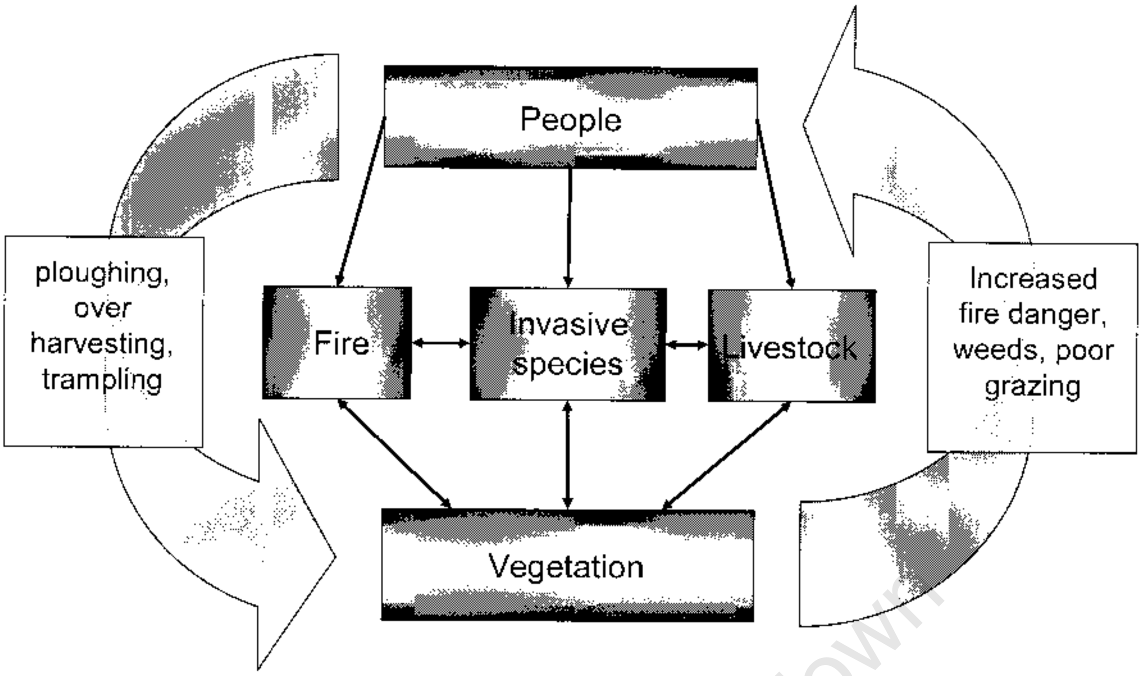


Figure 22 The negative interactions between people and vegetation

The initiation of agriculture at De Rif affected the abundance of *Elytropappus* and the Poaceae, Cyperaceae and Restionaceae families. *Elytropappus* abundance generally decreased while Poaceae abundance increased as people used fire and other techniques in order to improve grazing. This would be an affect of people on vegetation both through fire and through livestock (Figure 22). This increase in Poaceae abundance resulted in a decrease in Restionaceae abundance although the effects of ploughing, over harvesting and invasive grass species (Figure 22) also probably played a role. Likewise, Cyperaceae may have also increased in abundance because of disturbance (e.g. trampling and grazing).

The effects of ploughing combined with intensive livestock grazing and transhumance resulted in the introduction and persistence of invasive grass species on the De Rif site which are still present today. These invasive grasses in turn can affect fire, resulting in a fire grass cycle (D'Antonio and Vitousek 1992) with continued feedbacks between invasive grasses, fire and vegetation (Figure 22) as the increase in fire results in the increase in grasses which can tolerate fire at the expense of other types of vegetation that cannot. At De Rif this feedback may have important conservation consequences due to the presence of the endangered *Widdringtonia cedarbergensis* (IUCN 2009) which is fire sensitive and occurs in the vegetation bordering the De Rif site. Any increase in fire would further threaten this tree.

The study successfully demonstrates how changes in land use at De Rif over the past 2 000 years have affected the vegetation of the area. The factor to have had the largest influence on vegetation is agriculture through the effects of ploughing and the introduction of invasive species, as well the use of fire and grazing as part of agricultural practices. Fire on its own does affect the abundance of different types of vegetation in the area, but when combined with the disturbance associated with agriculture, it leads to a suite of changes in the vegetation community, some of which become self sustaining and appear irreversible.

