The Vegetation of Paulshoek, Namaqualand: Phytosociology and landuse impacts

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Abstract

The succulent karoo biome is acclaimed internationally for its high biodiversity and endemism. At the same time the area is perceived to be under threat from extensive livestock production. Extensive research has been under taken in the last twenty years to describe and understand the underlying mechanisms that influence vegetation composition and distribution in this biome.

A detailed summary of the main phytosociological studies completed in the succulent karoo biome is included. This includes Adamson's classic 1938 description of the vegetation of the Kamiesberg. A further six studies are described which provide a platform for the phytosociological analysis carried out in this thesis. A context for this thesis is provided by a brief synthesis of the vegetation of the succulent karoo biome including aspects concerned with the climate, plant diversity and history of land use practices in the region.

This study was undertaken primarily, however, to classify and describe the vegetation of Paulshoek, a small village comprising 20 000 ha in the communal area of Leliefontein, Central Namaqualand. The Braun-Blanquet vegetation classification approach was used and modelled satellite imagery was applied to classify the perennial vegetation of Paulshoek. The vegetation data was also subjected to canonical correspondence analysis (CCA) to determine the associated environment variables. Furthermore, this study also aimed to determine the impact of different management strategies on the diversity (species richness, similarity, evenness and dominance/diversity), composition and structure of uplands and lowlands vegetation. Data was subjected to TWINSPAN analysis, CCA, diversity, similarity and evenness investigations. Furthermore, the data set was subjected to Kruskal-Wallis one way ANOVA, multiple comparisons with t distribution test and Mann-Whitney statistical tests to determine significant differences between vegetation types and landuse treatments.

Four vegetation communities with sub-communities were classified in Paulshoek. The four communities were determined largely by their geomorphological position in the landscape. Community 1-*Galenia africana*-low evergreen shrubs on flats is found mainly to the south-east and north-east of the village. This community is characterised by low evergreen shrubs less than 50 cm high. It is restricted to low lying flats and footslopes of the landscape. The rock cover is low, with shallow and slightly acidic sand to sandy loam soils. Phosphorus and magnesium concentrations are highest in this community and the 0.2-4 cm rock cover class dominates it. Livestock grazing is extensive in this community and as a result it is the most transformed community. Community 2-*Ruschia robusta*-low leaf succulent shrubs on footslopes is found to the east of the villages with patches throughout the landscape. This community appears to be transitional between communities

found on the flats and those that occur on the midslopes. Floristically, dwarf leaf succulents less than 50 cm high dominate this community. The total rock cover is low and soils are more acidic and less sandy than community 1. Phosphorus and magnesium concentrations are lower than community 1 but the percentage soil organic matter and litter are generally higher than for community 1. The levels of livestock disturbance are lower than in community 1. Community 3-*Pteronia glomerata*-low evergreen shrubs on midslopes is distributed mainly to the west and north-west of the village. Low evergreen shrubs dominate this community. It has a high rock cover, with deep clayey soils that contain a high percentage of soil organic matter and litter. Sodium, calcium and potassium concentrations are generally highest in this community. This community is less impacted by livestock grazing due to its relatively far distance from waterpoints. Community 4-*Diospyros austro-africana*-tall-evergreen shrubs on upper slopes and crests is confined to the north-west of the village, which receives the highest rainfall for the entire study site. Tall evergreen shrubs, many with mountain fynbos and mountain renosterveld affinities dominate it, although low evergreen shrubs with succulent karoo affinities are also present. Rock cover is highest in this community which contains a high percentage of exposed bedrock. Deep and relatively alkaline sandy loam soils characterized this community. Nitrogen concentrations, percentage soil organic matter and litter is relatively high in this community, which is furthest from the village with no permanent waterpoints in close proximity and hence experiences relatively low livestock impact.

The results from the comparisons of species composition between communal and privately owned land showed that there is a clear distinction between species composition of uplands and lowlands vegetation in both areas with very little overlap. The community diversity analysis showed no difference in species richness or evenness indices between vegetation communities of communal and privately owned areas. Lowlands vegetation, however, exhibited a higher degree of dominance than the uplands communities for both management strategies. Community composition and structure showed no change under the different management strategies in the uplands vegetation. However, lowlands vegetation under communal grazing was significantly different from privately owned land in terms of composition and structure. There was no significant difference in growth form composition between communal areas and privately owned land. These results are different from previous studies in the area and suggest that grazing impacts in communal areas are relatively low at sites away from waterpoints and villages.

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Chapter 1: An introduction to the succulent karoo biome and a brief account of vegetation research in the region

1.1 Background

This thesis forms part of a larger, more comprehensive project entitled "Global change and subsistence rangelands in Southern Africa: Resource variability, access and use in relation to rural livelihoods and welfare", hereafter referred to as the Global Change and Subsistence Rangelands Project. This project is funded in part by the European Union (EU) and enjoys significant support from the National Botanical Institute (NBI), the Programme for Land and Agrarian Studies (PLAAS) at the University of the Western Cape and the Agricultural Research Council's Range and Forage Institute (RFI). The project has adopted an inter-disciplinary approach, integrating biophysical and socio-economic studies and issues pertaining to community and national policies. This approach has been adopted in order to understand the complexities of rangelands as well as to understand their functioning, and to contribute to the broader debate concerning rangeland management.

The overall objectives of the Global Change and Subsistence Rangelands Project are to:

- → determine how rangeland state influences the components of rangeland productivity;
- → establish how the components of rangeland productivity contribute to the welfare of rural communities;
- → assess the impacts of current formal and informal policies and practices (at scales ranging from household to global) on resource access, use by different groups within the rural community as well as policies on their welfare;
- → assess the impacts of the variability in biophysical processes and socio-economic influences on rangeland state, rangeland productivity and human welfare;

- → collate and evaluate the data, derive models and relevant hypotheses, and develop policy and intervention options designed to optimise human welfare and sustainable rangeland use;
- → make preliminary estimates of the dynamics of the impacts of human-induced global changes on rangeland productivity and rural welfare.

This project is based in three countries, with study sites in each country - Botswana, Lesotho and South Africa. European partners on the project are from Norway, Spain and Wales.

This thesis aims to present an understanding of environmental variables and land use impacts on rangeland condition. It will describe the vegetation communities in the South African study site in terms of its structure and composition, and relate these vegetation communities to environmental variables and land use impacts. Thus, this thesis ultimately contributes to a broader understanding of the rangelands of Southern Africa, and in particular the succulent karoo biome.

1.2 The succulent karoo biome

1.2.1 Location and description

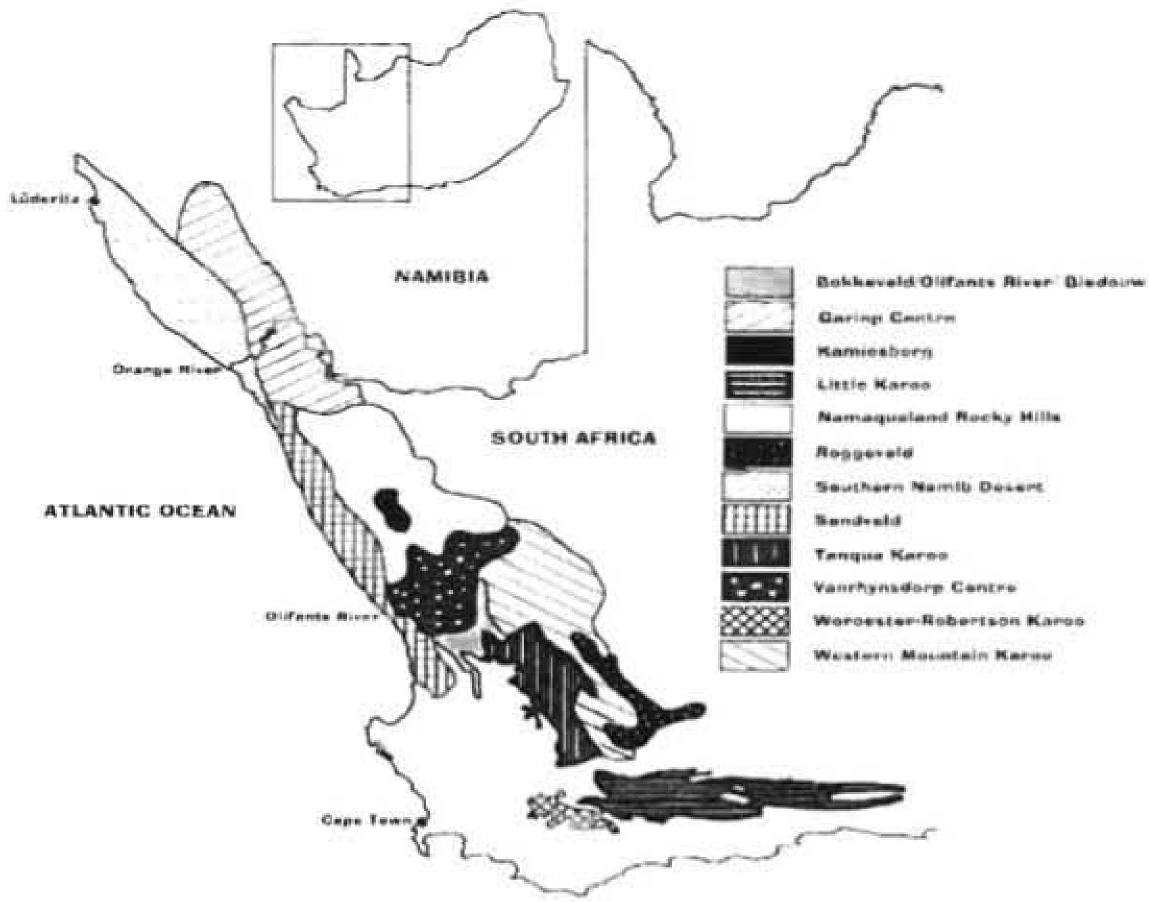

Figure 1.1. Bioregions of the succulent karoo biome (modified after Lombard *et al.* 1999)

The succulent karoo biome (Lombard *et al.* 1999 *sensu* Rutherford and Westfall 1986) stretches from the western part of southern Namibia (26°8' S", 14°56' E), southwards along the western side of the South African escarpment to the eastern border of the Western Cape Province in the Little Karoo (34° S, 23°11'E) (Figure 1.1). The succulent karoo biome is one of six biomes in Southern Africa (Rutherford 1997) and covers approximately 100 000 km^2. It is a vast region of rugged landscapes and low treeless vegetation. The altitude of the biome ranges from sea level to 1 500 meters above sea level (masl), but on average the area lies at about 800 meters (Rutherford and Westfall 1986). This region experiences a reliable (coefficient of variation <30%), low (mean 170 mm per annum) winter rainfall with 60% of it received during winter (Rutherford and Westfall 1986; Hoffman and Cowling 1987; Hilton-Taylor 1996; Milton *et al.* 1997; Desmet and Cowling 1999a). Some areas of the succulent karoo biome may also receive rain at any time of the year (Hilton-Taylor 1996). Summer temperatures are relatively high but winter temperatures are seldom below freezing (Hoffman 1996; Hilton-Taylor 1996).

The succulent karoo biome is bounded by the desert, savanna, Nama-karoo and fynbos biomes. In the west it is confined by the cold Atlantic coastline and in the south by the fynbos biome. The arid savanna biome forms the boundary in the north-east while the succulent karoo biome grades into the Nama-karoo biome in the east (Palmer and Hoffman 1997). The desert biome forms the northern boundary (Rutherford and Westfall 1986; Milton *et al.* 1997).

The succulent karoo biome can be divided into smaller units called bioregions (Hilton-Taylor 1996; Lombard *et al.* 1999) (Figure 1.1). This division is based on the different geology, topography, total amount of rainfall received and the season of the rainfall in each bioregion (Hilton-Taylor 1996). The distinct differences in the biophysical environments are reflected in the different floristic composition present in each of twelve bioregions. A clear distinction can be drawn between the arid bioregions (Gariep Centre, Southern Namib Desert, Sandveld, Vanrhynsdorp Centre) and less arid bioregions (Namaqualand Rocky Hills, Western Mountain Karoo, Bokkeveld/Olifants River/ Biedouw, Roggeveld Tanqua Karoo, Worcester-Robertson Karoo, Little Karoo). The arid bioregions occur mostly at low rainfall and usually contain a higher proportion of succulent elements. Vegetation height and canopy cover in the arid bioregions is also generally lower than in the less arid bioregions (Rutherford and Westfall 1986).

1.2.2 What makes the succulent karoo biome so unique?

The succulent karoo biome has many outstanding features. Amongst these are the rich culture of the indigenous Nama people, the fascinating fauna, the extremely diverse geology and topography, and the highly predictable winter rainfall. Perhaps the most outstanding feature, however, is the flora.

The succulent karoo biome has approximately 5000 plant species and this is considered the highest species richness recorded for a semi-arid area anywhere in the world (Gibbs Russell 1987; Cowling *et al.* 1989; Milton *et al.* 1997; Cowling and Hilton-Taylor 1999). For example, the Sonoran Desert has a flora of 2440 species in an area an order of magnitude larger than the succulent karoo biome, while the Sinai Desert has 1130 species in an area 1.2 times the size of the succulent karoo biome (Cowling *et al.* 1989). More than 50% of the taxa in the succulent karoo biome are endemic (Gibbs Russell 1987; Cowling *et al.* 1989; Cowling and Hilton-Taylor 1994; Milton *et al.* 1997). The floral diversity and high concentration of endemic taxa has resulted in the succulent karoo biome being the only semi-arid region in the world to qualify as a hot spot of global significance (Cowling and Hilton-Taylor 1994, Hilton-Taylor 1996; Myers *et al.* 2000).

1.2.3 Climate

While the climate of southern Africa is influenced by several weather systems the succulent karoo biome is influenced primarily by the subtropical south Atlantic anticyclone, cold fronts which move from west to east and the cold Benguela current (Tyson and Preston-Whyte 2000). Fine weather and mildly disturbed conditions are invariably associated with subtropical anticyclones. Cold fronts on the other hand are responsible for rain in the succulent karoo biome during winter. Cold fronts are also associated with inversions of cold air from the south and south-west that produce characteristic cold snaps, which last a few days. Locally, the climate of the succulent karoo biome is influenced by the topography of the landscape.

In the discussion that follows special emphasis is placed on rainfall and temperature, as these are the primary limiting climatic factors that influence plant growth in arid lands (Schulze and McGee 1978).

1.2.3.1 Rainfall

The succulent karoo biome is dry with a mean annual rainfall of 170 mm but with a broad rainfall range of between 50 and 500 mm per annum (Dent *et al.* 1989; Schulze 1997; Desmet and Cowling 1999a). The mean annual precipitation ranges from 380 mm in the Kamiesberg (1450 masl) to 140 mm at Garies (240 masl) which is 60 km to the south-west of the Kamiesberg. There is a general trend for rainfall to decrease uniformly westwards (Desmet and Cowling 1999a).

The succulent karoo biome is predominantly a winter rainfall area with most of the rainfall received between May and September. In the north-eastern, eastern and south-eastern parts of this biome it grades into the summer rainfall area (Desmet and Cowling 1999a). Although most of the rainfall is received in the winter months there can be great variability in the monthly rainfall peaks. Thus, within the succulent karoo biome, there is great variation in the distribution of rainfall, even though the mean annual rainfall might be the same in some areas (Desmet and Cowling 1999a). Linked to the seasonality there is also great variation in the reliability and intensity of rainfall events.

1.2.3.2 Temperature

There is great seasonal and daily variation in temperatures of the succulent karoo biome. This is characteristic of arid climates in general (McGinnis 1979). However, this is different for the west coast of the succulent karoo biome where there is abundant moisture in the air due to the onshore sea breezes, relatively high humidity and low temperatures that are regulated by the cold Benguela current. Due to this current the mean monthly minimum temperatures, 12.9 ^{0}C, are lowest along the west coast and increase as one moves closer to the equator (Schulze 1997). The coldest minimum temperatures are measured along the high lying areas of the succulent karoo biome (Schulze and McGee 1978), *e.g.* the Kamiesberg bioregion (Figure 1.1) with a mean minimum temperature of 2.2 ^{0}C for the coldest month.

Compared to the Nama-karoo biome the succulent karoo biome has a relatively low likelihood of frost occurring. According to Schulze (1997) this area has between 31 to 60 days of frost per year. Frost often occurs as a result of a surface inversion, especially in valleys, where dense cold air flows down from the sides of the hills and accumulates (Gabler *et al.* 1982).

1.2.4 Vegetation of the succulent karoo biome

The vegetation of the succulent karoo biome can be described as an open to sparse (15 to 50% canopy cover), low to dwarf (usually less that 1 m tall) shrubland (Hilton-Taylor 1994). Succulents, fine-leaved evergreen shrubs and deciduous shrubs dominate it. During spring, especially in disturbed areas there are spectacular mass flowering displays of annuals (mainly Asteraceae, Brassicaceae and Scrophulariaceae) (van Rooyen *et al.* 1992). Small trees (less than 3 m tall) (*e.g. Diospyros ramulosa, Lebeckia sericea* and *Rhus burchellii*), occur on rocky outcrops and along river courses. Grasses (*e.g. Bromus japonicus*, *Ehrharta calycina* and *Schmidtia kalihariensis*) are rarely found in this biome (Hilton-Taylor 1994; Milton *et al.* 1997)

1.2.4.1 Diversity and endemism

The flora of the succulent karoo biome, with its vast number of succulent species, is exceptional (Rutherford and Westfall 1986; ; Cowling and Hilton-Taylor 1999; Goldblatt and Manning 2000). The flora of this biome includes 730 genera of which 67 are endemic (Hilton-Taylor 1996). This is more than three times the number of endemic genera in the Sahara-Arabian and North American arid lands (Shmida 1985; Major 1988). Both these areas are orders of magnitude larger in terms of area than the succulent karoo biome (Cowling and Hilton-Taylor 1999). The dominant families in terms of local endemics in this biome are mainly the Aizoaceae (Mesembryanthema), Crassulaceae and Asclepiadaceae (Van Jaarsveld 1987;

Cowling and Hilton-Taylor 1994), which are predominantly succulent (Desmet 1996).

Succulents are extremely well represented in the flora of the succulent karoo biome and are associated with many of the larger families (Aizoaceae, Asteraceae, Liliaceae, Crassulaceae, Geraniaceae, Euphorbiaceae and Asclepiadaceae (Cowling and Hilton-Taylor 1999). The succulent karoo biome has about one third of the world's approximately 10 000 succulent species (Van Jaarsveld 1987; Smith *et. al.* 1993).

The succulent karoo biome has very few affinities with other arid land floras of the world (Shmida 1985). There is general consensus that the succulent karoo biome flora is largely derived from an ancient Cape stock (Acocks 1953; Werger 1978; Goldblatt 1978; Raven and Axelrod 1978; Cowling and Hilton-Taylor 1999). It is closely related to the fynbos biome and shares over a half of its taxa and three quarters of the large genera (with 10 or more taxa, *e.g. Arctotis*, *Wiborgia*, *Tetragonia*) with the fynbos biome (Gibbs Russell 1987).

1.2.4.2 Vegetation and phytosociological research in the succulent karoo biome

While many ecological studies have been completed in the succulent karoo biome (*e.g.* Milton 1994 a, b; Desmet 1996; Allsopp 1999; Eccles *et al.* 1999; Todd and Hoffman 1999; Schmiedel and Jürgens 1999) only a few vegetation and phytosociological surveys have been done. The most important ones are shown in Table 1.1. Generally, research on the vegetation structure and composition of the succulent karoo biome has been overlooked. Even Acocks (1953) neglected data collection in the succulent karoo biome in his vegetation map of southern Africa.

Table 1.1. Key phytosociological studies completed in the succulent karoo biome.

Location	Year	Title of report	Area (ha)	Researcher
Kamiesberg	1938	Notes on the vegetation of the Kamiesberg	ha [1]	R.S. Adamson
Hester Malan (now Goegap) Nature Reserve	1984	'n Fitososiologies studie van die Hester Malan Natuureservaat	4543	A. Le Roux
Vaalputs	1985	A plant ecological study of the farm "Vaalputs", Bushmanland, with special reference to edaphic factors	7800	J. W. Lloyd
Karoo National Botanic Garden Reserve	1990	A vegetation survey of the Karoo National Botanic Garden Reserve, Worcester	154	J. Smitheman and P. Perry
Tierberg	1992	Tierberg Karoo Research Centre. History, physical environment, flora and fauna	100	S. Milton *et al.*
Between Port Nolloth and Alexander Bay	1996	Vegetation and restoration potential of the arid coastal belt between Port Nolloth and Alexander Bay, Namaqualand, South Africa.	750	P.G. Desmet
Tankwa-Karoo National Park	1996	The physical and major vegetation communities of the Tankwa-Karoo National Park	27064	F. Rubin and A.R. Palmer

[1] the area includes the central part of the Kamiesberg range which extends from Garies in the south to the Buffels River in the north.

One of the earliest attempts to describe the vegetation of the succulent karoo biome was that of Adamson (1938) in the Kamiesberg. The Kamiesberg, a mountainous terrain in central Namaqualand, is the highest area in the region. It is a mountain range that forms part of the escarpment of the interior tableland of South Africa. Adamson (1938) gave a description of the different communities rather than a numeric analysis of the species composition of each community. The vegetation was classified into divisions that corresponded with topographic regions as the vegetation showed a close correlation with climate and habitat conditions. The general features of the plateau vegetation are characteristic of the winter rainfall region of the south western Cape Province. Adamson (1938) was of the opinion that this vegetation should be grouped with the "Cape" vegetation. The plateau community is distinctly stratified into three layers dominated *by Vexatorella alpina, Anginon difforme, Chrysocoma sparsifolia, Cullumia rigida, Passerina glomerata* and *Metalasia muricata* with a continuous ground cover layer of *Pentameris speciosa*.

The northern slopes descending to the Buffels River have similar vegetation to that described above, only simpler. No more than two layers are formed and the ground layer is rarely continuous. The actual composition and structure of this community shows considerable variation with altitude, aspect and many other factors. The species that were abundant and locally dominant on the southern slopes are *Passerina glomerata* with a discontinuous ground layer. Adamson (1938) describes the other species in the community present on the south facing slopes as *Cliffortia ruscifolia, Cullumia rigida, Anthospermum spathulatum* and *Diosma hirsuta*. The vegetation of the escarpment is influenced by slope steepness and the upper regions of the escarpment slopes are moister than the tops of the northern slopes and have a more luxuriant growth. The upper slopes have open vegetation with some large succulents also present, *e.g. Tylecodon paniculatus*. Other shrubs that occur are *Oedera sedifolia*, which may be dominated by *Pteronia incana*. Mid slopes are dominated by *Olea verricosa* and other associated plants like *Rhus undulata, R. horrida, Dodonaea angustifolia, Pteronia divaricata* and *Tylecodon paniculatus*. At the lower levels the vegetation becomes more open, poorer in species and has small succulents in the under layer. On the lower slopes, species such as *Euclea undulata, Diospyros galpinii* and *Maytenus heterophylla* dominate.

The vegetation of the eastern ridge is characterised as open vegetation with a discontinuous open and sparse ground layer. Species such as *Diosma hirsuta, Indigofera* spp. and *Pelargonium scabrum* are amongst the most abundant species. On the ground layer, isolated tufts of *Ischyrolepsis sieberi* and *Zygophyllum* sp. are found. The slopes of these hills exhibit great differences in relation to aspect. The south facing slopes, have in the uppermost parts, closed vegetation in which *Cliffortia ruscifolia, Anthospermum spathulatum* and *Athanasia sp.* occur together with the occasional plant of *Dicerothamnus rhinocerotis.* On the northern facing slopes at the same altitude a totally different community, a very open bush with low vegetation, dominates. Adamson (1938) acknowledges that this work is only a baseline study and that a more detailed study of the area is needed to fill the gaps in the succulent karoo biome. No phytosociological study of the Kamiesberg has been undertaken since Adamson's (1938) early survey of the region.

The first recognised phytosociological study in the succulent karoo biome was undertaken almost fifty years after Adamson's first description in 1938 by Le Roux (1984) who worked in the Goegap Nature Reserve Hester (formally the Hester Malan Nature Reserve) which is 30 km east of Springbok, in the centre of the Namaqualand Rocky Uplands and the Bushmanland Plateau. The vegetation was classified using the Braun-Blanquet method. Both perennial and annual plants were recorded, but only the perennial plants were considered in the analysis of the communities. Four different communities with sub communities were distinguished in the rocky uplands. Present in the depressions of rockbanks, are the dwarf shrublands dominated by *Crassula atropururea* var. *purchelli* and *Conophytum breve*. On the rocky hills two shrublands and one tall shrubland vegetation community were distinguished. The shrublands and tall shrublands are dominated by *Galenia africana, Zygophyllum meyeri, Didelta spinosa, Pteronia leptospermoides, Antizoma miersiana* and *Ruschia cymosa.* In the lowlands, four communities with six sub communities were identified. The flats are characterised by two shrubland communities dominated by *Ruschia robusta, Galenia africana, Galenia sarcophylla* and *Eriocephalus ericoides.* The dwarf shrubland communities on the flats are dominated by *Galenia africana* and *Drosanthemum albens.* The old lands on the flats are characterised by shrubland communities dominated by *Galenia africana* and *Galenia filiformis*.

Phytosociological research continued in the succulent karoo biome through the work of Lloyd (1985) in Vaalputs. This site is situated approximately 100 km south-east of Springbok. The study area occurs in a transition zone between the Nama-karoo biome (summer rainfall) and the succulent karoo biome (winter rainfall). The flat to gently undulating landscape is positioned at an altitude of 999 m to 1030 masl, on the western edge of the Bushmanland Plateau. The vegetation was classified using the Braun-Blanquet method. Only the perennial species, which constitute the more permanent component of the vegetation, were considered in the classification. On the basis of their floristic and structural characteristics eleven vegetation communities were identified. These were divided into four major groups, each of which is associated with a different substrate. Soils characterised by calcrete nodules, with little sand and stones in places, are identified by dwarf/low, semi-open/moderately closed shrubland. *Aptosimum procumbens var. procumbens* and *Psilocaulon junceum* dominate this group. Shallow soils, which overlie granite-gneiss basement or dorbank, are identified by low open/semi-open shrublands with *Arenifera stylosa, Tripteris sinuata* and *Eriocephalus ericoides* dominating. The soils mixed with aeolian sand are identified by low/short grassy shrubland dominated by *Stipagrostis brevifolia, Lycium spp* complex and *Sarcocaulon salmoniflorum*. The fourth group is associated with deeper, strongly acid aeolian sand characterised by low open grasslands. The ecotone between this and the adjacent communities is fairly sharp, over a distance of about 1 m. *Stipagrostis ciliata* var *capensis* and *Centropodia glauca* dominate this community. A strip of *Tripteris armatum* shrubs often marks the ecotone between this community and surrounding communities.

In 1990 Smitheman and Perry contributed to the ongoing phytosociologically research in succulent karoo biome through the completion of their study in the Karoo National Botanical Gardens. This study site is ± 2 km north of Worcester between the flats of the Breede River Valley and the Hex River Mountains.

Characteristic of this area are the low hills of Malmesbury shale, which ranges between 300 to 526 masl. The vegetation was classified using the Braun-Blanquet method. Data was collected in the summer when only perennial plants were visible. Additional sampling was carried out in winter and spring to assess the distribution of geophytes and annuals among the communities. Seven vegetation communities were identified with differing floristic and environmental characteristics. The major environmental characteristic attributed to the distribution of the seven communities was found to be aspect. The very steep to steep south-west and a few north-west facing slopes are characterised by a sparse shrubland dominated by *Passerina obtusifolia, Ischyrolepsis gaudichaudiana* and *Dodonaea angustifolia*. The community found on the very steep south, south-east and south-west facing slopes is a dense shrubland dominated by *Dicerothamnus rhinocerotis, Euryops linifolius, Eriocephalus africanus* and *Anthospermum aethiopicum*. Dense shrublands are associated with steep or very steep south-facing slopes that are dominated by *Senecio junceus, Pteronia incana, P. paniculata, Euphorbia mauritanica, Galenia africana* and *Felicia filifolia*. The small gullies in the landscape are characterised by dwarf thicket vegetation dominated by *Euclea undulata, Rhus incisa, Lycium oxycarpum, Asparagus burchellii* and *Tylecodon paniculatus*. The most widespread community covering the gentle north and south slopes is characterised as a shrubland dominated by *Ruschia caroli, Pteronia paniculata, Felicia filifolia* and *Senecio junceus*. A sparse succulent shrubland community is restricted to north, north-east or north-west slopes and is dominated by *Aloe microstigma, Pteronia incana, Euclea undulata* and *Euphorbia mauritanica*. The seventh vegetation community consists of two forms and is characterised as a sparse succulent shrubland. The first form refers to distinct circular patches created by termites that are known locally as "heuweltjies" and found on any aspect, whereas the second form occurs on scree slopes in gullies, on steep south-facing slopes or in valley bottoms. *Pteronia incana, Tylecodon paniculatus, Aloe microstigma, Euphorbia mauritanica* and *Euphorbia burmanii* dominate this sparse succulent shrubland community.

species diversity or cover in this community. The dominant soft-fruited trees, shrubs and hemiparasites include *Asparagus spp., Carissa haematocarpa, Rhus spp., Euclea undulata, Lycium spp., Viscum spp., Moquinella rubra* and *Septulina glauca*.

In 1996 Desmet completed a phytosociological study on the western arid coastal belt of the succulent karoo biome. The study site is located between Port Nolloth and Alexander Bay and covers a narrow band, approximately 10 km wide along the coast. This study site falls within the southern zone of the Namib Desert and is one of five west coast deserts in the world lying within subtropical latitudes. The coastal belt has slight undulating dunes and is referred to as the Sandveld. Data was collected by means of parallel line transects, perpendicular to the dominant wind direction in homogenous stands of vegetation. A modification of the McAuliffe (1990) method for measuring sparsely vegetated areas was used. In the analysis Desmet (1996) used an association as the basic level of classification. An association is any grouping of plants that compares to a vegetation community in the field. Detrended correspondence analysis (DCA) showed that the vegetation of this area could be divided into two broad groups based on substratum type. The first group occupies deeper, loose sand on dune crests where sand accretion is the dominant process. The two indicator species are *Stoeberia utilis* (which occurs on deeper, loose sands) and *Stoeberia beetzii* (which occurs on shallow compact sands. The DCA axis 2 showed that plant associations could be arranged along a latitudinal and biogeographical gradient. The DCA axis 3 indicated that the division of vegetation communities might also relate to sand age. All of these environmental parameters were considered in describing the sixteen vegetation communities.

