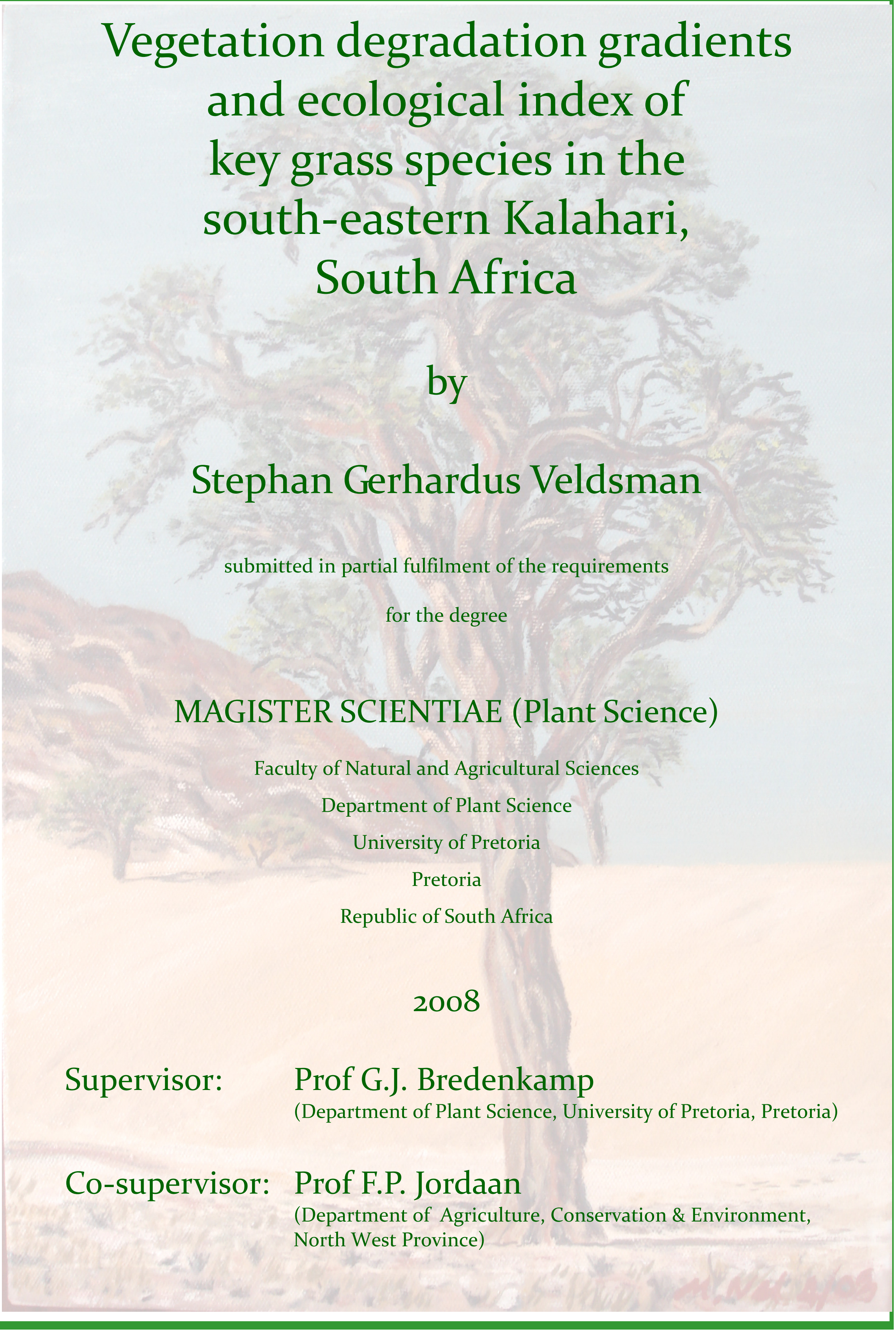

Vegetation degradation gradients and ecological index of key grass species in the south-eastern Kalahari, South Africa

by

Stephan Gerhardus Veldsman

submitted in partial fulfilment of the requirements

for the degree

MAGISTER SCIENTIAE (Plant Science)

Faculty of Natural and Agricultural Sciences
Department of Plant Science
University of Pretoria
Pretoria
Republic of South Africa

2008

Supervisor:	Prof G.J. Bredenkamp (Department of Plant Science, University of Pretoria, Pretoria)
Co-supervisor:	Prof F.P. Jordaan (Department of Agriculture, Conservation & Environment, North West Province)

Declaration:

I, Stephan Gerhardus Veldsman declare that the thesis/dissertation, which I hereby submit for the degree MAGISTER SCIENTIAE (Plant Science) at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

SIGNATURE:____________________

DATE:________________

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Abstract

An ecological assessment of the vegetation was conducted in the south-eastern part of the Kalahari. Detailed classification of the vegetation of Witsand Nature Reserve to determine small scale plant communities for a Nature Reserve management plan – 44 Braun-Blanquet plots revealed 7 detailed plant communities. One hundred and twenty six (126) sample plots, making up 45 sites, were used for the TWINSPAN classification, refined by Braun-Blanquet procedures, illustrated in a dendrogram, revealed 3 broad plant communities. A description of the communities is given and a vegetation map of the study area is provided. The step-point method was used and data collected at each sample plot in such a way that different degradation stages could be identified, an ordination technique (multivariate analytical procedures) was used to define the grazing gradient. Species abundance curves were statistically fitted to the grazing gradient and used to classify the species objectively into categories. Ecological index values were determined for each of the significant species within each community.

TABLE OF CONTENT PP

Chapter 5 Vegetation analysis on Witsand Nature Reserve 45

FIGURES PP

TABLES PP

Chapter 1 Introduction

Natural pasture management is regarded as part of plant ecology / agroecology (Pretty 2000), an attempt is made to improve the quantity and quality of plant production over short- and long term (Danckwerts & Tainton 1996). Short term productivity of a pasture ecosystem is a function of climate variation, number and type of animals and the type of management practises (Snyman 1999). Long term optimisation of plant and animal production is, however, related to the prevention of veld degradation (Snyman 1998). In areas with high rainfall (wetter areas) the vegetation change and – production are relatively predictable, as the rainfall is predictable. Overgrazing in wetter areas mostly results in slow plant- and soil degradation. In drier areas, such as arid and semi-arid grasslands, overgrazing, especially due to cattle, has a major influence on the vegetation composition (Snyman & Fouche 1991; Jeltsch *et al.* 1997), also causing an increase in shrub-encroachment (Jeltsch *et al.* 1997) and a change in ground cover and erosion (Snyman & Fouche 1991).

Large scale veld degradation and desertification are two of the biggest threats for sustainable grass production in arid and semi-arid (dryland) areas where rainfall is low and unpredictable (Roux 1983; Dean *et al.* 1995; Wiegand *et al.* 1998). In spite of the fact that grass production is dependent on rainfall, the interactions between rainfall and grazing are not well understood (Jeltsch *et al.* 1997). The change of plant community composition in response to grazing will depend on year-to-year rainfall variability (O'Connor & Bredenkamp 1997). Incorrect utilization of natural veld for animal production, cause world wide changes in botanical composition and has a lowering effect on veld conditions (Friedel *et al.* 1990; Schlesinger *et al.* 1990; Friedel 1991; Dean & Macdonald 1994). Further studies of range and environmental parameters are needed to assess the nature, extent and rate of change, especially global change (Dean *et al.* 1995).

Rangeland degradation is, as described by Abel & Blaikie (1989), an effective and permanent deterioration in the tempo that rangeland can deliver stock production under a certain management system. Jacoby (1989) defines rangeland degradation as the deterioration of a certain site or area as a result of biotic and abiotic factors that have affected it. The result is a lower successional phase, which means that the ecological potential of the site or area has changed (Jacoby 1989), such as an increase in woody vegetation cover (Weber *et al.* 1998).

Another view point, especially in arid areas, is that incorrect veld management can be regarded as an event, which could change veld condition to another state, which is not as predictable as successional phases (Westoby 1979). This type of vegetation change is known as event-driven, *e.g.* the state and transition model of Westoby *et al.* (1989).

Overgrazing is a major cause for veld degradation, especially in South Africa (Fourie & Fouche 1985; Fourie *et al.* 1985; Danckwerts & Tainton 1996; Hoffman & Ashwell 2001). Van der Westhuizen (2003) describes this disturbance of habitat due to over-estimation of the potential of the veld as, when perennial species with a high utilisation (grazing) value are replaced with species with a lesser utilisation value. Such changes have influences on the hydrological status (Snyman & Fouche 1991; 1993), stability (Snyman 1998), quality (Potgieter 1991), and quantity (Kirkman & Moore 1995; Snyman 1997) of the veld and hold great economic implications (Van der Westhuizen 1994; Snyman 1998). Milton *et al.* (1994) describes five steps of veld degradation of arid or semi-arid rangelands and its effects:

1. Biomass and composition of vegetation varies with climatic cycles and stochastic events – Perennial vegetation varies with weather.
2. Herbivory reduces recruitment of palatable plants, allowing populations of unpalatable species to grow – Demography (age structure) of plant population changes.
3. Plant species that fail to recruit are lost, as are their specialised predators and symbionts – Decrease in rangeland diversity (plant and animal losses), reduced secondary productivity.
4. Biomass and productivity of vegetation fluctuates as ephemerals benefit from loss of perennial cover – Perennial biomass is reduced, short-lived plants and instability increase.
5. Denudation and desertification involve changes in soil function and detritivore activity – Bare ground, erosion and aridification (soil salinized).

Range condition according to Trollope *et al.* (1990*)* is the condition of vegetation in terms of climate against soil erosion. The production potential, condition and stability of the veld provide an overview of the current range condition in relation to the maximum potential of it in a certain area. Vegetation is not static and always on the change (Trollope 1990; Van der Westhuizen 2003), especially due to human activities (Bredenkamp & Brown 2001; Bredenkamp *et al.* 2001). These changes are either progressive or retrogressive. If veld condition assessments are repeated over time on the same area, then vegetation changes can be monitored effectively, and the direction of change determined. This tendency should be followed in veld management for sustainable animal production (Trollope 1990; Van der Westhuizen 2003).

Veld management refers to the management of natural vegetation for specific objectives either for agricultural purposes, conservation or any other land uses (Trollope 1990). Several components should be evaluated to understand veld management, these include climate, vegetation, geology, soil (Lubbinge 1998), and geographical changes over an area on a large scale as well as on a small scale.

To be able to study changes in the vegetation, and to indicate the long term effect of grazing on natural pastures, monitoring of sites at or near water-points is necessary. The use of a single sampling period is however possible if using different assumed stages of degradation around a watering point (Bosch & Janse van Rensburg 1987; Van Rooyen *et al.* 1991a).