6 CONCLUSION AND CONSERVATION IMPLICATIONS

The various effects of the intensification of land use, disturbance and fire management as identified in this palaeoecological study at De Rif are summarised below. The conservation implications of these changes are considered and areas for future research are suggested. Specifically, fire appears to have become more frequent during the transition from hunter gathering to farming especially during the period ±1750 AD to ±1900 AD.

6.1 HUMAN IMPACT ON FIRE AND VEGETATION

6.1.1 The fire history of De Rif from hunter-gatherers to the present

The analysis of fossil charcoal suggests that fire has increased with the introduction of more intensive forms of land use such as agriculture and permanent settlement in the Cederberg during the period of study from 2320 ±30BP until present. Specifically, fire appears to have become more frequent during the transition from hunter gathering to farming especially during the period ±1750 AD to ±1900 AD. The highest levels of charcoal were reached over a hundred years ago as they predate the high *Widdringtonia* values which originate from a cedar plantation that was established around the 1900s. This is the first study in the fynbos region to demonstrate an increase in fire with an increase in land use from pre-agricultural periods and tracks the changes in the plant community that result. The study demonstrates that palaeoecological techniques can be successfully applied to land use studies in the fynbos region where suitable deposits exist.

6.1.2 The effects of fire on vegetation

6.1.2.1 The effects of fire on grass, and the grass fire cycle

This study shows that the proportion of grasses in the plant community of the Northern Inland Shale Band Vegetation (Rebelo et al. 2006) around De Rif has increased through time and in tandem with an increase in fire. The increase in grass abundance after fire was in accordance with previous studies in the fynbos (Kruger 1977, Hoffman et al. 1987, Kruger 1987) and Renosterveld communities (van Rensburg 1962). This increase occurs because several Cape grasses resprout after fire (Linder and Ellis 1990b) and the post fire environment is favourable to grasses e.g. Verboom (2002) This result suggests that by manipulating the fire regime, a community with a greater abundance of grass could emerge (Cowling 1983, Cowling et al. 1986). The largest peak in charcoal abundance in the pollen diagram is found directly after a period of novel, high grass abundance and probably represents the largest fire in the last 2300 years in the area. Although the landscape was generally grassier due to patch burning, the peak in grass abundance is probably also due in part to the introduction of weedy grasses to De Rif as these are currently still present in the landscape. Grass invasions can often cause a change in fire regimes (D'Antonio and Vitousek 1992, Hobbs 2001). A change in fire regime due to the invasion of grass species can become a self-sustaining pattern (D'Antonio and Vitousek 1992) and can lead to the transformation of the vegetation in an area. Grass can also increase the horizontal connectivity of the vegetation (Brooks et al. 2004) which may allow it to carry a fire into areas that might otherwise have been isolated from a fire e.g. the Cedar areas below the De Rif site. The results show that a large fire has occurred after the increase in grass abundance and suggests that this grass fire cycle will persist in the area as long as high grass abundance continues.

6.1.2.2 The effects of fire on Cyperaceae

During the hunter/ herder period (2320 +30 BP until ±1800s) and the farmer period (1720s until +1940) the amount of charcoal and the amount of Cyperaceae pollen increase together. This suggests that as fire increases in the system, so does the abundance of Cyperaceae. Sedges recover quickly from fire and are often a dominant component of the post fire vegetation for several years after fire (Kruger 1987). The correlation between sedge pollen and charcoal can then be explained; periods of low charcoal abundance are inter-fire periods and Cyperaceae abundance is low as shrubs and woody vegetation are now dominant and shade out the shorter sedges, whilst after fires when high charcoal abundance occurs, Cyperaceae abundance increases (Kruger 1987) because the over shadowing vegetation has been removed.

6.1.2.3 The resilience of Proteas to fire

In this study Proteaceae pollen reached high abundance at both low and high amounts of charcoal, suggesting that the amount of fire in the system does not determine the abundance of Proteaceae in the Cederberg. This is unexpected as Proteas are thought to be one of the species most affected by changes in fire frequency (Bond et al. 1984, Richardson and van Wilgen 1992) and fire management has often been based around the recruitment requirements of this family (Richardson and van Wilgen 1992).