Rubin and Palmer (1996) carried out the most recent phytosociological study in the Tankwa-Karoo National Park. The study site is situated in the northern section of the Tankwa Karoo about 110 km north of Ceres and 90 km south of Calvinia. The area is characterised by long, gentle slopes with regular erosion rills fanning out from about 350 to 488 masl. Using the Braun-Blanquet method classification of the vegetation was completed. Eight major vegetation communities were identified. Three dominant geological formations (all older glacigenic deposits of the Dwyka

Milton *et al.* (1992) completed another descriptive vegetation study at Tierberg. The Tierberg Karoo Research Centre is situated on the southern edge of the Great Karoo and 20 km north of the Swartberg mountain range. The 100 ha study site lies at 800 masl in the 5 km wide and 80 km long valley of the Sandriver. Four vegetation communities were identified from aerial photographs of the study site: plains, heuweltjies, minor drainage lines, and major drainage lines. The plains cover 77.7 % of the Tierberg study site. The plains vegetation is characterised by low-growing (10-40 cm high) evergreen and deciduous succulents such as the spinescent *Ruschia spp.*, *Rhinephyllum spp.*, and *Brownathus ciliatus.* Included in the plains vegetation community are a few annual forbs with grass being completely absent from this habitat. The asteraceous shrubs, *Pteronia pallens* and *Ruschia. cf. empetrifolia* are the tallest plants (40-70 cm) in the plains vegetation community. The heuweltjies vegetation community has a higher cover of vegetation when compared to the surrounding plains. The most abundant plants on the heuweltjies are succulent shrubs such as *Malephora lutea* and *Psilocaulon junceum,* which were present on almost all the heuweltjies sampled in this study. Other common species include *Augea capensis* and *Drosanthemum hispidum.* Woody shrubs in the genera *Lycium* and *Salsola* occurred on a third of the heuweltjies sampled, and were rare elsewhere on the plains. The minor drainage lines cover 16.6 % of the study site. This vegetation community is species rich and includes species found in all other habitats. The vegetation of the minor drainage lines is taller (up to 60 to 200 cm) and less succulent than the plains shrubland, with non-succulents making up 55% of the total cover. The tree-like *Rhigozum obovatum*, smaller asteraceous shrubs in the genera *Berkheya, Felicia* and *Eriocephalus* as well as various Fabaceae, differentiate the minor drainage lines from the plains communities. Most of the plants found in minor drainage lines are wind-dispersed, but a variety of other dispersal mechanisms are also represented. The fourth community found along major drainage lines, covers 2.5% of the study site. This community is an important one, since it provides essential food sources, shelter and nesting materials for many birds and mammal species. Drainage line vegetation is denser and taller (up to 4 m) than the other communities. Six tree species are found in this study site and are restricted to this habitat type. Succulents are of little importance in terms of either

Group, with flat dolerite sills and dykes, which underly the eight vegetation communities and the general landscape) seem to be the major factors influencing the distribution of the vegetation communities. The prominent hills, with Mispah and Glenrosa as the most common soils, are characterised by dwarf shrublands dominated by *Euphorbia hamata* and *Felicia lasiocarpa*. The dolerite plateau with fairly alkaline soils is characterised by grassland dominated by *Stipagrostis ciliata* and *Salsola aphylla*. The limestone outcrops with high pH and low phosphate concentrations are characterised by dwarf shrublands dominated by *Antimima wittebergensis, Bulbine alooides* and *Pteronia glabrata*. The plains of this study site are characterised by *Lycium cinereum* and *Malephora luteola*. Vegetation communities occurring on the more elevated areas where the soils are generally shallow and stony are characterised by succulent dwarf shrubland dominated by *Ruschia spinosa, Ruschia rob*usta and *Drosanthemum eburneum*. The Kimberlite hills, which are conspicuous mound-shaped hills, are characterised by dwarf shrublands dominated by *Brownathus ciliatus, Enneapogon scaber* and *Galenia crystallina*. The denuded to bare areas on desert paving gravel and shale hills are characterised by spectacular displays of almost monocultural stands of annual species such as *Gazania lichtensteinii, Osteospermum pinnatum var. pinnatum, Euryops annuus*, and *Ursinia nana*. The alluvial floors generally have no vegetation. After good rains these areas are rapidly covered by succulent forbs which are characteristic of saline soils (*e.g. Psilocaulon absimile*).

In recent years, the focus in vegetation studies worldwide has changed from merely a description of the vegetation communities and the production of a colourful map with the different vegetation communities to a study of the underlying processes that have influenced the distributions of plant species and communities (Milton 1994b; Desmet 1996; Allsopp 1999; Eccles *et al.* 1999; Schmiedel and Jürgens 1999; Todd and Hoffman 1999). More recently, studies in the succulent karoo biome and outside of it are more focused on the interaction of the vegetation and the environment and the way in which people use the landscape. This study will follow the current approach and will thereby contribute to our knowledge of the succulent karoo biome. This will enable comparisons with other areas and a greater understanding of community structure and dynamics in the succulent karoo biome.

1.2.5 Conservation status of the succulent karoo biome

Considering the high level of biodiversity and endemism in the succulent karoo, the biome is poorly conserved. Due to the high species richness and unique global status of the succulent karoo biome it requires urgent conservation attention (Cowling and Hilton-Taylor 1994; Low and Rebelo 1996; Lombard *et al.* 1999). Before October 2000 only 2% of the entire succulent karoo biome was formally protected within publicly owned areas (Lombard *et al.* 1999). This has changed, however, with the purchase of new land by the Leslie Hill Succulent Karoo Trust (LHSKT) under the auspices of the World Wide Fund for Nature – South Africa (WWF-SA).

The South African National Parks and the provincial Departments of Nature Conservation currently manage several large reserves in the succulent karoo biome. These reserves represent four of the 12 bioregions in the biome. They include the nationally protected areas in the Gariep Centre (Richtersveld National Park), the Tanqua Karoo (Tankwa Karoo National Park) and the Namaqua Rocky Hills (Namaqua National Park) (Lombard *et al.* 1999).

Conservation areas in the Gariep Centre (Helskloof Nature Reserve), the Namaqualand Rocky Hills (Goegap Nature Reserve) and the Little Karoo (Anysberg Nature Reserve) are the only provincial nature reserves (Lombard *et al.* 1999). The Anysberg Nature Reserve has recently been expanded by 14 000 hectares, as well as the Namaqua National Park (previously Skilpad Wild Flower Reserve) by 53 800 hectares of land that was bought under the auspices of the LHSKT. Within the Western Mountain Karoo, Bokkeveld/Olifants River/Biedou bioregion, Worcester-Robertson Karoo and Little Karoo a number of smaller provincial, local authority and private reserves occur (Lombard *et al.* 1999).

The major threats to the flora in the succulent karoo biome are overgrazing by domestic livestock, mining, cultivation and illegal plant collecting (Hilton-Taylor and Le Roux 1989; Hilton-Taylor 1994). Overgrazing by domestic livestock has the tendency to change the composition of vegetation to a less useful condition that cannot be reversed by resting (Milton *et al.* 1997). Thus, recovery from overgrazing is not possible in a short time frame of a few decades due to the lack of dormant seed, short dispersal distances, or the exclusion through competition by other perennials that have filled the spaces left by their demise (Milton and Hoffman 1994). Strip-mining for surface mineral deposits usually results in the destruction of overlying vegetation. Subterranean mining has a relatively small impact on the above ground vegetation. Apart from the destruction of vegetation, surface mining has left unsightly heaps of unvegetated spoil (Milton *et al.* 1997). The succulent karoo biome is too arid for regular dry land agriculture and less than 10% of the ploughed land is under irrigation (Milton *et al.* 1997). Thus wind erosion is a problem in ploughed and unvegetated areas of this biome (Pickett and Hoffman 1992). Many of the small endemic succulents are also threatened due to unscrupulous collecting (Hilton-Taylor and Le Roux 1989). Ecotourism has good potential, as an alternative form of income generation in this biome. However, it requires that the area be properly used and managed (Lombard *et al.* 1999). Proper representation from the surrounding communities as well as all the relevant role players should be included in decision making with regard to how the land is utilised and managed.

As a signatory to the Convention on Biological Diversity developed out of the United Nations Conference on Environment and Development held in Rio de Janeiro, 1992, South Africa is committed to providing adequate conservation of its exceptionally high biodiversity. The succulent karoo biome has been identified as one of the least conserved biomes in South Africa, and the biome requiring the largest proportion of additional reserves to protect its flora (Low and Rebelo 1996). It has been argued that Biosphere Reserves are required to improve the conservation status of the area as only an area larger than 150 km^2 will enable the possibility of re-establishing pre-settlement animals (Cowling 1986). However, smaller reserves that include highly restricted endemics and high species diversity of the region are also needed (Hilton-Taylor 1994). It should be remembered that much of the succulent karoo biome (about 87%) is used as a rangeland for livestock grazing purposes, and the major focus of conservation in this region should be aimed at improved land-use management by private landowners.

1.2.6 Land use practices in the succulent karoo biome

1.2.6.1 Historical practices and a general chronology for the region

Most landscapes within the succulent karoo biome are no longer pristine (Forman & Russell 1983; Smith 1999) and have been impacted by humans for over 300 000 years (Table 1.2) (Thackeray *et al.* 1990; Smith 1999). It is important to reflect on these impacts in order to understand the vegetation patterns and trends of the past (Hoffman 1997) as this is the best way to strategise for the future.

Pre-colonial period

San hunter-gathers have been in the succulent karoo biome for more than 300 000 years (Deacon and Deacon 1999). Their main activity involved hunting, gathering and in some cases fishing (Hoffman *et al.* 1999). They lived under dry and difficult conditions. Before the end of the nineteenth century (when wind-driven pumps were first utilised) they were unable to tap into the deeply-situated, underground water supply. However, this was not necessarily a problem for hunter-gathers, as they knew where water was to be found. They would, if they had to, dig in dry riverbeds for underground water-bearing plants (Smith 1999). Hunting and gathering had a low impact on the landscape as they only removed resources from the landscape to sustain their livelihoods (Hoffman 1997). This area is dry and any rainfall event creates a micro-environment for animals and plants. The hunter-gathers were highly mobile and could thus take advantage of these highly localised conditions.

Table 1.2. A generalised chronological account of events in the succulent karoo biome. (BP refers to Before Present, from 1688 onwards the date refer to centuries and years).

Time frame	Defining event or activity
300 000 years BP	The succulent karoo biome is occupied by nomadic hunter gathers
2100 years BP	The arrival of semi-nomadic Khoi herders in the region; evident through the collection of sheep bones at Spoegriver Cave.
800 year BP	The earliest evidence found of goats in the succulent karoo biome at the Bethelsklip site, in Leliefontein Reserve.
1688	Simon van der Stel's expedition to Namaqualand and first contact between colonial government and indigenous people in the region.
1700-1800	Encroachment by colonial settlers into traditional grazing lands of Khoi herders.
1800-1825	Earliest mission station in Namaqualand was established in 1806. Barnabas Shaw of the Wesleyan Church instituted the first permanent settlement for herders at Leliefontein. The nomadic lifestyles were restricted to areas within the mission station/commons.
1825-1910	In 1854 the governor of the Cape, Lord Cathcart, awarded a Ticket of Occupation to the church. This reinforced the authority of the missionaries and effectively gave land tenure to the Leliefontein Namaquas. The increasing threats from outside of the settlements increased the number of people present at the station, thus promoting the permanent settlement of the indigenous people in these settlements. In 1878 Colonial Authorities registered the Namaqualand population in order to curtail the nomadic lifestyles of the people. As a result this increased the pressure on the natural resources.
1910-1950	The Mission Station and Communal Reserve Act of 1909, which began to be enforced in 1913, removed authority from the missionary societies and churches. This marked the beginning of direct State intervention and effectively separated the Methodist Church and politics in Leliefontein.
1950-1994	In 1963 an act that made provision for the subdivision and privatisation of landholding in the reserve was passed. This was known as the betterment schemes and in Namaqualand specifically it was known as "economic units". This was implemented in the late 1970's and early 1980's and entitled *bona fide* farmers to their own piece of land. In 1988 this scheme was abandoned when the Cape Town Supreme Court ruled against the implementation of this act.
1994-to present	With the second democratic elections in December 2000 the *Leliefontien Oorgangsraad* was replaced with the Kamiesberg Municipality. Commage Committees have been established in former communal reserves. At village level a Development Forum manages administration.

The earliest traces of herder occupation in the succulent karoo biome were around 2000 BP as demonstrated by excavations at the Spoegriver Cave at the mouth of the Spoegriver near Hondeklipbaai which suggest that there was a gradual shift from a hunter-gather existence to one centred on pastoralism (Webley 1992). Khoi herders mostly kept sheep and goats, and to a lesser extent cattle (Smith 1999). The Khoi engaged in large transhumance movement cycles between winter and summer rainfall areas. They used the seasonal difference in availability of grazing and water resources to their advantage when moving between these areas. They would control a territory within which they moved seasonally (Smith *et al.* 1987). This did not necessarily mean the exclusion of other groups, who might have paid a symbolic tribute to the "owners" when they entered the territory (Penn 1986).

Early colonial period

Simon van der Stel undertook the first extensive colonial expedition to the succulent karoo biome in 1688 in search of copper (Valentyn 1971). By the late eighteenth century however, settlers had colonised much of the region in search of a new, brighter future. European colonisation and settlement disrupted indigenous people in various ways: through direct competition for land and grazing; through the introduction of mercantile capital; through the imposition of new forms of state power and administration, and through the introduction of smallpox and land dispossession (Hoffman *et al.* 1999). As a result of the above, many Khoi pastoralists were forced into slavery or serfdom.

Ironically, the colonial expansion was driven by the trekboers who were themselves semi-nomadic pastoralists who depended on livestock herds for subsistence (Penn 1986). The trekboers also moved long distances across seasonally variable rangeland, but had the advantage of military strength. Whilst private ownership of land and privately owned livestock production slowly became dominant practices in the region, most of the semi-arid land of the Khoi pastoralists had been expropriated by the end of the nineteenth century. From the mid 1820's onwards, the pastoralist economy of the Khoi was restricted to areas immediately surrounding the mission stations.

These mission stations were formed in the early nineteenth century as white settlers dispossessed the indigenous people of their land. They were formed when churches secured mission stations to curtail the nomadic lifestyles of indigenous people and also to inadvertently protect them from further dispossession of their traditional lands (Hoffman 1999; Rodkin and Rohde 2000). This was the case with the Leliefontein Mission station, which was established upon the request of the Namaqua Hottentot chief, Jantjie Wildschut. He came into contact with Barnabas Shaw, a reverend of the Wesleyan Missionary Society, and requested the establishment of a mission station as a protection for his tribe (Kelso 2000). With the implementation in 1913 of the Communal Reserve Act of 1909 the mission stations and their surrounding areas became known as "reserves"(Kelso 2000). These "reserves" called "Rural Coloured Reserves" were communal systems of land management that were confined largely to the Namaqualand magisterial district in the Northern Cape Province (Hoffman 1999). Presently, each of these reserves commonly consists of more than one village. In the Leliefontein "Coloured Reserve", which was formed in 1843, there are nine villages.

Twentieth century

The confinement to mission stations and reserves severely constrained indigenous people's ability to move with the herds or to engage in transhumance (Hoffman *et al.* 1999; Rodkin and Rohde 2000). Although constrained within the broad mission station areas, communal farmers remained widespread throughout the landscape and continued to practice subsistence farming. Concomitantly the missionaries promoted crop cultivation and permanent village settlement (Khrone and Steyn 1991). The reduction in local agricultural production led to the movement outside the settlement to secure an income. From the mid-nineteenth century dispossessed people turned to settler farms, and copper and diamond mines, which were opened in the region (Hoffman *et al.* 1999). Local agricultural production gradually became a supplement to wages and remittances for many local residents (Sharp 1984; Boonzaier 1987).

1.2.6.2. Current land-use practices

There are two different agricultural production systems in the succulent karoo biome, divided largely as to whether the land is owned and managed under a communal or private land tenure regime. Each of these systems has a different history, land tenure, institutional arrangement, land use practice and set of production objectives (Hoffman *et al.* 1999). In communal systems, all individuals who have birthrights in a village have access to the natural resources (May *et al.* 1997). Unlike privately owned land, communal areas have more than one farmer with various herds of different sizes. Each farmer within the communal system has his own management strategy, which he undertakes within the confined area of the village and surrounding areas.

Livestock production objectives within the communal farming systems in the succulent karoo biome are numerous, as farmers not only keep animals for consumption and selling, but also as an investment (Hoffman *et al.* 1999). This is a shared feature of communal systems, although it should also be remembered that communal areas are not all the same but differ significantly from place to place. Generally, each farmer tries to increase his herd size to the maximum, and thus animal numbers increase if the veld conditions allow. This means a bigger total investment to the individual farmer. In Paulshoek farmers have on average kept twice the number of animals recommended by the Department of Agriculture since 1971 (Todd and Hoffman 1999).

This contrasts sharply with farmers on privately owned land who pursue a different management strategy. Usually, a single landowner with one herd of animals manages one or several privately owned farms. In this case the major objective is maximisation of total cash income. Since 1970, with the introduction of stock reduction schemes in the Karoo, farmers on privately owned land have been stocking at recommended stocking rates of the Department of Agriculture. On the

(Pressy and Bedward 1991) or any other development project (*e.g.* building of a dam) which might arise in the future. It could also be used to determine which areas should be rested or which sites should be used for long-term monitoring. The map will also assist fellow researchers in the planning of their vegetation or ecological research, especially restoration projects that are currently in progress. In addition, it could be used for predicting the impact of disturbance on species composition and distribution. Furthermore, it may be important in highlighting areas, which may be vulnerable to species loss, and for predicting the impact of species loss on vegetation community structure and function (Cowling *et al.* 1989).

Fourthly, it aims to correlate environmental variables to associated vegetation communities. This would contribute to the broader understanding of factors influencing vegetation distribution and composition in the succulent karoo biome.

Finally, this study aims to determine whether there are any significant differences in the species composition and distribution of the vegetation under different management strategies, (*i.e.* communal areas and privately owned land). It also seeks to determine whether there are any shifts in the distribution of the vegetation under the different management systems and along a topo-moisture gradient or altitude gradient. Other studies (Austin *et al.* 1984; Minchin 1987; Birch *et al.* 1999) have shown that under disturbance (*e.g.* heavy grazing pressure) there is a shift in vegetation communities along a topo-moisture gradient defined largely by altitude. The hypothesis is that with an increase in grazing pressure, low altitude vegetation communities will move towards the community occupying the higher altitudinal areas.

1.4 Thesis structure

The dissertation starts by giving an overall understanding of the context of the study. This is an important consideration as this study forms part of a bigger project called the Global Change and Subsistence Rangelands Project that is funded by the EU and partly by the NBI. This first chapter gives a detailed description of the location of the succulent karoo biome. It also gives a broad understanding of the biophysical environment of the succulent karoo biome, the vegetation studies that have been completed, the conservation status and a history of land-use practices within this biome. The second chapter gives a detailed description of the study site, including the location, size, biophysical environment and socio-economic aspects of the study site. Chapter three comprises the detailed phytosociological study, which looks at the distribution of species throughout the landscape. It also includes a checklist of all perennial plant species found in the study site. This chapter also relates the environmental variables to the different vegetation communities that were identified. It tries to understand how plants are distributed throughout the landscape and why. Chapter 4 assesses the impact of grazing on areas managed under privately owned and communally managed regimes. Finally, the main findings from this study are summarised in chapter 5.

Chapter 2: Paulshoek, the place and its people

2.1 Location

The study site is located at Paulshoek (30^0 20' S, 18^0 15' E), one of nine villages in the Leliefontein Communal Reserve in Namaqualand, Northern Cape Province (Figure 2.1). Leliefontein is in the Kamiesberg, an escarpment (900-1500 masl) about 50 km wide between the low lying Sandveld in the west and the Bushmanland plateau in the east (Todd and Hoffman 1999). This site also includes a section which extends approximately 2 km from the Paulshoek boundary into three of the surrounding privately owned farms- Remhoogte (south-east from Paulshoek village), Rietfontein (north-east from Paulshoek village) and Paulskraal (west from Paulshoek village) (Figure 2.2). The entire study area stretches from -30^0 15' S, 18^0 08' E to 30^0 24' 40" S, 18^0 21' 20" E.

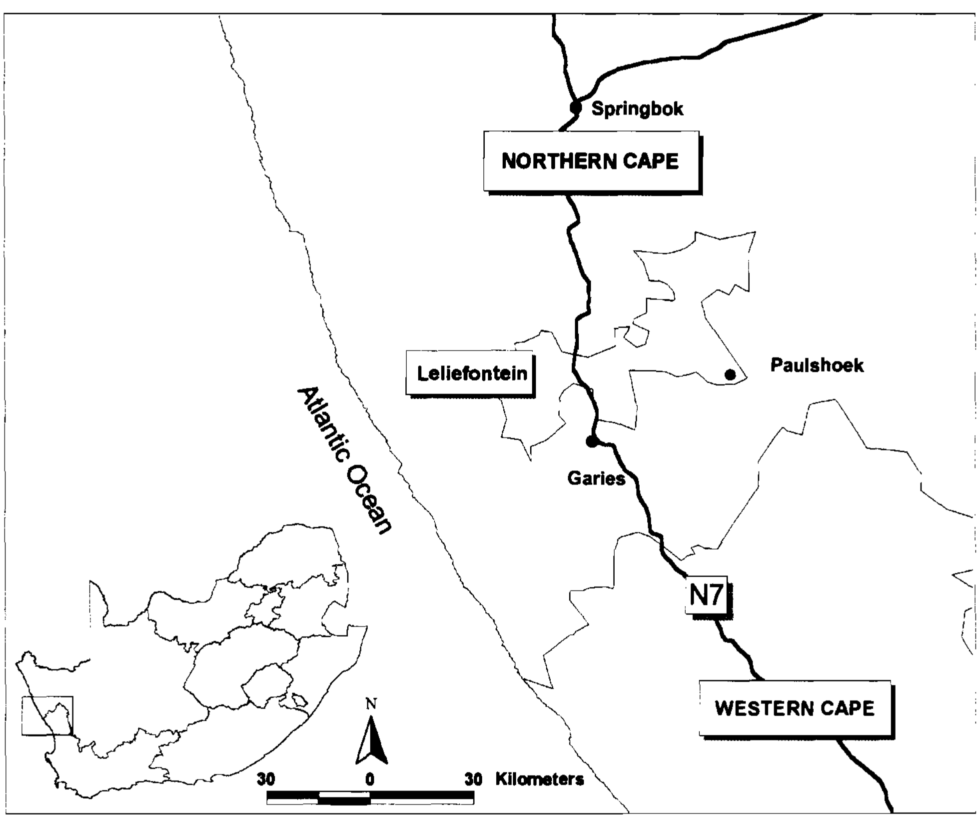

Figure 2.1. Map of Paulshoek in relation to the Leliefontein communal reserve, Namaqualand, South Africa, and the two provinces in the region.

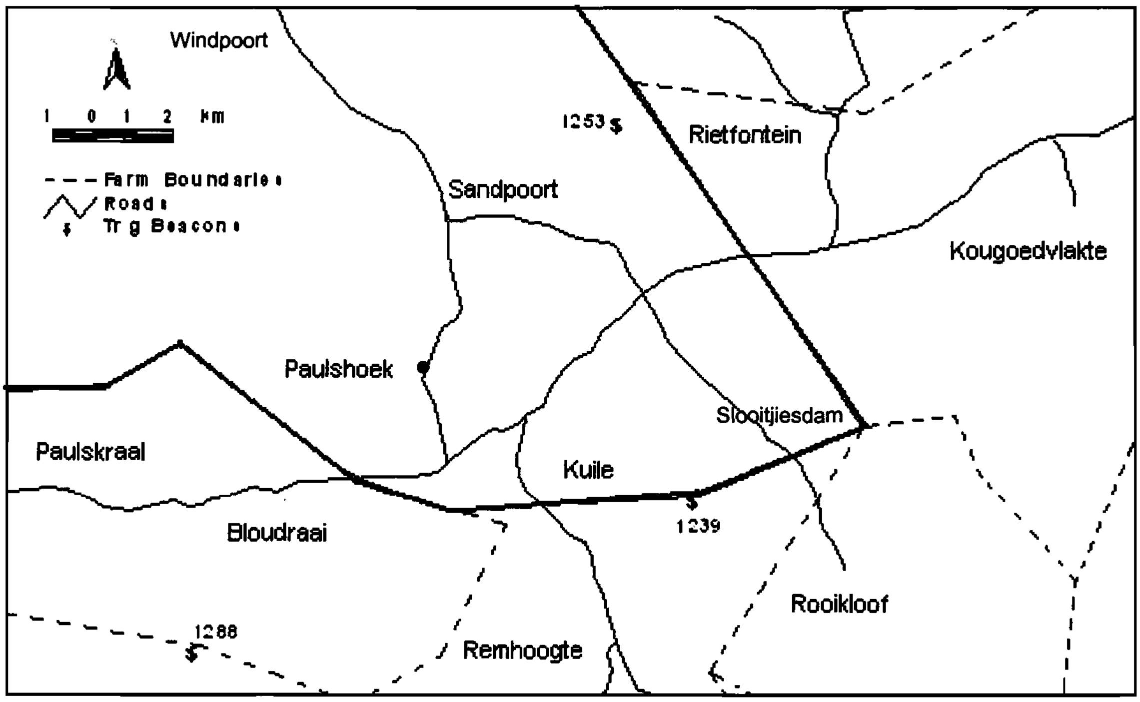

Figure 2.2. A detailed map of the 20 000 ha Paulshoek area, in relation to surrounding privately owned lands, showing the main roads in the region as well as the communal area boundary (bold line) and private farm boundaries (dashed lines).

2.2 Topography

Paulshoek lies at the eastern foothills of the Kamiesberg. The topography is characterised by flat lowlands in the south-east, and gentle undulating slopes to steeper slopes in the north-west (Plate 2.1). The lowlands are flat plains with isolated inselbergs and koppies. The steep mountain slopes are characterised by big gneiss boulders and domes. The altitude ranges from 950 masl in the south-east to 1400 masl in the north-west. This area can be classified into three altitude classes: low altitude (900-1120 m) which covers 34% of the total area; medium altitude (1120-1200 m) covers 37% of the total area; and high altitude (1200-1400 m) which covers 29% of the total area.

Plate 2.1. The topography of Paulshoek is characterised by steep slopes in the west to north-west with flats in the south-east and isolated inselbergs and koppies. The photograph shows a kraal in the foreground with the stockpost adjacent to the ploughed land in the distance

2.3 Geology

Joubert (1971) completed a geology map for Paulshoek as part of a greater Namaqualand geological survey. Gneiss and metamorphic rock dominate the complex geology of the Paulshoek landscape. However, superficial deposits overlie the valley bottoms, which are comprised of sand, soil and alluvium. Augen gneiss are the basal rocks that generally appear light brown in colour due to weathering. This augen gneiss is overlain by pink gneiss, which has a red-brown weathered surface (May *et al.* 1997). In turn, pink gneiss is overlain by fine grained biotite gneiss and porphyroblastic granitic gneiss. Other geological features mapped by Joubert (1971) include sheared rocks, phyllonite, basic instrusive, ultramafic gneiss and some mafic meta-instrusives, mafic bands, cordierite gneiss, leptite and leptynite.

2.4 Soils

Large gneiss domes, characteristic of the succulent karoo biome, which break down into gravel and coarse sand, dominate Paulshoek. The soils are thus coarse, with a particle size of greater than 0.1 mm, allowing rapid infiltration but with low water holding capacity (Milton and Dean 1996). Allsopp (1999) has demonstrated that the soils of Paulshoek are generally infertile with nitrogen content around 350 $\mu g\ g^{-1}$, total phosphorus of 154 $\mu g\ g^{-1}$, soil organic matter of 1.5% and pH ranging between 6.5-7.9. Burke (2002) suggests that soils derived from granite soils are generally low in clay and silt. Paulshoek has little evidence of soil erosion except for shallow run-off gullies along some of the major footpaths and tracks. The soil in this area generally appears stable in relation to wind or water erosion despite the large bare and exposed areas. The soil becomes more vulnerable to erosion when disturbed by ploughing or footpaths. There has been no formal measurement of the extent of soil loss in the study area.

2.5 River and drainage systems

There are no perennial river courses in Paulshoek and it does not have a well-developed drainage system due to the low average rainfall (Allsopp *et al.* 1999). Most of the drainage in Paulshoek is to the north with the main non-perennial river courses of the Klein Nourivier and Eenwiliger River draining into the Buffels River, eventually reaching the Atlantic Ocean at Kleinsee (May *et al.* 1997). There are many smaller tributaries, which drain to the south and ultimately form part of the Hartebeesrivier/ Swart Doringrivier/ Groenrivier drainage basin (Allsopp *et al.* 1999).

2.6 Climate

Climate data was collected by an automatic weather station situated 2 km south-east of the village at Slooitjiesdam (Figure 2.2). In addition to the automatic weather station, 13 standard rain gauges are positioned throughout the landscape and people from the village have collected the rainfall data from these gauges since *early 1997.*

2.6.1 Rainfall

Paulshoek falls within an ecotone between the summer and winter rainfall regions of South Africa. The mean annual rainfall for Paulshoek, derived from the modelled data of the Computing Centre for Climate and Water Research (CCWR) (Schulze 1997) is 200 mm per annum, most of which is received during winter (June-August). However, the mean annual rainfall measured over the last four years from three rainfall gauges spread widely throughout the landscape has been only 141.5 mm per annum (Table 2.1). In 1996 an exceptionally high rainfall total was observed in Paulshoek and recorded in surrounding weather stations in Namaqualand. Unfortunately, no measurement of the rainfall in Paulshoek was taken, but from observations by researchers it was evident that 1996 was an above average rainfall year (Todd and Hoffman 1999). The years (1997, 1999, 2000 and 2002) showed little difference in the total rainfall, but 1998 was a dry year since only 37% of the mean of the other three years were recorded. The year 2001 received above average rainfall.

Paulshoek has a high degree of local rainfall variability despite the fact that the succulent karoo biome generally has a low coefficient of variation (<30%) (Hoffman and Cowling 1987; Desmet and Cowling 1999a). The Kamiesberg massif and local topographical features in the landscape give rise to significant spatial differences in temporal variability in rainfall across the Paulshoek landscape. Rainfall is generally higher in the north-western regions of Paulshoek (Windpoort, 196 ± 66 mm) and lower in the south-eastern regions (Slooitjiesdam, 134 ± 55 mm) (Table 2.1). Although, Paulshoek falls between the summer and winter rainfall regions, rainfall is generally low during the hot summer months. Isolated convective thunderstorms between October and February can sometimes be expected due to the strong easterly winds from Bushmanland. Winter rains are mainly received from the rain-bearing winds from the north-west, especially between May and September when large frontal systems sweep past the sub-continent bringing rain to a large part of the region. During the autumn and spring months rainfall is at its most unpredictable in Paulshoek, and large downpours can result from a single event which is usually associated with south-westerly winds and cut-off lows (Desmet and Cowling 1999a).

Table 2.1. Annual rainfall totals for three stations in Paulshoek showing the annual mean and coefficient of variation (CV) values.

Year	Windpoort 30° 18' 45" S 18° 11' 05" E	Paulshoek 30° 22' 00" S 18° 15' 18" E	Slooitjiesdam 30° 22' 05" S 18° 18' 30" E	Annual mean for all stations
1997	203	119	161	161
1998	93	45	41	62
1999	194	170	135	166
2000	219	163	151	177
2001	294	201	205	233
2002	170	160	112	147
Mean ± std dev.	196 ± 66	143 ± 55	134 ± 55	158 ± 56
CV (%)	34	38	41	36

Fog can be an important alternative source of moisture for plants, although there is generally no direct precipitation of water on the soil surface. It plays a significant role in areas close to the coast in Namaqualand (Desmet and Cowling 1999b). The occurrence of fog in Paulshoek is relatively insignificant and is generally confined to the high lying western parts and the low lying valleys to the south of the village.

2.6.2 Temperature

Winter months in Paulshoek are surprisingly cold probably because of the relatively high altitudes (Table 2.2). Absolute maximum temperatures have not been recorded above 37.4 ^{0}C, but temperatures below 0^{0}C have been recorded at least once in the months from June to as late as September. The mean daily temperatures between May and September (the winter months) are relatively cool (11.6^{0}C) and fall by more than four degrees celsius in one month between April and May. This change in temperature marks the onset of winter, which continues to the end of September when the temperature abruptly increases again. During October and November dramatic fluctuations in daily temperature (between 2.2 to 37.4^{0}C) are experienced, which can be disastrous for livestock owners. These critical extremes in the climate affect livestock and crop production in this area and have had a significant influence on the way in which people from Paulshoek manage their natural resources.

2.7 Vegetation

Paulshoek is situated within the succulent karoo biome (Rutherford and Westfall 1986). Details of the succulent karoo biome vegetation are discussed on a biome level in the literature review (chapter 1). The two main veld types in the Paulshoek area are Namaqualand Broken Veld (Veld type number 33) and Mountain Renoster Veld (Veld type number 43) (Acocks 1988). The Namaqualand Broken Veld occurs in the hot and drier south-eastern regions of the area at low altitude. Farmers in this area refer to the Namaqualand Broken Veld as "*soetveld*" – sweetveld. It is characterised by dwarf evergreen shrubs such as *Hirpicium alienatum* and low growing succulent shrubs such as *Ruschia robusta*. The Mountain Renoster Veld is wetter and occurs at a higher altitude and is restricted to the north-western regions of the area. This veld is known by farmers as "*suurveld*" - sourveld, and is characterised by woody shrubs such as *Dicerothamnus rhinocerotis* and *Pteronia incana*. A detailed phytosociological analysis of the vegetation of Paulshoek is undertaken in chapter 3 and is not elaborated on further here.

Table 2.2. Temperature measurements at Moedverloor, Paulshoek for the period May 1999 to May 2003. Tmax and Tmin are the mean daily maximum and minimum temperature for the month respectively; Tmean is the mean daily temperature while Tmthmax and Tmthmin are the highest and lowest (*i.e.* absolute maximum and minimum) temperature recorded for the month.