The Kalahari, an arid area, is sensitive for degradation and it is important to protect its biodiversity (Cloudsley-Thompson 1993). A study was conducted in 2003 to classify, describe and map the vegetation of the Witsand Nature Reserve in detail. The range condition of the major plant communities was assessed and the ecological grazing and browsing capacities of these communities were determined. Based on the calculated grazing and browsing capacities recommendation were made on the stocking density for the Reserve. The grazing- and browsing capacities along with the recommendations were compiled in a report for the Department of Agriculture, Conservation, Land Reform and Environment, and not included within this thesis. The calculation of the grazing capacity for the different communities on Witsand Nature Reserve, were conducted using Increaser and Decreaser values determined from Van Oudtshoorn (1994; 2002). The application of the veld condition management plan showed that there is a shortage in knowledge about the ecological status of the grass species within this area, hence this study. The aim of this study is to determine the effect grazing has on the veld (grass) in the south-eastern portion of the Kalahari.

The study comprises of:

- Determine the phytosociology of the study area, to relate plant communities and hence plant species composition to environmental conditions.
- Determine the degradation gradients based on the perennial grass species (identified key species) in the different plant communities identified within the study area.
- Relate these grass degradation gradient values to ecological index values.

Chapter 2 Concise literature overview

2.1 Introduction

Over the years several ecologically-based techniques for assessing rangeland conditions have been developed in South Africa. According to Dyksterhuis (1949) the rangeland condition of a certain area should be compared to the ideal condition, also known as the climax or benchmark site. Several authors such as: Roberts *et al.* (1975); Tainton *et al.* (1980); Vorster (1982); Fourie & Du Toit (1983); Heard *et al.* (1986); Hardy & Hurt (1989); Stuart-Hill & Hobson (1991); Jordaan (1997) discussed ecologically-based veld condition techniques. Several of these techniques make use of veld condition scores. These scores are derived from a subjective classification of species into groups: decreaser species (species dominant in well-managed vegetation, and tend to decrease when the veld is under- or over utilised) and increaser species (species which increase in abundance due to poor-management, the veld is either under- or over utilised) (Foran *et al*. 1978; Tainton *et al.* 1980; Vorster 1982; Fourie & Du Toit 1983; Janse van Rensburg & Bosch 1990). Some of these techniques have been severely criticised over the years (Jordaan 1997). Moir (1989) mentions two components that are usually involved when determining rangeland condition: The ecological status or floristic composition of the vegetation compared with the ideal, and the production or agronomic value of the rangeland for the maintenance of livestock units. Ecologically-based techniques in South Africa are also based on these principles (Jordaan 1997).

Jordaan (1997) found in literature that it is evident that the rangeland condition assessment techniques should be more objective, interpretable and quantifiable. Austin (1977); Austin *et al.* (1981); Mentis (1983) suggested the use of multivariate analytical techniques to approach rangeland condition assessment. The use of degradation gradient techniques for assessing rangeland condition and ecological interpretation of the rangeland condition were suggested by Whittaker (1978); Bosch & Kellner (1991); Bosch & Gauch (1991).

2.2 Multivariate analysis techniques

Multivariate analysis techniques, such as ordination techniques, can be used to simplify and summarise complex data (Austin 1977). Ordination can be defined as the process where sites or species are arranged in terms of one or more gradients, or axes (x- or y-axes) of variation (Whittaker 1967). Gabriel & Talbot (1984) describe ordination as the arrangement of observations in a single or multidimensional way. Martens *et el.* (1990) used multivariate techniques to assess vegetation change by ordinating sites from repeated measurements and tracing site trajectories through ordination space. The trends they found along the axes were strongly correlated with assessed veld condition scores. Stuart-Hill & Hobson (1991) proposed that the position which a sample site occupies in multivariate space (in terms of similarity, floristically or structurally, to all other sites), from the ordination analysis, should be its index or vegetation condition state.

Hurt & Bosch (1991) found that the Degradation Gradient Method provides the best indices for assessing range condition, along with the Weighted Key Species Method. Degradation gradients can facilitate the ecological interpretation of a specific rangeland condition. It is possible to identify the reason of the change in condition and to rectify it by means of certain management options (Bosch & Kellner 1991). Jordaan (1997) mentions that other advantages of the use of degradation gradients in the assessment of rangeland conditions are that species reaction to grazing and the rehabilitation ability of degraded vegetation can be better understood.

Certain computer programmes such as simulation models and expert systems, had debatable success in the past. Decision Support Systems (DSS) combine all available technology within one integrated system with sufficient flexibility to contribute to the end user's needs for effective information (Jordaan 1997). ISPD – Integrated System for Plant Dynamics (Bosch *et al.* 1992) is an example of such a system. Jordaan (1997) evaluated existing models (rangeland dynamics models that are used in ISPD), as a basis for assessing rangeland conditions. These models also form the basis for determining grazing capacity, thus making the evaluation of these models of cardinal importance. Jordaan (1997) further evaluated CANOCO (Ter Braak, 1988) as an aid to optimise the management model of ISPD.

Several authors had success using degradation models to assess rangeland conditions (Bosch & Janse van Rensburg 1987; Jordaan 1997; Van der Westhuizen *et al.* 1999).

Jordaan (1997) constructed degradation models of 741 historical sites within the former Highveld Region. Jordaan's study was conducted on an extensive collection of surveys on plant communities covering spatial and temporal changes in order to subdivide the areas of concern into more relative homogeneous grazing areas that can be managed on a self sustainable and resilient basis; to compile degradation models for these relative homogeneous grazing areas which can be used in assessing rangeland conditions in terms of the ecological stability; to study associations of plant communities with particular habitat characteristics and management practices, quantified by means of CANOCO statistics; and to compile extension directives for each relative homogeneous grazing area.

Bosch & Janse van Rensburg (1987) classified grasses, on the shallow soils of the western grassland biome of South Africa, on their ecological status on the basis of their reaction to grazing. They collected vegetation data in such a way that the different successional stages could be identified. An ordination technique was used to define the grazing gradient. Species abundance curves were statistically fitted to the grazing gradient and used to classify the grass species into decreaser and increaser categories.

Janse van Rensburg & Bosch (1990) grouped individual species into ecological groups (Decreaser and Increaser groups) by assessing species responses to grazing and soil. They found that the same species often react differently to grazing in different topographical localities as well as between sub-habitats of the same topographical unit. According to these results broad standardized grouping of species in ecological groups (Decreaser and Increasers) is scientifically wrong and of little practical value.

Van der Westhuizen *et al.* (1999) used the degradation gradient technique to quantify rangeland condition within the sweet grassland of southern Africa. They linked ecological values to species by means of their individual positions on the degradation gradient and further classified the species according to ecological index values. Index values and Gaussian distribution curves were used in calculations to determine the rangeland condition. The advantages they found by using this technique are that it is simple to use and that only important indicator and dominant species are used to determine rangeland condition.

Chapter 3 Study area

3.1 Introduction

The broad phytosociology of the Kalahari has been described previously by several authors. Pole-Evans (1936) and Acocks (1953/1988) described the vegetation of the southern Kalahari as one unit while Leistner (1967) described different vegetation types. Leistner (1967) classified the Kalahari as Savanna that consists of trees and shrubs [Savanna Biome (Scholes 1997)], an arid savanna (Van Rooyen 2001). Most of the research in the Kalahari was conducted in the northern part of the southern Kalahari, and the Kalahari Dune Veld (mostly in the Kalahari Gemsbok National Park).

The Savanna is divided into two broad categories namely Broad-leaved and Fine-leaved. The southern Kalahari falls within the Fine-leaved category (Scholes 1997). The southern Kalahari, stretching through Botswana, Namibia and South Africa, is an area where surface water is scarce. It is part of an area called the Mega Kalahari (IGBP 1997), a single large area covered with sand deposits probably from the late Cretaceous (Main 1987: in Smit 2000; Partridge 1997). The Kalahari Basin lies within the semi-arid zone of the western interior of the subcontinent (Partridge 1997), within the boundaries of nine countries, from north to south; Gabon, Congo, Republic of Congo, Angola, Zambia, Namibia, Botswana and South Africa (Thomas & Shaw 1991; IGBP 1997), as far south as the Orange River (Main 1987: in Smit 2000). The Mega Kalahari (IGBP 1997), stretches east-west about from 11° East in Angola to 32° East in Zimbabwe (Thomas & Shaw 1991).

The southern Kalahari includes the Kalahari Gemsbok National Park in the north (the southern Kalahari dune veld). The study area (Figure 3.1) falls within the most south-eastern part of the Kalahari, and the area is seen as a more flat sandy part of the Kalahari.

The study area is on the border between the Kalahari Savanna biome and the Nama-karoo biome. According to Rutherford (1997) biome transitions can produce limited areas of transitional life-form combinations such as co-dominance of phanerophytes [mainly trees and shrubs (Brewer 1994)], chamaephytes [trailing and creeping shrubs (Brewer 1994)] and hemicryptophytes [rosette plants, and plants with shallow rhizomes (Brewer 1994)], found in the southern Kalahari.

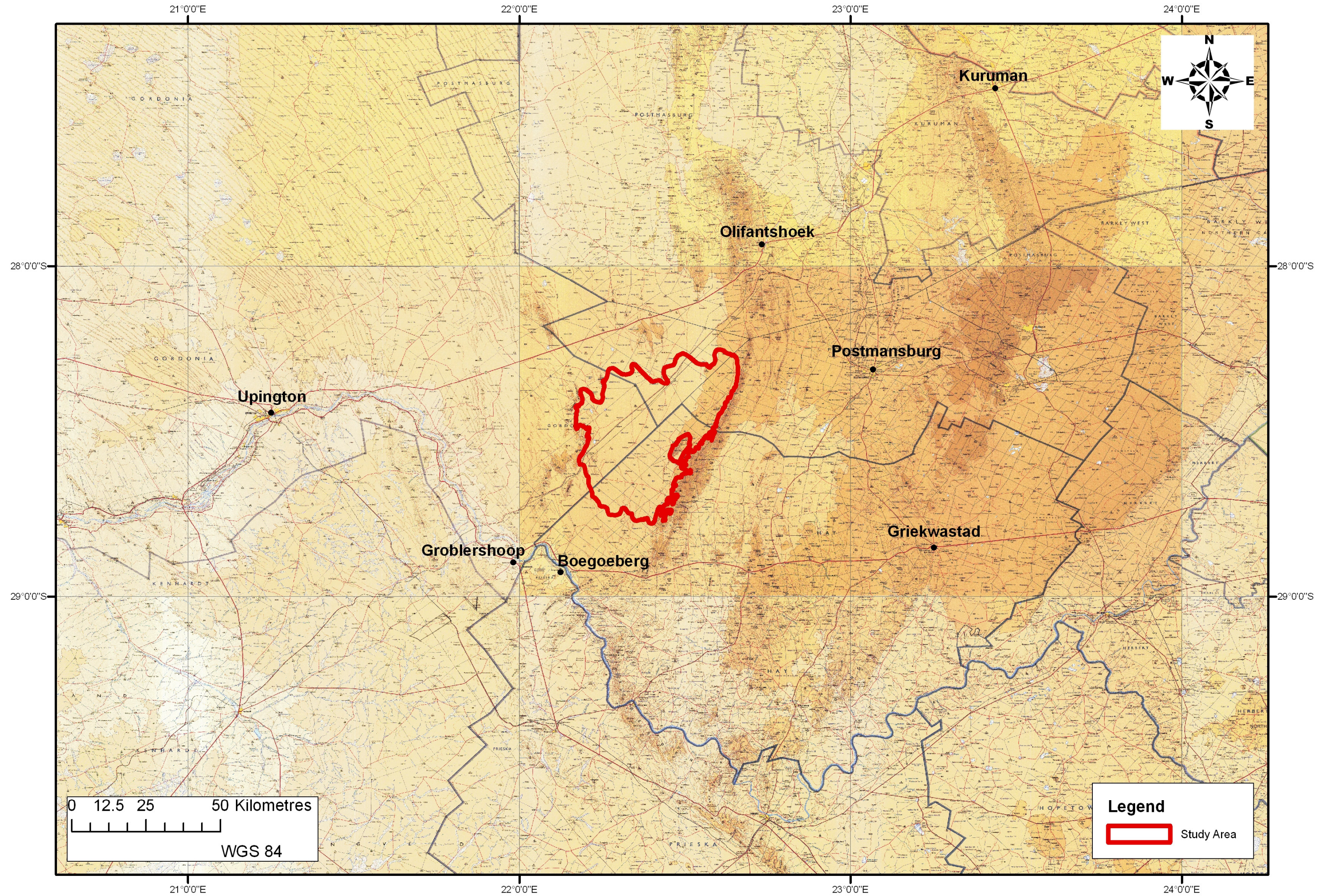


Figure 3.1 Locality map of the study area. The study area falls within the range of the following coordinates: Northern Border: 28^{o} 00’ S; Southern Border: 28^{o} 48’ S; Western Border: 22^{o} 09’ E; Eastern Border: 22^{o} 39’ E.