Proteaceae found in the area of De Rif may be resilient to changes in fire frequency as there are both resprouting and reseeding members of the family in this area of the Cederberg (Rebelo 1995, Taylor 1996, Cape Nature 2009). This suggests that while some members of the family may fail to recruit if fire frequencies become too high (Richardson and van Wilgen 1992), other resprouting members, such as *Protea nitida,* commonly found on the slopes around De Rif, may be unaffected or may increase in abundance. This change in species composition towards fire tolerant species would not show in the pollen record as the grains are not distinguishable below the family level. However, it is possible that threshold that would affect protea abundance at a family level has not yet been exceeded, and if it was, declines would result.

The resilience of Proteaceae to changes in fire in this study suggests that in future, palaeoecological interpretations of changes in protea pollen abundance should not be interpreted as being informative about past fire regimes. Furthermore, as there is no clear separation between hunter/herder and farmer phase space, the intensification of land use around De Rif has also not affected the Proteaceae family as a whole.

6.1.2.4 The sensitivity of Ericas to fire and climate

The phase diagram of *Erica* pollen and charcoal shows that ericas are most abundant when charcoal levels are at their lowest. The decrease in *Erica* abundance in relation to fire suggests that ericas have a very low tolerance of fire or that they were only more abundant during much wetter periods, or a combination of the two factors. The period of highest *Erica* abundance occurs in the oldest sediments of the core (2320 +30 BP) which is also a period of high moisture availability inferred from the high proportion of spores found in this zone of the core. The low abundance of ericas in the vegetation of the Cederberg as represented at De Rif may a signal that fire frequencies are currently higher than they were 2300 years ago.

6.1.3 The impacts of disturbance other than fire on vegetation

6.1.3.1 The impacts of disturbance on grass

During the farming period (+1750 AD to **±1900** AD) the abundance of grass increased to levels not seen during the hunter/herder period (2300BP to +1750 AD). This shows that the intensification of land use in this area of the Cederberg led to an increase in the abundance of the Poaceae family. This probably occurred due to a combination of factors, the most important of which is farming. Ploughing caused a change in the grass community. On a previously ploughed area, invasive weeds make up nearly 45% of the grass abundance, while none were present on the unploughed site. Of the current grass species found at De Rif, only around 10% are endemic to fynbos, compared to 47% for the Cederberg as a whole. A survey of present vegetation and the pollen record, demonstrates the disturbed nature of the site nearly seventy years after ploughing was abandoned.

6.1.3.2 The impacts of disturbance on Cyperaceae

Although Cyperaceae is naturally more abundant in the post fire community (Kruger 1977, 1987), the highest values in Cyperaceae occur at relatively low values of charcoal suggesting that other factors_may have resulted in Cyperaceae reaching a new level of abundance in the De Rif community. An increase in Cyperaceae pollen abundance has been shown to be an indicator of increased disturbance and trampling associated with livestock farming (Dull 1999). Cyperaceae could also be colonising the disturbed paths and agricultural land around the farmstead as several of the Cyperaceae found in the Cape are weedy, cosmopolitan species (Goldblatt and Manning 2000). Thus there is potential for using Cyperaceae abundance as an indicator of disturbance if the amount of fire in the system is quantified.

The largest peak in Cyperaceae may have been related to changes in the total surface area of the wetland (Gillson 2006). The farmers at De Rif may have dammed the wetland in order to store water for the irrigation of the terraced wheat fields, as furrows are still visible in the landscape today. A bigger wetland would support a greater abundance of Cyperaceae around the margins of the wetland (Gillson 2006, Duffin

2008) and thus increase the abundance of Cyperaceae pollen compared to the amount of charcoal. This would represent another form of disturbance to the De Rif site.

6.1.3.3 The impacts of disturbance on the Restionaceae

During the hunter/herder period (2300BP to +1750 AD) restios were relatively abundant, but changes during the farmer period (+1750 AD to 1900 AD), led to restio pollen halving in abundance. The restios found at De Rif were subject to several different forms of disturbance including changes in nitrogen cycling, grazing, an increase in competition from grasses and an increase in harvesting, which may all have contributed to the decline in restio abundance.