Month	Tmax	Tmin	Tmean	Tmthmax	Tmthmin
January	28.6	12.5	20.3	37.1	5.1
February	30.6	13.7	21.8	37.3	7.2
March	28.8	13.2	20.4	35.3	7.3
April	25.7	10.5	17.5	33.1	4.1
May	20.9	6.5	13.2	26.8	1.4
June	19.8	5.1	11.6	24.7	-1.9
July	17.0	4.2	10.1	23.3	-1.6
August	18.5	4.2	10.8	26.8	-1.7
September	20.5	5.3	12.4	31.0	-0.4
October	25.6	8.0	16.4	34.8	1.2
November	26.5	9.8	17.9	35.7	3.9
December	29.1	12.2	20.4	36.1	7.3
Mean	24.3 ± 4.7	8.8 ± 3.7	16.1 ± 4.2	31.8 ± 5.1	2.7 ± 3.6

2.8 Socio-economic aspects

2.8.1 History of the village

The "Leliefontein Coloured Reserve" was established in 1843 as a "Rhenish Mission Society of Germany" mission station (May *et al.* 1997; Rodkin and Rohde 2000; Rohde *et al.* 2003). The village of Paulshoek is one of nine villages in the Leliefontein Reserve. It is comprised of about 20 000 ha and named after a herder, Paul Joseph, who took care of the rams. Therefore people would refer to the area as *Paul se hoek*–Paul's corner. The village came into existence in the early 1940's with the establishment of the school there. Before this most people were settled evenly throughout the landscape of Paulshoek at their stockposts. A stockpost includes the area where the farmer kraals his animals, a *matjieshut* (structure made from reed mats used for sleeping) and a *kookskerm* (structure made from dead shrubs (especially *Polymita albiflora*) used mainly for cooking and socialising (Plate 2.2).

Plate 2.2. Typical *kookskerm* made with dead shrubs (*e.g.* Polymita albiflora) used for cooking, shelter and socializing.

Prior to the establishment of the village of Paulshoek, farmers would move their stock from the high lying areas in summer to the low lying areas in winter. This was due to the fact that cropping played an important role in determining the movement of livestock. Animals were moved away from the croplands in the high lying areas during the cropping season (May-November). The movement of stockposts was made easier since the *matjieshuts* and *kookskerms* were easy to disassemble. However, stockpost movements have changed since the 1960's and today livestock movement is largely determined by water supply and available grazing (Solomon 2000; Combrink 2003). Plate 2.3, shows a typical cropping area.

Plate 2.3. Croplands in the valley bottom of select high-lying areas where no grazing would be allowed during the winter months cropping season.

2.8.2 General socio-economic aspects

Paulshoek is administered by the Kamiesberg Municipality, which was established in December 2000. This institution manages formal arrangements in the region. Formal management of natural resources still needs to be developed for the region. A series of Commage Committees have been established in the former communal reserves, but their role and activities are in the process of being developed. At the village level the Paulshoek Development Forum manages aspects of the village administration. The relevant sub-committees manage various components such as policing, agriculture and welfare. These sub-committees allow the Paulshoek community to express their democratic voice since members in the community elect the committees. However, some of the sub-committees are still weak due to a lack of capacity in dealing with organisational structures and functions. Although the general infrastructure of the village (*e.g.* telephones, electricity, sanitation) has been improved dramatically over the last five years, essential services such as medical facilities and transport, remain a significant problem due to the isolated location of the village from other large centres (Solomon 2000).

The village of Paulshoek has 140 households and 28 stockposts in the surrounding 20 000 hectares with approximately 800 people living in the area (May *et al.* 1997; Solomon 2000) (Plate 2.4). Most people in the village are unemployed and depend on welfare and remittances.

Plate 2.4. Houses and roads in the Paulshoek village.

There is great disparity in the living conditions and access to services among different household groups. Approximately 45% of households live in brick houses, 40% in corrugated iron houses and 15% in other types of structures (May *et al.* 1997). Although many people (97,8%) have running water on the premises (outside taps), water based sanitation and ablution facilities are still absent and probably unsustainable give the general limitation of water in the region.

Despite the isolation of the village (the nearest town Garies is 52 km from Paulshoek) it has a primary school with 100 children, a crèche and a rugby field. A taxi can be hired at approximately R180 per trip to Garies. This is expensive taking into consideration that the per capita income in Paulshoek is less than US$ 1 (1$ USD = R7.1 at current exchange rate; 22 October 2003) per day (Rodkin and Rohde 2000).

2.8.3 Economy

Paulshoek, like other Namaqualand Rural Reserves, is characterised by high levels of poverty, a lack of resources and a dependency on pensions, child disability grants and remittances from family members living away from Paulshoek. Income within households receiving remittances from migrant workers exceeded those of other households by 50-80%. At least 50% of the households in Paulshoek indicated that they own livestock (May *et al.* 1997). However, income from livestock sales only contributes 2% to the total income of households (Rodkin and Rohde 2000). This suggests that livestock farming may not be a major contributor to household income, but rather serves several social needs. As accessible land has diminished and populations have grown over the last two centuries traditional pastoral livelihoods have decreased. As a result the income from agriculture has declined over time (Kerridge 1997).

2.9 Human impacts

2.9.1 Livestock

Livestock production is an important activity in the lives of the Paulshoek community even though it may not be a major contributor to household income. It plays an important role in subsistence production and employment in the area. Fifty percent of the households in Paulshoek own at least one animal, which is kept in one of the 28 herds, scattered throughout the surrounding area. The herds in Paulshoek are mixed herds with hybrid sheep (Karakul, Persian, Dorper and indigenous Afrikaner) and Boer goats (Todd and Hoffman 1999). The average size of a herd is 104±64 animals. Other domestic animals include donkeys and a few cattle (May *et al.* 1997). The donkey population is at present estimated between 100-180 individuals.

The mean stocking rate over the last 30 years has been approximately 6 hectares per small stock unit. This is twice the recommended stocking rate for this area as determined by the South African Department of Agriculture for the neighbouring private farmers who have been farming at the recommended stocking rates and even at times lower than the recommended rate of 12 hectares per small stock unit (Todd and Hoffman 1999). The management strategies between communal and private farmers are very distinct. In the communal area, grazing practices are heavy and continuous throughout the year, whereas on the privately owned side, grazing is moderate and rotational.

Livestock farming has a major impact on vegetation structure and composition. A fence-line contrast exists between the communally farmed area of Paulshoek and the adjacent privately owned farmed area (Plate 2.5). Todd and Hoffman (1999) have shown that there are changes in the community composition and structure of this vegetation. A marked increase was observed in the annuals and geophytes on the communally farmed area. The more palatable plant species have also decreased significantly on the communal lands. These differences are explored more fully in chapter 4.

Plate 2.5. Fenceline contrast between communally owned Paulshoek (left) and adjacent privately owned land.

2.9.2 Cropping

There are a total of 26 cropping areas in Paulshoek. Cropping takes place in the low lying areas of the landscape where there is low rock cover and relatively deep soils (May *et al.* 1997). Although the cropping areas vary in size and shape and are not often contiguous, cropping areas of about 13,7 hectares are allocated to each lessee. The most important crops are wheat, lucerne, oats, barley and rye (Allsopp 1999). However, this has changed, as oats is now the most common crop due to its use as a primary supplementary feed for goats and sheep.

Cropping takes place without irrigation and due to the low rainfall has a high failure rate. Farming practises that have been used in the 19[th] century are still used today. Communally owned tractor has recently replaced donkeys for ploughing although some farmers still rely on donkeys. Sowing is still done by hand and threshing is done using donkeys on a dung-lined threshing floor.

The dependence of the community on crop production has decreased since the late 1950's in this area (May *et al.* 1997). Before this wheat formed part of the staple diet of inhabitants and a cash income was gained from the surplus. Even though some croplands have not been ploughed in the last 50 years they have not returned to their original state (Plate 2.6). The unpalatable and poisonous shrub, *Galenia africana*, mainly dominates fallow land. Even after an extensive resting period, succulents and annuals fail to establish on old crop sites. Surveys showed an overall reduction in soil fertility, especially a reduction in nitrogen and organic matter as a result of cropping (Allsopp 1999). This could be due to the fact that ploughing of the croplands removes the vegetation cover and changes the soil structure. As a result of this disturbance in soil structure there is a corresponding change in the vegetation community structure and composition (Allsopp 1999).

Plate 2.6. Although numerous cropland areas have not been ploughed in the past 50 years they have not returned to their original state and remain dominated by kraalbos (*Galenia africana*) as seen in this photograph.

2.9.3 Fuelwood collection

Fuelwood plays an important role in the livelihoods of people in Paulshoek village. Electricity was installed in June 2003. Prior to this, the village did not have electricity and every household depended on fuelwood for their energy requirements. More than 90% of households in the village use mixed fuels (gas, wood, candles and paraffin) (May *et. al.* 1997). A household uses an average of 8.7 kg of wood per day, which amounts to approximately 2.18 tonnes/hh/yr. On average, wood collectors, usually women and children, walk 7.2 km to collect wood and make at least 152 trips per year (Solomon 2000) (Plate 2.7).

Plate 2.7. Women and children collect most of the fuelwood required for the household needs, which is on average 8.7 kg of wood per day.

Fuelwood collection has a negative impact on the vegetation. Through the collection of shrub skeletons the rate of seedling mortality increases (Milton 1995; Solomon 2000). This is due to the exposure of seedlings to trampling, grazing, uprooting and desiccation. This practise also contributes to vegetation change through a change in soil nutrient status, erosion and the promotion and establishment of unpalatable species in the spaces created by the disturbance (Solomon 2000). Wood is also collected for poles to make the structure of matjieshuts although few people still construct these forms of shelter in the village. Plants such as *Galenia africana*, *Polymita albiflora* and *Euphorbia mauritanica* are also used to pack "*kookskerms*" or cooking shelters.

2.9.4 Medicinal plants

Archer (1994) and Goldberg (1998) have shown that despite the apparent loss of traditional knowledge about 75% of the village's inhabitants still use medicinal plants. Although villagers do not depend entirely on medicinal plants, as in earlier times, they still make use of them. At present, a mobile clinic visits the community once every two weeks and the closest doctor is 52 km away from the village. Paulshoek has three recognised "*bossiesdokters*" or herbalists.

Goldberg (1998) has shown that most medicinal plants species that are used in the village are used in a sustainable manner. However, there are medicinally important species such as *Mentha longifolia* and *Sceletium exalatum* that are declining largely as a result of overgrazing.

2.10 Concluding remarks

This chapter has provided a brief description of the study area in terms of its abiotic environment and the socio-economic context of the areas' inhabitants. In summary the region may be described as a rugged relatively hot and arid shrubland with low winter temperatures and well-drained soils derived from coarse-grained gneiss substrata. People in the village are poor and isolated and augment their income by using the natural resources of the surrounding commons for firewood, medicinal plants, cultivating crops and most importantly, for grazing their animals (primarily sheep, goats and donkeys).

Chapter 3: Paulshoek vegetation and associated environmental variables

3.1 Introduction

The formal study of vegetation is often associated with Alexander Von Humboldt, although early naturalists frequently added ecological notes to their lists and vegetation descriptions. The first recognised ecological paper was published in 1783 by Jean Louis Girand-Soulavie (Werger 1973). Humbolt and other nineteenth century botanists like Heer, Schouw and Griesbach developed the concept of vegetation based on physiognomic units, often called formations (Whittaker 1962). The formation classification was widely used, and although it was a coarse level of information it allowed preliminary description of an unexplored area in a short time frame. Thus, for a more detailed study of the vegetation of an area criteria other than physiognomy, preferably floristical criteria, were needed (Whittaker 1962; Werger 1973; Bruun and Ejrnaes 2000).

By the turn of the twentieth century a number of different vegetation classification systems had been developed (Werger 1973). These approaches developed into five different traditions or schools of thought. These were, the Zürich-Montpellier school also called the Southern tradition, Uppsala School or the northern tradition, the Russian tradition, British tradition and the American tradition with a few other approaches of less importance (Kent and Coker 1992; Bruun and Ejrnaes 2000; Chytry 2001; Spribille *et al.* 2001). All these schools of thought started from the so-called community-unit theory which suggests that vegetation consists of community-types, representing well-defined natural entities, which are part of the structure of vegetation and which generally contact one another along narrow boundaries (Whittaker 1962; Werger 1973; Bruun and Ejrnaes 2000; Chytry 2001; Spribille *et al.* 2001). What is common to all of the community-unit theorists is that they use a method of subjective selection of representative samples on which vegetation classification is based. All of these schools of thought have their own merit. However, the Zürich-Montpellier school has been the most widely accepted approach in South Africa (Werger 1978; Lloyd 1985; Bredenkamp *et al.* 1994;

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Bezuidenhout *et al.* 1994; Privette1998; Burgoyne *et al.* 2000; Hoare *et al.* 2000; Perkins *et al.* 2000; van Wyk *et al.* 2000; Siebert *et al.* 2002). This is due to three factors: it is scientifically sound; it fulfils the need of classification at an appropriate level; and it is efficient and versatile amongst comparable approaches (Werger 1973).

There are many benefits to vegetation mapping. It is relatively cost-effective as only a sub-sample of an area is sampled and used in the analysis, with the end result being representative of the entire area. Since only a sub-sample is necessary for the analysis it saves time in collecting the data compared to collecting data for the whole area. With a vegetation map there is immediate visual access to the communities of the study site, be it in electronic form or hardcopy (Austin 1991; Kent and Coker 1992). Moreover it allows for the understanding of both spatial and temporal structure of the vegetation communities (Rosenzweig 1995; Decocq 2002). This product is available to many end users (*e.g.* researchers, community members, planners, etc.) without repetition being necessary. Furthermore, vegetation classification and mapping forms an integral part of ecological planning in conservation areas (Privette 1998; Decocq 2002; De Klerk *et al.* 2003). Many studies in South African have been undertaken as part of a preliminary planning, based line monitoring and evaluation process, with the aim of identification of further research questions in areas in need of conservation and used as a basis for the prediction of future change (Kooij *et al.* 1990; Coetzee *et al.* 1995; Privette 1998; Bonyongo *et al.* 2000; Morgenthal *et al.* 2001)

3. 2 Context of the study

The vegetation of the Kamiesberg is under-studied, although it has been granted hotspot status of global significance. The only vegetation study performed in the Kamiesberg was that of Adamson (1938). The vegetation and phytosociological research section of chapter one discusses the vegetation study of Adamson (1938) and other vegetation studies completed in the succulent karoo biome, in great detail. The focus in chapter one was to place the flora of the study site within a broader context of regional and global vegetation. Complimenting previous chapters, this chapter focuses on the distribution of the vegetation of Paulshoek at a community level.

A study of this nature has importance in understanding and managing the vegetation of Paulshoek. At a local level the vegetation of the Kamiesberg region is distinct from other bioregions in the succulent karoo biome. This study serves as a baseline study for the existing vegetation of the Kamiesberg region. Based on the outcome of the vegetation community classification it assists various interested stakeholders in the planning of research, rehabilitation and sustainable development programmes (Coetzee *et al.* 1995; Privette 1998; Bonyongo *et al.* 2000; Morgenthal *et al.* 2001).

Part of the motivation for this type of study was that the succulent karoo biome, particularly the Kamiesberg region, is under-collected. It is for this reason that plant specimens were collected, identified and good specimens deposited in the Compton Herbarium.

The construction of a colour map showing the different vegetation communities and their modelled distribution throughout the landscape was another objective of this study. The availability of a vegetation map for the area contributes to the overall understanding of the distribution of the vegetation of this area, more so, since only a few phytosociological studies have been completed in the succulent karoo biome (Table 1.1). The data collected in this study have also been incorporated into the "Vegetation of Southern Africa Map Project". This is a project managed by the National Botanical Institute (NBI), which revises the vegetation map of Southern Africa that was produced, by Acocks in 1953. The vegetation map was also produced to assist the Paulshoek community in making sound sustainable development decisions (*e.g.* building of a dam). Hence they would be capable of identifying areas which are vulnerable to disturbances (*e.g.* overgrazing), assisting and driving decisions on areas requiring restoration, rehabilitation and conservation, and informing locals and researchers on which areas should be rested or which sites should be used for long-term monitoring. The map can also assist fellow researchers in the planning of their vegetation or ecological research, especially restoration projects that are currently in progress. It can also be used for predicting the impact of disturbance on species composition and distribution. Furthermore, it may be important in highlighting areas, which may be vulnerable to species loss, and for predicting the impact of species loss on plant community structure and function (Cowling *et al.* 1989, Privette 1998; Hoare 2002; Hellberg *et al.* 2003).

This chapter focuses on describing the present perennial vegetation into vegetation community units and correlates the associated environmental variables with each of the communities. The methods of the Zürich-Montpellier school of phytosociology were employed in the sampling of data. Relevés were selected by the use of the direct gradient analysis approach. The vegetation data was subjected to a TWINSPAN classification and ordination analysis. Based on the analysis of TWINSPAN and the ordination, four vegetation communities were identified. Using IDRISI (a raster-based GIS) the four vegetation communities were modelled for the whole of the study area.

3.2 Methodology

3.2.1 Data collected in the field

3.2.1.1 Relevé size

The nested plot technique as described in Mueller-Dombois and Ellenberg (1974) was used to determine the minimal sample size required for the relevés in this study. Relevé sizes ranged from 1 to 64 m^2. Data were collected in three altitude classes: 900-1120 m; 1120-1200 m and 1200-1400 m. A species/area curve for each relevé was prepared. Table 3.1 summarizes the results of the minimum area curves. A line using 10% of total species and 10% of total area was drawn on this graph as well as a more conservative line using 50% of the total species and 100% of the total area. The results for the average minimal area for the different altitude classes 900-1120 m, 1120-1200 m and 1200-1400 m were 32 m^2, 35 m^2 and 33 m^2 respectively, according to the 10% of total species and 10% of total area line (Table 3.1). However, the average minimal area from the more conservative 50% of the total species and 100% of the total area line was 47 m^2, 50 m^2 and 51 m^2, for the

the field the relevés were subjectively placed in a homogenous area, which appeared to represent the vegetation of the unit. This is in accordance with the Braun-Blanquet method (Werger 1978; Lloyd 1985; Bredenkamp *et al.* 1994; Bezuidenhout *et al.* 1994; Privette1998; van Wyk *et al.* 2000;Perkins *et al.* 2000; Hoare *et al.* 2000; Burgoyne *et al.* 2000; Siebert *et al.* 2002) which requires an area to be subjectively selected and to be structurally and floristically representative. According to Lloyd (1985) an area is considered homogenous where the vegetation is structurally and floristically uniform and where there are no marked changes in the habitat. No relevés were placed in areas that are presently used as cropland areas or areas that were previously used for cropping. Sampling of data took place during the spring of 1998 and 1999.

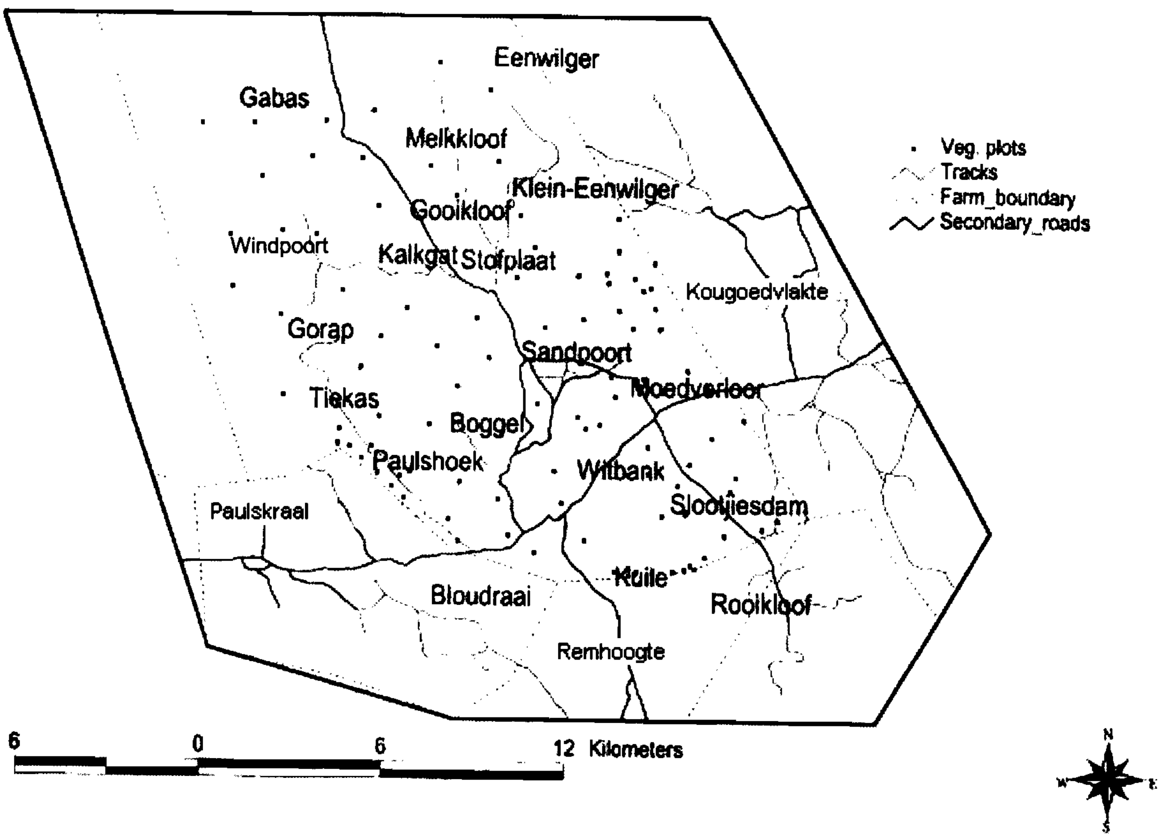

Figure 3.1. Detailed map of the Paulshoek communal area with the 94 randomly selected relevés that were subjected to analysis.

3.2.1.3 Landfacet type

The landfacet types (Tongway and Hindley 1995) were recorded for each relevé (Figure 3.2). A distinction can be made between: (1) crest; (2) upper slope; (3) mid slope; (4) lower slope; (5) closed depression; (6) flats; (7) dry river or stream channel. In addition to landfacet type several other variables were either measured or noted during the surveying of each relevé. These variables are explained in Table 3.2.

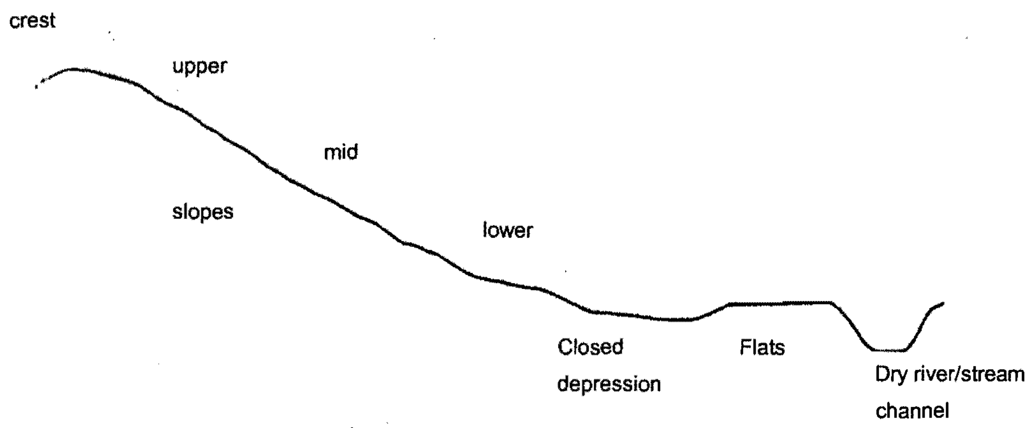

Figure 3.2. The different landform types used to describe the area. (after Tongway and Hindley 1995).

Table 3.2. Summary of information collected for each relevé.

Information collected	Units	Method
Location	-	Recorded latitude and longitude with a GPS
Altitude	m	Read from GPS
Geology	-	This was obtained from the geological map for this area completed by Joubert (1971) which distinguishes between: (1) superficial deposits, sand, soil, alluvium; (2) sheared rocks, phyllonite; (3) basic intrusive rock; (4); porphyroblastic granite gneiss (5) ultramafic gneiss and some mafic meta-instrusives; (6), mafic bands, cordierite gneiss; (7) leptite, leptynite and pink gneiss; (8) augen gneiss.
Landfacet type	1-7	Determined from a chart as described by Tongway & Hindley (1995); divided into 7 main types.
Aspect	-	Determined by using a handheld compass
Slope	degree	Taking into consideration the overall slope of the landscape the slope was measured (in degrees) using an Abney level.
Soil depth	cm	Soil depth was determined by using a metal rod of 1 cm diameter, with a sharpened point. The metal rod was knocked into the soil until it reached bedrock. A measurement was taken at three different places in the relevé and the mean value was used.
Soil colour	-	This was determined by using the soil sample, which was collected in each relevé. A standard Munsell soil colour chart (Munsell Colour Company, 1985) compiled by the Soil and Irrigation Research Institute was used to determine the soil colour.
Soil nutrient analysis	mg/g and µg/g	A soil sample was collected for each relevé by taking ten sub-samples in each relevé. Each sub-sample was taken at a depth of 10 cm. The soil sub-samples were mixed in one bag and chemical analysis was done on 121 soil samples, which were collected across the Paulshoek landscape during the vegetation survey.

		Analysis was performed to determine total nitrogen, phosphorus, sodium, potassium, magnesium, calcium and pH.
Vegetation cover and abundance values	%	The percentage vegetation cover was visually estimated (as describe by Mueller-Dombios and Ellenberg, 1974; Kent and Coker, 1992) and recorded using the Braun-Blanquet scale.
Percentage litter cover	%	The percentage litter cover was visually estimated and scored as a percentage cover value. Dead plant material and animal droppings were included in the estimation.
Percentage rock cover	%	The percentage rock cover was visually estimated for five rock size classes: 0.2-4 cm, 4-20 cm, 20-50 cm, >50 cm and bedrock.
Number of faecal pellets	$\#/m^2$	The number of faecal pellets is a reliable indicator of recent grazing intensity (Riginos and Hoffman, 2003). The number of sheep and goat droppings were counted around the boundary of the relevé. The boundary was marked with a tape measure and droppings in a 40 cm periphery inside (20 cm) and outside (20 cm) the relevé was included. This total was then expressed as the total number of faecal pellets per $1m^2$
Water infiltration	ml/s	An 810 g tin (20 cm meter diameter) with both ends removed, were placed inside the relevé without breaking the soil crust, thus, ensuring no leakage from the sides. Water (500ml) was gradually added into the tin and the time for all the water to be absorbed by the soil was recorded.
Disturbance	1-4	Disturbance was the visual assessment of the impact of human influences, *e.g.* overgrazing. The disturbance classes were (1) no disturbance; (2) light disturbance; (3) moderate disturbance; (4) heavy disturbance. This measurement was subjective and dependent on personal knowledge of the area

3.2.1.4 Floristic check list and vegetation sampling of the relevé

Species composition in semi-arid areas can vary from season to season and from year to year depending on the rainfall for that year (Van Rooyen *et al.* 1992; Oosthuizen *et al.* 1996; Rösch *et al.* 1997). This is especially true for ephemeral species and geophytes which can differ significantly in abundance from year to year at the same site (Lloyd 1989). Changes in floral displays of geophytes and annuals from year to year are due to the intensity, duration and season of rainfall (Van Rooyen *et al.* 1992; Oosthuizen *et al.* 1996; Rösch *et al.* 1997; Desmet and Cowling 1999b). As shown in the study done by Le Roux (1984) of the Goegap Nature Reserve in Namaqualand the ephemeral component of the reserve differed significantly between two successive years, 1975 and 1976. Another study by Robinson (1976) gives an example of the *Sesuvium sesuviodes- Stipagrostis obtusa* community in the Namib Desert Park where geophytes, which were numerous following rains in 1972, were absent from the same sites in 1973. This study in Paulshoek, therefore, only considered the permanently visible perennial plant species. All perennial plants in the relevé were recorded and given a cover-abundance value following the Braun-Blanquet cover-abundance scale.

R	very rare with negligible cover
+	present but not abundant, and with small cover value (less than 1% of the quadrat area)
0	rare, but present just outside the quadrat
1	numerous but covering <1% of the quadrat area, or not so abundant but covering between >1% and 5% of the quadrat area
2m	very numerous and covering < 5% of the quadrat
2a	covering between >5% and 12% of the quadrat area, independent of abundance
2b	covering between >12% and 25% of the quadrat area, independent of abundance
3	covering between >25% and 50% of the quadrat area, independent of abundance

4 covering between > 50% and 75% of the quadrat area, independent of abundance

5 covering between >75% and 100% of the quadrat area, independent of abundance

3.2.1.5 Plant identification and nomenclature

Plant specimens were collected for each unknown plant. All unknow species were identified and good specimens were incorporated into the Compton Herbarium. Nomenclature followed Germishuizen and Meyer (2003). Because of the current uncertainty in many Mesembryanthemaceae genera, working species names were assigned to some of the *Ruschia, Leipoldtia and Drosanthemum* species (P.Chesselet, personal communication). A list of all species found in the relevés was recorded. In addition, plants distributed throughout the landscape that were in flower were also recorded (these included both annual and perennial species) as this contributed to a more complete plant checklist of the area (Appendix 1).

3.2.2 Environmental variables in digital form

Digital data were obtained to assist with the modelling of the vegetation.

3.2.2.1 Digital terrain model (DTM) of Paulshoek

The original digital terrain model (DTM) was obtained from the Director General, Surveys and Mapping, Mowbray at 200m contour intervals. The DTM was in a gauss conforming projection. This data was converted into an IDRISI image and geo-coded, using the geo-codes given by the department, into a gauss projection. This image was then resampled to a spatial +/- 30 meters resolution (0.0002778 degrees per pixel) and filtered using a 7x7 mean filter. The image was truncated to integers and converted into real numbers.

3.2.2.2 Aspect

IDRISI (Eastman 1990) was used to generate an aspect surface from the DTM model. The conversion from meters to degrees was 0.0000089953. Due to stripping in the first analysis a 3x3 median filter was used.

3.2.2.3 Slope

The slope surface was prepared using IDRISI (Eastman 1990). To smooth out the image, a 3x3 median filter was passed over the image. Using the reclass in IDRISI (Eastman 1990) an image comprised of 8 classes was compiled (Table 3.3).

Table 3.3. Slope data were categorised in eight classes as shown.

Class	Slope (degree)
1	0-4
2	5-9
3	10-14
4	15-19
5	20-24
6	25-29
7	30-34
8	35-39

3.2.3 Satellite images

Satellite sensors acquire digital data in several different wavebands. Each waveband represents the amount of information emitted or reflected from the Earth in a particular part of the electromagnetic spectrum. Thus, data from waveband 1 of the Landsat Thematic Mapper (TM) represents the amount of blue light reflected from the earth's surface to the satellite sensor. Data from waveband 2 of the Landsat Multi Spectral Scanner (MSS) represents the amount of green light reflected. At the satellite, a measurement of light received is converted into a digital number (usually between 0-255), proportional to the amount of light in that waveband that is arriving at the sensor (D'Souza and Drake 1995).

A Landsat MSS image, recorded on 20th January 1973, was obtained from the United States Geological Survey, Sioux Falls, South Dakota (scene ID-LM1188081007302090). Four bands (4,5,6 and 7) were extracted.

3.2.3.1 Landsat thematic mapper principal components analysis (TMPCA)

A Landsat TM scene recorded on 19th September 1995 was purchased (scene ID-4219074221). Three bands (2-green; 3-red; and 4-near infra red) were extracted. The scenes were geo-referenced using ground control points by Mr X. Hintsa of the Agricultural Research Council, Range and Forage Institute, Grahamstown. A principal components analysis was performed on the Landsat TM images in IDRISI.

3.2.3.2 Normalised difference vegetation index (NDVI)

Green vegetation has a low reflectance at red wavelengths but a high reflectance at near-infrared wavelengths (Drake *et al.* 1995). The ratio of near infrared to red reflected light thus provides an indicator of the amount of green vegetation in each pixel. An increase in a pixel will increase near infrared reflectance, and reduce red reflectance, so the value of the ratio will be higher for greater amounts of vegetation. The Normalised Difference Vegetation Index (NDVI) was used. NDVI is thought to minimise the effect of variable look angle and illumination conditions and also uses a scale between known limits (theoretically –1 to +1), allowing comparisons of images from different dates. This was calculated as follows:

$$\text{NDVI} = \frac{(\text{near infra red} - \text{red})}{(\text{near infra red} + \text{red})}$$

The NDVI was computed for the Landsat TM image using IDRISI (Eastman 1990), and stretched using the "enhancement" option.