The area is classified as part of the Shrubby Kalahari Dune Bushveld (28) by Van Rooyen & Bredenkamp (1996). The study area falls within the boundaries of the Griqualand West Centre of plant endemism (Van Wyk & Smit 2001).

Acocks (1998) described the area as the Western Form of the Kalahari Thornveld; Kalahari Thornveld A16 (4), which is an extremely open savanna consisting of species such as *Acacia erioloba* and *Acacia haematoxylon,* except near rivers and hills.

Leistner (1967) concentrated on the Kalahari Dune Veld of the southern Kalahari, which mainly occurs towards the west of the study area. Leistner & Werger (1973) described the vegetation of the Kalahari Gemsbok Park (KGNP). Other studies that have been done are by White (1983) that divides the Kalahari vegetation into Dune Veld and Thorn Veld. Lubbinge (1998) divided the southern Kalahari Dune Veld into Dune Veld and Rivers & Pans. The areas covered by these studies, all fall outside the current study area.

Smit (2000) classified the vegetation of the area as *Acacia mellifera – Eragrostis lehmanniana* Closed Shrub Veld, a community that occurs on plains with deep sandy soils. Smit's classification for the area is as follows:

Class 1: *Acacia mellifera – Eragrostis lehmanniana* Closed Shrub Veld
Order 1.2: *Tarchonanthus camphoratus – Acacia mellifera* Closed Shrub Veld
    Alliance 1.2.1: *Acacia haematoxylon – Acacia mellifera* Closed Woodland
        Association 1.2.1.2: *Acacia hameatoxylon – Eragrostis pallens* Open Shrub Veld

Smit (2000) mentioned that this vegetation type occurs on deep sandy soils with undulating to flat sand plains. The Class mainly consists of species such as the trees and shrubs *Acacia mellifera, Acacia erioloba, Grewia flava, Ehretia rigida, Acacia habeclada, Ziziphus mucronata* and *Lycium hirsutum,* and the grasses *Eragrostis lehmanniana, Aristida congesta, Schmidtia kalihariensis, Eragrostis trichophora, Tragus racemosa* and *Stipagrostis obtusa*.

The Order, *Tarchonanathus camphoratus – Acacia mellifera* Closed Shrub Veld, described by Smit (2000), occurs west of the Langberg. The study area falls within the *Acacia haematoxylon – Acacia mellifera* Closed Woodland alliance, found directly adjacent to the Langberg to the west. This alliance is recognised by deep sandy soils.

The association which occurs within the study area, *Acacia hameatoxylon – Eragrostis pallens* Open Shrub Veld, is restricted to the western portion of Smit's (2000) study area. This association occurs directly adjacent to the Kalahari Dune Veld.

Five vegetation units (Mucina & Rutherford 2006) found within the study area can broadly be related to the vegetation communities identified in the current study (Figure 3.2):

AZi 4 – Southern Kalahari Salt Pans (= pans within the study area, only in the western portion occurring within Community 1: *Acacia haematoxylon – Elephantorrhiza elephantina – Eragrostis lehmanniana* Low Grassy Bushland and Community 3: *Pentzia calcarea – Eragrostis lehmanniana – Stipagrostis obtusa* Open Grassland)

SVk 13 – Olifantshoek Plains Shrubland (= Mainly Community 2: *Acacia mellifera – Rhigozum trichotomum – Eragrostis lehmanniana* High Open Shrubland, and a small area in the west of the study area Community 3: *Pentzia calcarea – Eragrostis lehmanniana – Stipagrostis obtusa* Open Grassland)

SVk 15 – Koranna – Langeberg Mountain Bushveld (= in the east adjacent the study area – Langberg; and adjacent the study area in the west – Skurweberg)

SVk 16 – Gordonia Plains Shrubland (= Community 1: *Acacia haematoxylon – Elephantorrhiza elephantina – Eragrostis lehmanniana* Low Grassy Bushland)

SVkd 1 – Gordonia Duneveld (= Mainly west of the study area)

(Note: The word "Langeberg" used by Mucina & Rutherford (2006) within their vegetation unit name and description is incorrect. It should read Langberg).

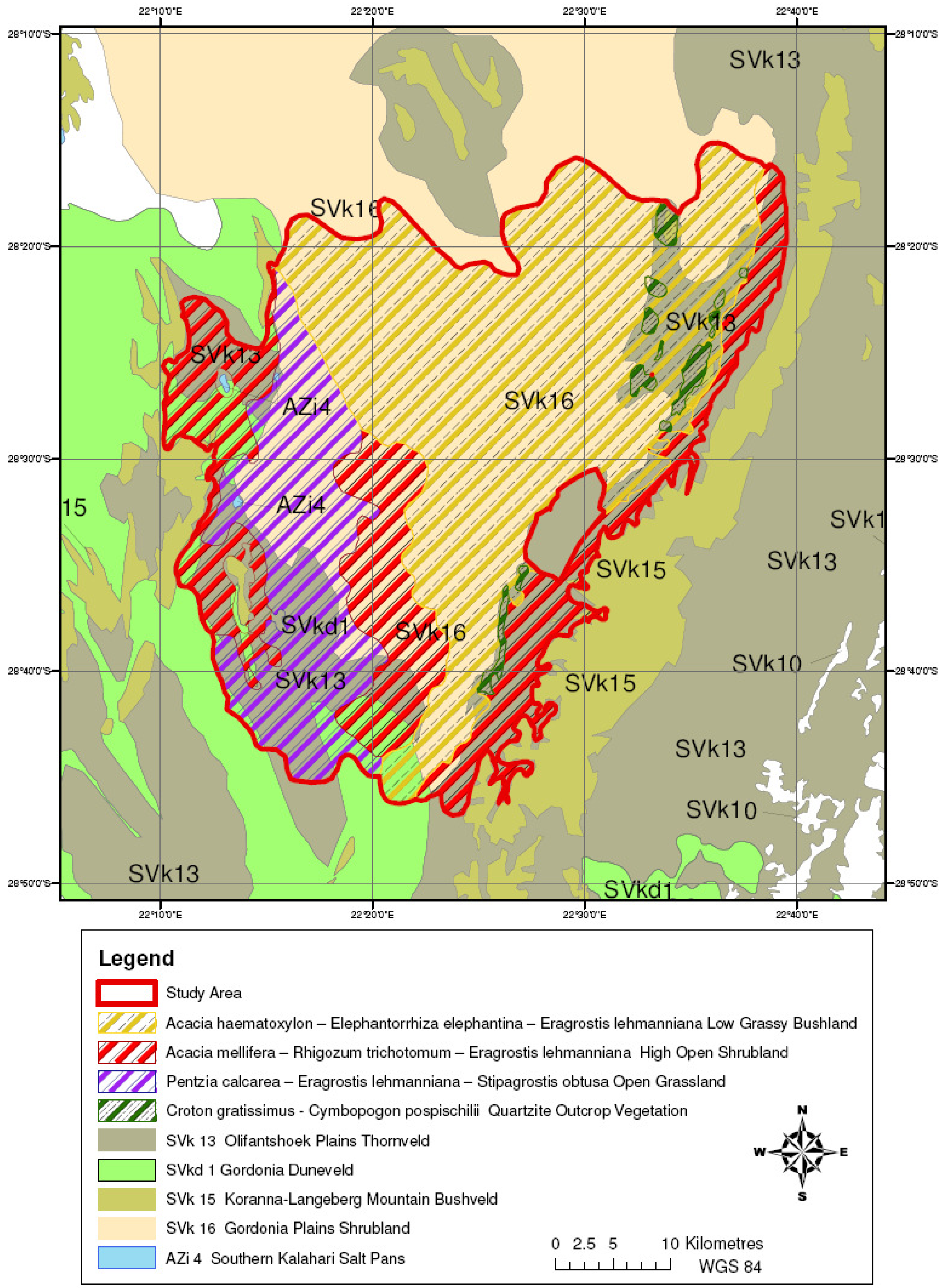


Figure 3.2 Vegetation communities classified during this study and vegetation unit described by Mucina, *et al.* (2005) and Mucina & Rutherford (2006).

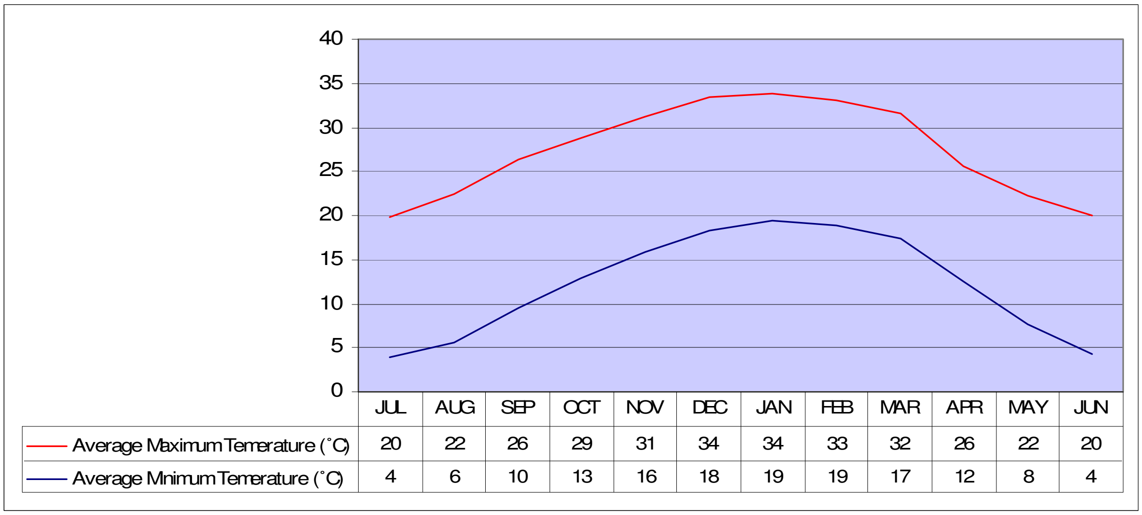
3.2 Climate

The climatic data was obtained from the South African Weather Bureau – Boegoeberg Dam weather station. The climatic data of the southern Kalahari from Smit (2000) were studied, and found insufficient to the current study. Smit (2000) used data from six other weather stations: Van Zylsrus, Armoedsvlakte (Vryburg), Kuruman, Kimberley, Koopmansfontein II, and Plessisdraai (Hopetown).