Changes in nitrogen cycling caused by livestock and agriculture probably resulted in increased competition from grasses, which in turn caused the abundance of restios to halve. The introduction of regular grazing to the De Rif site, another intensive form of disturbance, may have also contributed to a threshold in restio persistence being exceeded during the farmer period. Furthermore, restios were also commonly used for thatching in the Cape (Taylor 1978) and it seems likely that the inhabitants of De Rif would have harvested restios growing in the vicinity of the homestead for this purpose. Thus people in the Cederberg decreased the abundance of a key fynbos taxon probably though a combination of grazing, changes in land use and over exploitation.

6.1.4 The effects of pasture management on vegetation

6.1.4.1 The effects of pasture management on Elytropappus

This is the first study to show that during the farmer period (+1750 AD to 1900 AD), which included intensive management in order to improve grazing, there were switches between periods of high *Elytropappus* dominance with periods of high Poaceae dominance, one occurring at the expense of the other. The results suggest that herders and farmers were able to use fynbos for grazing by manipulating the fire regime in order to increase the abundance of grasses at the expense of *Elytropappus*. This form of management has been used in the grassy fynbos of the southern Cape (Cowling et al. 1986), but this is the first study to demonstrate the historical use of this technique and its effectiveness in the winter rainfall area of the fynbos. The decrease in *Elytropappus* abundance was probably achieved through a combination of physical removal through bush cutting (McDowell 1988) and the judicious use of fire (Cowling et al. 1986) with a break from grazing (Taylor 1978).

6.1.4.2 The effects of pasture management on weedy grasses

Pasture management, together with disturbance probably led to the introduction of weedy species to the De Rif site and these are still present in the landscape today. *Bromus diandrus* and *Hainardia cylindrical,* both exotic grasses, make up nearly 45% of the grass abundance on the formerly ploughed site. These species were most likely introduced to the area by livestock (van Sittert 2000) as grass seeds can be transported hundreds of kilometres externally in the fleece of sheep (Manzano and Malo 2006) and internally after being consumed before being deposited in the faeces of animals (Manzano et al. 2005). Cederberg farmers regularly moved their flocks to the Karoo in winter months (van der Merwe 1937, Brown et al. 1991, Taylor 1996) and this form of pasture management probably led to the spread of weedy species as well as generalist and succulent Karoo species to De Rif. Once alien grasses have established, grazing is generally thought to allow introduced grasses to persist (Hobbs 2001) and even increase in abundance especially if they are unpalatable species (McClaran and Anable 1992). Thus the consequences of past pasture management are still present in the landscape today.

6.2 CONSERVATION AND REHABILITATION IMPLICATIONS

6.2.1 The effect of past disturbance on De Rif

This study clearly demonstrates that the consequences of past disturbance by ploughing are still affecting the area of De Rif today and that such impacts within a wilderness area require monitoring and rehabilitation. The study is the first to demonstrate that two species of weedy grasses, *Bromus diandrus* and *Hainardia cylindrical* which are not on the Cape Nature list for the Cederberg are still present in the formerly ploughed areas. These species are declared weeds (Gibbs Russell et al. 1990) and may pose a threat to conservation within the wilderness area in future, especially as the future impacts of climate change on invasive species are generally poorly understood (Richardson and van Wilgen 2004). The site would need to be monitored in order to ensure that these species are not spreading into neighbouring uninvaded areas.

This study also demonstrates the irreversibility of the impacts of farming on fynbos. The ploughed wheat fields not only harbour invasive weeds, but also have a different vegetation and height composition to the surrounding vegetation nearly seventy years after the farming was abandoned. Although the physical aspects of De Rif farmstead were dismantled in the 1970s after the declaration of the Cederberg Wilderness Area, the vegetation still shows the signs of past land use and disturbance.