3.2.3.3 Composite Landsat MSS (COMPMSS) and Landsat TM (COMPTM)

Two composite images were generated from the MSS 4,5,6 and 7 bands and TM 2,3 and 4 bands using the IDRISI (Eastman 1990) composite algorithm. These three images formed part of the GIS layers for Paulshoek and the surrounding area.

The scaling option was based on symmetric distances instead of inter-species or inter-sample distances. The rationale behind the selection of symmetric distances was to weight sample and species distances equally. The analysis determined the floristic association between samples and the associated environmental variables (Whittaker 1962; Kent and Coker 1992). An association is a group of character species that are restricted to, and characteristic of, a particular plant community in the field. The description of communities is based on a concept of specific units. These units consist of character species and associated environmental variables (Table 3.2 variables and TMNDVI) and are recognisable in the field (Kent and Coker 1992; Desmet 1996). Furthermore, CCA also determines the environmental gradient associated with the determined vegetation communities.

The forward selection of the environmental variables was used to determine the minimum set of explanatory variables which best explained the variation in the floristic data (Ter Braak 1990). This approach was adopted with all the defaults. Conopost version (1.0) was used to graphically illustrate scatter diagrams and biplots.

3.2.4.3 Statistical analysis

Data was subjected to the Kruskal-Wallis One-way ANOVA with a t-distribution test using UNISTAT (version 4.5) at a 95% confidence level. The significance of each environmental variable was calculated. This statistical test calculated which environmental variable is significantly different between the different vegetation communities that were identified in the TWINSPAN, DCA and CCA analyses.

3.2.4.4 Modelling of vegetation map

The groups identified in the TWINSPAN analysis and the CCA were then subjected to Discriminant Functional Analysis (DFA) using STEPS version 7.0. This technique is similar to Canonical Variate Analysis (CVA) in that the groups subjected to analysis should be assigned before the analysis (Dytham 2001). DFA analysis calculates a set of weightings that allows the groups to be distinguished from each other. These weightings could then be assigned to individuals not assigned to a group to assess the probability of them belong to each of the possible groups. If the probability is high then the unknown can confidently be assigned to that assigned group and conversely when the probability is low the unknown can confidently be excluded from the assigned group (Sokal and Rohlf 1995; Dytham 2001).

Using the groups confidently identified by the DFA analysis, the four vegetation communities were modelled. The image of band tm4 and the DTM was multiplied by the standardised coefficients for canonical variables 0.043622 and –0.81317 respectively. These two new images were then added together. This single image was then multiplied with a constant 10.90521. This image was then re-classed into five classes by using the diagram produced by CANOCO with the observed data:

$$Z=(x_1y_1+x_2y_2)\ k_3$$

(With Z being the final image, x_1 represents the tm4 image, x_2 represents the DTM image, y_1 & y_2 the standardised coefficient for canonical variables tm4 and DTM respectively, k the constant)

3.2.5 Nomenclature of communities

The nomenclature used by Lloyd (1985) for the vegetation community identification was applied in the study. This approach is comprised of three components: the first component represents the diagnostic or dominant species, which would make the vegetation community easily identifiable in the field; the second component is a structural classification (Edwards 1983) and the third component reflects the habitat that this vegetation community occupies.

3.3 Results

3.3.1 Floristic checklist

Thirty-nine families with two hundred and fifty five plant species were recorded in the entire study area (Appendix 1). The dominant families are the Asteraceae, Mesembryanthemaceae, Crassulaceae and Aizoaceae with 66, 40, 18 and 14 species respectively in each family. Sixteen families have only one species (Figure 3.3).

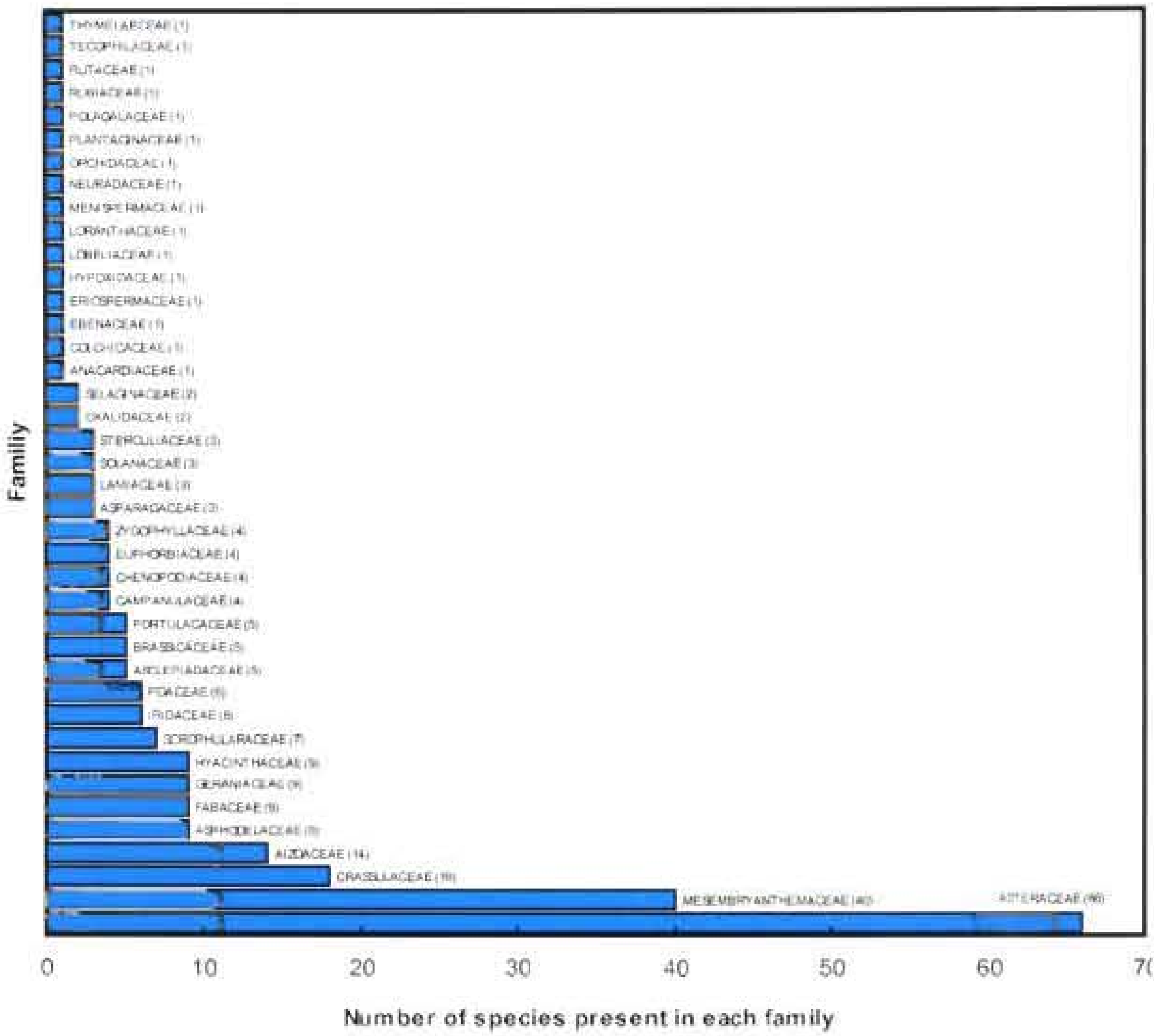

Figure 3.3. Histogram of the 39 plant families and 255 plant species collected in study site. The dominant families are Asteraceae, Mesembryanthemaceae, Crassulaceae and Aizoaceae. Bars on the graph are labelled with the family and the number of species present in the family.

3.3.2 Plant community determination

3.3.2.1 TWINSPAN

The output from the TWINSPAN analysis was manipulated in an attempt to produce a table with distinct division of the plant communities from one another (Appendix 2). The TWINSPAN table produced a division of two groups at level one. This division separated the lowlands (landfacets 4-7) from the uplands (landfacets 1-3). At the second level of division the analysis produced a further division of the lowlands and uplands into two groups based on their position in the landscape. The lowlands were divided into the lowlands flats and foot slopes. The uplands were separated into mid-slope to upper slope and upper slope to crest respectively. Sub-communities existed at the third level of division but further divisions did not result in the meaningful separation of groups (Allen *et al.* 1991; Parker 1991). The results of the TWINSPAN analysis are represented as a dendrogram (Figure 3.4). This analysis is based on indirect gradient analysis and does not consider environmental variables. TWINSPAN analysis is based on presence and absence data of species and is unable to identify clear communities beyond the third level of division.

In the most useful classification systems a single vegetation community would be based on true indicator species (Privett 1998). However, the high disturbance in the study area renders itself difficult to select only species that occur in a vegetation community to define such a community. Therefore the criteria used to differentiate between community 1 and the other communities were the presence of species that occur in this particular community at an abundance of more than 50% of the relevés and were completely absent from the other communities.

The outlier relevés numbers 65, 63, 120 and 111 were placed in the appropriate communities, 1, 3 and 4 respectively, by incorporating the TWINSPAN analysis, thus using the floristic data associated with the different communities.

Relevé 46 falls within the boundaries of community 1 in the CANOCO analysis. However, in the TWINSPAN analysis this relevé is placed with the group of samples that is associated with community 3, due to the presence of *Rhus burchellii,* which is completely absent from community 1. However it also contains *Pelargonium alternans, Eriocephalus microphyllus, Hallianthus planus and Pteronia glomerata* which are found in community 1.

Relevé 118 is placed in community 2 in the CANOCO analysis. The TWINSPAN analysis shows that it is floristically more characteristic of relevés associated with community 3. At the third level of division, sample 118 falls within the transitional sub-community between communities 3 and 4. The characteristic species in this sample are *Ehrharta barbinodis, H.planus and P. glomerata.*

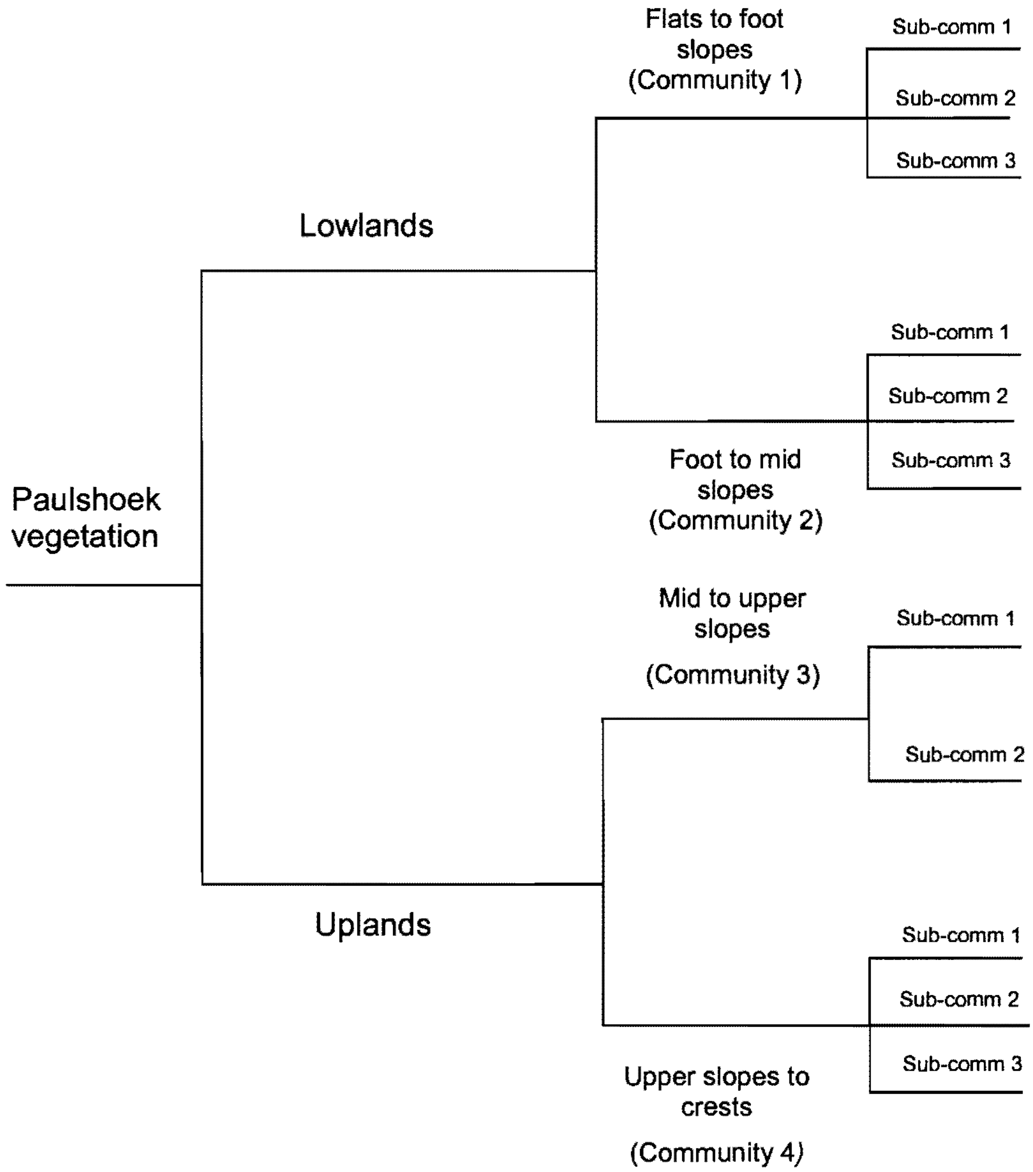

Figure 3.4. TWINSPAN dendrogram of the 94 relevés shows the four main vegetation communities and sub-communities in Paulshoek. The communities are associated with the landfacet indicated in the dendrogram.

3.3.3.2 Ordination of relevés

CCA (Vegetation community)

CCA analysis produced four distinct communities based on floristics and the underlying environmental associations (Figure 3.4). Using the two-way output table of the TWINSPAN analysis clear boundaries were drawn in the CANOCO diagram.

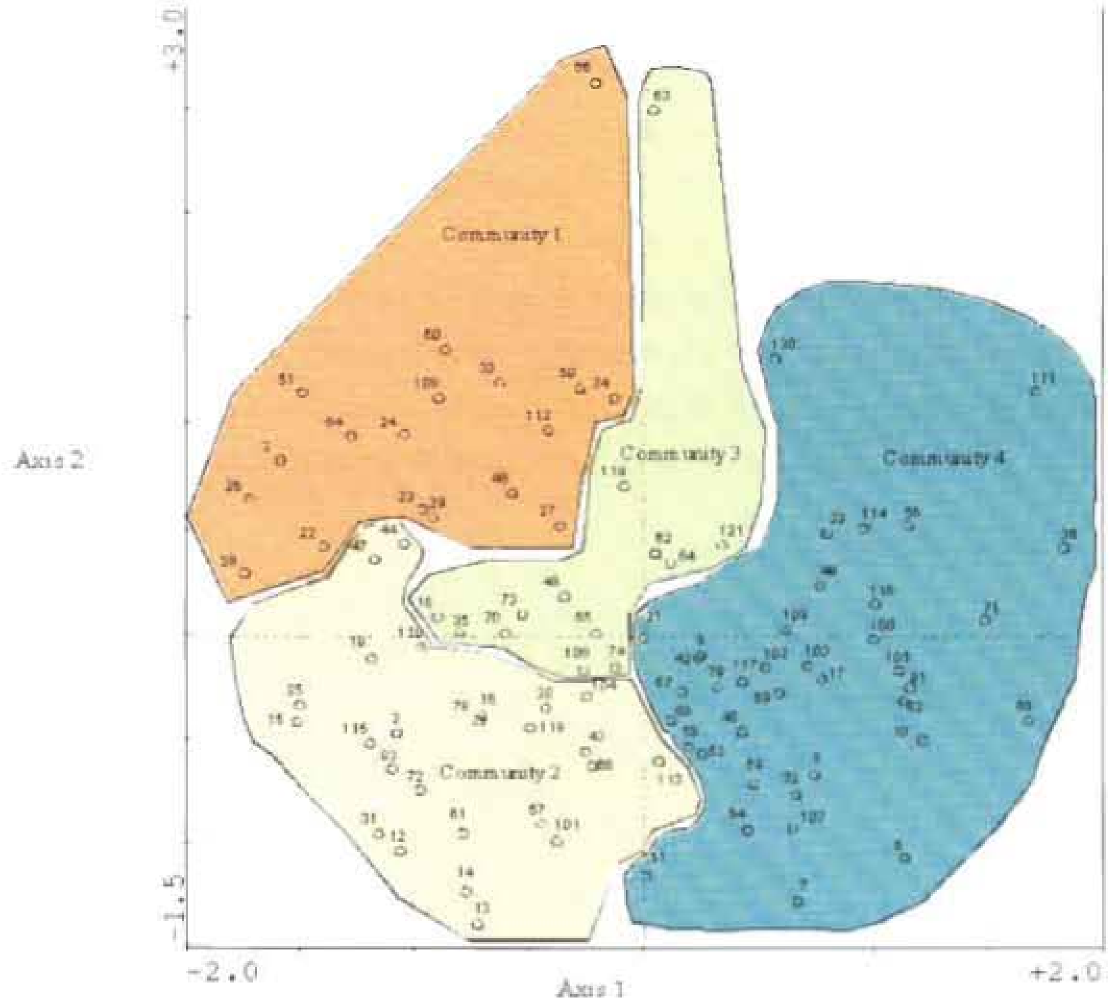

Figure 3.5. CCA biplot of site scores for the 94 relevés. The group of samples associated with each of the different four plant communities (see Figure 3.4) in Paulshoek is colour coded.

CCA (Environmental variables)

The eigenvalues for the CCA axis 1 and 2 were 0.43 and 0.35 respectively (Table 3.4). The inertia in species data (the sum of all constrained eigenvalues) accounted for 11% of explained measured environmental variables (Ter Braak 1990). Eleven percent of the variance in species data and 34.9% of the variance in the species-environment relationship was explained by the first two axes respectively.

The highest canonical coefficient was calculated for the rock cover class 20-50 cm (r=0.66) and bedrock (r=0.62) for axis 1 and calcium (r=0.57) and soil texture (r=0.56) for axis 2 (Figure 3.5). The CCA's forward selection procedure produced a minimum of nine environmental variables that best explained the floristic data. The significant variables in order of decreasing importance are 20-50 cm rock class, bedrock rock class, calcium, soil texture, sodium, nitrogen, magnesium, 50 cm rock class and disturbance (Table 3.4). Landfacet, pH and altitude are strongly correlated with axis 1 with canonical coefficients of r=0.51, r=0.40 and r=0.33 respectively. However, these environmental variables did not prove to be significant according to the results of the Monte Carlo test at the 5% level.

Table 3.4. Eigenvalues and canonical coefficients of the environmental variables for axis 1 and 2 of the CCA analysis. The first nine variables represent the minimum set of environmental variables that explains the floristic data.

	Symbol used	Axes		Forward selection
		1	2	
Eigenvalues		0.43	0.35	
Environmental variables				
20-50 cm rock cover (%)	20-50 cm	0.66	0.14	1
Bedrock (%)	Bedrock	0.62	-0.12	2
Calcium (mg/g)	Ca	0.11	0.57	3
Soil texture	Soil tex	0.21	0.56	4
Sodium (mg/g)	Na	0.08	0.20	5
Nitrogen (mg/g)	N	0.52	-0.07	6
Magnesium (mg/g)	Mg	-0.18	0.48	7
>50 cm rock cover (%)	50 cm	0.61	-0.04	8
Disturbance (index 1-4)	Distur	-0.30	0.01	9
Landfacet (1-7 types)	Facet	-0.51	0.10	NS
Altitude (m)	Alt	0.33	-0.06	NS
Slope (^{O})	Slope	0.28	0.14	NS
Faecal pellets (#/m^2)	Faecal	-0.22	-0.02	NS
% Litter (%)	Lit	0.08	-0.22	NS
Potassium (mg/g)	K	0.13	0.37	NS
Soil depth (cm)	Depth	0.11	-0.08	NS
0.2-4 rock cover (cm)	0.2-4 cm	-0.14	0.13	NS
Water infiltration (ml/s)	Infil	0.02	-0.10	NS
% Organic matter (%)	Org	0.18	-0.07	NS
4-20 rock cover (cm)	4-20 cm	0.03	0.08	NS
Phosphorus (µg/g)	P	-0.20	0.17	NS
pH	pH	-0.40	0.18	NS
TmNDVI	TmNDVI	-0.26	0.06	NS

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TmNDVI	TmNDVI	-0.26	0.06	NS

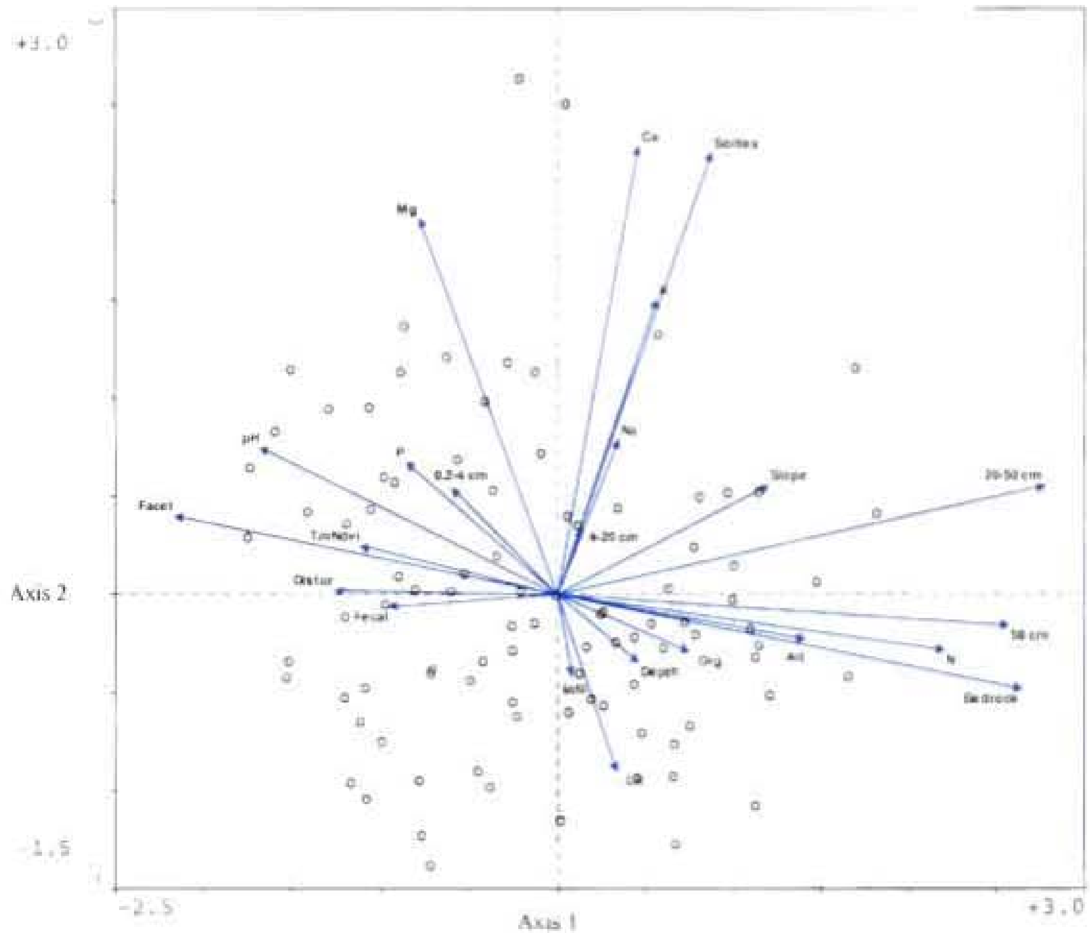

Figure 3.6. CCA plot of site scores for the 94 relevés and the environmental variables on the first two axes. (See Table 3.4 for an explanation of the symbols used).

3.3.2.4 Statistical analysis

The results of the Kruskal-Wallis one-way ANOVA to test for the significant differences between variables are presented in Table 3.5. All environmental variables were significantly different between the communities at the $p<0.05$ level except for 0.2-4 cm rock cover, faecal pellet density, infiltration rate, organic matter, phosphorus, and sodium levels.

Table 3.5. The four vegetation communities present in Paulshoek with mean (± std dev) values for key environmental variables. (Kruskal-Wallis one-way ANOVA was used to test for significant differences between communities).

Feature	Vegetation Community				*P* value
	Community 1. *Galenia africana* - low evergreen shrubs - flats	Community 2. *Ruschia robusta* - low leaf succulent shrubs - footslopes	Community 3. *Pteronia glomerata* - low evergreen shrubs - mid-slopes	Community 4. *Diospyros austro - africana* tall evergreen shrubs - upper slopes and crests	
Altitude (m)	1114.0 ± 47.0 [a]	1132 ± 78.8 [a]	1161 ± 102.7 [ab]	1182 ± 70.7 [b]	0.001
Landfacet (1-7 types)	5.1 ± 1.4 [c]	3.4 ± 2.1 [b]	2.5 ± 1.2 [ab]	2.2 ± 1.5 [a]	< 0.001
Slope (^{0})	6.8 ± 4.5 [b]	3.8 ± 2.2 [a]	6.7 ± 4.0 [b]	7.9 ± 7.4 [b]	0.028
Soil depth (cm)	28.5 ± 15.4 [ab]	33.5 ± 19.7 [c]	21.8 ± 6.3 [ab]	20.8 ± 7.6 [a]	0.030
Soil texture	Sandy loam to clay loam	Sandy clay loam to sandy clay	Loam sandy to sandy loam	Sandy loam to sandy clay loam	0.001
% Plant cover	12.8 ± 6.5 [a]	22.1 ± 8.7 [b]	29.9 ± 10.5 [c]	23.8 ± 6.6 [bc]	< 0.001
% Litter	1.3 ± 1.2 [a]	3.5 ± 2.4 [b]	3.5 ± 2.5 [b]	3.2 ± 2.7 [b]	< 0.001
0.2-4 cm rock cover (%)	6.2 ± 9.2 [a]	3.1 ± 3.7 [a]	2.8 ± 2.7 [a]	2.8 ± 4.6 [a]	0.787
4-20 cm rock cover (%)	4.2 ± 4.3 [b]	2.2 ± 4.2 [a]	6.5 ± 8.1 [b]	4.1 ± 5.1 [b]	0.010
20-50 cm rock cover (%)	3.8 ± 5.5 [ab]	1.9 ± 3.1 [a]	5.2 ± 4.3 [b]	10.0 ± 7.4 [c]	< 0.001
>50 cm rock cover (%)	1.4 ± 4.7 [a]	0.7 ± 2.1 [a]	4.0 ± 4.0 [b]	9.9 ± 7.6 [b]	< 0.001
Bedrock cover (%)	0.3 ± 1.2 [a]	0.2 ± 1.0 [a]	1.9 ± 4.8 [a]	18.4 ± 16.2 [b]	< 0.001
Faecal pellets no/m^2	14.0 ± 9.9 [a]	13.6 ± 8.0 [a]	14.7 ± 8.0 [a]	11.0 ± 7.3 [a]	0.317
Disturbance index (1-4)	3.7 ± 0.5 [b]	3.2 ± 0.4 [a]	3.2 ± 0.7 [a]	3.0 ± 0.6 [a]	0.003
Water infiltration rates (ml/min)	5.4 ± 10.5 [a]	3.3 ± 3.3 [a]	2.6 ± 1.9 [a]	3.8 ± 5.2 [a]	0.647
Organic matter (%)	2.6 ± 0.7 [a]	2.8 ± 1.2 [a]	2.8 ± 0.7 [a]	3.1 ± 1.2 [a]	0.608
Nitrogen (mg/g)	0.3 ± 0.1 [a]	0.4 ± 0.1 [ab]	0.4 ± 0.1 [b]	0.6 ± 0.2 [c]	< 0.001
Phosphorus (µg/g)	507.0 ± 378.0 [a]	427.0 ± 603.8 [a]	418.6 ± 211.2 [a]	290.5 ± 131.6 [a]	0.169
Na (mg/g)	0.05 ± 0.04 [a]	0.06 ± 0.03 [a]	0.08 ± 0.08 [a]	0.06 ± 0.08 [a]	0.608
Mg (mg/g)	0.20 ± 0.08 [c]	0.14 ± 0.08 [a]	0.19 ± 0.10 [bc]	0.14 ± 0.05 [ab]	0.003
K (mg/g)	0.11 ± 0.04 [b]	0.08 ± 0.03 [a]	0.13 ± 0.07 [b]	0.11 ± 0.06 [b]	0.008
Ca (mg/g)	0.58 ± 0.34 [b]	0.34 ± 0.20 [a]	0.55 ± 0.25 [b]	0.48 ± 0.28 [b]	0.01
pH	6.3 ± 0.6 [c]	5.6 ± 0.6 [b]	5.3 ± 0.5 [b]	4.8 ± 0.6 [a]	< 0.001
TmNdvi	0.26 ± 0.03 [b]	0.25 ± 0.03 [ab]	0.22 ± 0 .05 [a]	0.24 ± 0.04 [a]	0.015

3.4 Discussion

3.4.1. Vegetation map description

The vegetation of Paulshoek can be divided into four different communities with distinct environmental variables (Figure 3.7). These results are consistent with those of Le Roux (1984) who drew a clear distinction between four vegetation communities at the Goegap Nature Reserve. In the Goegap vegetation study a much clearer distinction could be seen between the different vegetation communities (Le Roux, personal communication). The inconsistency in the level of distinction between an open access area and conserved area is supported by studies that have argued that heavy grazing results in homogenization of the vegetation, thus creating more overlap between the different vegetation communities under heavy grazing. However, as a result of the conservation status of Goegap, less homogenization of the vegetation was observed. Each vegetation community was further subdivided into two or three sub-communities based on the presence of species in that sub-community only. In the discussion of each vegetation community, the characteristic plant species for each sub-community are listed. However, no emphasis is placed on the environmental variables for the sub-community as these are not significantly different from the broader community. A summary of the characteristic plant species for each community and sub-community are listed in Table 3.6. The sub-communities were defined in the TWINSPAN classification (Figure 3.4 and Appendix 2).

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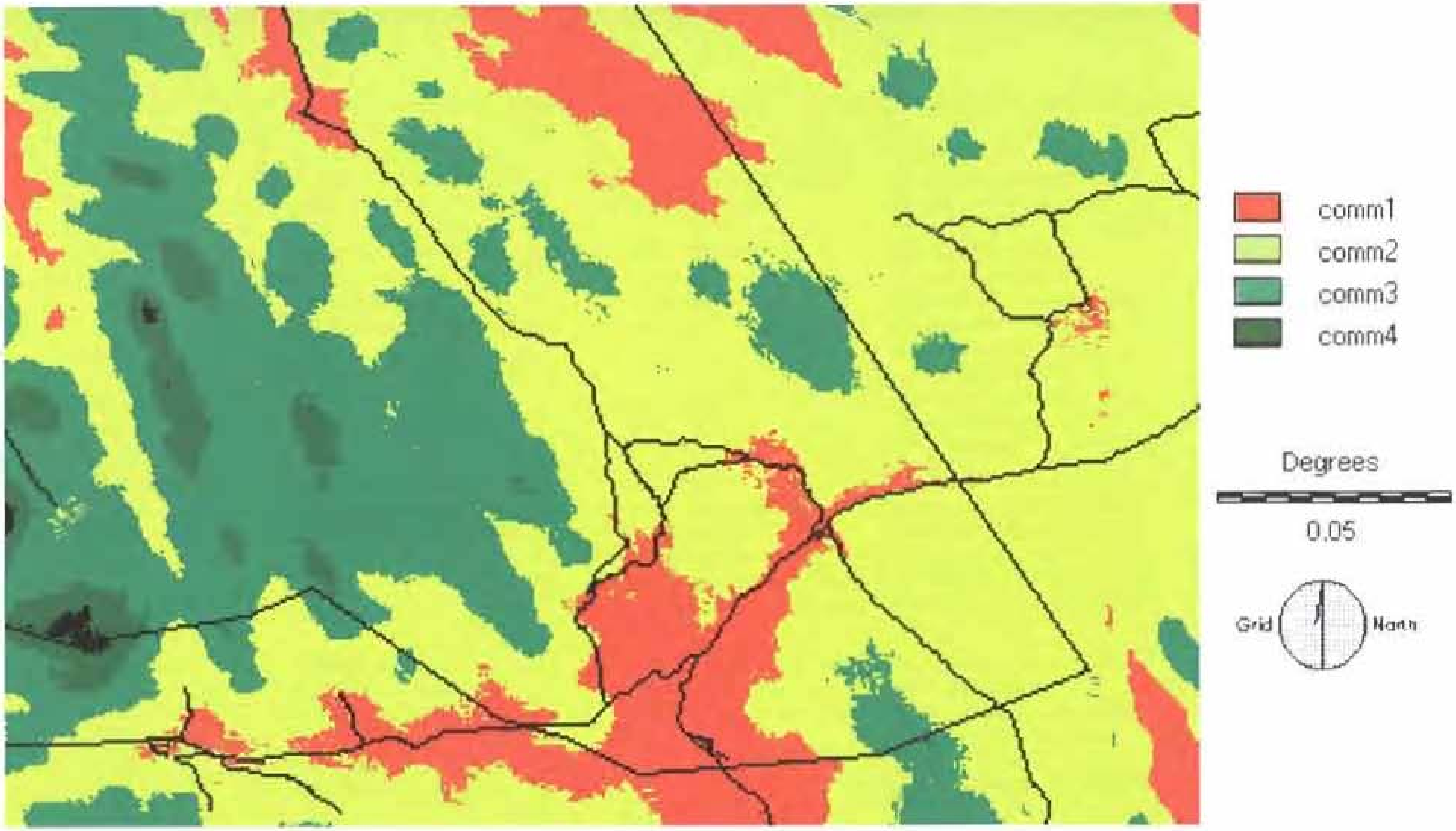

Figure 3.7. Vegetation map of Paulshoek with the four modelled communities (Community 1. *Galenia africana* – low evergreen shrubs on flats, Community 2. *Ruschia robusta* - low leaf succulent shrubs on footslopes, Community 3. *Pteronia glomerata* - low evergreen shrubs on mid-slopes, Community 4. *Diospyros austro-africana* - tall evergreen shrubs on upper slopes and crests).