3.2.1 Temperature

Schulze (1997) shows that the Kalahari has the highest means of daily maximum temperatures in the country during January. The temperature ranges with lows from -10°C in the winter to summer highs of 45°C (van Rooyen 2001). The Kalahari sands have greater volumes for moisture storage than the Nama-karoo (Palmer & Hoffman 1997).

At Boegoeberg Dam the summer temperature monthly averages range from 31 – 38 °C (Table 3.1), whereas Smit (2000) found that the maximum temperatures in the summer range from 34 – 41.2 °C. December and January is the warmest months, with a maximum temperature average of 34 °C over a period of 1951 - 2003 (Figure 3.3; Table 3.1), with June and July as the coldest months with a minimum temperature average of 4 °C (Figure 3.3; Table 3.2). Smit (2000) found that the temperature in the winter in the Kalahari go down to an average of -3.8 to -10.6 °C.



	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
Average Maximum Temerature (˚C)	20	22	26	29	31	34	34	33	32	26	22	20
Average Mnimum Temerature (˚C)	4	6	10	13	16	18	19	19	17	12	8	4

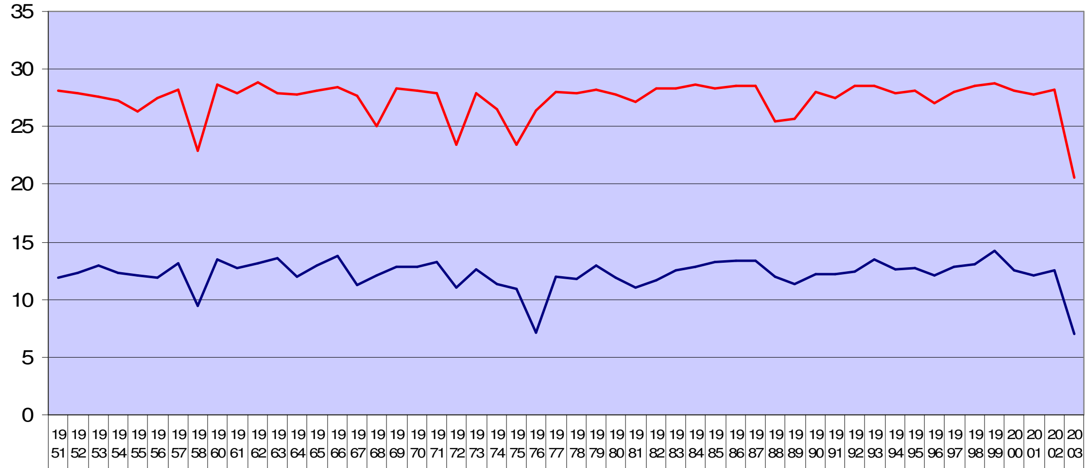
Figure 3.3 Average of the daily maximum and minimum temperatures in °C by month; BOEGOEBERG DAM – IRR; Lat: -29.0550, Lon: 22.2000, Altitude: 891 m. Measured at 8:00 from 1951 – 2003.

Table 3.1 Average of the daily maximum temperature in °C by month; (=) – Indicates that the average is unreliable due to missing daily values. BOEGOEBERG DAM – IRR; Lat: -29.0550, Lon: 22.2000, Altitude: 891 m. Measured at 8:00 from 1951 – 2003.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1951	33.2	35.1	31.7	28.5	22.5	19.3	19.0	22.2	25.9	29.3	33.3	36.7
1952	37.6	33.4	32.5	29.4	23.4	23.2	20.5	22.8	24.0	30.8	22.5	34.5
1953	38.1	33.2	32.0	24.1	23.7	19.6	19.2	20.5	27.5	29.9	31.0	32.6
1954	34.6	34.8	27.4	25.9	21.2	20.1	18.3	22.8	26.9	29.3	31.6	34.6
1955	34.2	30.3	30.5	26.0	24.1	18.2	19.2	19.9	25.8	26.8	29.4	31.3
1956	35.2	31.7	29.6	27.9	21.4	20.0	21.3	22.7	25.4	30.1	32.7	32.1
1957	35.8	33.4	33.5	28.0	24.0	18.4	20.3	22.3	25.0	28.5	33.8	35.1
1958			32.8	29.2	23.3	19.9	22.7	23.1	26.6	29.0	32.8	35.3
1960	35.5	34.4	31.6	26.1	22.8	20.2	20.4	24.7	27.7	31.4	33.9	34.5
1961	32.8	35.5	30.9	27.7	21.6	19.8	21.7	21.5	27.9	28.5	32.3	34.3
1962	35.9	32.1	32.8	27.6	25.3	20.3	21.9	23.2	27.7	31.1=	31.9=	37.0
1963	34.1	34.1	30.7	25.7	22.4	20.2	18.4	23.0	30.1	29.7	31.7	34.1
1964	36.9	34.9	33.7	26.7	24.4	17.4	19.3	21.3	25.6	28.5	30.6	34.1
1965	36.0	35.7	31.5	25.7	23.7	18.3	20.7	24.6	28.2	26.4	32.3	33.8
1966	36.6	33.0	32.1	26.2	23.7	21.8	19.6	23.5	25.0	30.0	33.4	36.2
1967	35.1=	33.7	30.5	24.0	22.0	18.5	18.6	22.9	27.8	29.7	33.0	36.2
1968	36.2	34.5	29.4		20.3=	16.3	19.4	21.6	27.2	28.2	33.1	34.7
1969	36.9	35.4	31.4	25.6	22.7	19.9	21.4	23.3	25.5	28.2	32.8	36.4
1970	36.8	35.1	33.6	29.0	23.0	18.9	19.4	20.3	25.5	30.3	31.8	33.1
1971	35.0	33.1	33.2	28.2	23.2	20.0	19.8	20.7	27.2	28.2	31.5	34.3
1972		33.0	30.4		23.0	21.2	22.7=	22.3	27.0	31.7	34.9	35.6
1973	36.9	33.8	31.5	26.3	22.4	22.3	20.9	21.6	24.0	29.7	32.2	32.6
1974	31.9	29.7	27.6	25.0	22.0	20.3	21.1	18.9	25.7	29.2	32.1	34.4
1975	35.6	33.0	28.6			21.9	20.1	22.5	28.4	28.2	31.6	30.8
1976	31.1	30.6	28.4	26.6	22.6	18.4	19.9	22.3	26.8	27.5	28.9	33.9
1977	35.0	33.7	30.3	27.3	21.5	20.6	20.9	22.1	26.2	30.0	33.4	34.5
1978	34.2	33.7	32.4	25.4	23.7	20.7	22.4	21.9	24.0	27.4	34.3	34.1
1979	34.5	34.6	32.4	30.1	22.7	19.8	19.0	22.3	24.9	28.9	33.5	35.9
1980	36.1	34.5	31.6	27.4	17.7	20.5	22.3	23.5	25.6	31.2	29.6	33.6
1981	34.8	32.1	30.0	28.4	23.9	19.9	20.4	19.5	21.7	27.0	32.8	34.8
1982	35.5	35.4	31.9	24.5	24.7	20.4	19.7	24.1	29.5	29.7	31.8	33.2
1983	38.0	34.6	32.8	29.5	21.6	20.1	19.8	22.3	26.8	29.9	30.5	34.2
1984	36.3	36.8	33.0	27.1	22.0	20.7	20.8	24.0	27.1	28.8	32.9	33.8
1985	35.9	33.6	30.0	26.7	23.9	21.9	20.6	24.4	26.1	31.2	33.2	31.8
1986	36.0	34.5	31.4	28.6	25.7	20.2	20.1	22.3	26.1	29.4	32.0	36.7
1987	36.2	35.1	33.6	29.1	26.2	19.8	19.3	22.2	23.6	30.3	32.7	34.3
1988	36.6	32.4	30.2	24.8		18.9	20.8	23.7	25.5	27.7	32.1	32.9
1989	33.6	30.2	30.7	26.0	23.4	18.9		23.6	25.8	28.3	31.9	35.5
1990	36.1	32.2	32.3	26.3	23.9	19.1	19.8	23.4	27.7	29.7	32.0	32.9
1991	33.7	33.7	29.7	29.1	25.3	18.5	19.8	21.9	25.3	27.6	31.6	33.0
1992	36.9	34.9	33.2	29.3	24.8	19.8	21.0	21.0	27.7	27.9	31.4	35.1
1993	36.3	32.1	32.9	26.1	23.3	20.6	21.1	22.9	29.3	31.8	32.0	34.3
1994	33.6	32.4	31.5	28.9	25.0	18.4	19.2	23.4	27.3	28.6	31.7	34.6
1995	35.5	37.5	31.5	27.6	23.2	20.4	19.3	23.8	27.8	27.5	31.6	31.3
1996	34.9	33.2	31.7	27.9	24.1	21.0	16.6	18.8	25.7	29.4	28.6	32.7
1997	33.8	35.1	30.5	25.5	22.1	19.3	20.3	24.7	29.3	30.2	30.8	35.0
1998	33.7	34.1	32.3	30.4	23.8	22.7	20.3	23.1	27.0	29.2	31.5	34.2
1999	35.6	36.6	34.8	29.1	22.0	20.9	21.4	23.7	25.1	29.4	34.2	32.0
2000	31.5	33.9	31.0	26.5	23.2	22.1	21.1	25.2	24.3	31.1	31.3	35.6
2001	35.2	34.8	33.8	26.4	23.9	21.6	18.9	21.7	23.9	30.6	29.9	33.1
2002	34.3	34.7	32.7	28.9	23.9	18.9	19.3	21.5	27.0	31.4	31.7	34.7
2003	36.3	35.3	32.3	29.8	23.6	20.7	22.4	20.4=	26.0			