6.2.2 Investigating the rehabilitation of De Rif

6.2.2.1 What does the seed bank of De Rif contain?

Fourie (2008) has shown that soil seed banks can enough to re-establish a sufficient cover of fynbos vegetation in a naturally grassy fynbos site after an invasion by alien trees. To what extent this is possible following an invasion of alien grasses remains to be seen. A useful study at the De Rif site would be to investigate the current soil seed bank to see what species and guilds are still naturally present. If the seed bank still contains a functional assemblage of fynbos species then the control of grasses alone may be sufficient to rehabilitate this area without having to transplant in new species as is planned (Cape Nature 2000). Such an intervention may be cheaper as well. The results of the vegetation survey suggest that restios are not found on the previously ploughed site. Further study could investigate if restio seeds were present in the seed bank of the previously ploughed area. If so, further investigation into what is limiting the recruitment of the family would be needed. If restio seeds are not present in the seed bank then rehabilitation may involve the transplanting of restios. Research could focus on the fate of these transplanted restios and determine the costs and viability of such a rehabilitation option.

6.2.2.2 What species should the site contain?

A detailed vegetation survey of the less degraded areas around De Rif would allow for the better conservation and rehabilitation of the site as it would show which species may be missing due to past disturbance and changes in fire regime, while the current study can only demonstrate changes in vegetation at family level.

6.2.2.3 The control of invasive grasses

An investigation into the control of the grasses present on De Rif would also prove useful as several different options are possible (Musil et al. 2005). Reducing grass competition has been shown to increase the survival of other species in old field rehabilitation experiments in the Renosterveld (Midoko-Iponga et al. 2005). *Bromus diandrus* and *Hainardia cylindrical* are also the only grasses to follow the C_4 photosynthetic pathway in this area and the significance of this is unknown and may require further investigation. Cowling (1983) showed that C_3 grasses in the South Eastern Cape could still dominate when competing with C_4 grasses if disturbance and nitrogen inputs were both low but this does not explain what may happen when these factors are both high and the site is in the winter rainfall region of the fynbos biome.

6.3 FUTURE RESEARCH

6.3.1 The refinement of palaeo proxies

The interpretation of several pollen types in palaeoecological studies in the Cape has been challenged by this study. One is the assumption that *Stoebe* type pollen is an indicator of disturbance. In this study Elytro/Stoebe type pollen it is an indicator of intact *Elytropappus* vegetation. The use of Cyperaceae and Ericaceae pollen as moisture indicators is another. This study suggests that Cyperaceae are responding to changes in disturbance and fire rather than changes in climate, although this may be because of the time period and scale of the current study. Only one major peak in Cyperaceae could be attributed to hydrological change. Further investigation into the morphology of pollen from Cape sedges may allow for the division of Cyperaceae pollen types, which display considerable morphological variation (Nagels et al. 2009) into sedges that favour dry areas and those which favour wet areas. This would prove very useful in climatic reconstructions for the Cape. Further research linking specific aspects of changes in fire regime to changes in charcoal abundance, may help further refine climatic reconstructions and provide a much greater insight into vegetation and fire dynamics in fynbos through time.

7 APPENDICES

APPENDIX 1. INFORMATION ON SPORE TABLETS

Lycopodium spore tablets (batch 483216) (September 2004)

Lycopodium spore tablets can be dissolved in water or in HC1, but not in NaOH. They have been prepared in a slightly different way compared to that described by Stockmarr (1971, 1973). The tablets are thus based mainly on sodium bicarbonate together with polyvinylpyrilidon and polyethyleneglycol, which must be carefully washed away with water and finally with diluted HCl before further treatment. The spores are acetolysed. The spore concentration has been determined with an electronic particle counter, Coulter Counter ZB (cf.Stockmarr 1973), tube size 140 pm. 100 samples of five tablets each taken from different places in the batch were prepared by dissolving the tablets in Isoton II NaCl solution in 100 ml flasks. 20 counts each of 0.5 ml were made on each sample.