3.4.2 Community 1. *Galenia africana* – low evergreen shrubs on flats

Community 1 is mainly found to the south-east and north-east of the village with isolated patches throughout the landscape. Low evergreen shrubs less than 50 cm high are dominant (Plate 3.1) and are restricted to the low lying flats and footslopes of the landscape. Rock cover is low (15.9%) and the rock cover class 0.2-4 cm (6.2%) is highest for this community (Table 3.5). The area covered by the community is used extensively by farmers and is mostly degraded due to the permanent waterpoints positioned throughout the community, which has the highest disturbance index (3.7). The soil is a sand to sandy loam and is slightly acidic (pH 6.3). Phosphorus (507 µg/g) and magnesium (0.20 mg/g) in the soil is highest in this vegetation community. Soils are moderately deep (28.6 cm) with low percentage soil organic matter (2.6%) and percentage litter (1.3%).

This community has the lowest percentage plant cover of all the communities. The vegetation is characterised by low evergreen shrubs such as *Galenia africana, Hermannia cuneifolia* as well as the low leaf succulent shrub *Drosanthemum floribundum.*

Sub-community 1: This sub-community appears to be transitional between community 1 and 2. The characteristic plant species are *Crassula subaphylla, Tripteris sinuatum and Pelargonium karooicum.*

Sub-community 2: The characteristic plant species are *Aridaria serotina, Aptosimum indivisum, Chaetobromus involucra* and *Drosanthemum floribundum.* These plant species are mainly found on the flats with low rock cover.

Sub-community 3: The characteristic plants species are *Crassula atropurpurea, Galenia sarcophylla* and *Euphorbia mauritanica*. This sub-community is found mainly between the flats and footslopes.

Plate 3.1. Community 1: *Galenia africana* – low evergreen shrubs on flats.

3.4.3. Community 2. *Ruschia robusta*-low leaf succulent shrubs on footslopes

Community 2 lies mainly to the east of the village with patches throughout the landscape (Figure 3.7). It is difficult to distinguish from community 1 by only visual observation since the transition between these two communities is less dramatic than in the other communities. However, they can be clearly separated on the basis of their floristic composition (Appendix 2) as well as a number of environmental variables (Table 3.5). Dwarf leaf succulent shrubs less than 50 cm high dominate this community (Plate 3.2) which is found mainly on the footslopes and mid-slopes of the mountains. This community usually occurs between 1054 and 1210 masl. The total rock cover is low and is dominated by the 4-20 cm rock cover class with patches within this community dominated by the bigger rock cover classes, 20-50 cm and >50 cm. This community is also exposed to heavy grazing due to its proximity to permanent waterpoints, but not to the same extent as the vegetation of community 1. It has an intermediate disturbance index score (3.2) with 13.6 faecal pellets per 1 m^2. The sandy loam soils are deeper than in community 1, and are more acidic (pH 5.6). The phosphorus (427 μg/g) and magnesium levels (0.14 mg/g) are lower in this community than in community 1.

The percentage soil organic matter (2.8%) and percentage litter (3.5 %) are generally higher than in community 1. This could be due to the higher levels of rockiness, which might act to trap dead plant material.

The vegetation in this community is taller and comprises a greater mean cover (22.1%) than in community 1. It is characterised by low leaf succulents such as *Ruschia robusta*, *Hallianthus planus* and *Crassula subaphylla*. Other species are characteristic (and restricted) to certain sub-communities rather than the broader community.

Sub-community 1: This vegetation community is characterised by *Pterotrix* species 1 and *Hermannia cuneifolia*. It also has *Polymita albiflora*, *Pelargonium alternans* and *Eriocephalus microphyllus* present. These species are characteristic of rockier and steeper habitats.

Plate 3.2. Community 2: *Ruschia robusta*-low leaf succulent shrubs on footslopes

Sub-community 2: This is dominated by *Hallianthus planus* that is the characteristic species of community 3. This suggests that this sub-community is transitional between communities 2 and 3.

Sub-community 3: This vegetation is characterised by *Leipoldtia schultzei, Ruschia compacta* and *Pterothrix* species 2. *Leipoldtia schultzei* is a characteristic species of community 3 although it is also found in other communities.

3.4.4 Community 3. *Pteronia glomerata-* low evergreen shrubs on mid-slopes

This community occurs mainly to the west and north-west of the village with isolated patches south-east and east of the village (Figure 3.7). It occurs mainly on mid to upper slopes in the area between 1059 to 1263 masl (Plate 3.3). It has a high rock cover and is dominated by the 4-20 cm rock cover class with the 20-50 cm and 50 cm rock classes also present (Table 3.5). This vegetation community is dominated by deep clayey soils with a high percentage of soil organic matter and percentage litter. The sodium, calcium and potassium levels are generally highest in this community. The rate of water infiltration is lowest here. This community does not appear to be as heavily disturbed as the previous two communities. The major contributing factor is the inaccessibility for the herders and the lack of waterpoints. Also, vegetation of this community is generally further from the village than the other communities and is less impacted than communities 1 and 2.

The vegetation of this community is characterised by low evergreen shrubs such as *Pteronia glomerata, Pteronia laterifolius, Eriocephalus microphylus, Pelargonium karooicum* and *Asparagus capensis*. Leaf succulents such as *Leipoldtia schultzei, Hallianthus planus* and *Ruschia robusta* dominate this plant community. It is also characterised by the mid-high evergreen shrub *Rhus burchelli*. This community is densely vegetated and has the highest average percentage cover.

Sub-community 1: This community has no characteristic plant species but can be distinguish from sub-community 2 through the absence of plant species rather than their presence.

Sub-community 2: This community is characterised by *Pelargonium alternans*, *Polymita albiflora*, *Eriocephalus microphyllus*, *Eriocephalus brevifolius* and *Ruschia robusta*. The presence of *Ruschia robusta* could indicate that it is transitional between vegetation community 2 and 3, whereas the presence of *Eriocephalus brevifolius* could indicate that it is transitional between community 3 and 4. *Pelargonium alternans* is normally dominant on the 20-50 cm and 4-20 cm rock class, since the plant cover is low, the rockiness provides some shelter from grazing. The presence of *Polymita albiflora* in the community could also be due to the rockiness of this vegetation community. Another reason could be the fact that this plant species is extensively used for the building of cooking shelters and since this vegetation community is further from the village and stockposts than community 2, it is less collected.

Plate 3.3. Community 3: *Pteronia glomerata* - low evergreen shrubs on mid slopes

3.4.5 Community 4. *Diospyros austro-africana*-tall evergreen shrubs on upper slopes and crests

This community is confined to the north-west of the village, which receives the highest annual rainfall for the entire area (Figure 3.7, Table 2.1). It is restricted to upper slopes and crest with between 1072 and 1252 masl (Plate 3.4). It occurs on deep, alkaline, sandy loam soils. Rock cover is highest in this community with exposed bedrock, >50 cm and 20-50 cm rock cover classes common (Table 3.5). Nitrogen, % soils organic matter and % litter is highest in this community. Because this vegetation community is furthest from the village with no permanent waterpoints and hence low grazing impact, it has the lowest disturbance score.

Community 4 has a high percentage plant cover and is characterised by tall evergreen species with mountain fynbos affinities such as *Diospyros austro-africana, Antizoma miersiana*, *Lebeckia multiflorum* and *Dicerothamnus rhinocerotis* (Appendix 2). Low evergreen shrubs such as *Osteospermum rigidum, Arctotis cuprea* and *Pteronia glomerata* are also present. Although leaf succulent shrubs are not a distinct feature of and do not dominate this community, *Ruschia lerouxii* and *Ruschia viridifolia* are characteristic species.

Sub-community 1: This community is characterised by *Felicia dregei, Ruschia lisabeliae, Euryops dregeanus, Drosanthemum floribundum* and *Lycium ferocissimum.* The latter two are species that generally occur on the flats. This sub-community groups all the relevés that have plant species with fynbos affinities.

Sub-community 2: This community is dominated by *Wiborgia monoptera, Passerina glomerata, Osteospermum grandiflora* and *Eriocephalus brevifolius* that are also present in community 3.

Sub-community 3. This community has no characteristic plant species but can be distinguished from sub-community 1 and 2 through the absence of plant species rather than their presence.

Plate 3.4. Community 4: *Diospyros austro-africana*-tall evergreen shrubs on upper slopes and crests.

3.5 Environmental variables

Based on the species composition data, analysis of the environmental variables for the vegetation communities showed that each community could be distinguished by a unique set of environmental variables. The rock cover classes (20-50 cm, >50 cm and bedrock) appeared to the most significant variables in determining community composition in this study. These results were confirmed by the Kruskal-Wallis one way ANOVA that displayed a significant difference for 20-50 cm ($p<0.001$), >50 cm ($p<0.001$) and bedrock ($p<0.001$) between the four communities. Cowling *et al.* (1999); Hoare *et al.* (2000) and Burke (2002) suggest that mountaineous habitats provide potential buffers in capturing moisture and nutrients. Furthermore, Petersen (2003) has shown that the nutrient recycling status and infiltration rates were significantly higher on rocky habitats within this study area. Other studies have obtained similar results

(Austin and Smith 1989; Palmer and Cowling 1994; Rietkerk and van de Koppel 1997; Pugnaire and Luque 2001). It was hypothesised that altitude would be the determining factor that influenced community composition, but results from the CCA forward selection procedure (Table 3.4) showed that attitude was insignificant in explaining the species composition data. However, further analyses displayed a positive correlation between altitude and rock cover classes (r^2= 0.59) and between altitude and landfacet (r^2 = 0.63). Soil texture and soil chemical properties (Ca, Na, N, Mg) appeared to be the other determining factors that influence community distribution in this study. Soil texture (p = 0.001) was highly significantly different between the four communities, as was Ca (p = 0.010), N (p<0.001) and Mg (p = 0.003). This analysis supports other studies that have shown that soil chemical properties influence community distribution in arid environments (Burke, 2001). However, it was somewhat surprising that although the CCA analysis showed that Na was a determining factor in community distribution, the results from statistical analysis showed that there were no significant differences (p = 0.608) between the different communities. Disturbance through livestock has also proved to be a determining factor in vegetation community distribution in this study and this result was supported by the statistical analysis (p = 0.003). Other environmental variables of importance in arid environments, such as slope and aspect, played a minor role in the distribution of communities in this study.

Chapter 4. Impact of communal and privately owned management strategies on community diversity, composition and structure

4.1 Introduction

The impact of heavy grazing by livestock in the succulent karoo biome is cause for great concern as a result of the major impact on the vegetation structure and composition of the area (Stokes 1994; Todd and Hoffman 1999; Hendricks *et al.* 2004). Relative to other arid and semi-arid areas in the world the succulent karoo biome has an exceptional high species diversity and endemism. It is the only semi-arid area in the world that has qualified as a biodiversity hotspot of global significance (Cowling and Hilton-Taylor 1999; Desmet and Cowling 1999b; Myers *et al.* 2000).

Heavy continuous grazing practices are especially common in the communal areas of the succulent karoo biome. There are eight communal areas in Namaqualand which comprise 25 percent of the area in this region (Hoffman and Ashwell 2001). Hoffman *et al.* (1999) have suggested that during the last 30 years the communal areas of Namaqualand have had a stocking rate that has on average been twice that recommended by the National Department of Agriculture. The communal areas are surrounded by privately owned farms and create the opportunity to assess the impact of grazing under the two different management strategies.

The mountainous areas in the succulent karoo biome are renowned for their high plant spcies diversity (Cowling *et al.* 1999; Harrison *et al.* 2000; Hendricks *et al.* 2004). Rockier areas are thought to support a higher density of plants due to the physical environment. Mountainous vegetation shows clear patterns of zonation along an environmental gradient. Most plants are restricted to these altitudes (Ter Braak 1988; Gottfreid *et al.* 1999). However under heavy grazing this natural distribution along an environmental gradient can be disturbed, resulting in species occurring outside of the predicted position along this gradient (Brown 1994; Birch *et al.* 1999).

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Plant species diversity and composition is influenced by livestock grazing in the succulent karoo biome (Cowling *et al.* 1994; Desmet and Cowling 1999b; Todd and Hoffman 1999; Hendricks *et al.* 2004). Various studies have shown that species richness may increase or be unchanged under heavy grazing (Todd and Hoffman 1999; Riginos and Hoffman 2003; Hendricks *et al.* 2004). Plant composition, however, usually becomes dominated by unpalatable species under heavy grazing regimes (Noy-Meir *et al.* 1989; Cunliffe *et al.* 1990; Oakwood *et al.* 1993; Milton 1994b; Hoare 1997; Westoby 1998; Jurgens *et al.* 1999). Palatable species are reduced due to several mechanisms: 1) direct impact on the plants (Hunt 2001); 2) reduction in competitive ability (Stokes 1994; Hoare 1997; Milton *et al.* 1997; Assaeed and Al-Doss 2001); 3) reduction in flower and seed production (Milton and Dean 1990; Milton 1994b; Todd and Hoffman 1999; Riginos and Hoffman 2003); 4) impact on seedling establishment (Milton 1995; Milton and Dean 1995; Hunt 2001; Riginos and Hoffman 2003). The combination of one or several of these impacts results in the dominance of unpalatable species under heavy grazing.

Milton (1995) has argued that unpalatable woody shrubs replace palatable species. More recent studies in the succulent karoo biome have echoed this by showing that under high livestock grazing the palatable leaf and stem succulents are reduced and replaced by annuals, geophytes and unpalatable woody perennials (Todd and Hoffman 1999; Riginos and Hoffman 2003; Hendricks *et al.* 2004). Studies outside the succulent karoo biome have reported similar trends (Shackleton *et al.* 1994; Stokes 1994; Evans *et al.* 1997; Higgins *et al.* 1999).

4.2 The specific aims of this chapter

As an overarching aim, this chapter evaluates whether rockiness of the uplands provides a buffer against the effects of heavy grazing and whether these uplands environments are less impacted than the sandier lowlands. This study also determines whether communal areas and privately owned land differ in terms of perennial plant species diversity. Finally, this study assesses whether the different grazing regimes influence vegetation composition and structure.

4.3 Methodology

4.3.1 Data collected in the field

4.3.1.1 Relevé selection

Relevés were placed in three different sites in Paulshoek along both sides of the boundary fence of the communal and privately owned land (Figure 4.1). The same minimum relevé size of 50 m^2 (5x10 m) was used as discussed in chapter 3.At each site, three relevés were selected in each land use system at three altitude classes (900-1120, 1120-1200 and 1200-1400). There were, therefore, 18 relevés at each site and 54 in total. Relevés were placed on the privately owned farms of Paulskraal, Remhoogte and Kougoedvlakte (Figure 4.1). Relevés were subjectively placed in homogenous areas, representing the vegetation of the area. The placement of relevés follows the method used in chapter 3. Where possible they were placed across fencelines to minimize the potential influence of climate and soil differences between sites. No relevés were placed in areas that are presently used as croplands or in areas that were previously used for cropping. Sampling of data took place during the spring of 1998 and 1999.

4.3.1.2 Environmental variables

All the environmental variables discussed in chapter three and summarised in Table 3.2 were recorded for these relevés.

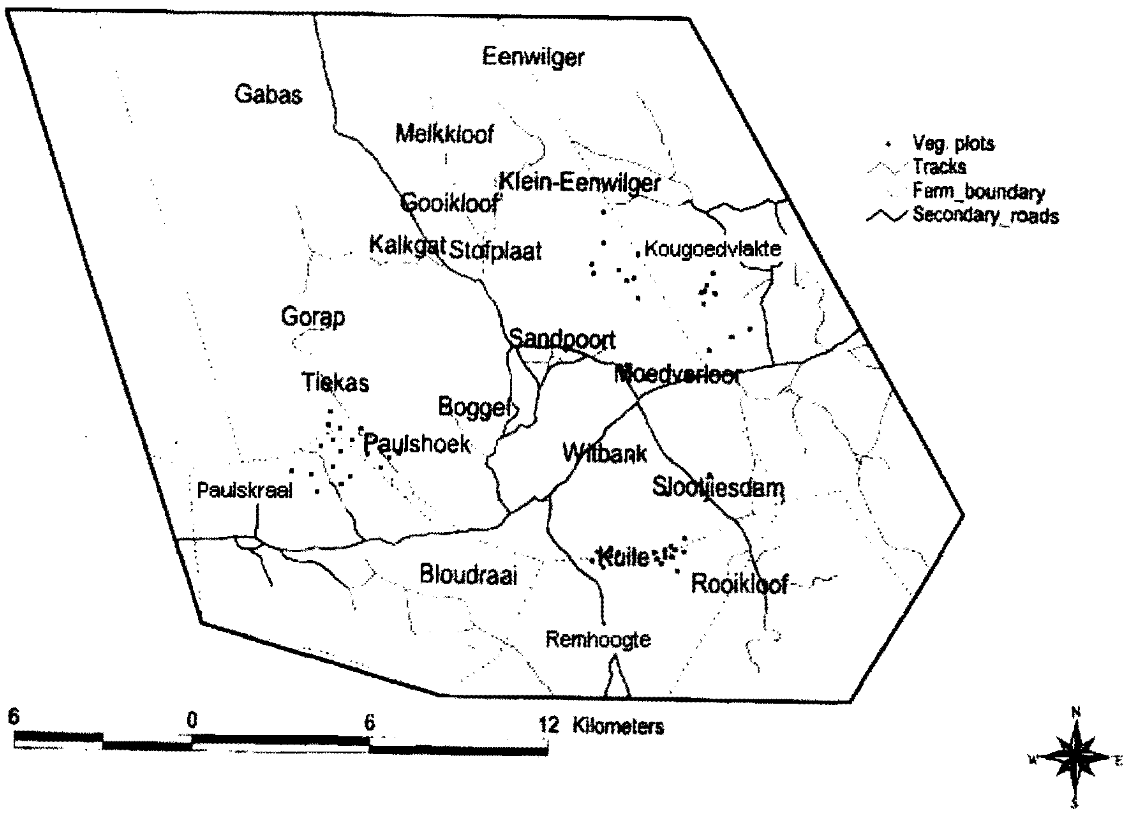

Figure 4.1. Detailed map of Paulshoek with relevés on the inside communal area and ones outside of it on the adjacent privately owned land.

4.3.2 Data analysis

4.3.2.1 TWINSPAN

The initial paired data set was divided into communal areas and privately owned land. A TWINSPAN classification (Hill 1979) was completed for the 27 communal areas and privately owned land relevés independently. This was done to by-pass the effect of the different management strategies on the data and to focus on the factors which were more likely to manifest themselves at the next level of division. The direct gradient analysis of the relevés was based on an altitude gradient. However, analysis in chapter three revealed that altitude was not the major determining factor in vegetation community distribution but rather that landfacet had a stronger influence. It is for this reason that the data was separated into two groups.

TWINSPAN analysis is based on the division of the data set into distinct groups on the basis of similarities and differences in the floristic composition between samples and groups of samples. The analysis was also done to determine whether land facet was in fact the determining factor in vegetation distribution of these paired data and also to divide the samples into categories that could be compared with each other. Relevés were subjectively moved within the table to refine it. Although the moving of relevés is controversial, it is considered acceptable if it is to find structure (relevés /species coincidence patterns) which carry important ecological information (Hoare 1997).

4.3.2.2 Ordination

A Canonical Correspondence Analysis (CCA) using CANOCO (Canonical Community Ordination) version 4.0 (Ter Braak 1988) was conducted on the 54 relevés from both the communal areas and privately owned land. This analysis was used to determine the floristic association between samples and the associated environmental variables (*e.g.* land facet) (Whittaker 1962; Kent and Coker 1992). Relevés 45 and 46 were omitted from the analysis, as they were outliers which distorted the analysis.

4.3.2.3 Diversity

Diversity and stability in ecosystems has attracted much research and discussion (Goodman 1975; Margalef 1975; May 1984; Magurran 1988; van der Maarel 1988; Kent and Coker 1992; Lande 1996; Smith and Wilson 1996; Collins *et al.* 2000). There is confusion over the meaning of diversity, its measurements and the ecological interpretations of it at various levels. Magurran (1988) has provided a review of diversity concepts and their calculation, in which she has emphasised that diversity is difficult to define.

Magurran (1988) defines two components of diversity. The first is species richness (a count of the number of species in a certain area) and the other is relative abundance (or evenness). Evenness is also linked to heterogeneity or homogeneity depending on the distribution of species abundance. A community is said to be homogeneous if the relative abundance of species is fairly equal. The opposite is true for heterogeneous communities where, relative to the other species, one species dominates to an extent that the species abundances are very unequal. The two components, species diversity and evenness can be combined to provide an overall index of diversity.

Species richness

This was calculated by determining the mean number of species for each plot on both the communal area and privately owned land. This is a measurement of α diversity (variation in species composition within the same area).

Similarity matrix

The degree of association or similarity of sites or samples is an alternative approach to measuring β diversity (variation of species composition between areas) (Magurran 1988). Similarity indices measure the degree to which the species composition of different relevés is matched. A wide range of similarity indices exists (Bray and Curtis 1957; Mueller-Dombois and Ellenberg 1974; Magurran 1988; Kent and Coker 1992).

Using the Bray and Curtis (1957) approach a similarity matrix was constructed with PRIMER 5. The percentage cover value data was transformed using the square root transformation to reduce the contribution of high percentage cover data. The Bray and Curtis (1957) index of similarity (*IS*) is calculated by:

$$IS = \frac{2w}{A + B}$$

where *w* is the sum of the smaller of the two quantitative values of the species that are common to two relevés, A is the sum of all quantitative values in one of the stands, and B is the sum of all the quantitative values in the other stand. The *IS* value can be expressed as a fraction or as a percentage (Mueller-Dombois and Ellenberg 1974).

Evenness

Evenness was determined by using the transformed version of the Simpson diversity index (1949). According to Begon *et al.* (1990) the Simpson diversity index is the simplest measurement of diversity that takes into account both the abundance (number of individuals, % cover or biomass) and species richness. The equation of Williams (1964) used 1/D to convert the Simpson's "dominance" index into an index of diversity. Dominance is weighted towards the abundance of the commonest species rather than providing a measurement of species richness (Magurran 1988). The equation is

$$E_{1/D} = \frac{1/D}{S}$$

Where D (Simpson's "dominance" index) is

$$D = \sum_{s=1}^{s} p^2_s$$

and S is the number of species in sample and p is

$$p_s = x_s \sum x$$

where

$$\sum x = \sum_{s=1}^{S} x_s$$

and x is the abundance of the s^{th} species.

This equation was selected from many other variations of the original Simpson index (1949), since it was independent of species richness and no symmetry was required between minor and abundant species. This means that a community with several abundant species and one minor species would have the same diversity as one with several minor species and one abundant species (Smith and Wilson 1996). The evenness calculation was done in EXCEL version 5.1.

Dominance/Diversity Curves

Dominance / diversity curves provide a manner in which evenness or equitability amongst species can be determined (Whittaker 1972). This is done by plotting the relative abundance on the x-axis with the species rank arranged from most to least abundant on the y-axis. These curves allow for the investigation of the

Mann-Whitney U test to test for significant differences between two independent variables (Zar 1984).

4.4 Results

4.4.1 TWINSPAN analysis

The output from the TWINSPAN analysis from the communal areas and privately owned land produced a division of two groups at the first level of division (Appendix 3 and 4). The division of the relevés was along a land facet gradient, into the uplands and lowlands. The results of the TWINSPAN output table was consistent with the results in chapter three where land facet was the determining factor in the vegetation community distribution. In chapter three the initial separation of relevés was also into uplands and lowlands. The communal areas data set was divided into 15 and 12 relevés each, for the uplands and lowlands respectively (Appendix 3). The privately owned lands were separated into 14 and 13 relevés each for the uplands and lowlands respectively (Appendix 4). Table 4.1 shows the indicator species for the different vegetation communities.

4.4.2 Ordination

There was a general separation of uplands and lowlands vegetation for both communal areas and privately owned land Figure 4.2. The biplot of the CCA analysis separated the uplands and lowlands on the privately owned land as two groups with no overlap. The uplands and lowlands of the communal areas, however, were not separated into two distinct groups, but exhibited some overlap between the two. This overlap occurred mainly as a result of three relevés, 18, 26 and 31 being associated with samples in the uplands communities. These three relevés all have a high total percentage rock cover and specifically the rock cover class 20-50 cm.

The eigenvalues for the CCA axis 1 and 2 (Figure 4.2) were 0.53 and 0.35 respectively. The first two axes explained only 15.2 % of the variance in the species data but 37.2 % of the species/ environment relation respectively. The highest canonical coefficient was calculated for the rock cover class 50 cm ($r = 0.59$) and rock cover class less than 20 cm ($r = 0.54$) for axis 1 and land facet ($r = 0.48$) and sodium ($r = 0.43$) for axis 2 (Figure 4.3). Statistical analyses showed that altitude, landfacet, rock cover class 20-50 cm, rock cover class >50 cm, faecal pellets, disturbance index, nitrogen, phosphorus and pH were significantly different between the uplands and lowlands for both communal and privately owned land (Table 4.2). All of these environmental variables (except for the disturbance index) divide the data into an uplands group and a lowlands group for both communal areas and privately owned land.

Table 4.1. Summary of the five indicator species in the vegetation of the communal area and privately owned land for the uplands and lowlands vegetation.

Communal land		Privately owned land	
Uplands (15 relevés)	Lowlands (12relevés)	Uplands (14 relevés)	Lowlands (13 relevés
Eriocephalus microphylla	*Ruschia robusta*	*Pelargonium alternans*	*Ruschia robusta*
Ruschia viridifolia	*Pentzia lanata*	*Polymita albiflora*	*Leipoldtia schultzei*
Polymita albiflora	*Asparagus capensis*	*Pteronia incana*	*Eriocephalus ericoides*
Pelargonium alternans	*Crassula subaphylla*	*Eriocephalus microphylla*	*Galenia africana* var. *africana*
Lebeckia multiflora	*Galenia africana* var. *africana*	*Ruschia* sp.1	*Crassula subaphylla*

Table 4.2. A summary of the mean of the environmental variables for the uplands and lowlands vegetation communities in communal areas and privately owned farms. Results of Kruskal-Wallis one-way ANOVA and the Multiple comparisons with *t* distribution are shown. Within a row, values with a different superscript are significantly different.

Environmental variables	Communal area		Privately owned land		*P* value
	Uplands	Lowlands	Uplands	Lowlands	
Altitude (m)	1200 ± 43.3^{b}	1099.7 ± 60.4^{a}	1181 ± 70.1^{b}	1121 ± 49.3^{a}	0.00
Landfacet (1-7 types)	2.1 ± 1.1^{a}	4.7 ± 1.5^{b}	2.0 ± 1.0^{a}	4.6 ± 1.9^{b}	0.00
Slope (^{0})	10.2 ± 8.9^{b}	6.2 ± 11.8^{ab}	10.2 ± 9.2^{ab}	6.8 ± 4.0^{a}	0.06
Soil depth (cm)	26.6 ± 6.1^{a}	38.7 ± 44.5^{a}	21.6 ± 7.2^{a}	25.7 ± 6.2^{a}	0.34
% Litter	6.1 ± 5.3^{ab}	3.1 ± 2.1^{a}	3.4 ± 2.6^{b}	2.3 ± 2.4^{ab}	0.06
<20 cm rock cover (%)	4.8 ± 7.2^{a}	10.0 ± 9.4^{a}	5.0 ± 4.7^{a}	12.2 ± 11.0^{a}	0.14
20-50 cm rock cover (%)	6.6 ± 6.4^{b}	3.5 ± 4.2^{a}	10.9 ± 8.2^{ab}	4.3 ± 4.6^{a}	0.02
>50 cm rock cover (%)	32.9 ± 29.6^{b}	2.7 ± 6.0^{a}	20.4 ± 15.4^{ab}	3.1 ± 4.9^{a}	0.02
Faecal pellets (no./m^{2})	113.2 ± 92.3^{ab}	228.4 ± 203.6^{bc}	111.3 ± 63.6^{a}	165.4 ± 71.3^{c}	0.03
Disturbance index (1-4 index)	2.4 ± 0.5^{b}	3.0 ± 0.4^{c}	2.9 ± 0.6^{a}	3.7 ± 0.5^{b}	0.00
Water infiltration (ml/s)	12.9 ± 8.7^{a}	20.3 ± 24.1^{a}	16.0 ± 7.8^{a}	14.6 ± 11.3^{a}	0.56
Organic matter (%)	3.2 ± 1.1^{ab}	2.5 ± 0.9^{a}	3.6 ± 1.5^{b}	2.9 ± 0.9^{ab}	0.10
Nitrogen (mg/g)	0.56 ± 0.25^{b}	0.38 ± 0.13^{a}	0.59 ± 0.18^{b}	0.40 ± 0.20^{a}	0.00
Phosphorus (µg/g)	278.7 ± 139.8^{a}	709.3 ± 655.7^{b}	294.6 ± 144.0^{a}	573.4 ± 412.9^{b}	0.05
Na (mg/g)	0.06 ± 0.06^{a}	0.07 ± 0.06^{a}	0.07 ± 0.06^{a}	0.05 ± 0.03^{a}	0.83
Mg (mg/g)	0.14 ± 0.07^{ab}	0.20 ± 0.09^{ab}	0.15 ± 0.05^{a}	0.16 ± 0.06^{b}	0.20
K (mg/g)	0.11 ± 0.04^{a}	0.13 ± 0.09^{a}	0.09 ± 0.04^{a}	0.09 ± 0.03^{a}	0.40
Ca (mg/g)	0.51 ± 0.47^{a}	0.53 ± 0.4^{a}	0.39 ± 0.21^{a}	0.39 ± 0.24^{a}	0.73
pH	4.7 ± 0.6^{a}	5.8 ± 0.9^{b}	4.7 ± 0.3^{a}	5.6 ± 0.7^{b}	0.00
TmNDVI	0.20 ± 0.07^{ab}	0.26 ± 0.04^{b}	0.24 ± 0.05^{a}	0.25 ± 0.03^{b}	0.08

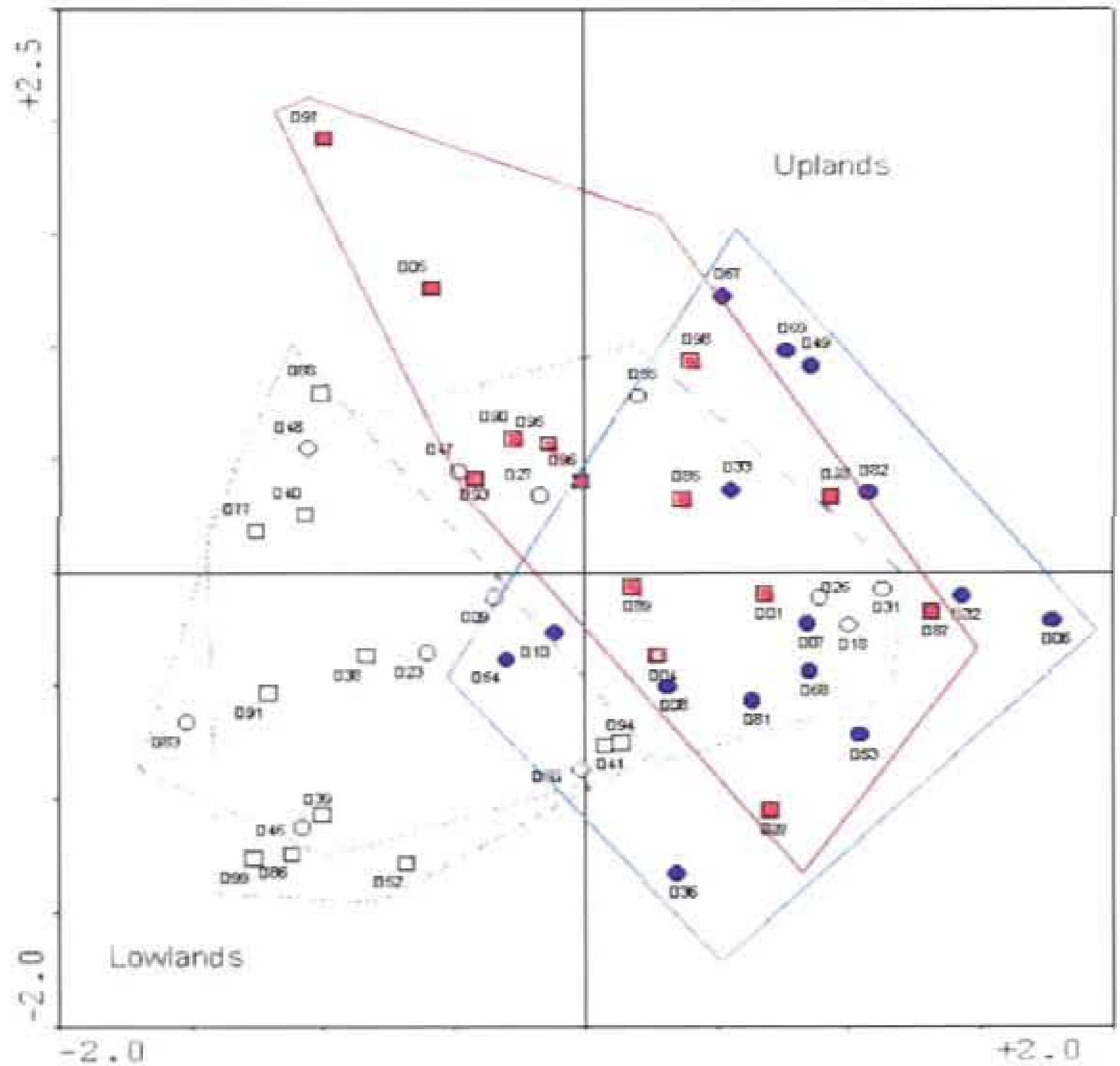

Figure 4.2. CCA scatter plot of site scores for communal area and privately owned land (54 relevés). The blue and open circles represent communal areas, uplands and lowlands respectively. The red and open squares represent privately owned land, uplands and lowlands respectively. The solid lines are the uplands communities and the dashed lines the lowlands communities for the respective management strategies.