Table 3.2 Average of the daily minimum temperature in ^{o}C by month; (=) – Indicates that the average is unreliable due to missing daily values. BOEGOEBERG DAM – IRR; Lat: -29.0550, Lon: 22.2000, Altitude: 891 m. Measured at 8:00 from 1951 – 2003.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1951	17.5	20.9	15.9	11.8	8.1	4.6	1.9	6.3	7.9	12.4	16.1	19.6
1952	21.4	20.7	15.5	14.0	8.3	6.2	5.9	6.0	8.4	13.7	7.9	19.1
1953	21.5	21.4	18.1	12.7	7.5	3.9	3.8	5.3	10.6	15.5	16.7	18.9
1954	19.6	19.9	17.8	12.4	9.0	4.0	2.2	6.0	9.6	13.1	15.4	18.8
1955	23.7	18.6	17.5	11.2	11.5	6.0	3.1	3.7	8.1	10.7	15.0	15.7
1956	20.7	18.3	17.5	11.1	6.8	4.2	5.4	4.3	8.0	12.0	17.5	17.3
1957	20.6	19.4	20.0	11.7	8.9	5.1	6.0	7.1	10.3	12.4	16.0	20.2
1958			17.6	13.0	6.8	4.3	5.3	5.7	9.9	13.2	16.3	21.6
1960	19.9	20.8	18.3	12.5	7.9	4.7	4.0	8.8	11.9	14.0	19.2	19.7
1961	19.4	19.2	18.7	14.0	7.9	6.6	6.4	6.4	10.0	9.4=	16.9=	18.1
1962	20.5	19.5	18.2	12.2	8.8	4.8	5.5	7.8	9.7	13.1	16.7	21.4
1963	21.3	20.3	17.7	12.2	8.1	5.4	4.2	6.6	13.7	15.1	18.7	19.7
1964	20.8	18.5	18.7	11.8	8.3	-0.9	3.7	6.1	9.4	12.9	15.2	19.3
1965	20.5	19.3	17.3	13.7	7.9	2.3	4.8	8.4	13.2	12.7	17.0	17.7
1966	22.2	18.9	18.0	14.0	8.1	7.3	4.3	8.1	9.7	16.2	17.1	21.1
1967	20.4	21.4	18.1	14.7=	1.5	4.3	6.0	3.1	2.0	6.3	17.7	19.8
1968	18.3	17.4	17.9	12.6	10.0	2.7	3.7	5.2	8.9	12.4	17.4	18.6
1969	20.3	20.3	18.5	12.1	8.7	5.1	4.2	6.5	8.6	12.9	16.8	20.6
1970	20.8	20.8	18.0	14.8	10.3	5.8	3.7	3.8	8.9	14.8	15.2	17.3
1971	20.0	20.2	18.2	13.5	9.9	7.6	6.6	4.6	9.4	13.3	16.4	19.1
1972	18.5	17.0	16.9		6.7	4.9	2.5	4.2	9.3	14.4	19.6	18.6
1973	19.9	19.9	17.9	13.8	7.1	4.7	5.6	5.8	7.9	13.5	16.7	18.6
1974	19.7	19.3	15.9	13.3	7.5	4.1	3.8	3.1	7.4	9.9	15.2	17.3
1975	18.7	18.6	15.5	10.6	5.5	3.9	3.9	3.7	10.3	10.1	14.8	15.7
1976	18.5=		2.5	12.9	9.0	4.1	2.6	3.1	9.4	12.8	11.4	17.5
1977	18.9	20.9	16.9	13.9	6.2	3.1	1.6	4.4	9.6	13.1	16.2	19.1
1978	19.1	19.5	18.4	13.6	7.0	1.7	4.7	3.6	8.3	9.9	16.7	18.6
1979	18.9	20.7	16.0	14.6	8.9	5.1	3.8	7.5	8.8	13.0	17.2	20.3
1980	20.3	20.0	18.6	11.7	4.1	4.6	3.5	7.7	8.4	11.5	14.5	18.1
1981	19.0	19.6	12.4=	13.5	9.3	3.6	3.9	4.9	6.5	10.0	13.7	15.7
1982	17.3	18.4	16.3	11.1	5.6	3.4	3.1	3.2	14.7	15.1	14.9	17.2
1983	21.2	17.0	17.3	14.7	7.5		4.7	4.9	11.3	14.9	16.5	19.8
1984	20.4	21.3	19.2	12.6	7.6	4.9	2.6	6.7	10.6	13.9	16.8	18.0
1985	21.9	21.4	15.6	13.1	8.5	3.6	3.6	7.4	10.1	17.0	19.3	17.6
1986	20.7	19.0	17.3	13.2	8.8	6.9	4.4	6.5	10.0	15.5	16.9	20.7
1987	19.6	20.8	19.0	14.1	9.9	4.8	4.8	6.3	10.7	15.0	16.9	18.7
1988	21.1	21.2	18.7	12.1		4.4	3.2	6.7	8.6	11.5	17.6	18.6
1989	19.7	17.7	16.1	13.4	8.2	1.8		5.1	8.5	11.0	16.0	18.8
1990	21.1	18.8	17.3	12.6	8.1	3.3	1.8	6.4	10.1	12.8	16.3	18.4
1991	20.7	19.1	16.1	13.1	8.0	4.6	2.4	3.7	9.4	13.5	16.7	18.8
1992	19.8	19.8	17.8	14.4	6.9	3.2	4.0	5.8	10.3	12.3	15.6	18.5
1993	21.6	18.4	19.2	12.0	7.0	3.8	6.7	7.7	10.9	16.5	18.0	19.9
1994	21.0	20.2	17.3	13.5	8.3	3.3	2.4	6.5	11.5	13.2	16.1	18.5
1995	20.7	21.1	18.6	12.5	9.8	4.4	3.0	6.6	10.9	11.3	16.7	17.5
1996	21.4	19.2	17.0	13.5	9.8	4.4	2.6	3.3	7.9	12.5	14.8	18.1
1997	20.7	18.7	17.6	10.6	7.2	4.9	4.8	7.6	11.4	15.6	15.1	19.5
1998	19.3	20.6	17.8	14.4	8.2	3.4	4.7	7.8	10.4	14.1	16.8	19.5
1999	21.5	21.6	21.1	13.9	10.0	6.0	6.8	5.7	9.1	16.5	18.1	20.1
2000	18.0	20.5	18.8	13.2	6.2	4.9	3.3	7.0	8.8	14.3	15.3	19.5
2001	19.1	19.5	19.2	14.2	6.7	4.7	3.5	4.7	7.9	13.6	15.6	16.6
2002	17.5	19.2	17.8	13.0	6.6	8.0	5.3=	3.7=	11.2=	13.5	15.0	19
2003	20.2	20.5	17.6		8.1	3.0	2.0	3.0	9.0			



	1951	1952	1953	1954	1955	1956	1957	1958	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
Average Maximum Temerature (˚C)	28	28	28	27	26	28	28	23	29	28	29	28	28	28	28	28	25	28	28	28	23	28	26	23	26	28
Average Mnimum Temerature (˚C)	12	12	13	12	12	12	13	9	13	13	13	14	12	13	14	11	12	13	13	13	11	13	11	11	7	12

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Average Maximum Temerature (˚C)	28	28	28	27	28	28	29	28	29	29	25	26	28	27	29	29	28	28	27	28	29	29	28	28	28	21
Average Mnimum Temerature (˚C)	12	13	12	11	12	12	13	13	13	13	12	11	12	12	12	13	13	13	12	13	13	14	12	12	12	7

Figure 3.4 Average of the daily maximum and minimum temperatures in ^{o}C by year; BOEGOEBERG DAM – IRR; Lat: -29.0550, Lon: 22.2000, Altitude: 891 m. Measured at 8:00 from 1951 – 2003.

There seem to be a cold spell every 20-25 years within the area. The average temperature in the area of Boegoeberg Dam seems to have stayed very invariable, except for the cold spells, over the period from 1951 to 2003, thus showing no signs of Global Warming within the area over this period (Figure 3.4)

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3.2.2 Rainfall

The study area receives summer rainfall, mainly in the form of scattered showers and thunderstorms. The wettest period is from January to April (van Rooyen 2001).

Rainfall values for the region were obtained from the South African Weather Bureau. The rainfall was measured at Boegoeberg Dam, about 25 km south-west of the study area, over a period from 1951 to the beginning of 2008.

The data in Table 3.3 show that the rainfall within this area is very variable, with the highest averages in January (33mm), February (41mm) and March (40mm) (Figure 3.5; Table 3.3).

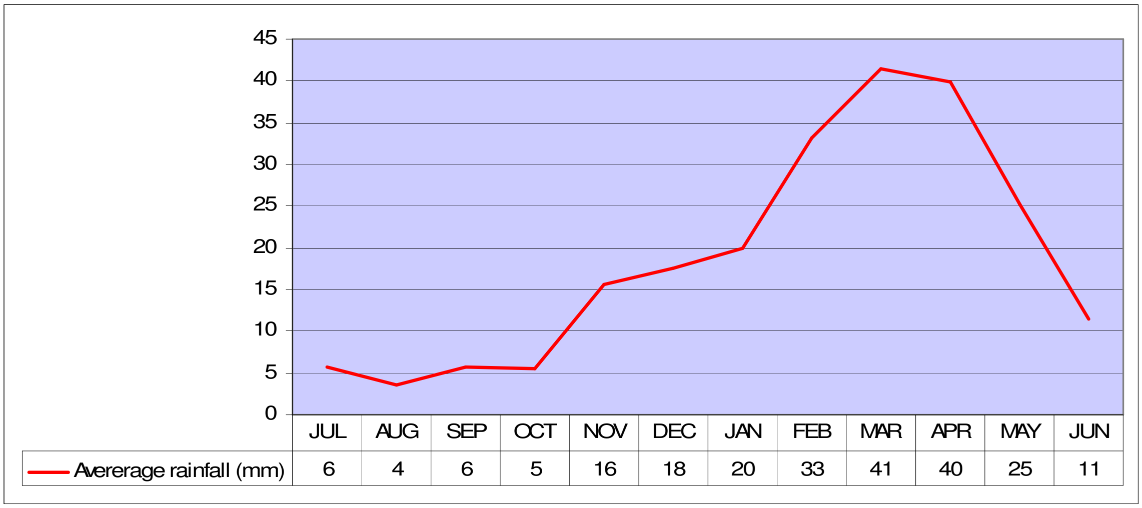


Figure 3.5 Average of the monthly rainfall (mm); BOEGOEBERGDAM – IRR; Lat: -29.0550, Lon: 22.2000, Altitude: 891 m. Measured at 8:00 from 1951 – 2007.

The study was done during January 2005 – June 2005. During this period the rain was 199.5 mm, which was the start of a wet cycle. The previous years had less rain over the same period. This average rainfall of 199.5 mm was higher than the average total (150 mm) over the same period, measured from 1951 – 2007 (Figure 3.6). Dry / wet cycles is prominently visible (5 – 8 years) in Figure 3.6 showing how variable the rainfall within this area is.