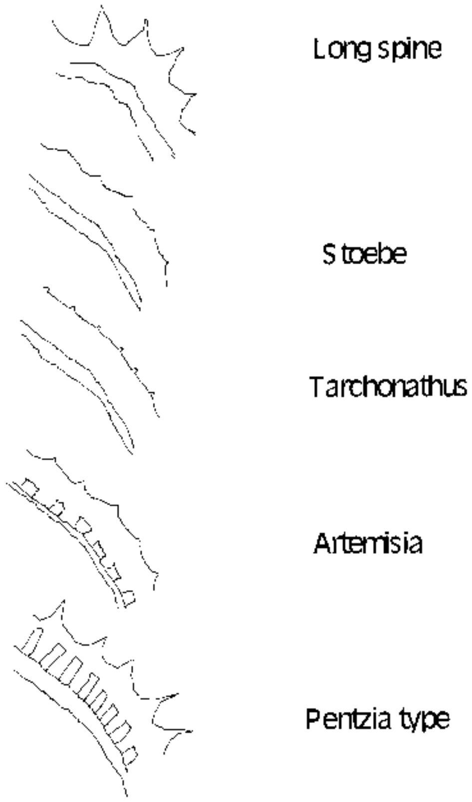
Result of the calibration (5 tablets): X = 92914 s = ± 3820 V = ± 4.1 %

For one tablet: X = 18583

Production

Spore tablets for calibration of pollen analyses have earlier been produced and distributed by Dr Jens Stockmarr, Copenhagen. In October 1980 this business was taken over by the Department of Quaternary Geology in Lund. It is performed as an official commission approved by the University of Lund. A new batch, No. 483216, is now produced and calibrated and tablets are available. The tablets were manufactured in Denmark.

APPENDIX 2. ASTERACEAE IDENTIFICATION



From Professor Louis Scott

7.1 APPENDIX 3. PLANT COMMUNITIES THAT CONTRIBUTE TO THE FLORA OF DE RIF

Table 7 Plant communities that potentially contribute flora to the vegetation of De Rif

Adapted from Taylor (1996) with family information from Trinder-Smith (2003). Species richness is given as an average with the maximum and minimum values in brackets

Community	Dominants	Family
1	*Brabejum stellatifolium*	Proteaceae
Thicket of fire-protected kloofs and screes	*Metrosideros angustifolia*	Myrtaceae
River kloofs	*Prionium serratum (palmiet)*	Prioniaceae
Pteridium aquilinum — Brabejum stellatfolium	Also	
Species richness: 14 (13-15)	*Brachylaena neriifolia (waterwitels)*	Asteraceae
	Calopsis paniculata	Restionaceae
	Rhus angustifolia	Anacardiaceae
2	*Metrosideros angustifolia*	Myrtaceae
Thicket of fire-protected kloofs and screes	*Elegia capensis*	Restionaceae
River kloofs	Also	
Pteridium aquilinum — Todea Barbara	*Clutia pulchella*	Euphorbiaceae
Species richness: 13 (12-14)		
3	*Metrosideros angustifolia*	Myrtaceae
Thicket of fire-protected kloofs and screes	*Heeria argentea*	Anacardiaceae
Scree and sand	*Podocarpus elongatus*	Podocarpaceae
Olea europaea subsp *africana — Metrosideros angustifolia*	*Hartogiella schinoides*	Celastraceae
Species richness: 23 (14-31)	*Maytenus oleoides*	Celastraceae
	Diospyros *glabra*	Ebenaceae
	Myrica serrata	Myricaceae
4	*Olea europaea subsp africana*	Oleaceae
Thicket of fire-protected kloofs and screes	*Heeria argentea*	Anacardiaceae
Scree and sand	*Cassine peragua*	Anacardiaceae
Olea europaea subsp. *africana Myrsine africana*	*Maytenus oleoides*	Celastraceae
Species richness: 23 (16-32)	*Podocarpus elongatus*	Podocarpaceae
	Kiggelaria africana	Kiggelariaceae
	Hartogiella schinoides	Celastraceae
	Rhus undulata	Anacardiaceae
17	*Elytropappus adpressus*	Asteraceae
Fynbos of well-drained habitats	*Protea acuminata*	Proteaceae
Sandy habitats	*Leucadendron glaberrimum*	Proteaceae
Silt	*Aspalathus triquetra*	Fabaceae
Elytropappus adpressus - - Leucadendron glaberrimum community of the Welbedacht shaleband	*Metalasia densa*	Asteraceae
Species richness: 24 (12-36)	*Ischyrolepis unispicata*	Restionaceae
	Cannomois parviflora	Restionaceae
	Ischyrolepis virgea	Restionaceae
	Willdenowia arescens	Restionaceae
	Calopsis viminea	Restionaceae
	Also	