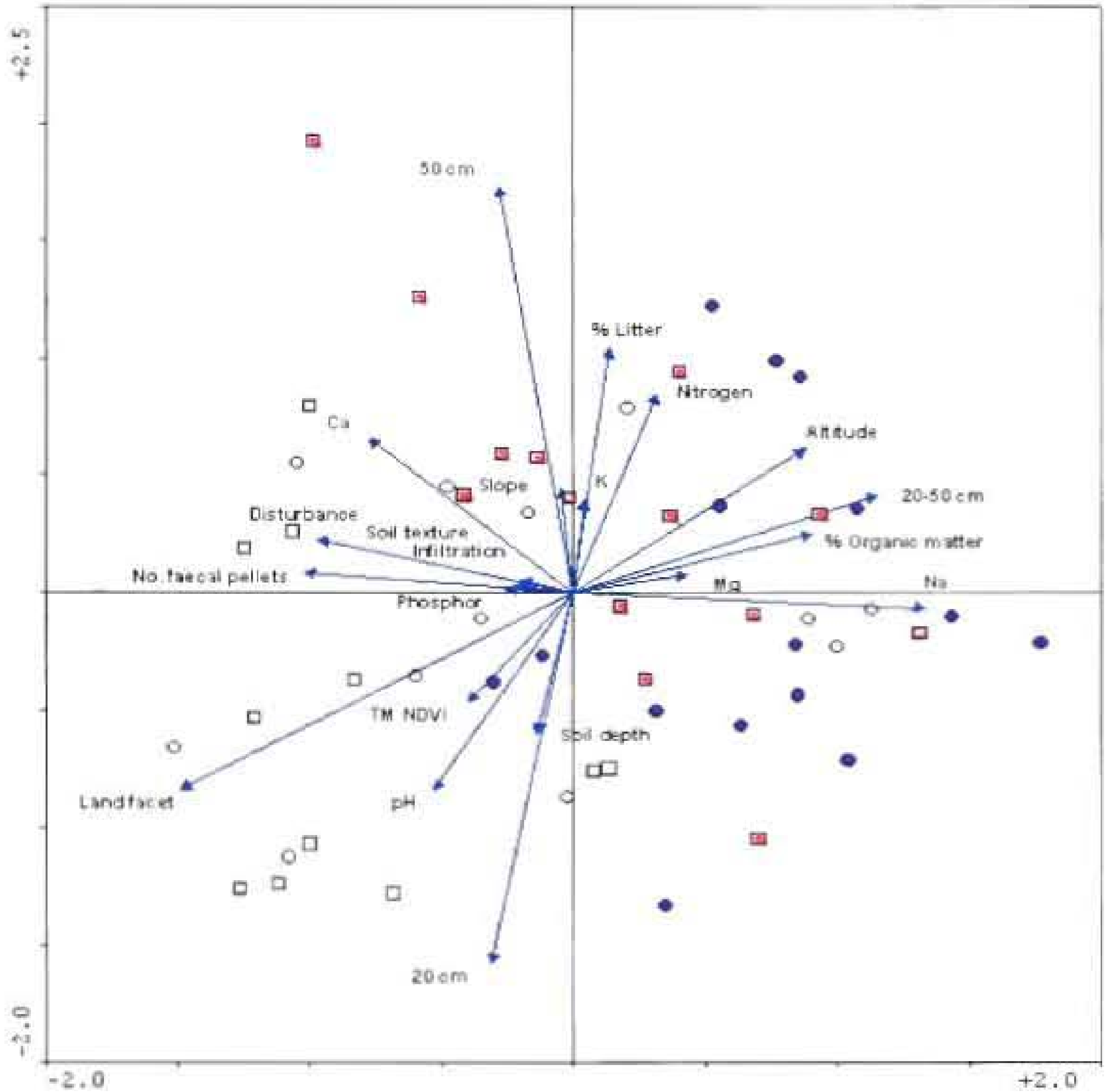

Figure 4.3. CCA biplot of site scores for communal land and privately owned farms (54 relevés) and the environmental variables on the first two axes. (See Table 4.2 for an explanation of the symbols used.)

4.4.3 Diversity

4.4.3.1 Similarity matrix

Table 4.3 displays the mean percentage similarity in species composition between uplands and lowlands relevés located in communal areas and privately owned land. Results demonstrate that there is only 20.9% similarity between species composition in the relevés of the communal area lowlands. A similar level of similarity was calculated between communally owned uplands (21.5%) and privately owned uplands (20.0%). There is less similarity (14.1%) between communally owned lowlands and communally owned uplands, The lowest similarity (11.6%) was observed between communally owned uplands and privately owned lowlands. The greatest similarity (27.1%) was observed between the lowlands of communal area and lowlands of privately owned land. The Kruskal-Wallis one way ANOVA demonstrated that there is a significant difference ($p < 0.001$) between the uplands and lowlands species composition of both the communal and privately owned land respectively. The multiple comparisons with *t* distribution show the different groups that are significantly different (Table 4.3.).

Table 4.3. The mean percentage similarity for uplands and lowlands in communal areas and privately owned land vegetation communities. Values indicate the percentage similarity when compared to itself and other vegetation communities as well as the standard deviation. The Kruskal-Wallis one-way ANOVA analysis showed that there was a significant difference ($p < 0.001$) between the mean percentage similarity between the different vegetation communities while Multiple comparisons with the *t* distribution test identified the groups that are different. Within a row, values with a different superscript are significantly different ($p<0.05$).

		Communal areas		Privately owned land	
		Uplands	Lowlands	Uplands	Lowlands
Communal areas	Uplands	21.7 ± 7.0^{df}			
	Lowlands	14.1 ± 4.7^{b}	20.9 ± 9.2^{d}		
Privately owned land	Uplands	21.5 ± 7.2^{d}	17.1 ± 6.9^{c}	20.0 ± 9.1^{d}	
	Lowlands	11.6 ± 4.5^{a}	21.9 ± 6.1^{de}	13.6 ± 8.4^{ab}	27.1 ± 8.9^{f}

4.4.3.2 Species richness

The highest mean number of species per relevé was recorded for the privately owned uplands areas (Table 4.4). The lowest number was recorded on the communally owned lowlands. The multiple comparisons with *t* distribution demonstrated a significant difference between mean number of species per relevé for the communal uplands and lowlands vegetation communities. There is a significant difference between uplands and lowlands in both communal areas and privately owned lands.

Table 4.4. The mean number of species per relevé with the standard deviation and mean evenness per relevé for communal areas and privately owned land for both uplands and lowlands vegetation communities. The different groups are separated by the multiple comparison with *t* distribution. Within a row, values with a different superscript are significantly different (t-test, P<0.05).

Land tenure		Number of relevés	Mean no. of species/relevé	Mean evenness/ relevé
Communal areas	Uplands	15	$11.2^{ab} \pm 3.3$	0.45 ± 0.13^{a}
	Lowlands	12	$13.9^{ab} \pm 2.8$	0.42 ± 0.14^{a}
Privately owned land	Uplands	14	$13.1^{a} \pm 4.2$	0.56 ± 0.13^{b}
	Lowlands	13	$12.6^{b} \pm 3.9$	0.43 ± 0.14^{a}

4.4.3.3 Evenness

Evenness is expressed as a fraction. The closer to one the greater the evenness. Results from the calculation of the Williams (1969) modification of the Simpson's index of dominance show that the highest evenness was determined for the uplands vegetation on privately owned land (Table 4.4). The lowest evenness was measured for the lowlands in the communal area. The mean evenness per relevé varied significantly between communal and privately owned uplands and lowlands.

4.4.3.4 Dominance/ Diversity Curves

Only minor differences in the dominance/ diversity curves between the communal areas and privately owned land for both the uplands and lowlands vegetation were observed (Figure 4.4). The first five species for all vegetation types showed a high proportional abundance value. The other species from rank five to ten showed a marked decrease and then after the 10^{th} rank a marked tapering off of the proportional abundance followed. Figure 4.5 displays the mean percentage cover for the 10 most dominant species only. This figure shows that for the lowlands in communal areas three species (*Eriocephalus ericoides, Galenia africana* and *Pteronia incana*) dominate the area. The lowlands of privately owned land are also dominated by only three species (*Polymita albiflora, Lebeckia multiflora* and *Eriocephalus ericoides).* The uplands communities of privately owned land, in contrast, are not dominated by only a few species but instead exhibit relatively more evenness than the other three communities.

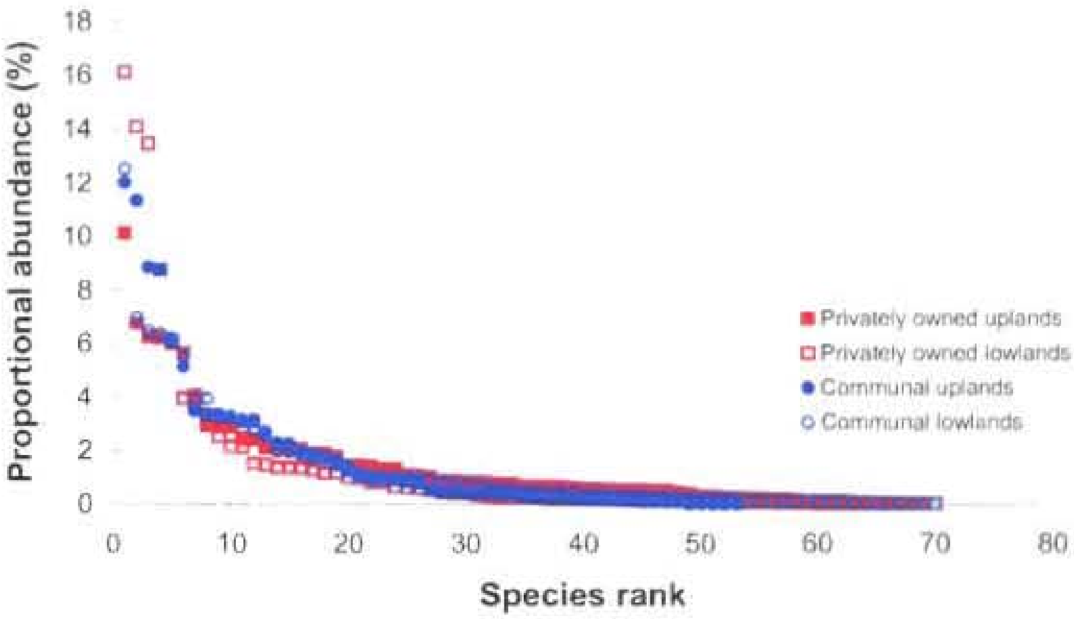

Figure 4.4. Dominance/diversity curve of the proportional abundance vs. the species rank for both uplands and lowlands of the communal areas and privately owned land.

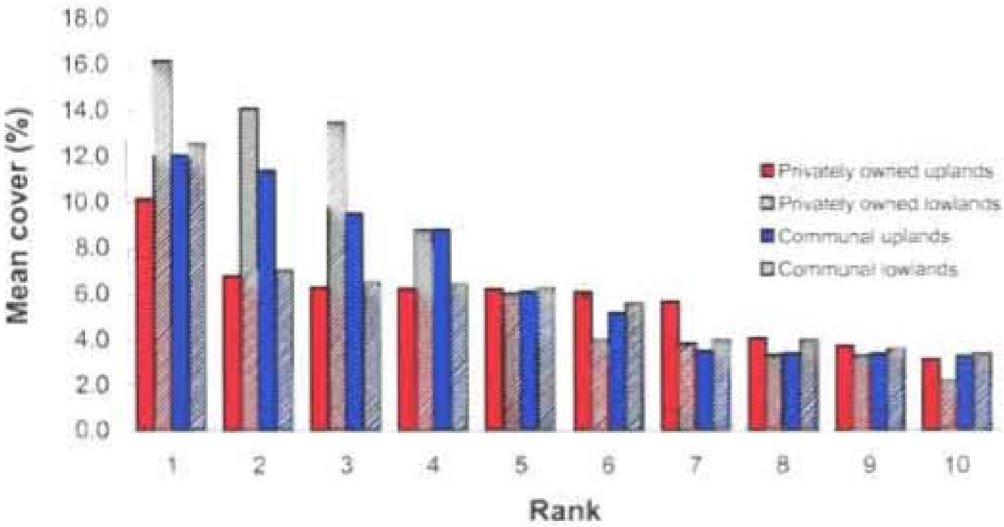

Figure 4.5. The mean percentage cover of the 10 most abundant species for the uplands and lowlands of communal areas and privately owned land.

4.4.4 Growth forms

Table 4.5 displays the descriptive statistics and *p* values of the growth forms between lowlands and uplands for communal areas and privately owned lands. There is no significant difference in the mean percentage cover of the different growth forms between uplands and lowlands communities under the different management strategies. This is probably due to the high standard deviation which indicates great variability in the data set or that the number of the samples compared was too small (Zar 1984).

Evergreen, deciduous and leaf succulent shrubs (Table 4.5) dominate uplands and lowlands vegetation in both communal areas and privately owned land. Evergreen shrubs (*e.g. Eriocephalus ericoides* and *Pentzia incana*) dominate the uplands vegetation of both communal areas and privately owned land as well as the lowlands vegetation of communal areas. Deciduous shrubs such as *Tetragonia fructicosa* and *Tripteris sinuata* are common in the landscape but rarely dominate the vegetation in terms of their cover. Leaf succulent shrubs, such as *Ruschia robusta* and *Leipoldtia schultzei* dominate lowlands vegetation of privately owned land. Stem succulent shrubs (*e.g. Euphorbia dregeana* and *Tylecodon reticulatus*) are uncommon while perennial grasses (*e.g. Chaetobromus involucratus* and *Ehrharta calycina*) are relatively rare in the landscape.

Table 4.5. The mean % cover per relevé for each growth form under the different management strategies. Significant differences between communal areas and privately owned land for uplands and lowlands were compared using the Mann-Whitney U test at 95% confidence level. Where there is no p-value in the table the sample number was too low to subject it to statistical analysis.

	Uplands			Lowlands		
	Communal areas	Privately owned land	*p* value	Communal areas	Privately owned land	*p* value
Evergreen shrubs	6.06 ± 3.30	11.12 ± 5.53	0.59	8.53 ± 8.04	4.06 ± 10.42	0.26
Deciduous shrubs	3.75 ± 2.74	6.26 ± 4.61	0.24	3.34 ± 2.01	5.29 ± 5.06	0.84
Leaf succulent shrubs	9.78 ± 3.11	6.16 ± 3.26	0.59	6.11 ± 5.86	4.93 ± 4.71	0.54
Stem succulent shrubs	3.94 ± 4.42	1.79 ± 2.24	-	1.56 ± 2.34	1.90 ± 1.61	0.66
Perennial grasses	0.67 ± 0.03	0.45 ± 0.64	-	0.08 ± 0.16	0.16 ± 0.06	0.67

4.5 Discussion

Results of an ecological study of this nature are strongly influenced by the sampling design and historical land use practices (Mueller-Dombois and Ellenberg 1974; Kent and Coker 1992; Cowling and Hilton-Taylor 1997). Therefore, the location of relevés relative to stockposts, waterpoints and the village could potentially influence the outcome of the study. Other studies have shown that species diversity and composition are changed along a disturbance gradient away from a resource point (Tolsma *et al.* 1987; van Rooyen *et al.* 1994; Shackleton *et al.* 1994; Moleele and Perkins 1998; Thrash and Derry 1999; van Rooyen 2000; Landsberg *et al.* 2002; Riginos and Hoffman 2003; Hendricks *et al.* 2004).

The relevés used in this analysis, while selected randomly (see chapter three), were generally located far from the village, stockposts or waterpoints, thus suggesting that the grazing intensity was lower than sites closer to the village, stockposts or waterpoints. Nonetheless, the results showed that there were some important differences between the responses of uplands and lowlands vegetation to the different management systems in communal areas and privately owned land.

There was a positive correlation between altitude and landfacet in the study. The flats and the footslopes occurred at a lower altitude compared to midslopes, upper slopes and crests that occurred at a higher altitude. The total percentage rock cover of the flats and footslopes was lower than the midslopes, upperslopes and crests, which had a higher total percentage rock cover. This result was supported by the TWINSPAN and CCA ordination analyses. However, the vegetation of the uplands and lowlands in the communal areas was not as clearly differentiated as in the privately owned land.

The environmental gradient that influences vegetation distribution in this study is land facet, which is directly correlated with total percentage rock cover. Studies have shown that along a land facet gradient from lowlands to uplands there is an increase in resources available to plants (Austin and Smith 1989; Palmer and Cowling 1994; Rietkerk and van de Koppel 1997; Pugnaire and Luque 2001). The increase in resources is due to the amount of moisture (being trapped by the total rock cover) and soil nutrients (as a result of litter or faecal pellets being trapped). This is consistent with other studies that have demonstrated that arid environments generally have a higher diversity on rockier upper slopes than on the lowlands (Whittaker *et al.* 1983; Cowling *et al.* 1994; Burke 2002) and generally have lower growth form diversity (Milton 1990; Cowling *et al.* 1994; Desmet and Cowling 1999b; Hendricks *et al.* 2004). Furthermore, this opinion is supported by Ter Braak (1987) who has indicated that generally plants are most abundant around their particular environmental optimum. However, under heavy grazing, this natural distribution along an environmental gradient can be disturbed, resulting in species occurring outside of the predicted position along this gradient (Brown 1994; Birch *et al.* 1999). This could explain the results obtained for the species richness in this study. Species richness results have shown no significant difference between uplands and lowlands communal land. Concomitantly, a significant difference was obtained between uplands and lowlands privately owned land.

Results from this study displayed minor and generally insignificant differences between uplands and lowlands vegetation from communal areas and privately owned land in terms of their diversity, measured as the number of species, similarity and evenness. The mean number of species per relevé appears not to be a good measure of the impact of disturbance (*e.g.* grazing) (Magurran 1988). The number of species does not necessarily decline under heavy grazing when compared to lighter grazing intensity (Milton 1994b; Todd and Hoffman 1999; Callaway *et al.* 2000). A study by Rusch and Osterheld (1997) found that species richness increased even if the increase was due to an increase in unpalatable species. This study was consistent with that of Prolux and Mazumder (1998) who completed a review on the impact of grazing on species richness in nutrient rich and nutrient poor environments. They showed that there is no change in species richness under high grazing in nutrient rich environments and that species richness might even increase under heavy grazing. However, species richness under heavy grazing in nutrient poor environments was unchanged or decreased due to the lack of essential resources. In another study of the impact of grazing in Paulshoek, Todd and Hoffman (1999) have similarly observed that there was no significant difference in the mean number of species per relevé, although the evenness and especially the species composition had changed. There is a general understanding that disturbance is necessary to maintain diversity in species communities (Connell 1978) and that areas of intermediate disturbance often have the highest diversity (Whittaker 1980; Noy-Meir *et al.* 1989).

The similarity values between uplands and lowlands vegetation were generally low but are consistent with values of less than 30% that have been obtained for the succulent karoo biome (Cowling *et al.* 1989). The similarity matrix also *showed that there was a low similarity (<15%)* between uplands and lowlands vegetation when compared with each other for both communal areas and privately owned land. However, when the uplands were compared to uplands or lowlands to lowlands for both the communal areas and privately owned land the similarity was higher (>21%). However, the similarity was still much lower than expected. It was expected that when relevés from the uplands in the communal areas were compared with each other, they would have greater similarity than when compared with relevés from the privately owned land. This was, however not the case. It was also expected that relevés from the lowlands would have a greater similarity value when compared to each other, specifically the communal lowlands that was subjected to a higher grazing intensity than the privately owned lowlands (Combrink 2003). Again this was not the case. Extensive grazing results in the dominance of only a few species as was indicated by the diversity/dominance curves of this study. This study showed that the lowlands under communal grazing were only dominated by five species (Figure 4.5). Other studies showed similar results with only a few species dominating under heavy grazing (Hoare 1997; Todd and Hoffman 1999; Riginos and Hoffman 2003; Hendricks *et. al.* 2004). However, these results showed less similarity when the relevés of the lowlands of the privately owned land were compared to each other (20%).

The similarity results are inconsistent with the CCA results, which showed an overlap between communal uplands and lowlands relevés, contrary to the privately owned uplands and lowlands relevés. It can thus be concluded that although vegetation on uplands and lowlands for both communal areas and privately owned land is subjected to a range of grazing intensities, plant species are still present at their environmental resource optimum, albeit at a low percentage cover (Birch *et al.* 1999).

Heavy grazing usually results in a shift in species composition with a decrease in palatable plant species and an increase in less palatable plant species (Milton 1994b; Steinschen *et al.* 1996, Evans *et al.* 1997; Watson *et al.* 1997; Todd and Hoffman 1999; Hendricks *et al.* 2004). This study did not support this view; it showed no difference in palatable species between uplands and lowlands of communal areas and privately owned land. Result of the species abundances (Figure 4.4) showed that the first 10 species, which are different in each community, dominated in abundance. However, thereafter there is a tapering off of species abundances in the rest of the species. It is for this reason that the results in Figure 4.4 were further explored. Figure 4.5 displays the results of the 10 dominant species. The dominant five species corresponded to those displayed in Table 4.1. Table 4.1 shows the five indicator plant species that were common in both uplands and lowlands in the communal areas and privately owned lands. There is, however, a difference in the total cover and the frequency of the five species that dominate the different communities. Overall, the uplands vegetation in the communal areas have similar plant species to the uplands in the privately owned land (Table 4.1). Apart from the four species they have in common (*Eriocephalus ericoides*, *Pelargonium alternans*, *Polymita albiflora* and *Ruschia sp.1*) they differ in one species. The difference is in the species composition of *Lebeckia multiflora* and *Pteronia incana* that grow in the uplands of the communal areas and privately owned land respectively. *Lebeckia multiflora*, a palatable shrub (mainly the new growth, flowers and pods are eaten) is present in the communal areas, whereas in the privately owned uplands *Pteronia incana*, a palatable to unpalatable shrub, dominates. Thus, although the total number of palatable species was similar, the difference was in the identity of the species and not the palatability status. Similar results were obtained for the lowlands of the communal areas and privately owned land, which had three indicator plant species in common (*Crassula subaphylla*, *Galenia africana* and *Ruschia robusta*). *Pentzia lanata* was present in the lowlands of the communal area whereas *Eriocephalus ericoides* was present in the lowlands of privately owned land. Both these species are palatable. Furthermore, instead of *Leipoldtia schultzei* that was dominant on the privately owned land, *Asparagus capensis* dominated the lowlands of the communal area. Both these plants are unpalatable. Thus it can be concluded that there was little to no difference in the number of palatable and unpalatable plant species between privately owned and communally managed areas.

Evenness analysis showed that there were low evenness values for the communal and privately owned uplands and lowlands. The species evenness, results revealed that the proportional cover was more evenly distributed amongst species in the privately owned than communally managed area. Evenness values for the privately owned uplands were significantly higher than for the privately owned lowlands and for the communal area lowlands and uplands. It was expected that the evenness would be higher on privately owned land when compared to communal land. This could be as a result of the high species turnover of leaf and stem succulent species and growth forms, which indicates a high level of specialisation in habitat (Jurgen *et al.* 1999; Riginos and Hoffman 2003; Hendricks *et al.* 2004). Literature has shown that under heavy disturbance (*e.g.* grazing) there is a decrease in the evenness. Wilson and Potvin (2000) have argued that a decrease in evenness results in a decrease in biodiversity, irrespective of what the dominant species are (Li and Reynolds 1995; Tilman 1997; Wilsey and Potvin 2000; Hoare 2002). Furthermore, Wilsey and Potvin (2000) have shown that not only is there a decline in biodiversity but also ecosystem processes decline as a result of a decrease in evenness.

The evenness results were further explored by the dominance/diversity curves. Generally there was higher dominance in the lowlands communities than the uplands communities. In both the communal and privately owned lowlands three species dominated the vegetation. The uplands for both the communal and privately owned land, however, demonstrated a more even distribution in the cover of the 10 most abundant species. Generally the dominance results are not consistent with those of other studies (Noy-Meir *et al.* 1989; Hoare 1997; Hoare 2002) that have demonstrated an increase in the dominance of unpalatable species under heavy grazing. Hoare (2002) has argued that heavy grazing results in the dominance of only a few species, which are generally unpalatable. Vegetation is dominated by unpalatable species as a result of livestock grazing selectively on palatable species, which in turn allows a few unpalatable species to dominate. However, the species dominance results of this study indicate that fewer palatable species are contributing to the proportional cover in the communal areas when compared to privately owned land. This is consistent with studies that have illustrated that unpalatable species are able to survive under heavy grazing (Noy-Meir 1989; Cunliffe *et al.* 1990; Oakwood *et al.* 1993; Milton 1994b; Hoare 1997; Westoby 1998; Jurgens *et al.* 1999). Under heavy grazing conditions the vegetation shifts from a high evenness (heterogeneity) landscape to a low evenness one (Tilman 1997; James *et al.* 1999; Wilsey and Potvin 2000; Hoare 2002).

The succulent karoo biome is rich in stem and leaf succulents (Esler and Rundel 1997; Evans *et al.* 1997; Cowling and Hilton-Taylor 1999; Hendricks *et al.* 2004). Many studies have demonstrated that these growth forms are the ones most negatively affected by heavy grazing (Vetter 1996; Todd and Hoffman 1999; Riginos and Hoffman 2003; Hendricks *et al.* 2004). However, in this study no significant differences were observed between stem and leaf succulents in the communal lowlands which is inconsistent with other studies that have found changes in the abundance of these growth forms as a result of heavy continuous grazing. Several studies have also reported a change from leaf succulents to woody perennials under heavy grazing pressure in Paulshoek (Todd and Hoffman 1999; Riginos and Hoffman 2003) and others who have worked in the succulent karoo biome at large (Milton and Dean 1995; Hendricks *et al.* 2004). However, the results from this study were inconsistent with these findings. The growth form composition of the uplands communities appears not to have been affected as much by the different management strategies as were the lowlands.

Generally the communal grazing system is one of heavy continuous grazing which has an impact on diversity, plant composition and structure particularly around resource points (*e.g.* stockposts, waterpoints). However, there are areas in the communal grazing system that are less impacted by grazing. These are the areas that are far from stockposts, waterpoints and the village. This study makes a clear separation between uplands and lowlands communities in that uplands communities generally have a higher nutrient status. Petersen (2003) has shown the amount of nutrient recycling, infiltration rates and soil stability levels are higher in high altitude vegetation communities than in lower altitude communities. Thus, these communities are able to resist the impact of grazing and also recover sooner from the impact than lowlands communities. Lowlands communities are consistently subjected to heavy grazing. Coupled with the low nutrient status, they are less able to withstand heavy grazing and recover less easily from the impact. Uplands vegetation also showed no marked differences in diversity when the different management strategies were compared. This is consistent with other studies in the succulent karoo biome (Milton and Dean 1995; Todd and Hoffman 1999; Cowling *et al.* 1999; Hendricks *et al.* 2004). However, no differences in the number of species in the communal lowlands were shown. This casts doubt on whether species diversity on its own can be used as an assessment of the impact of grazing in the succulent karoo biome.

Chapter 5. Thesis summary and conclusions

The first section of the thesis focuses on the succulent karoo biome that is renowned for its high levels of diversity and endemism. It has approximately 5000 plant species, and is considered the most diverse semi-arid environment anywhere in the world. Compared to the Sonoran desert in North America that has 2240 plant species in an area an order of magnitude large than the succulent karoo biome, and the Sinai desert in the Middle East with 1130 plant species in an area 1.2 times the size of succulent karoo biome, it is indeed rich. More than 50% of the taxa in the biome are endemic. As a result of the high floral diversity and high concentration of endemic taxa, the succulent karoo biome is the only semi-arid region in the world that has been granted the status of a hot spot of global significance. However, this biome has not been as extensively researched as other biomes in southern Africa. Adamson, who undertook the first vegetation study in 1938, described the vegetation of the Kamiesberg. To date six vegetation studies have been completed in this highly diverse and unique flora.

The literature review chapter continues by depicting the biophysical environment of the succulent karoo biome. Special emphasis is placed on the physical environment as this biome has a low (170 mm) but predictable (CV 30 %) rainfall. There is a general increase in rainfall from east to west, with high lying areas receiving higher rainfall than lower lying areas. There is great seasonal variation in temperature, which is characteristic of arid climates in general. The mean annual temperature is 12.9°C. The presence of the cold Benguela current on the west coast brings considerable moisture particularly in the form of coastal fog as a result of the onshore sea breezes.

A general description of the landuse history of the region follows. The succulent karoo biome has been inhabited for thousands of years. The first evidence of humans in the region is estimated at 300 000 years BP. The main activities of the first inhabitants involved hunting, gathering and to a lesser extent fishing. Hunter gatherers were mobile and could take advantage of highly localised conditions. Archaeological studies suggest that although the hunter gathers and later the herders occupied the succulent karoo biome, the use of the resources was in a sustainable manner. European settlement in the region from the mid

18th century disrupted indigenous people lifestyles through direct competition for grazing land, the introduction of mercantile capital, the imposition of new forms of state power and administration, the introduction of smallpox and through land dispossession. As a result many Khoi pastoralists were subjugated and forced into serfdom. At present the descendants of which San and Nama-speaking herders own a small percentage of the land in the biome. The small percentage that is being occupied by indigenous people is being over-utilised through various livelihood activities that include livestock and crop production. Other activities that impact on the biome to a lesser extent include fuelwood and medicinal plant collection. People live in and around small towns or are confined to communal reserves. This chapter concludes by suggesting that the biome is no longer pristine and has been impacted heavily over the last 200 years. It is important to reflect and understand these impacts to interpret the present vegetation patterns and trends, as this seems to be the best manner to strategise for the future.