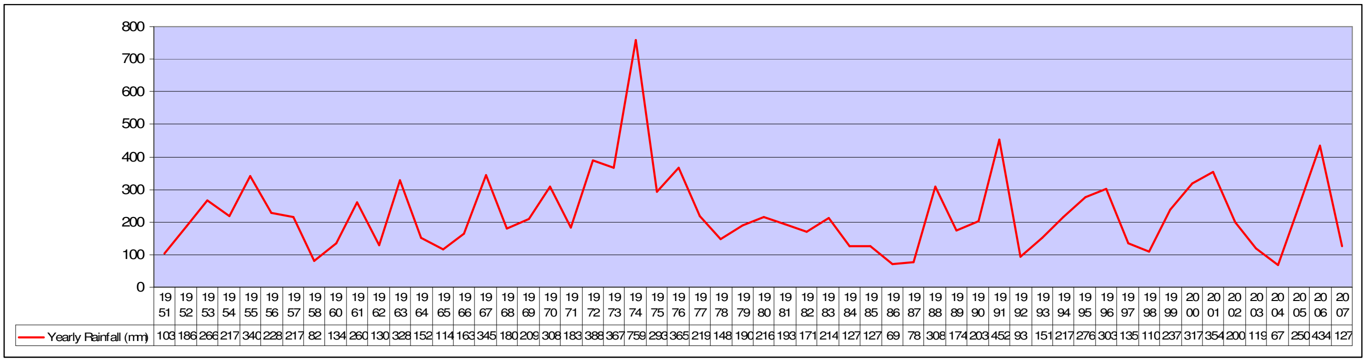


Figure 3.6 Total yearly rainfall (mm); BOEGOEBERGDAM – IRR; Lat: -29.0550, Lon: 22.2000, Altitude: 891 m. Measured at 8:00 from 1951 – 2007.

Table 3.3 Average of the daily rainfall (mm) by month; (=) – Indicates that the average is unreliable due to missing daily values. BOEGOEBERGDAM – IRR; Lat: -29.0550, Lon: 22.2000, Altitude: 891 m. Measured at 8:00 from 1951 – 2008. Values above 90 mm of rainfall in bold.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1951	24.3	19.3	14.2	9.1	17.5	2.0	0.0	0.0	3.0	2.0	0.8	10.4
1952	0.0	**120.9**	7.6	0.0	17.5	2.8	28.3	0.0	3.0	2.0	0.0	3.7
1953	10.8	65.5	4.4	54.2	1.3	1.7	0.0	8.4	0.0	25.4	43.8	50.3
1954	9.3	5.0	156.9	32.0	6.5	0.0	2.4	0.0	0.0	0.0	5.2	0.0
1955	**117.7**	33.8	21.8	12.8	13.8	9.1	5.0	2.3	0.0	18.5	67.0	38.5
1956	41.3	35.5	**107.2**	3.1	25.8	1.3	0.0	0.0	0.0	0.6	0.0	13.2
1957	10.8	13.4	31.1	4.5	27.1	3.1	4.2	14.4	6.0	27.2	36.7	38.0
1958		0.0=	0.4	5.6	34.3	0.0	0.0	0.0	2.5	2.8	11.6	24.5
1960	17.5	37.2	32.6	8.1	19.2	0.8	0.0	3.5	6.0	0.0	4.0	5.5
1961	57.0	5.0	76.5	25.0	22.5	23.0	21.5	0.0	2.5	0.0	27.0	0.0
1962	8.2	60.0	9.5	2.0	0.0	1.7	1.7	7.0	1.7	0.0	33.0	5.0
1963	65.0	17.8	48.3	62.3	7.7	3.5	7.6	11.0	0.0	38.9	17.6	48.0
1964	0.0	17.5	32.0	7.5	0.0	28.5	0.0	0.5	1.0	15.5	15.5	33.6
1965	0.0	0.6	51.0	33.2	0.0	4.5	1.3	0.0	5.0	16.5	2.0	0.0
1966	26.5	8.7	23.5	33.0	0.0	3.5	0.0	0.0	3.5	36.0	0.0	28.2
1967	21.0	72.7	39.3	**134.7**	24.0	3.6	0.0	3.0	0.0	24.2	22.3	0.0
1968	0.0	2.5	67.2	34.6	52.0	0.0	0.0	0.0	0.0	12.3	0.7	10.5
1969	0.0	65.0	24.5	73.6	10.0	2.5	0.0	0.0	0.0	25.5	4.5	3.0
1970	17.5	**94.0**	0.0	25.0	12.5	16.0	0.0	51.5	0.0	19.0	16.4	56.0
1971	35.5	34.0	4.0	20.5	19.5	20.0	2.5	0.0	0.0	36.0	8.5	2.0
1972	**211.5**	6.3	**147.5**	13.0	0.0	0.0	3.0	0.0	3.0	2.0	2.0	0.0
1973	0.0	**111.5**	41.5	**115.0**	0.0	0.0	23.5	1.7	10.0	20.0	6.0	38.0
1974	**260.5**	**168.2**	**114.0**	**93.6**	21.2	5.2	0.0	34.5	0.0	0.0	21.5	40.0
1975	36.5	27.5	**109.3**	1.0	9.0	2.0	9.0	0.0	9.0	0.0	43.5	46.5
1976	56.0	**126.5**	54.0	51.0	2.5	25.5	5.5	0.0	4.1	37.5	0.0	2.5
1977	27.7	28.0	38.0	6.9	18.0	0.0	0.0	0.0	17.0	0.0	82.0	1.1
1978	42.0	37.0	35.0	16.0	0.0	0.0	0.0	7.0	1.7	4.0	0.0	5.0
1979	24.0	5.7	0.0	22.0	42.0	0.0	4.0	29.0	0.0	46.0	17.0	0.0
1980	0.0	16.0	44.5	28.0	0.0	0.0	0.0	18.5	15.0	0.0	64.5	29.0
1981	0.0	65.0	20.0	6.0	3.0	0.0	0.0	52.0	0.0	42.0	5.0	0.0
1982	0.0	22.0	68.5	27.5	0.0	4.5	0.0	0.0	0.0	20.2	0.7	28.0
1983	3.5	0.0	24.0	35.0	16.1	13.0	0.0	0.0	2.0	25.5	41.0	53.5
1984	0.0	0.0	13.0	40.0	15.0	14.0	0.0	18.5	0.0	21.0	5.0	0.0
1985	5.0	32.5	26.5	2.7	0.0	0.0	0.0	0.0	1.0	3.7	40.0	15.3
1986	5.5	0.0	28.0	18.3	0.0	15.1	0.0	0.0	0.4	1.0	1.1	0.0
1987	0.0	3.6	2.0	10.8	1.5	0.0	20.3	0.0	11.3	5.0	23.0	0.0
1988	3.0	79.0	48.0	15.3	9.0	0.0	0.0	0.8	22.0	1.1	1.6	**128.5**
1989	5.2	**113.4**	0.3	15.8	20.0	0.1	2.0	0.0	17.0	0.0	0.5	0.0
1990	10.0	**116.0**	9.0	53.0	0.0	15.0	0.0	0.0	0.0	0.0	0.0	0.0
1991	**127.0**	40.0	89.0	2.0	0.0	9.0	0.0		20.0	**115.0**	16.0	34.0
1992	6.0	13.0	49.0	0.0	0.0	1.0	0.0	4.0	0.0	13.0	7.0	0.0
1993	0.0	45.0	13.0	2.0	0.0	11.0	28.0	1.0	0.0	17.0	13.0	21.0
1994	75.0	55.0	30.0	2.0	0.0	18.0	0.0	0.0	0.0	6.0	24.5	6.0
1995	76.0	0.0	72.0	0.0	2.0	0.0	0.0	4.0	2.0	6.0	44.0	70.0
1996	54.0	**100.0**	17.0	1.0	6.0	0.0	23.0	2.0	0.0	0.0	70.0	30.0
1997	16.0	2.0	**94.0**	5.0	9.0	9.0	0.0	0.0	0.0	0.0	0.0	0.0
1998	29.0	25.0	22.0	1.0	0.5	0.0	2.0	0.0	3.0	9.0	12.0	6.0
1999	22.0	6.0	34.5	10.0	68.0	0.0	0.0	0.0	0.3	49.0	0.0	47.0
2000	58.0	**96.0**	65.0	51.0	0.0	0.0	0.0	3.0	39.0	0.0	2.0	3.0
2001	2.0	19.0	41.0	57.0	0.0	19.0	0.0	0.0	60.0	38.5	**93.5**	23.5
2002	28.5	54.0	6.0	3.0	0.0	19.0	0.0	21.0	5.0	0.0	7.0	56.5
2003	0.0	55.0	20.0	31.0	2.5	0.0	0.0	3.0	7.0			
2004					0.0	0.0	0.0	0.0	22.0	33.0	0.0	12.0
2005	44.0	84.5	20.5	24.5	26.0	10.0	0.0	0.0	0.0	10.0	13.0	17.0
2006	**160.0**	52.0	69.0	52.0	59.0	0.0	1.0	14.0	0.0	9.0	6.0	11.5
2007	3.5	10.5	13.0	21.0	0.5	3.0	6.0	0.0	0.0	41.0	9.0	19.3
2008	52.0	20.0	36.0	4.0	0.0=							

3.2.3 Wind

Hourly wind direction and speed analysis (South African Weather Bureau). Wind direction ranges that are used is shown in Table 3.4.

Table 3.4 Wind direction ranges – Direction and Decimal degrees

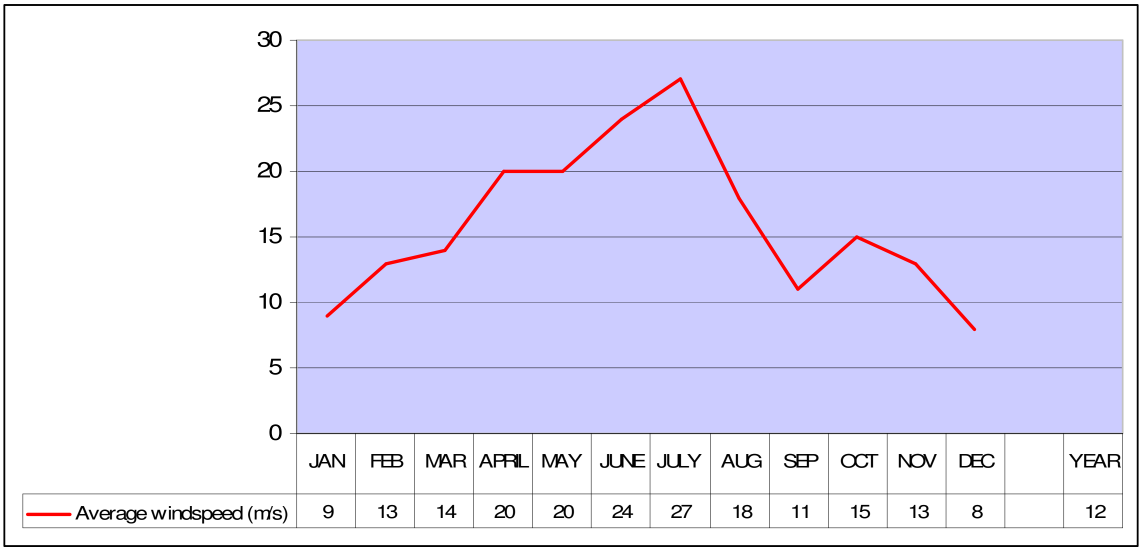
N	direction >= 348.75	or	direction < 11.25
NNE	11.25 to 33.74		
NE	33.75 to 56.25		
ENE	56.25 to 78.74		
E	78.75 to 101.24		
ESE	101.25 to 123.74		
SE	123.75 to 146.24		
SSE	146.25 to 168.74		
S	168.75 to 191.24		
SSW	191.25 to 213.74		
SW	213.75 to 236.24		
WSW	236.25 to 258.74		
W	258.75 to 281.24		
WNW	281.25 to 303.74		
NW	303.75 to 326.24		
NNW	326.25 to 348.74		

The main wind direction throughout the year is South-East (Table 3.5). July has the highest average wind speeds (27 m/s). April, May and June also have strong winds with averages ranging from 20 – 24 m/s (Figure 3.7). The area has an average yearly wind speed of 12 m/s, measured from 1992 to early 2008.