	Leucadendron pubescens	Proteaceae
	Leucadendron dubium	Proteaceae
	Cannomois virgata	Restionaceae
	Athanasia microphylla	Asteraceae
	Cannomois aristata	Restionaceae
18	*Ischyrolepis monanthos*	Restionaceae
	Thamnochortus platypteris	Restionaceae
Fynbos of well-drained	*Willdenowia arescens*	Restionaceae
habitats	*Willdenowia incurvata*	Restionaceae
Sandy habitats	*Ischyrolepis sieberi*	Restionaceae
Sand	*Cannomois parviflora*	Restionaceae
Willdenowia acrescens -	*Hypodiscus neesi*	Restionaceae
Thamnochortus platypteris	*Rafnia diffusa*	Fabaceae
community of local sandy	*Metalasia agathosmoides*	Asteraceae
flats	*Cliffortia ruscifolia*	Rosaceae
Species richness: 22 (16-37)	*Diosma meyeriana*	Rutaceae
	Also	
	Tetraria compar	Cyperaceae
	Tetraria nigrovaginata	Cyperaceae
	Ficinia bulbosa	Cyperaceae
	Cymbopogon marginatus	Poaceae
	Merxmuellera stricta	Poaceae
	Stipagrostis zeyherei	Poaceae
	Stoebe leucocephala	Asteraceae
	Macrostylis tenuis/decipiens	Rutaceae
	Lampranthus laetus	Aizoaceae
	Protea acaulos	Proteaceae
	Pelargonium coronopifolium	Geraniaceae
	Anthospermum aethiopicum	Rubiaceae
	Athanasia oligophylla	Asteraceae
	Leucadendron salignum	Proteaceae
	Leucadendron loranthifolium	Proteaceae
	Othonna parviflora	Asteraceae
24	*Tetraria spp*	Cyperaceae
Fynbos of poorly-drained	*Elegia asperiflora*	Restionaceae
habitats	*Restio occultus*	Restionaceae
Mid-altitude plateaux and	*Macrochaetium ecklonii*	Cyperaceae
terraces	*Also*	
Permanently moist habitats	*Utricularia capensis*	Lentibulariaceae
Tetraria sp nov (T 11230) -	*Fuirena hirsute*	Cyperaceae
Elegia asperiflora	*Chrysithrix junciformis*	Cyperaceae
community on seepages	*Epischoenus gracilis*	Cyperaceae
Species richness: 14 (10-19)	*Juncus capensis*	Juncaceae
	Andropogon appendiculatus	Poaceae

APPENDIX 4.GRASS SPECIES OF THE CEDERBERG

Table 8 Cederberg grass species list

Complied from Cape Nature species list (Cape Nature 2009), Taylor (1996) and Rebelo et al (2006). Status from Gibbs Russel (1990) and Milton (2004) unless otherwise stated

Poaceae	Status	Sources
Aira cupaniana Guss.	Weed	(Cape Nature 2009)
Andropogon appendiculatus Nees	South Africa	(Cape Nature 2009) (Rebelo et al. 2006)
Anthoxanthum tongo (Trin.) Stapf	Fynbos endemic, competitor avoider	(Cape Nature 2009)
Briza maxima L.	Weed, old lands and homesteads, palatable (Macdonald et al. 1987)	(Cape Nature 2009)
Briza minor L.	Weed, likes damp areas and around old homesteads (Macdonald et al. 1987)	(Cape Nature 2009)
Cymbopogon marginatus (Steud.) Stapf ex Burtt Davy	Fynbos and Nama Karoo endemic	(Cape Nature 2009)
Ehrharta calycina Sm.	South Africa, coppicing	(Rebelo et al. 2006, Cape Nature 2009),
Ehrharta capensis Thunb.	Fynbos endemic, geophytic	(Cape Nature 2009)
Ehrharta ramosa (Thunb.) Thunb.	Fynbos endemic, competitor	(Rebelo et al. 2006, Cape Nature 2009)
*Ehrharta thunbergii Gibbs-**Russ.***	Fynbos and Succulent Karoo endemic	(Cape Nature 2009)
Ehrharta villosa Schult.f.	South Africa, competitor	(Rebelo et al. 2006, Cape Nature 2009)
Eragrostis curvula (Schrad.) Nees	South Africa	(Cape Nature 2009)
Festuca scabra Vahl	South Africa, geophytic	(Cape Nature 2009)
Holcus setiger	Fynbos and Succulent Karoo endemic	(Taylor 1996)
*Merxmuellera arundinacea **(P.J.Bergius)** Conert*	Fynbos endemic, coppicing	(Rebelo et al. 2006, Cape Nature 2009)
Merxmuellera rufa (Nees) Conert	Fynbos endemic, geophytic	(Rebelo et al. 2006, Cape Nature 2009)
Merxmuellera stricta (Schrad.) Conert	South Africa, coppicing	(Rebelo et al. 2006, Cape Nature 2009)
Paspalum dilatatum Poir.	Weed	(Cape Nature 2009)
Pennisetum macrourum Trin.	South Africa	(Cape Nature 2009)
Pennisetum thunbergii Kunth	South Africa	(Cape Nature 2009)