The third chapter provides a phytosociological description of the vegetation of Paulshoek village – a 20 000 ha communal area in the Leliefontein Reserve, Namaqualand. Using a direct gradient sampling approach 121 relevés were sampled across the landscape with 94 relevés in the communally owned area and 27 relevés on three different adjacent privately owned farms. Only data collected in the communal area (94 relevés) was analysed in this chapter. At the first level of division, TWINSPAN analysis divided the relevés into uplands and lowlands communities. With the second level of division the uplands communities were separated into mid to upper slope and upper slope to crest communities. A similar division was observed for the lowlands where division occurred between flats and footslope communities. Each of these four communities was further divided into sub-communities, some of which appeared transitional from one community to the next. Further division of relevés was not considered meaningful. A Canonical Correspondence Analysis (CCA) demonstrated a clear distinction between the four communities. The analysis also presented a strong correlation of the environmental variables with the communities. Land facet (*i.e.* position in the landscape) and total cover were the significant environmental variables that influenced community distribution throughout the landscape. Similar results were obtained for vegetation communities described at the Goegap Nature Reserve, Namaqualand. This suggests that a more general control of plant distribution in Namaqualand might be exerted by their position in the landscape. This chapter also displays a map of the four communities for the region that was completed through a modelling process using satellite imagery and digital terrain models.

The four communities identified and mapped were: Community 1-*Galenia africana*-low evergreen shrubs on flats found mainly to the south-east and north-east of the village. This community is characterised by low evergreen shrubs less than 50 cm high. Rock cover is low, and the sand to sandy loam soils are shallow and slightly acidic. Phosphorus and magnesium concentrations are highest in this community which is dominated by the 0.2-4 cm rock cover class. Livestock grazing is extensive in this community and as a result it is the most impacted community of all. Community 2-*Ruschia robusta*-low leaf succulent shrubs on footslopes. This community appears to be transitional between the communities found on the flats and those that occur on the midslopes. Floristically, dwarf leaf succulents less than 50 cm high dominate it. Total rock cover is low and the soils are more acidic and less sandy than community 1. Phosphorus and magnesium concentrations are lower than community 1 but the percentage soil organic matter and litter are generally higher than community 1. The levels of livestock disturbance are lower than in community 1. Community 3-*Pteronia glomerata*-low evergreen shrubs on midslopes. Low evergreen shrubs dominate this community. It has a high rock cover, with deep clayey soils that contain a high percentage of soil organic matter and litter. The sodium, calcium and potassium concentrations are generally highest in this community, which is less impacted by livestock grazing due to its relative distance far from waterpoints and the village. Community 4-*Diospyros austro-africana*-tall-evergreen shrubs on upper slopes and crests. This community is dominated by tall evergreen species with mountain fynbos and renosterveld affinities, although low evergreen shrubs are also present. Rock cover is highest in this community with a high percentage of exposed bedrock. The sandy loam soil characteristic of this community is deep and alkaline. Nitrogen, percentage soil organic matter and litter is highest in this community. It is furthest from the village with no permanent waterpoints and hence has not been impacted by livestock to the same degree as the other communities.

Understanding the vegetation distribution and the associated environmental variables has contributed greatly to our understanding of a hotspot of global significance, the Kamiesberg. Furthermore the production of a vegetation map will contribute and assist the Paulshoek community in making sound sustainable development decisions (*e.g.* building of a dam). Thus they will be capable of identifying areas which are vulnerable to disturbances (*e.g.* overgrazing), assisting and driving decisions on areas requiring restoration, rehabilitation and conservation, and informing locals and researchers on which areas should be rested or which sites should be used for long-term monitoring. The map will also assist fellow researchers in the planning of their vegetation or ecological research, especially restoration projects. The vegetation map should be used for predicting the impact of disturbance on species composition and distribution. Furthermore, this map has highlighted areas that are vulnerable to species loss, and could be used in the future for predicting the impact of species loss on plant community structure and function. This vegetation study has moved a baseline study of the vegetation of Paulshoek on which many other projects could be built on. The sites sampled in this study could also be monitored for change in composition, diversity and structure over a long period.

The final chapter investigated the effects of heavy grazing on the vegetation of Paulshoek in relation to the moderately grazed rangelands of the neighbouring privately owned farms. Both lowlands and uplands environments were sampled to test the hypothesis that uplands environments are more buffered against the impact of heavy grazing because of their relative inaccessibility and high levels of moisture, rockiness and nutrients. Data was subjected to diversity analysis (similarity, species richness, evenness and dominance) and growth form analysis.

Evenness analysis displayed low values for the communally managed and privately owned lowlands and uplands communities respectively. The species evenness results revealed that the proportional cover was more evenly distributed amongst species in the private than communally owned areas. Similarity results obtained revealed that values between uplands and lowlands communities were generally low, although consistent with other studies. There was more similarity between relevés of the uplands communally owned communities when compared to the adjacent privately owned communities, than between relevés in uplands communally owned areas. Similar results were obtained for lowlands communally owned areas. The similarity analysis was inconsistent with the CCA results that showed an overlap between communal uplands and lowlands relevés, contrary to the privately owned uplands and lowlands relevés. These results suggest that more similarity exists between communal relevés on lowlands areas and uplands areas, thus suggesting that the landscape has been homogenized. Dominance results showed that there was higher dominance by one or a few species in the lowlands communities than in uplands communities. In both communal and privately owned lowlands three species dominated. Various studies have shown that growth form composition is most negatively affected by heavy grazing. However, results of this study showed that there were no significant differences between growth form abundance under the two management systems.

Community diversity results showed no significant difference when the different management strategies are compared. This could have been as a result of the relevés of the communal land being placed in areas of low grazing intensity relative to the rest of the communal area. Despite this, the study is in line with other studies, which suggests that community diversity is not a good indicator of grazing impact.

This chapter concluded that rock cover does provide refugia to plants subjected to heavy grazing. Furthermore, the lowlands are impacted on more than the uplands. However, this study showed that there were no significant differences between communally owned land and privately owned land in terms of species diversity, vegetation composition and structure. These findings cast doubt as to whether community diversity in the succulent karoo biome may not be the best way to assess vegetation change. More emphasis should be placed on the landscape as a whole, thus including soil, vegetation, climate and disturbances, (*e.g.* heavy grazing) in order to detect and predict changes expressed in the landscape. Future research efforts should, thererfore, be focused on an integrated approach with the soil, vegetation, climate and disturbance taken into account. The potential for exploring which species are increaser species and which are decreaser species could also be explored.

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Appendix 1. Checklist of species collected in Paulshoek during this study.

SPECIES	FAMILY	GROWTH FORM
Aizoon canariense L.	AIZOACEAE	Perennial herb
Albuca glandulosa Bak.	HYACINTHACEAE	Geophyte
Amphiglossa tomentosa (Thunb.) Harv.	ASTERACEAE	Dwarf deciduous shrub
Anacampseros albissima Marloth	PORTULACACEAE	Dwarf stem succulent
Anacampseros alstonii Schoenl.	PORTULACACEAE	Dwarf stem succulent
Anacampseros namaquensis H. Pearson & Stephens	PORTULACACEAE	Dwarf stem succulent
Anacampseros quinaria E. Mey ex Sond.	PORTULACACEAE	Dwarf stem succulent
Anacampseros retusa V. Poelln.	PORTULACACEAE	Dwarf stem succulent
Adromischus filicaulis (Eckl. & Zeyh.) C.A.Sm.	CRASSULACEAE	Dwarf leaf succulent
Antimima compacta (L.Bolus) H.E.K.Hartmann	MESEMBRYANTHEMACEAE	Low leaf succulent
Antimima compressa (L.Bolus) H.E.K.Hartmann	MESEMBRYANTHEMACEAE	Low leaf succulent
Antizoma miersiana Harv.	MENISPERMACEAE	Mid-high evergreen shrubs
Aptosimum indivisum Burch. ex Benth.	SCROPHULARIACEAE	Perennial herb
Aptosimum spinescens (Thunb.) Weber	SCROPHULARIACEAE	Perennial herb
Arctotis cuprea Thunb.	ASTERACEAE	Perennial herb
Arctotis fastuosa Jacq.	ASTERACEAE	Low deciduous shrub
Aridaria noctiflora (L.) Schwant. subsp. noctiflora	MESEMBRYANTHEMACEAE	Low leaf succulent
Aridaria serotina L. Bolus	MESEMBRYANTHEMACEAE	Low leaf succulent
Asparagus capensis (L.) Oberm.	ASPARAGACEAE	Low evergreen shrubs
Asparagus multituberosus R.A. Dyer	ASPARAGACEAE	Dwarf evergreen shrub
Asparagus spinescens Steud. ex Roem. & Schult.	ASPARAGACEAE	Low evergreen shrubs
Atriplex eardleyae Aell.	CHENOPODIACEAE	Perennial herb
Atriplex vestita (Thunb.) Aell.	CHENOPODIACEAE	Mid-high evergreen shrubs
Babiana dregei Bak.	IRIDACEAE	Geophyte
Ballota africana (L.) Benth.	LAMIACEAE	Low deciduous shrub
Bartholina etheliae H.Bol.	ORCHIDACEAE	Geophyte
Berkheya fruticosa (L.) Ehrh.	ASTERACEAE	Low deciduous shrub
Berkheya spinosissima (Thunb.) Willd.	ASTERACEAE	Low deciduous shrub
Bromus catharticus Vahl	POACEAE	Perennial grass
Bulbine abyssinica A.Rich.	ASPHODELACEAE	Geophyte
Bulbine hallii Williamson	ASPHODELACEAE	Geophyte
Bulbine sedifolia Schltr. ex V. Poelln.	ASPHODELACEAE	Geophyte
Bulbinella ciliolata Kunth	ASPHODELACEAE	Geophyte
Carpobrotus edulis (L.) L. Bolus	MESEMBRYANTHEMACEAE	Dwarf leaf succulent
Cephalophyllum ebracteatum (Pax ex Schltr.& Diels) Dinter & Schwantes	MESEMBRYANTHEMACEAE	Dwarf leaf succulent
Cephalophyllum rigidum L. Bol.	MESEMBRYANTHEMACEAE	Dwarf leaf succulent
Chaetobromus involucratus (Shrad.) Nees	POACEAE	Perennial grass
Cheiridopsis cigarettifera (Berger) N.E.Br.	MESEMBRYANTHEMACEAE	Dwarf leaf succulent
Cheiridopsis denticulata (Haw.) N.E.Br.	MESEMBRYANTHEMACEAE	Dwarf leaf succulent
Cheiridopsis derenbergiana Schwant.	MESEMBRYANTHEMACEAE	Dwarf leaf succulent
Cheiridopsis imitans L.Bol.	MESEMBRYANTHEMACEAE	Dwarf leaf succulent
Cheiridopsis paucifolia L.Bol.	MESEMBRYANTHEMACEAE	Dwarf leaf succulent
Cheiridopsis robusta (Haw.) N.E.Br.	MESEMBRYANTHEMACEAE	Dwarf leaf succulent
Cheiridopsis schlechteri Tischer	MESEMBRYANTHEMACEAE	Dwarf leaf succulent
Chrysocoma ciliata L.	ASTERACEAE	Dwarf deciduous shrub

Cleretum papulosum (L.f) L.Bolus subsp.papulosum	MESEMBRYANTHEMACEAE	Low leaf succulent
Conicosia elongata (Haw.) N.E.Br	MESEMBRYANTHEMACEAE	Dwarf leaf succulent
Conophytum calculus(A.Berger) N.E.Br. subsp vanzylii (Lavis) S.A. Hammer	MESEMBRYANTHEMACEAE	Dwarf leaf succulent
Cotula barbata DC.	ASTERACEAE	Annual
Cotyledon orbiculata L. var. orbiculata	CRASSULACEAE	Low leaf succulent
Crassula atropurpurea (Haw.) Dietr. var. watermeyeri	CRASSULACEAE	Dwarf leaf succulent
Crassula brevifolia Harv.subspecies brevifolia	CRASSULACEAE	Dwarf leaf succulent
Crassula capitella Thunb. subsp. thyrsiflora (Thunb.) Tölken	CRASSULACEAE	Perennial herb
Crassula columnaris Thunb. subsp. prolifera Friedr.	CRASSULACEAE	Perennial herb
Crassula corallina Thunb.var. macrorrhiza Tolken	CRASSULACEAE	Perennial herb
Crassula cotyledonis Thunb.	CRASSULACEAE	Dwarf leaf succulent
Crassula hemisphaerica Thunb.	CRASSULACEAE	Perennial herb
Crassula muscosa L.var.muscosa	CRASSULACEAE	Low evergreen shrubs
Crassula muscosa L.var.obtusifolia (Harv.) Rowley	CRASSULACEAE	Dwarf evergreen shrub
Crassula pseudohemisphaerica Friedrich	CRASSULACEAE	Perennial herb
Crassula subaphylla (Eckl. & Zeyh.) Harv.	CRASSULACEAE	Perennial herb
Crassula tetragona L.	CRASSULACEAE	Dwarf leaf succulent
Crassula thunbergiana Schult.	CRASSULACEAE	Annual
Cyanella lutea L.f.	TECOPHILACEAE	Geophyte
Cyphia schlechteri Phill.	LOBELIACEAE	Perennial herb
Diascia namaquensis Hiern	SCROPHULARIACEAE	Annual
Didelta spinosa (L.f.) Ai'ton	ASTERACEAE	Low deciduous shrub
Diosma acmaeophylla Eckl. & Zeyh.	RUTACEAE	Mid-high evergreen shrubs
Diospyros austro-africana De Winter var. austro-africana	EBENACEAE	Tall evergreen shrub
Drosanthemum breve L.Bolus	MESEMBRYANTHEMACEAE	Low leaf succulent
Drosanthemum eburneum L.Bolus	MESEMBRYANTHEMACEAE	Low leaf succulent
Drosanthemum hispidum (L.) Schwant.	MESEMBRYANTHEMACEAE	Low leaf succulent
Drosanthemum floribundum (Haw.) Schwant.	MESEMBRYANTHEMACEAE	Low leaf succulent
Drosanthemum otzenianum (Dinter) Friedrich	MESEMBRYANTHEMACEAE	Low leaf succulent
Ehrharta barbinodis Nees ex Trin	POACEAE	Perennial grass
Ehrharta calycina J.E.Sm	POACEAE	Perennial grass
Ehrharta melicoides Thunb.	POACEAE	Perennial grass
Dicerothamus rhinocerotis (L.f.)	ASTERACEAE	Mid-high evergreen shrubs
Eriocephalus africanus L. var africanus	ASTERACEAE	Low evergreen shrubs
Eriocephalus brevifolius (DC.) M.A.N.Müll.	ASTERACEAE	Low evergreen shrubs
Eriocephalus ericoides (L.f.) Druce	ASTERACEAE	Dwarf evergreen shrub
Eriocephalus giessii M.A.N.Müll.	ASTERACEAE	Dwarf evergreen shrub
Eriocephalus microcephalus DC.	ASTERACEAE	Low evergreen shrubs
Eriocephalus microphyllus DC. var microphylla	ASTERACEAE	Low evergreen shrubs
Eriocephalus pauperrimus Merxm. & Eberle	ASTERACEAE	Dwarf evergreen shrub
Eriocephalus purpureus Burch.	ASTERACEAE	Dwarf evergreen shrub
Eriospermum paradoxum (Jacq.) Ker-Gawl.	ERIOSPERMACEAE	Geophyte
Erodium cicutarium (L.) L'Herit.	GERANIACEAE	Perennial herb
Erodium moschatum (L.) L'Herit.	GERANIACEAE	Perennial herb
Euphorbia decussata E. Mey. ex Boiss.	EUPHORBIACEAE	Mid-high leaf succulent
Euphorbia dregeana E.Mey. ex Boiss.	EUPHORBIACEAE	Low stem succulent
Euphorbia mauritanica L.	EUPHORBIACEAE	Low stem succulent
Euphorbia multiceps Beiger	EUPHORBIACEAE	Dwarf stem succulent
Euryops dregeans Sch. Bip.	ASTERACEAE	Low evergreen shrub

Euryops lateriflorus (L.f.) DC.	ASTERACEAE	Mid-high deciduous shrub
Euryops multifidus (Thunb.) DC.	ASTERACEAE	Low deciduous shrub
Euryops tenuissimus (L.) DC.subsp.tenuissimus	ASTERACEAE	Low evergreen shrub
Felicia brevifolia DC.	ASTERACEAE	Perennial herb
Felicia deserti Schltr. ex Grau	ASTERACEAE	Perennial herb
Felicia dregei DC.	ASTERACEAE	Perennial herb
Felicia filiformis (Vent.) Burtt Davy	ASTERACEAE	Dwarf deciduous shrub
Felicia macrorrhiza (Thunb.) DC.	ASTERACEAE	Dwarf deciduous shrub
Felicia merxmuelleri Grau	ASTERACEAE	Perennial herb
Felicia tenella (L.) Nees var. tenella	ASTERACEAE	Annual
Ferraria divaricata Sweet	IRIDACEAE	Geophyte
Foveolina albida (DC.) Källersjö	ASTERACEAE	Annual
Galenia affinis Sond.	AIZOACEAE	Perennial herb
Galenia africana L. var. africana	AIZOACEAE	Low evergreen shrubs
Galenia africana L. var. pentandra Hiern.	AIZOACEAE	Low evergreen shrubs
Galenia crystallina (Eckl.& Zeyh.) Fenzl.var. crystallina	AIZOACEAE	Perennial herb
Galenia filiformis (Thunb.) N.E. Br.	AIZOACEAE	Perennial herb
Galenia sarcophylla Fenzl.	AIZOACEAE	Perennial herb
Gazania heterochaeta DC.	ASTERACEAE	Annual
Gazania tenuifolia Less.	ASTERACEAE	Annual
Gladiolus scullyi Baker	IRIDACEAE	Geophyte
Grielum humifusum Thunb.	NEURADACEAE	Perennial herb
Hallianthus planus (L.Bol.) H.E.K. Hartm.	MESEMBRYANTHEMACEAE	Low leaf succulent
Haworthia arachnoidea (L.) Duval	ASPHODELACEAE	Dwarf stem succulent
Helichrysum asperum (Thunb.) Hillard & Butt	ASTERACEAE	Annual
Helichrysum cylindriflorum (L.) Hillard	ASTERACEAE	Perennial herb
Helichrysum leontonyx DC.	ASTERACEAE	Annual
Helichrysum revolutum (Thunb.) Less.	ASTERACEAE	Annual
Helichrysum zeyheri Less.	ASTERACEAE	Dwarf evergreen shrub
Heliophila crithmifolia Sond	BRASSICACEAE	Annual
Heliophila seselifolia Burch.ex DC	BRASSICACEAE	Annual
Heliophila variabilis Burch. ex DC.	BRASSICACEAE	Annual
Hermannia cuneifolia var glabrescens	STERCULIACEAE	Dwarf evergreen shrub
Hermannia amoena Dinter ex M. Holzhammer	STERCULIACEAE	Low evergreen shrubs
Hermannia cuneifolia var cuneifolia	STERCULIACEAE	Dwarf evergreen shrub
Hirpicium alienatum (Thunb.) Druce	ASTERACEAE	Low evergreen shrubs
Homeria bifida L. Bol.	IRIDACEAE	Geophyte
Hyobanche sanguinea L.	SCROPHULARACEAE	Annual
Hypertelis salsoloides (Burch.) Adamson var. salsoloides	AIZOACEAE	Perennial herb
Ihlenfeldtia excavata (L.Bolus) H.E.K.Hartmann	MESEMBRYANTHEMACEAE	Low leaf succulent
Indigofera heterophylla Thunb.	FABACEAE	Dwarf deciduous shrub
Lachenalia carnosa Bak.	HYACINTHACEAE	Geophyte
Lachenalia inconspicua G.D.Duncan	HYACINTHACEAE	Geophyte
Lachenalia mutabilis Sweet	HYACINTHACEAE	Geophyte
Lampranthus watermeyeri (L. Bol.) N.E. Br.	MESEMBRYANTHEMACEAE	Low leaf succulent
Lampranthus godmaniae (L.Bolus) L.Bolus	MESEMBRYANTHEMACEAE	Low leaf succulent
Lasiopogon micropoides DC.	ASTERACEAE	Annual
Lavrania cactiformis (Hook.) Bruyns	ASCLEPIADACEAE	Dwarf stem succulent
Lebeckia multiflora E.Mey.	FABACEAE	Mid-high deciduous shrub

Leipoldtia compacta L. Bol.	MESEMBRYANTHEMACEAE	Low leaf succulent
Leipoldtia schultzei (Schltr. & Diels) Friedr.	MESEMBRYANTHEMACEAE	Low leaf succulent
Lepidium africanum (Burm. f.) DC.	BRASSICACEAE	Annual
Lepidium desertorum Eckl. & Zeyh.	BRASSICACEAE	Annual
Lessertia capitata E. Mey.	FABACEAE	Perennial herb
Lessertia diffusa R.Br.	FABACEAE	Annual
Lessertia excisa DC.	FABACEAE	Perennial herb
Leysera tenella DC.	ASTERACEAE	Perennial herb
Lycium cinereum Thunb. (Sens. Lat.)	SOLANACEAE	Mid-high deciduous shrubs
Lycium ferocissimum Miers	SOLANACEAE	Low deciduous shrubs
Malephora crocea (Jacq.)Schwantes var.purpurea-crocea (Haw.)	MESEMBRYANTHEMACEAE	Dwarf leaf succulent
Manochlamys albicans (Ait.) Aell.	CHENOPODIACEAE	Low evergreen shrubs
Massonia depressa Houtt.	HYACINTHACEAE	Geophyte
Melolobium exudans Harv.	FABACEAE	Dwarf deciduous shrub
Microloma sagittatum (L.) R. Br.	ASCLEPIADACEAE	Perennial herb
Moquinella rubra (Sprengl.) Balle	LORANTHACEAE	Mid-high evergreen shrubs
Moraea falcifolia Klatt	IRIDACEAE	Geophyte
Moraea serpentina Bak.	IRIDACEAE	Geophyte
Nenax cinerea (Thunb.) Puff	RUBIACEAE	Low evergreen shrubs
Nicotiana glauca Graham	SOLANACEAE	Tall evergreen shrub
Nylandtia spinosa (L.) Dumort.var spinosa	POLAGALACEAE	Mid-high deciduous shrubs
Oedera genistifolia L. Anderb. & Bremer	ASTERACEAE	Dwarf evergreen shrub
Oedera sedifolia (DC.) Anderb. & Bremer	ASTERACEAE	Dwarf evergreen shrub
Oncosiphon suffruticosum (L.) Kallersjo	ASTERACEAE	Annual
Ornithogalum multifolium Bak.	HYACINTHACEAE	Geophyte
Omithogalum pruinosum Leighton	HYACINTHACEAE	Geophyte
Ornithogalum secundum Jacq.	HYACINTHACEAE	Geophyte
Omithoglossum viride (L.f.) Ait.	HYACINTHACEAE	Geophyte
Ornithoglossum vulgare B. Nord.	COLCHICACEAE	Geophyte
Osteospermum glandiflorum DC.	ASTERACEAE	Low deciduous shrub
Osteospermum rigidum (Ait.) T.Norl.	ASTERACEAE	Low deciduous shrub
Othonna cylindrica (Lam.) DC.	ASTERACEAE	Dwarf leaf succulent
Othonna floribunda Schtr. P.B.	ASTERACEAE	Dwarf deciduous shrub
Othonna quercifolia DC.	ASTERACEAE	Dwarf deciduous shrub
Othonna retrofracta Less.	ASTERACEAE	Dwarf evergreen shrub
Oxalis foveolata Turcz.	OXALIDACEAE	Perennial herb
Oxalis obtusa Jacq.	OXALIDACEAE	Annual
Passerina glomerata Thunb.	THYMELAECEAE	Mid-high evergreen shrubs
Pelargonium alternans J.C.Wendl.	GERANIACEAE	Dwarf deciduous shrub
Pelargonium camosum (L.) L'Herit.	GERANIACEAE	Dwarf deciduous shrub
Pelargonium crithmifolium L'Herit	GERANIACEAE	Dwarf deciduous shrub
Pelargonium incrassatum (Andr.) Sims	GERANIACEAE	Dwarf deciduous shrub
Pelargonium karooicum Compton & P.E.Barnes	GERANIACEAE	Low deciduous shrub
Pelargonium pulchellum Sims FP	GERANIACEAE	Low deciduous shrub
Pentzia incana (Thunb.) Kuntze	ASTERACEAE	Low evergreen shrubs
Pharnaceum albens L. f.	AIZOACEAE	Perennial herb
Pharnaceum incanum L.	AIZOACEAE	Perennial herb
Pharnaceum lanatum Bartl.	AIZOACEAE	Perennial herb
Phamaeum confertum (DC.)Eckl.& Zeyh.	AIZOACEAE	Perennial herb

Piaranthus punctatus (Mass.) R. Br.	ASCLEPIADACEAE	Dwarf stem succulent
Plantago cafra Decne.	PLANTAGINACEAE	Annual
Polymita albiflora (L. Bol.) L. Bol.	MESEMBRYANTHEMACEAE	Low leaf succulent
Pteronia fastigiata Thunb.	ASTERACEAE	Dwarf evergreen shrub
Pteronia glauca Thunb.	ASTERACEAE	Dwarf evergreen shrub
Pteronia glomerata Linn.f.	ASTERACEAE	Dwarf evergreen shrub
Pteronia incana (Burm.) DC.	ASTERACEAE	Dwarf evergreen shrub
Pteronia mucronata DC.	ASTERACEAE	Dwarf evergreen shrub
Pteronia pallens L.f.	ASTERACEAE	Low evergreen shrubs
Pterothrix cymbifolia Harv.	ASTERACEAE	Dwarf deciduous shrub
Quaqua incarnata (L.f.) Bruyns	ASCLEPIADACEAE	Dwarf stem succulent
Quaqua mammillaris (L.) Bruyns FP	ASCLEPIADACEAE	Dwarf stem succulent
Rhus undulata Jacq.	ANACARDIACEAE	Mid-high evergreen shrubs
Rhynchopsidium pumilum (L. f.) DC.	ASTERACEAE	Annual
Ruschia aggregata L.Bolus	MESEMBRYANTHEMACEAE	Low leaf succulent
Ruschia brakdamensis (L. Bol.) L. Bol.	MESEMBRYANTHEMACEAE	Low leaf succulent
Ruschia cradockensis L. Bol. (D.Kuntze) H.E. Hartman	MESEMBRYANTHEMACEAE	Dwarf leaf succulent
Ruschia grisea (L.Bolus) Schwantes	MESEMBRYANTHEMACEAE	Dwarf leaf succulent
Ruschia lerouxiae(L.Bol.) L.Bolus	MESEMBRYANTHEMACEAE	Low leaf succulent
Ruschia leucosperma L.Bolus	MESEMBRYANTHEMACEAE	Low leaf succulent
Ruschia lisabeliae L.Bol.	MESEMBRYANTHEMACEAE	Low leaf succulent
Ruschia robusta L.Bol.	MESEMBRYANTHEMACEAE	Low leaf succulent
Ruschia viridifolia L.Bolus	MESEMBRYANTHEMACEAE	Low leaf succulent
Salsola zeyheri (Moq.) Bunge	CHENOPODIACEAE	Dwarf deciduous shrub
Salvia dentata Ait.	LAMIACEAE	Mid-high evergreen shrubs
Sarcocaulon salmoniflorum Moffett	GERANIACEAE	Low deciduous shrubs
Schismus barbatus (Loefl.ex L.) Thell	POACEAE	Perennial grass
Sceletium exalatum Gerbault	MESEMBRYANTHEMACEAE	Dwarf leaf succulent
Selago albida Choisy	SELAGINACEAE	Low evergreen shrubs
Selago glutinosa E.Mey.	SELAGINACEAE	Low evergreen shrubs
Senecio abruptus Thunb.	ASTERACEAE	Perennial herb
Senecio cakilefolius DC.	ASTERACEAE	Annual
Senecio cardaminifolius DC.	ASTERACEAE	Annual
Senecio cinerascens Ait.	ASTERACEAE	Perennial herb
Senecio corymbiferus DC.	ASTERACEAE	Dwarf leaf succulent
Senecio niveus (Thunb.) Willd.	ASTERACEAE	Perennial herb
Senecio parvifolius DC.	ASTERACEAE	Perennial herb
Spiloxene ovata (L.f.) Garside	HYPOXIDACEAE	Geophyte
Stachys rugosa Ait.	LAMIACEAE	Mid-high evergreen shrubs
Stoeberia beetzii (Dinter) Dinter & Schwant.	MESEMBRYANTHEMACEAE	Mi-high leaf succulent
Stoeberia frutescens (L.) Van Jaarsv.	MESEMBRYANTHEMACEAE	Mi-high leaf succulent
Sutherlandia frutescens (L.) R. Br.	FABACEAE	Low deciduous shrub
Tetragonia fruticosa L.	AIZOACEAE	Low deciduous shrubs
Tetragonia sarcophylla Fenzl	AIZOACEAE	Dwarf evergreen shrub
Thesium lineatum L. f.	FABACEAE	Low deciduous shrub
Trachyandra falcata (L.) Kunth.	ASPHODELACEAE	Geophyte
Trachyandra flexifolia (L.f.) Kunth	ASPHODELACEAE	Geophyte
Trachyandra revoluta (L.) Kunth.	ASPHODELACEAE	Geophyte
Trachyandra tortilis (Bak.) Oberm.	ASPHODELACEAE	Geophyte

Trichogyne polycnemoides (Fenzl) Anderb.	ASTERACEAE	Annual
Tripteris sinuata (DC.) T. Norl.	ASTERACEAE	Low deciduous shrub
Tylecodon paniculatus (L.f.) Tolken	CRASSULACEAE	Low leaf succulent
Tylecodon reticulatus (L.f.) Toelken	CRASSULACEAE	Low leaf succulent
Tylecodon wallichii (Harv.) E107	CRASSULACEAE	Low leaf succulent
Ursinia nana DC. subsp. nana	ASTERACEAE	Annual
Wahlenbergia annularis A. DC.	CAMPANULACEAE	Annual
Wahlenbergia meyeri A. DC.	CAMPANULACEAE	Annual
Wahlenbergia minuta V. Brehm.	CAMPANULACEAE	Annual
Wahlenbergia schlechteri V.Brehm.	CAMPANULACEAE	Annual
Wiborgia monoptera E. Mey.	FABACEAE	Dwarf evergreen shrub
Zaluzianskya benthamiana Walp.	SCROPHULARIACEAE	Annual
Zaluzianskya peduncularis (Benth.) Walp.	SCROPHULARIACEAE	Annual
Zaluzianskya villosa (Thunb.) F.W.Schmidt	SCROPHULARIACEAE	Annual
Zygophyllum divaricatum Eckl. & Zeyh.	ZYGOPHYLLACEAE	Low deciduous shrub
Zygophyllum meyeri Sond.	ZYGOPHYLLACEAE	Mid-high deciduous shrub
Zygophyllum microphyllum L.f.	ZYGOPHYLLACEAE	Low deciduous shrub
Zygophyllum retrofractum Thunb.	ZYGOPHYLLACEAE	Low leaf succulent

Appendix 2. TWINSPAN analysis of the relevés in Paulshoek. At the first level of division relevés are divided into lowlands and uplands. At the second level of division the lowlands are separated into flats to footslopes and footslopes to mid slopes respectively. The uplands are separated into mid to upper slopes and upper slopes to crests respectively. At the third level of division distinction is made between the different sub-communities.