Table 3.5 The percentage frequency (ff) for each wind direction (including calms) and average wind speed (ss) in m/s. Hourly wind analysis data from 1992 to 2008 at BOEGOEBERGDAM – IRR; Lat: -29.0550, Lon: 22.2000, Altitude: 891 m

MONTH	CALM	N		NNE		NE		ENE		E		ESE		SE		SSE	
	ff	ff	ss	ff	ss	ff	ss	ff	ss	ff	ss	ff	ss	ff	ss	ff	ss
JAN	0	8	2	0	0	15	1	0	0	18	1	0	0	27	1	0	0
FEB	0	5	2	0	0	9	1	0	0	33	1	0	0	33	1	0	0
MAR	0	5	3	0	0	6	1	0	0	24	2	0	0	29	1	0	0
APRIL	0	3	3	0	0	2	3	0	0	17	2	0	0	43	2	0	0
MAY	0	2	4	0	0	0	0	0	0	16	2	0	0	53	2	2	3
JUNE	0	3	3	0	0	5	3	0	0	13	3	0	0	35	3	0	0
JULY	0	5	3	0	0	2	3	0	0	8	3	0	0	50	3	2	3
AUG	0	5	3	0	0	0	0	0	0	10	3	0	0	42	2	0	0
SEP	0	2	1	0	0	2	1	0	0	18	1	0	0	55	2	0	0
OCT	0	6	2	0	0	8	2	0	0	23	2	0	0	37	1	0	0
NOV	0	7	1	0	0	5	2	0	0	17	2	0	0	45	1	0	0
DEC	0	3	1	0	0	8	1	0	0	19	1	0	0	39	1	0	0
YEAR	0	5	2	0	0	6	0	0	0	18	2	0	0	40	2	0	0

MONTH		S		SSW		SW		WSW		W		WNW		NW		NNW	
		ff	ss	ff	ss	ff	ss	ff	ss	ff	ss	ff	ss	ff	ss	ff	ss
JAN		4	2	0	0	0	0	0	0	16	1	0	0	12	1	0	0
FEB		7	2	0	0	4	2	0	0	2	3	0	0	7	1	0	0
MAR		6	2	0	0	10	2	0	0	10	2	0	0	10	1	0	0
APRIL		8	2	0	0	3	3	0	0	17	2	0	0	7	3	0	0
MAY		13	2	0	0	2	1	0	0	10	3	0	0	3	3	0	0
JUNE		20	3	0	0	7	3	0	0	7	3	0	0	10	3	0	0
JULY		16	3	0	0	6	3	0	0	10	3	0	0	2	3	0	0
AUG		11	2	0	0	5	3	0	0	11	3	0	0	16	2	0	0
SEP		5	2	0	0	5	1	0	0	8	1	0	0	5	2	0	0
OCT		6	1	0	0	8	2	0	0	6	2	0	0	3	3	0	0
NOV		3	3	0	0	2	1	0	0	8	2	0	0	13	1	0	0
DEC		2	1	0	0	5	1	0	0	11	1	0	0	13	1	0	0
YEAR		8	2	0	0	4	0	0	0	10	2	0	0	9	2	0	0



	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC		YEAR
Average windspeed (m/s)	9	13	14	20	20	24	27	18	11	15	13	8		12

Figure 3.7 The average windspeed (m/s) for Boegoebergdam area for a period 1992 – 2008; 1 m/s = 1.944 knots = 3.6km/hr.

3.3 Geology

The study area is situated in the south eastern corner of the Kalahari. Rocks of the Olifantshoek Supergroup (Volop Group), and the tectono-statigraphic Namaqua-Natal Province (Brulpan Group) occur in the area and are covered by the Kalahari Group (Table 3.6; Figure 3.8, 3.9) (Geological Survey 1977, 1995 & 1998; SACS 1980; Cornell *et al.* 2006; Moen 2006).

Table 3.6 Schematic lithology of the main geological features found at the study area (Cornell *et al.* 2006; Moen 2006; Partridge *et.al.* 2006)

Main Geological Feature	Group	Subgroup	Formation
Cenozoic Deposits of the Interior	**Kalahari Group**		Gordonia Formation
The Namaqua-Natal Province	**Brulpan Group**		Groblershoop Formation
			Uitdraai, Prynnsberg & Boegoeberg Formation
			Dabep Formation
Olifantshoek Supergroup	**Volop Group**	**Brulsand Subgroup**	Vuilnek & Vryboom Formation
			Top Dog Formation
			Verwater Formation
		Matsap Subgroup	Glen Lyon Formation
			Ellie's Rust Formation
			Fuller Formation
			Hartley & Boegoeberg Dam Formation
			Lucknow Formation
			Mapedi & Gamagara Formation

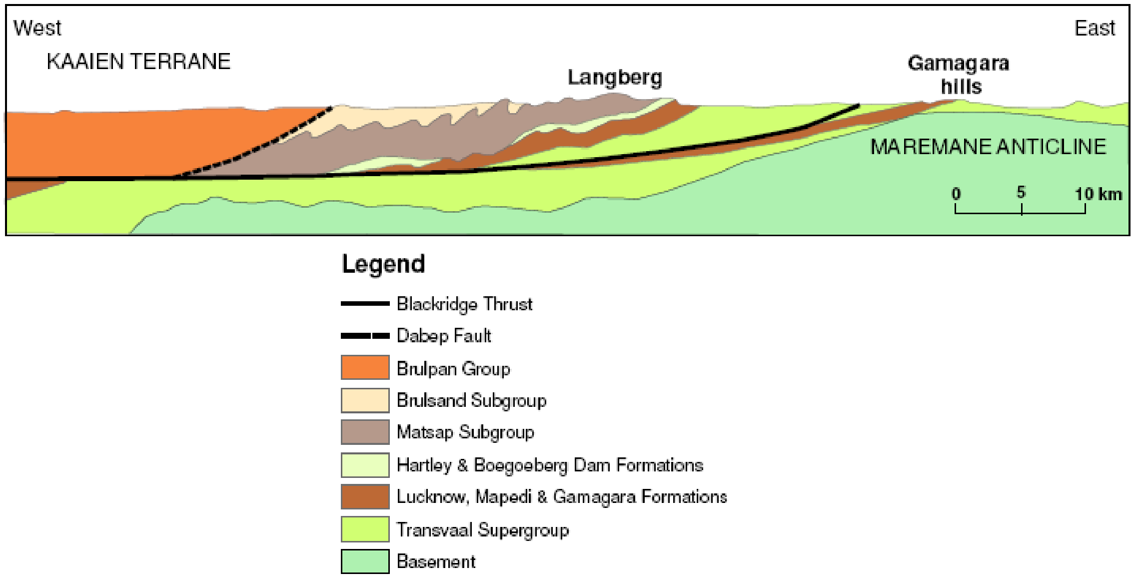


Figure 3.8 A section through the western edge of the Kaapvaal Craton, illustrating the sequence of strata (adapted from Moen 2006).

3.3.1 Olifantshoek Supergroup

The Olifantshoek Supergroup in the study area is comprised of a sequence of metamorphosed sedimentary strata mainly interbedded shale, quartzite, subgraywacke and andesitic lava overlain by a thick succession of coarse red and grey quartzite and minor shale with a total thickness of approximate 7 000 m (Geological Survey 1977, 1995 & 1998; SACS 1980; Moen 2006). The age of the Olifantshoek Supergroup ranges from 1893 Ma to 1928 Ma (Moen 2006).

At the base of the Olifantshoek Supergroup lie the Lucknow Formation (its thickness is estimated as 1500 m, might be less than 1000 m) and Mapedi Formation (with a thickness of about 500 m). Small outcrops of the two Formations are visible east of the prominent Langberg (Geological Survey 1977, 1995 & 1998; Moen 2006). The Gamagara Formation is regarded as equivalent to the Mapedi formation. However the Mapedi & Gamagara Formations consist of Shale with interbedded quartzite and basaltic lava, whereas the Mapedi Formation consists of White quartzite and shale with subordinate dolomite and conglomerate (Moen 2006).

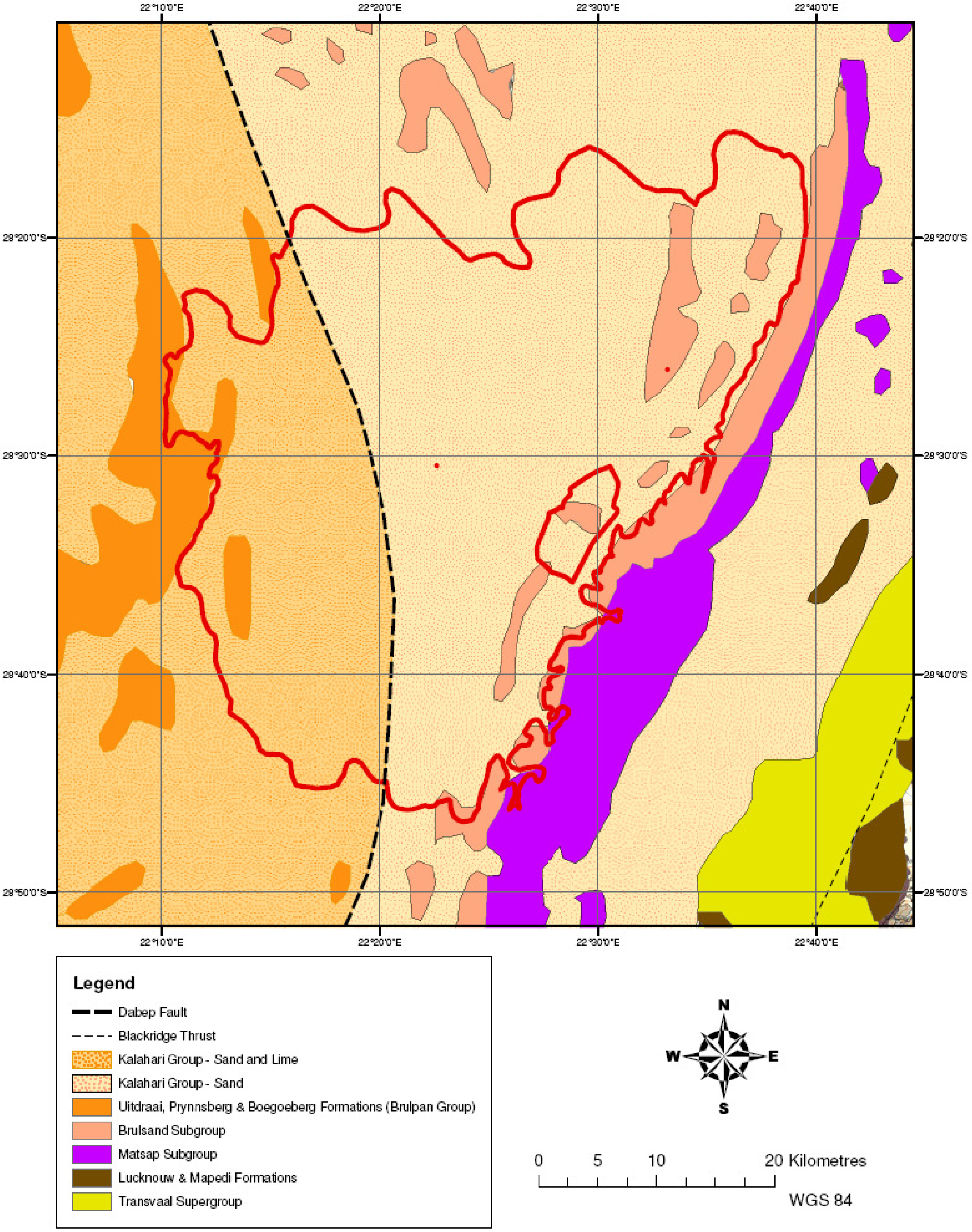


Figure 3.9 Geological map of the study area (adapted from Cornell *et al.* 2006; Moen 2006)