Pentameris distichophylla (Lehm.) Nees	Fynbos endemic,	(Cape Nature 2009)
Pentameris macrocalycina (Steud.) Schweick.	Fynbos endemic, coppicing and competitor	(Rebelo et al. 2006, Cape Nature 2009)
Pentaschistis alticola Linder	Fynbos endemic, fire stimulated flowering (Gibbs Russell et al. 1990)	(Rebelo et al. 2006)
Pentaschistis aristidoides (Thunb.) Stapf	Fynbos endemic, geophytic guild (Linder and Ellis 1990)	(Cape Nature 2009)
Pentaschistis colorata (Steud.) Stapf	Fynbos endemic, coppicing guild (Linder and Ellis 1990)	(Cape Nature 2009)
Pentaschistis curvifolia (Schrad.) Stapf	Fynbos endemic, coppicing guild (Linder and Ellis 1990)	(Cape Nature 2009)
Pentaschistis caulescens Linder	Fynbos shale band endemic	(Rebelo et al. 2006)
Pentaschistis densifolia (Nees) Stapf	Fynbos endemic, competition avoider (Linder and Ellis 1990)	(Rebelo et al. 2006, Cape Nature 2009)
Pentaschistis eriostoma (Nees) Stapf	Fynbos and Succulent Karoo endemic, competition avoider (Linder and Ellis 1990)	(Rebelo et al. 2006, Cape Nature 2009)
Pentaschistis malouinensis (Steud.) Clayton	Fynbos endemic, competition avoider (Linder and Ellis 1990)	(Cape Nature 2009)
Pentaschistis pallida (Thunb.) Linder	Fynbos and Succulent Karoo endemic, ephemeral reseeder/coppicing, likes disturbed places (Gibbs Russell et al. 1990)	(Rebelo et al. 2006)
Pentaschistis patula (Nees) Stapf	Fynbos and Succulent Karoo endemic	(Cape Nature 2009)
Pentaschistis pungens Linder	Fynbos endemic, ephemeral reseeder	(Cape Nature 2009)
Pentaschistis pusilla (Nees) Linder	Fynbos endemic . competitor avoider	(Cape Nature 2009)
Pentaschistis pyrophila Linder	Fynbos endemic . coppicing	(Cape Nature 2009)
Pentaschistis rosea subsp. purpurascenc Linder	Fynbos endemic . ephemeral reseeder	(Rebelo et al. 2006)
Pentaschistis velutina Linder	Fynbos endemic . geophytic	(Cape Nature 2009)
Pentaschistis viscidula (Nees) Stapf	Fynbos endemic . geophytic	(Cape Nature 2009)

Stipagrostis zeyheri macropus (Nees) De Winter	Fynbos and Succulent Karoo endemic,	(Cape Nature 2009)
Tribolium hispidum (Thunb.) Desv.	RSA	(Rebelo et al. 2006, Cape Nature 2009)
Tribolium uniolae (L.f.) Renvoize	Fynbos endemic	(Cape Nature 2009)
Vulpia bromoides (L.) Gray	Weed	(Cape Nature 2009)

**Previously Pentameris dregeana Stapf*

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