Relevé number	35	42	18	63	55	119	121	46	48	50	74	108	114	54	58	59	62	67	70	71	118
Plant community	3	4	3	3	3	3	3	1	3	1	3	3	4	3	4	4	3	4	3	4	3
Pteronia laterifolius	.	r	.	.	m	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.
Rhus burchellii	.	.	.	.	.	.	.	.	m	r	.	.	r	.	.	.	.	m	.	.	.
Asteraceae species 1	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.
Atriplex vestita	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.
Aizoaceae species 1	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.
Berkheya fruticosa	.	.	.	m	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Conicosia elongata	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.
Euphorbia drageana	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.
Nylandtia spinosa	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.
Ruschia aggregata	.	.	.	.	.	.	.	.	.	.	.	m	.	.	.	.	.	.	.	.	.
Wahlenbergia species	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.
Eriocephalus africanus	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	+
Elytropappus rhinocero	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Salvia dentata	.	.	.	m	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.
Senecio cinerascens	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Crassula cotyledonis	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Tylecodon paniculatus	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Galeni africa v. penta	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.
Pterothrix species 3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Felicia filifolia	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pharnaceum albens	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Felicia dregei	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ruschia lisabeliae	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Euryops dregeanus	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.
Lycium ferocissimum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Drosanthemum floribund	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Euryop tenuis s. tenui	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Selago glutinosa	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ruschia compressa	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Oedera sedifolia	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Berkheya spinosissima	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	r	.	.
Wiborgia monoptera	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Helichrysum zeyheri	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ruschia leroudi	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Passerina glomerata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Osteospermum rigidum	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Lebeckia multiflora	.	.	.	.	.	.	.	.	r	r	.	.	.	.	.	.	.	1	.	.	.
Antizoma miersiana	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.
Dioema acmaeophylla	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Osteospermum grandiflo	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Eriocephalus brevifoli	.	.	.	.	+	m	m	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Arctotis cuprea	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cephalophyllum rigidum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Lampranthus godmaniae	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	r
Crassula brevifolia	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ruschia brakdamensis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	r	.	.	.
Eriocephalus microceph	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.
Lavrania cactiformis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Crassula tetragona	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.
Asteraceae species 2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Antimima sp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Chaetobromus involucratu	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.
Eriocephalus geissii	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.
Cheiridopsis imitans	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.
Eriocephalus species 11	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Helichrysum revolutum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Diospyros austro-afric	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Lampranthus watermeyer	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ruschia viridifolia	.	a	.	.	m	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.
Polymita albiflora	.	r	.	.	r	.	.	.	.	.	.	.	.	.	1	m	m	r	.	m	.
Pelargonium alternans	.	.	.	.	.	.	.	r	.	.	.	.	.	r	r	r	r	r	r	r	.
Eriocephalus microphyl	.	.	.	r	.	.	.	r	.	.	.	.	r	.	+	+	.	r	.	+	.
Ehrharta barbinodis	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	r	r
Hellanthus planus	.	.	.	r	.	.	.	r	.	.	.	.	.	.	.	m	1	m	m	r	a
Pteronia glomerata	.	.	.	.	.	.	.	r	.	.	.	.	.	m	.	m	1	m	1	m	+
Crassula subaphylla	.	.	.	.	.	.	.	.	r	.	.	r	r	.	r	.	.	.	.	.	.
Tripte sinuati v. sinus	.	r	.	.	.	.	.	.	+	.	r	r	.	.	.	.	r	.	.	.	.
Pelargonium karooicum	.	r	r	.	.	r	r	.	.	.	.	.	.	.	.	+	.	.	m	.	r
Crassula muscosa	.	.	.	.	.	.	.	.	r	.	.	.	.	r	.	.	r	.	.	.	r
Leipoldtia schultzei	.	.	.	.	.	.	.	.	m	.	a	.	.	m	m	.	.	.	.	.	.
Ruschia compacta																					

Appendix 3. TWINSPAN analysis of the vegetation of Paulshoek. It divides the area into uplands and lowlands vegetation at the first level of division. Values are Braun-Blanquet cover-abundance values (Werger, 1973).

Communal	Uplands															Lowlands											
Relevé number	54	69	49	68	8	36	6	7	10	32	33	53	82	67	81	46	9	18	50	55	31	47	48	83	23	26	27
Crassu capite s. thyrs	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.
Ruschia species	.	.	2	4	.	.	.	.	.	.	.	.	.	1	.	.	.	5	.	4	.	.	.	.	.	.	.
Pteronia laterifolius	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	4	.	.	.	.	.	.	.
Drosanthemum sp. 1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	1	.	.	.	.	.	.	.	.
Atriplex vestita	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.
Zygophyllum species	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.
Aizoaceaea	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.
Cheiridopsis cigaretti	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.
Pteronia glauca	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.
Ruschia brakdamensis	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.
Berkheya spinosissima	.	.	.	.	.	.	.	.	.	.	.	.	2	2	.	.	.	.	.	.	.	.	.	.	.	.	.
Arctotis cuprea	.	.	.	1	.	.	1	.	.	.	.	.	1	.	.	.	1	.	.	.	.	.	.	.	.	.	.
Ehrharta barbinodis	.	1	.	.	.	1	.	.	.	.	.	.	.	.	1	.	1	.	.	.	.	.	.	.	.	.	.
Eriocephalus microhyll	.	2	.	5	1	.	3	1	.	3	4	.	.	1	4	1	1	.	.	.	.	.	.	.	.	.	.
Antizoma miersiana	.	.	4	.	.	.	1	.	2	.	1	.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Osteospermum grandiflo	.	.	.	.	.	1	2	.	.	3	1	.	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ruschia viridifolia	.	.	.	.	1	1	1	2	4	1	3	6	.	.	.	.	3	.	.	4	.	.	.	.	.	.	.
Eriocephalus brevifolia	.	.	.	.	.	2	.	1	.	2	.	1	4	.	.	.	.	.	.	2	.	.	.	.	.	.	.
Crassula atropurpurea	.	.	.	.	1	1	.	.	.	.	.	.	.	.	1	.	.	1	.	.	.	.	.	.	.	.	.
Oedera genistifolia	.	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Passerina glomerata	.	.	.	.	4	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pelargonium karooicum	.	.	.	.	1	.	.	.	.	.	2	.	.	.	1	.	.	1	.	.	.	.	.	.	.	.	.
Chaetobromus involucra	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.
Lampranthus watermeyer	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.
Ruschia compressa	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Herman cuneif v. glabr	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Crassula brevifolia	.	.	.	.	.	1	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Diosma acmaeophylla	.	.	.	.	.	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Oedera sedifolia	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pharnaceum albens	.	.	.	1	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Senecio cinerascens	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Wiborgia monoptera	.	.	.	.	.	1	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Galeni africa v. penta	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Felicia filifolia	.	.	.	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pterothrix species -t3	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Salvia dentata	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Helichrysum zeyheri	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ruschia lerouxii	.	.	.	.	1	.	.	1	1	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	1	.
Lebeckia multiflora	.	.	5	.	1	.	5	.	.	.	.	4	2	3	5	.	.	.	1	.	.	.	1	.	.	.	.
Polymita albiflora	.	5	.	.	.	.	1	5	2	2	2	.	.	1	3	.	3	.	.	1	.	.	.	.	.	1	.
Pelargonium alternans	1	1	.	.	1	.	.	1	.	1	.	.	.	1	1	1	1	.	.	.	.	.	.	.	.	.	.
Pteronia glomerata	4	2	.	.	.	.	.	2	.	.	.	.	.	4	.	1	.	.	.	.	.	2	.	.	.	.	.
Crassula tetragona	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

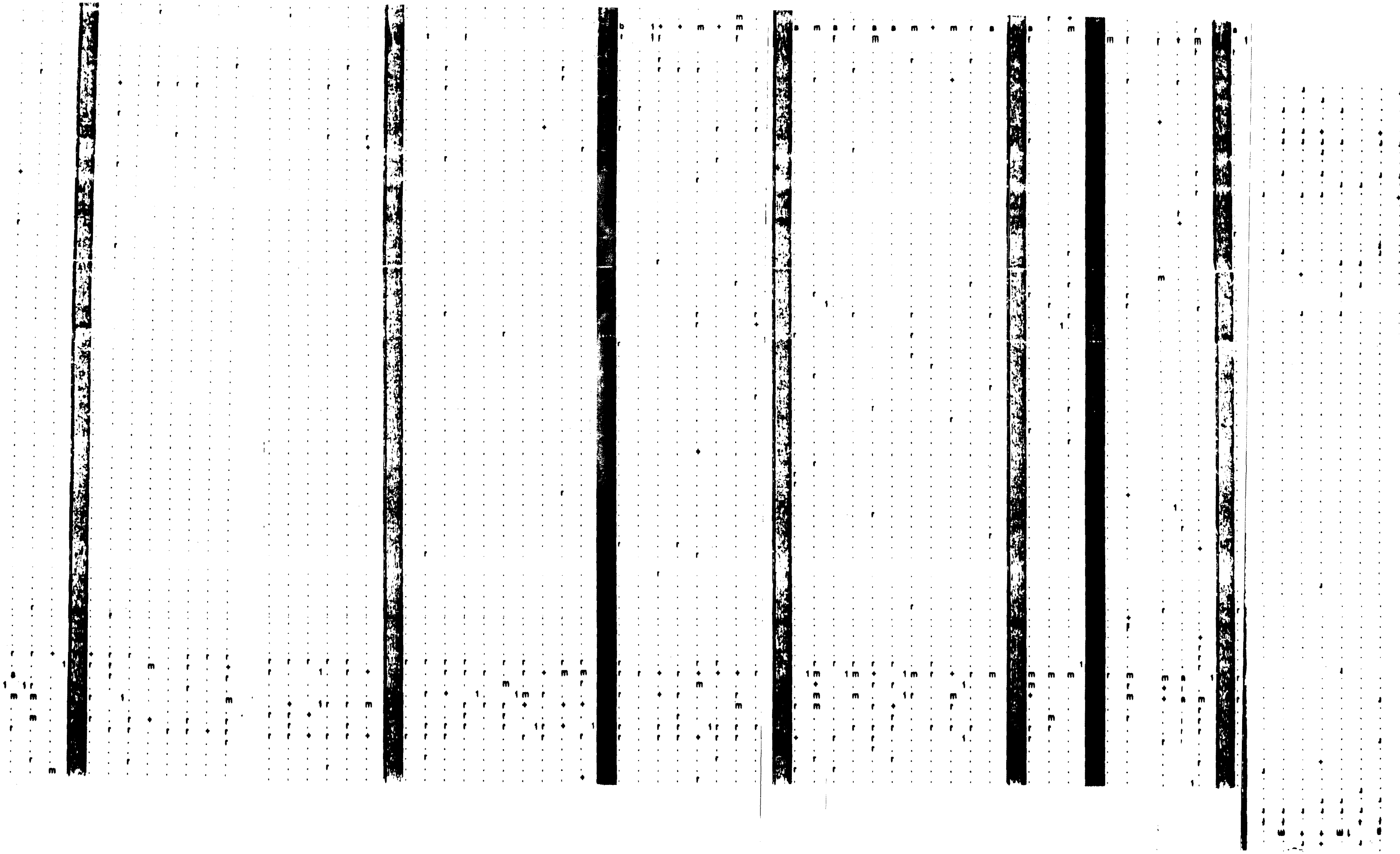
Pteronia fastigiata	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Crassula muscosa	1	.	.	.	.	1	.	.	.	.	1	.	.	.	.	.	1	.	.	.	.	1	1	.	.	.	.
Pterothrix species 2	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1	.	.	.	.	.	.	.	.	2	.	.	.
Galenia affinis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	1	.	.	1	.	.	.	.	.
Leipoldtia sp."salvatory"	.	.	.	.	.	.	.	.	1	1	.	.	.	4	.	1	.	.	.	.	2	4	.	.	.	.	.
Tylecodon wallichii	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	.	.	1	.	.	.	.	.
Rhus burchellii	.	.	.	.	.	.	.	.	.	.	.	.	.	4	.	.	.	.	1	.	.	.	4	.	.	.	.
Ehrharta calycina	.	.	.	.	.	1	.	.	.	.	.	1	.	.	.	1	.	.	1	.	.	.	.	.	.	1	.
Pteronia incana	.	1	.	.	.	1	.	.	4	1	.	.	2	.	.	.	.	.	1	5	.	4	5	.	.	.	.
Hirpicium alienatum	.	.	.	.	.	.	.	.	1	1	.	1	1	1	2	.	1	.	1	.	1	.	.	.	.	1	1
Tetragonia fruticosa	.	.	1	2	.	1	1	1	1	1	1	1	1	1	.	1	1	1	1	.	.	1	1	3	.	.	1
Chrysocoma ciliata	.	.	.	.	1	1	2	1	1	1	1	1	1	1	.	.	1	1	2	1	.	.	.	.	.	2	.
Euphorbia decussata	1	1	4	3	.	.	.	.	2	1	1	.	.	4	4	1	.	1	1	1	1	4	1	4	.	1	1
Pentzia lanata	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	4	.	3	.	2	.	2	2	.	1	.	.
Eriocephalus ericoides	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	1	1	5	2	.	4	4	.	.	1	3
Hermannia amoena	.	.	3	.	.	.	.	.	.	.	1	.	1	2	.	.	.	.	2	.	.	.	1	.	.	1	1
Galeni africa v. africana	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	1	.	.	.	.	.	.	3	2	.
Aridar noctiflora subsp. noctiflora	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Lycium cinereum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	2	.	.
Cheiridopsis schlechte	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1	.
Leipoldtia schultzei	4	1	.	.	.	.	.	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.	4	5	.	.	.
Eriocephalus purpureus	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	.	.	.	.	.
Herman cuneifolia v. cuneifolia	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	1	1
Aizoon canariense	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1
Aptosimum indivisum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
Drosanthemum hispidum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	1
Hypertelis salsoloides	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	1
Brownanthus sp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
Sceletium exalatum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Asparagus capensis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	.	.	1	.	.	1	.	1
Ruschia robusta	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	1	4	1	2	1
Nenax cinerea	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	2	.
Galenia sarcophylla	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	1
Pharnaceum incanum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	1
Tripte sinuatum v. sinuatum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	2	.	.	.	1
Crassula subaphylla	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	1	1	1	1	.	.	.
Helichrysum cylindriflora	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.
Leipoldtia species	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.
Pterothrix species 1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.
Sarcocaulon salmoniflorum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	1	.	.	.
Euryops multifidus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
Ruschia compacta	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	4	.	.	.
Aridaria serotina	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.
Asteraceae species	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.
Pentaschistis species	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.
Stapelia species	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.

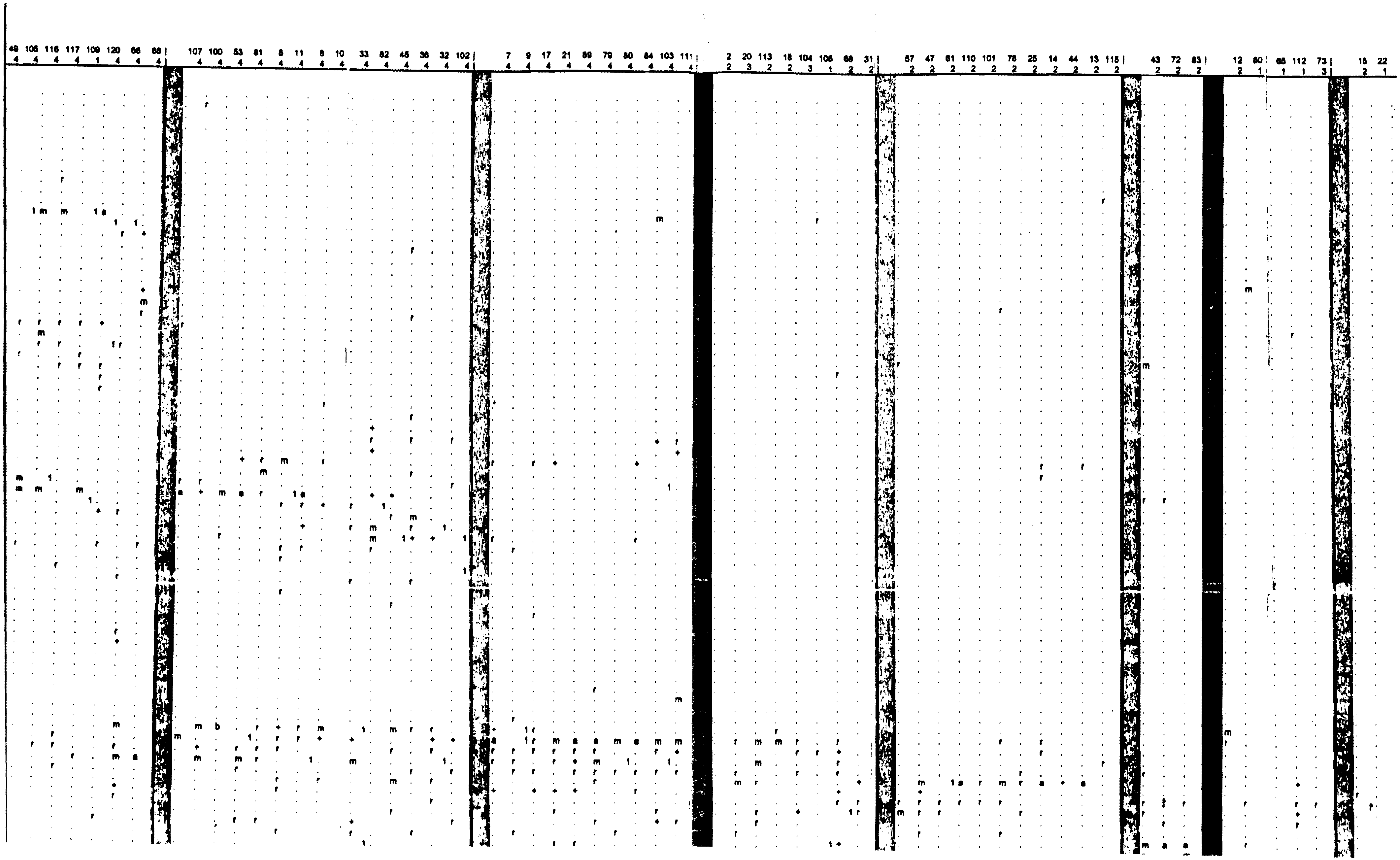
Appendix 4. Twinspan analysis of the privately owned land. The vegetation is divided into uplands and lowlands communities at the first level of division. Values are Braun-Blanquet cover-abundance values (Werger, 1973).

Community	Uplands														Lowlands												
Relevé number	85	89	90	98	95	97	4	37	1	5	87	96	92	93	88	40	75	75	77	86	94	99	38	39	41	52	91
Pentzia lanata	4	3	1	4	4	.	.	.	.	.	.	.	.	4	5	1	1	.	2	.	.	1	4	.	.	.	.
Lycium cinereum	2	1	.	.	.	.	.	.	.	.	1	.	.	.	.	1	1	4	.	.	.	.	.	.	.	.	.
Aptosimum indivisum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	1	1	.	.	1	.	.	.	.	.	.
Aridar noctiflora subsp. noctiflora	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.
Ihlenfeldtia excavata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.
Osteospermum rigidum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.
Zygophyllum retrofractum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	2	.	.	.	.	.	.	.	.
Aridaria serotina	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	.	2	.	2	.	.	.	.	.	.	.	.
Galenia affinis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.
Leipoldtia compacta	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.
Salsola zeyheri	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.
Drosanthemum sp.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	2	.	1	1	.	.	.	.	.	.	.
Drosanthemum sp. 4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	1	.	.	.	.	.	.	.	.	.
Ruschia grisea	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	.	.	.	.	.	.	.	.	.
Psilocaulon species	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	1	.	.	.	.	.	.	.	.
Drosanthemum otzenianum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.
Eriocephalus microcephyllus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.
Felicia tenella	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.
Galenia filiformis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.
Phyllobolus species	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	1	.	.	.	.	.	.	1	.
Cheiridopsis denticulata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1	.	.	.	.	.	.	.	1
Drosanthemum hispidum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	1	.	.	.	.
Herman cuneifolia v. cuneifolia	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	1	.	.
Galenia sarcophylla	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	1	.	.	.	.	.	.	.
Eriocephalus ericoides	.	4	4	.	.	3	.	.	.	.	.	.	.	.	2	4	2	.	4	.	.	.	5	.	4	4	4
Ruschia robusta	.	.	3	.	.	.	.	.	.	.	.	.	.	.	3	4	1	.	4	5	3	5	.	2	.	.	4
Crassula muscosa	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	1	.	.	.	1	.	.	.	.	.	.	1
Crassula subaphylla	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	1	1	.	1	1	.	.	1
Galeni africa v. africana	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	4	1	1	1	.	2	.
Leipoldtia schultzei	.	.	.	.	.	2	.	.	.	.	.	.	.	5	.	.	.	.	.	3	4	4	4	5	3	4	5
Aizoon canariense	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.
Berkheya fruticosa	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.
Crassula hemisphaerica	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.
Pharnaceum lanatum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.
Antimima sp. 1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.
Adromischus filicaulis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
Cheiridopsis robusta	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
Crassula brevifolia	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
Poaceaea sp1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
Avonia quinar s. quina	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.
Cheiridopsis schlechteri	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.
Cheiridopsis imitans	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.
Pharnaceum confertum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.
Pterothrix species 1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.
Pterothrix species 2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.
Felicia brevifolia	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Othonna quercifolia	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Asteraceae sp 2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Eriocephalus africanus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	.	.	.	.	.

Sarcocaulon salmoniflorum	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	.	.
Asparagus capensis	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.
Ruschia compacta	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.
Drosanthemum sp.2	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.
Galeni africana v. pentandra	.	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Lampranthus watermeyeri	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Drosanthemum sp. 2	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Leipoldtia sp."salvatory"	.	4	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Melolobium exudans	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Heliophila species	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Lessertia excisa	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Eriocephalus pauperrimus	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Wiborgia monoptera	.	.	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Hermannia amoena	2	.	1	1	1	.	.	.	.	.	1	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.
Felicia dregei	.	.	.	.	1	4	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.
Rhus burchellii	.	.	.	.	2	5	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.
Pteronia incana	3	1	.	4	4	1	.	.	4	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Zygophyllum meyeri	2	.	.	.	.	1	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ruschia species	5	.	.	4	4	2	.	.	.	.	2	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pteronia glomerata	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1	.	.
Tripteris sinuatum var. sinuatum	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	1	.	.	1	3	.	.	1
Hirpicium alienatum	.	.	.	.	1	.	.	.	.	.	1	1	.	4	.	.	2	.	.	.	.	2	.	1	1	1	4
Euphorbia decussata	2	4	5	3	.	3	.	1	2	1	2	.	.	1	2	4	4	1	4	.	.	2	1	1	3	1	1
Tetragonia fruticosa	.	.	.	1	1	4	1	1	1	1	1	.	.	1	.	.	1	.	.	1	.	2	1	.	1	.	1
Hypertelis salsoloides	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	1	2	.	.	.	.	.	.	.	.	.
Ehrharta barbinodis	1	.	.	.	.	.	.	.	1	1	2	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	1
Ruschia lerouxii	.	.	.	.	.	.	.	.	2	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	1	.
Eriocephalus microhyllus	3	.	1	3	.	.	.	.	4	1	4	.	.	.	.	.	.	.	.	.	4	.	.	.	.	.	1
Chrysocoma ciliata	.	.	1	.	2	.	1	1	2	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	1	2	.
Pelargonium alternans	1	1	1	.	.	.	1	.	1	1	1	1	.	1	1	.	.	.	.	.	.	.	.	.	.	1	.
Polymita albiflora	1	3	2	.	.	.	.	4	1	.	4	4	.	4	.	.	.	.	.	2	.	.	.	.	.	.	.
Thesium lineatum	4	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Chaetobromus involucratus	.	.	.	.	1	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Lebeckia multiflora	3	.	.	.	.	.	2	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pelargonium karooicum	.	.	.	2	.	.	.	.	1	1	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.
Pentaschistis species	.	.	.	.	.	.	.	.	.	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.
Tylecodon reticulatus	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Euryops dregeanus	.	.	.	.	.	.	.	.	.	.	.	3	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.
Ruschia viridifolia	.	.	.	.	.	.	3	5	4	1	.	.	4	1	.	.	.	.	.	.	.	.	1	.	.	.	.
Arctotis cuprea	.	.	.	.	.	.	1	.	.	.	2	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Eriocephalus brevifolia	.	.	.	.	.	.	1	2	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.
Dicerothamus rhinocerotis	.	.	.	.	3	.	2	4	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Euryops lateriflorus	.	.	.	.	.	4	.	.	.	2	.	1	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.
Oedera sedifolia	.	.	.	.	.	.	1	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Selago albida	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ehrharta calycina	.	.	.	.	.	.	.	1	1	1	2	1	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.
Oedera genistifolia	.	.	.	.	.	.	1	1	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Diosma acmaeophylla	.	.	.	.	.	.	1	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Euryop tenuissimus subsp. tenuissimus	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pharnaceum albens	.	.	.	.	.	.	.	1	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Crassula atropurpurea	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Senecio corymbiferus	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Felicia filifolia	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Crassula cotyledonis	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Hermannia cuneifolia v. glabrescens	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Osteospermum grandiflorum	.	.	.	.	.	.	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Passerina glomerata	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Atriplex vestita	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Berkheya spinosissima	2	1
Helichrysum zeyheri	3	1
Solanum species	1	1

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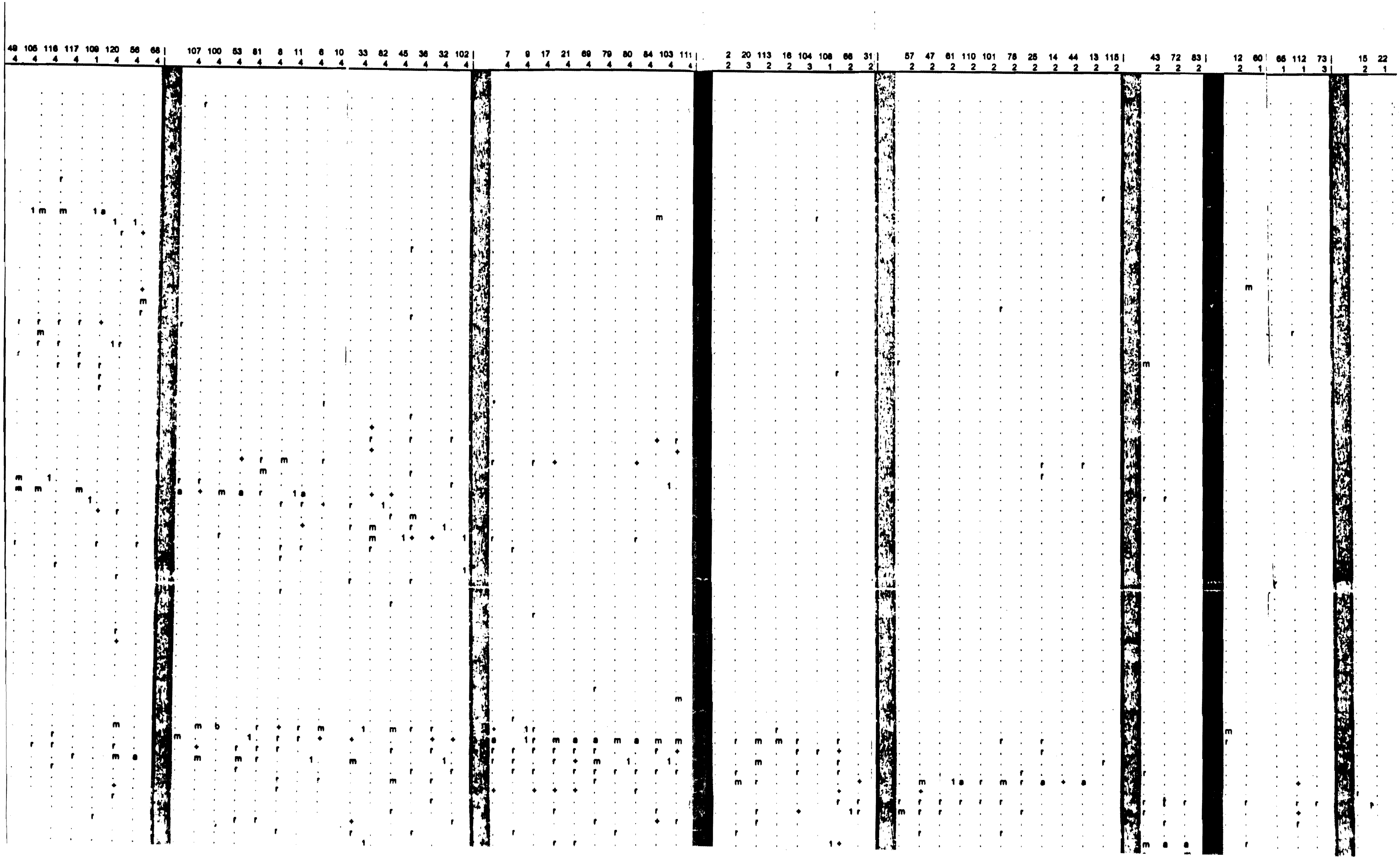
4 4 4 4 1 4 4 4 | 4 4 4 4 4 4 4 4 4 4 4 4 4 4 | 4 4 4 4 4 4 4 4 4 4 | 2 3 2 2 3 1 2 2 | 2 2 2 2 2 2 2 2 2 2 2 | 2 2 2 | 2 1 | 1 1 3 | 2 1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4 4 4 4 4 4 4 4 4 4
2 20 113 16 104 108 66 31
2 3 2 2 3 1 2 2
57 47 61 110 101 78 25 14 44 13 115
2 2 2 2 2 2 2 2 2 2 2
43 72 83
2 2 2
12 60
2 1
65 112 73
1 1 3
15 22
2 1

[illegible] species																							
Ruschia robusta									r		r					m		r		m	r		
Galeni africa v. afric		r	r				m																
Lycium cinereum				m				r										m					
Hypertelis salsoloides																							
Hermannia cuneifolia	r																						
Asparagus capensis		r	r			r	r			r		r											
Crassula atropurpurea			r															r					
Galenia sarcophylla									r			r										r	
Nenax cinerea																							
Euphorbia mauritanica	+			r														r					
Pterothrix species -t1											+											r	
Oedera genistifolia																							
Pterothrix species -s1																							
Chairidopsis cigaretti								+															
Drosanthemum sp. P1 -t								r		r													
Selago albida																							
Crassu capite s. thyrs		r	r																				
Eriocephalus species	+																						
Zygophyllum species										r													
Ruschia cradockensis													+										
Pelargonium species																							
Scelatium exalatum																							
Pentaschistis species																						r	
Melolobium exudens																					r		
Zygophyllum retrofract				1									r										
Chairidopsis schlechte															r								
Tylecodon wallichii			r							r												r	
Eriocephalus purpureus															r								
Sarcocaulon salmoniflo																							
Leipoldtia species																							
Amphiglossa tomentosa																							
Asteraceae (Petersen 4 -s																							
Ruschia species -t2																							
Chairidopsis denticula																							
Pharnaceum incanum																							
Aptosimum spinescens																							
Helichrysum cylindrifl																							
Stapelia species																							
Indigofera heterophyll																							
Manochlamys albicans																							
Pharnaceum species																							
Pteronia glauca								r															
Euryops multifidus																							
Othonna retrofracta																							
Zygophyllum species -t1																							
Ruschia leucosperma																							
Ruschia grisea																							
Cephalophyll ebracteat																							
Drosanthemum sp. P5 -t																							
Senecio niveus																							
Ihlenfeldtia excavata																							
Chaetobromus involucra																							
Drosanthemum sp. P3 -t																							
Mesembryanthemaceae						r																	
Brownanthus sp. (Peter																							
Phyllobolus species																							
Aptosimum indivisum																							
Aridaria serotina / [illegible]									r														
Pteronia fastigiata															r								
Asteraceae (Petersen 3 -t																							
Anacam filame s. namaq																							
Tetragonia fruticosa	r	r	r	+			+	r	r	r		1+				r			1r	r	r	r	r
Euphorbia decussata		r	r	+	r	r		r	r	r	m		1	1	r	m		1+	m		1m	+	m
Pentzia lanata	r	+		1r	+	r	a	m	+			+	m					m				r	
Eriocephalus ericoides		1m	r	m	+		1a	+	m	a	m		1			r	r	r					
Pteronia incana	r		1	+	a	a	m		a	r	+	r				m	m	r			+		
Hermannia amoena									r	+	+	r	+						+	r			
Hirpicium alienatum		r		r		r				r	r	+						+	r		+	r	
Chrysocoma ciliata	r		r		r					+			1			+			r			r	
Arider noctif s. nocti							m							1									
Galenia meziana			r							r		r											
Ehrharta calycina								r		r						r							
Ruschia species			a	a	m		1												r				+

24 51 23 64 26 28 29 3 1 30 34 27 19 2