Above the Lucknow Formation and Mapedi Formation lies the Hartly & Boegoeberg Dam Formations with a thickness of approximately 762 m. Age determination on the lava indicates an age of 1928 ± 4 million years (Geological Survey 1977, 1995 & 1998). A conglomerate layer referred to as the Neylan Bed, consisting of mainly basalt and tuff with interbedded lenses of quartzite and conglomerate (Moen 2006).

Overlying the Hartly & Boegoeberg Dam Formations is the Volop Group, divided into the Matsap and Brulsand Subgroups, with the Matsap Group as the older of the two.

The Fuller Formation of the Matsap Group, overlying the Hartly Formation, consists of cross-bedded, coarse-grained quartzite, 2 300 m thick. Overlying the Fuller Formation is the Ellie's Rust Formation. The Ellie's Rust Formation is represented by fine-grained, grey-coloured quartzite. Following the Ellie's Rust Formation, reddish-brown, is the coarse grained quartzite of the Glen Lyon Formation, the last two formations each approximately 700 m thick. These three formations belong to the Matsap Subgroup of the Volop Group and form the prominent Langberg (Moen 2006).

Overlying the Matsap Subgroup are the Verwater, Top Dog and Vuilnek & Vryboom Formations of the Brulsand Subgroup. The eastern part of the study area falls within the Brulsand Subgroup. The Verwater Formation consists of grey, medium-grained, cross-bedded quartzite with haematite nodules and thin pebble layers (approximately 300 m thick) and the Top Dog Formation comprises predominantly white quartzite with interbedded shale (approximately 600 m thick). The Top Dog Formation is overlain by the light-grey, cross-bedded quartzites with scattered pebble layers of the Vryboom and Vuilnek Formations. The last two formations occur in the sand covered region west of the Langberg. The top of the Volop Group is not exposed. The Volop Group has an apparent thickness of 4 000 – 4 500 m (Moen 2006).

Outcrops of the intensely folded quartzitic beds of the Top Dog Formation are visible between the Kalahari sand dunes, while the other formations form the prominent Langberg to the east of the study area (Geological survey 1977).

The strata of the Olifantshoek Supergroup are intensely folded. The general strike of the western limb of the regional synclinorium is from 30 – 45 degrees to the west. The strata are intensely folded and are visible in the Langberg Mountains. The strike of the syn- and anticlines axes are north-south and the plunch of the axes of the synclines are to the north. The folding of the strata to the west of the Langberg gives rise to the sand filled depression between the mountains and the dunes west of the Langberg. The quartzite outcrops could have acted as a trap for the sand (Geological Survey 1977).

3.3.2 Namaqua-Natal Province

The Namaqua-Natal Province is a compilation of igneous and metamorphic rocks, formed or metamorphosed around 1200 to 1000 Ma. It comprises of three main lithostratigraphic components: The reworked Kheisian rocks (approximately 2000 Ma), Juvenile supracrustal and plutonic rocks formed during the rifting, ocean spreading and subduction phases around 1600 to 1200 Ma, and assembled during collision events accompanied by intense deformation and metamorphism. The third lithostratigraphic sequence is the voluminous syn- and post tectonic granitoids formed between 1200 and 1000 Ma (Moen 2006). The Namaqua-Natal Province is subdivided into a number of tectonostratigraphic subprovinces and terranes. Five domains are recognised in the Namaqua Sector (from West to East): Richtersveld Subprovince (~2000 Ma), Bushmanland Terrane (~2000 Ma), Kakamas Terrane (~2000 Ma), Areachap Terrane (~1300 to 1000 Ma) and the Kaaien Terrane consisting of Kheisian rocks (~2000 Ma) and early Namaquan volcano-sedimentary rocks and undeformed, but thermally metamorphosed, bimodal volcanic rocks (Cornell *et al.* 2006).

The Brulpan Group consists mainly of quartz-muscovite schists and sercitic quartzite. In the east the group is structurally underlain by the Olifantshoek Supergroup. The Brulpan Group generally dips westwards. The Dapeb formation is the basal unit , and is directly against the Olifantshoek Supergroup. The contact is known as the Dabep Thrust. The Dapeb formation is composed of sheared quartz-sericite schist, subordinate quartz-chlorite schist and actinolite chlorite schists. This formation is overlain by the Boegoeberg Formation (the Skurweberg), consisting of a 550m thick succession of light grey, medium- to fine grained quartzite with a strong bedding-parallel foliation (Cornell *et al.* 2006).

The Kaaien Terrane consists of the following main stratigraphic components: Brulpan Group, Vaalkoppies Group, Wilgenhoutsdrif Group and the Koras Group. The study area fall within the Brulpan group (Cornell *et al.* 2006).

3.3.3 Kalahari Group

In the heart of the sub-continent, covering nearly one-third of the area is the sand-filled basin of the Kalahari (King 1963). It is perhaps the greatest expanse of sand in the world. Yet in times past its extent were ever greater and considerable portions of the surrounding countries, northern part of South Africa, Zimbabwe, Angola and Zaire were buried at the period of maximum sand spread.

Tankard *et al.* (1982) indicated that epeirogenesis and widespread erosion characterized the Cainozoic history of the interior of South Africa. Towards the end of the Mesozoic [65 million years ago (Geological Survey 1998)] the palaeo-geography of central southern Africa consisted of the internal drainage system of the Kalahari (Kgalagadi) basin and, further south, the Orange-Vaal drainage basin. Although deposition in the large Kalahari basin may have been initiated in the Cretaceous (Du Toit 1954), other deposits, including the hominid cave sites and river gravels, date back no further than the Pliocene (7 – 2.5 million years ago) (MacRae 1999).

The pre-Kalahari topography was moulded by northward-flowing streams. Initially deposition was concentrated on ephemeral braided floodplains (Tankard *et al.* 1982). Basal conglomerates show lithologic affinities with distant sources. However, the overlying conglomerates are more argillaceous and were probably derived from the basin margins (Tankard *et al*. 1982). In places the alluvial gravels are thicker than 90 m over bedrock channels and are caliche cemented (Du Toit 1954). The remainder of the succession consists mainly of red shales, marls, and sandstones with duricrusts. A maximum thickness in excess of 180 m is recorded for the last mentioned (Tankard *et al*. 1982).

Caliche crusts are most conspicuous in the southern regions of the Kalahari basin and represent a series of large pan terraces. The presence of caliche and silcrete crusts, together with an abundance of dolomite, indicate an arid climate and saline conditions (Tankard *et al*. 1982).

Since the Tertiary (65 million years ago) the Kalahari landscape has been characterized by aeolian dune sand accumulation, punctuated periodically by cold, wet periods. These climatic oscillations are recorded in the dolomitic Ghaap escarpment along the south-eastern margin of the Kalahari, just to the east of the study area where six major complexes of cryoclastic breccia and tufa accumulation have been identified. Van Rooyen & Verster (1983) proposed a tentative stratigraphic framework and paleoclimatic correlation for the Witsand features (Table 3.7). MacRae (1999) indicated that the global temperature was about 10^{o}C at the beginning of the Pleistocene. Late Quaternary pluvial conditions 18 000 – 11 000 years ago are correlated with high lake levels in the Makgadikgadi depression in the southern Kalahari (Tankard *et al.* 1982).

Table 3.7 Tentative stratigraphic framework and palaeoclimatic correlation for the Witsand features (Tankard *et al*. 1982; Van Rooyen & Verster 1983)

Events	**Chronostratigraphy (Date in year BP)**	**Possible or inferred climate**
Peat formation	Holocene (0 - 10 000)	Alternating warm & dry and warm & wet periods
Active dune formation		Warm and dry
Recharge of groundwater		Warm and wet
Habitation by Wilton people	Holocene (8 000- 10 000)	
Exposure of plinthite and hardening into ferricrete; erosion; lowering of the water table	Late Upper Pleistocene (10 000 - 14 000)	Warm & dry
Formation of plinthite; accumulation of groundwater in the two bases	Upper Pleistocene (20 000 - 45 000)	Cold wet to very wet
Habitation of Middle stone age people	Upper to middle Pleistocene (>40 000)	
Deposition of aeolian sand and admixture with locally derived sandy parent materials	Middle Pleistocene (>50 000)	Warm & dry
Sedimentation in and from water	Late-Pleistocene	Wet
Formation of calcretes	Mid-Pleistocene	Very dry
The landscape was aggradational, marls accumulation	Early Tertiary	

3.3.4 Vegetation correlation to the geology

The western part of the study area is situated on the Kaaien Terrane. The Dabep Thrust forms the boundary between the Brulpan Group of the Kaaien Terrane (Namaqua-Natal Province) and the Volop Group of the Olifantshoek Supergroup (Cornell *et al.* 2006). The Dabep Thrust runs almost through the middle of the study area from north to south. The Dabep Thrust also coincides with the boundary line between two of the vegetation communities (*Pentzia calcarea – Eragrostis lehmanniana – Stipagrostis obtusa* Open Grassland, occurring the Brulpan Group, and *Acacia haematoxylon – Elephantorrhiza elephantina – Eragrostis lehmanniana* Low Grassy Bushland, occurring the Volop Group). *Acacia mellifera – Rhigozum trichotomum – Eragrostis lehmanniana* High Open Shrubland occurs on the areas close to the mountains (outcrops) and right on top of the Dabep Thrust (Figure 3.10).

This association between plant communities and underlying rock type is in spite of the fact that the rocks are covered by aeolian sand, indicating the importance of geology for distribution of vegetation. Similar associations between geology and vegetation are *inter alia* described for the Suikerbosrand (Bredenkamp & Theron 1978, 1980), and the Kruger National Park area (Bredenkamp 1982; Coetzee 1983; Gertenback 1987; Bezuidenhout 1993)

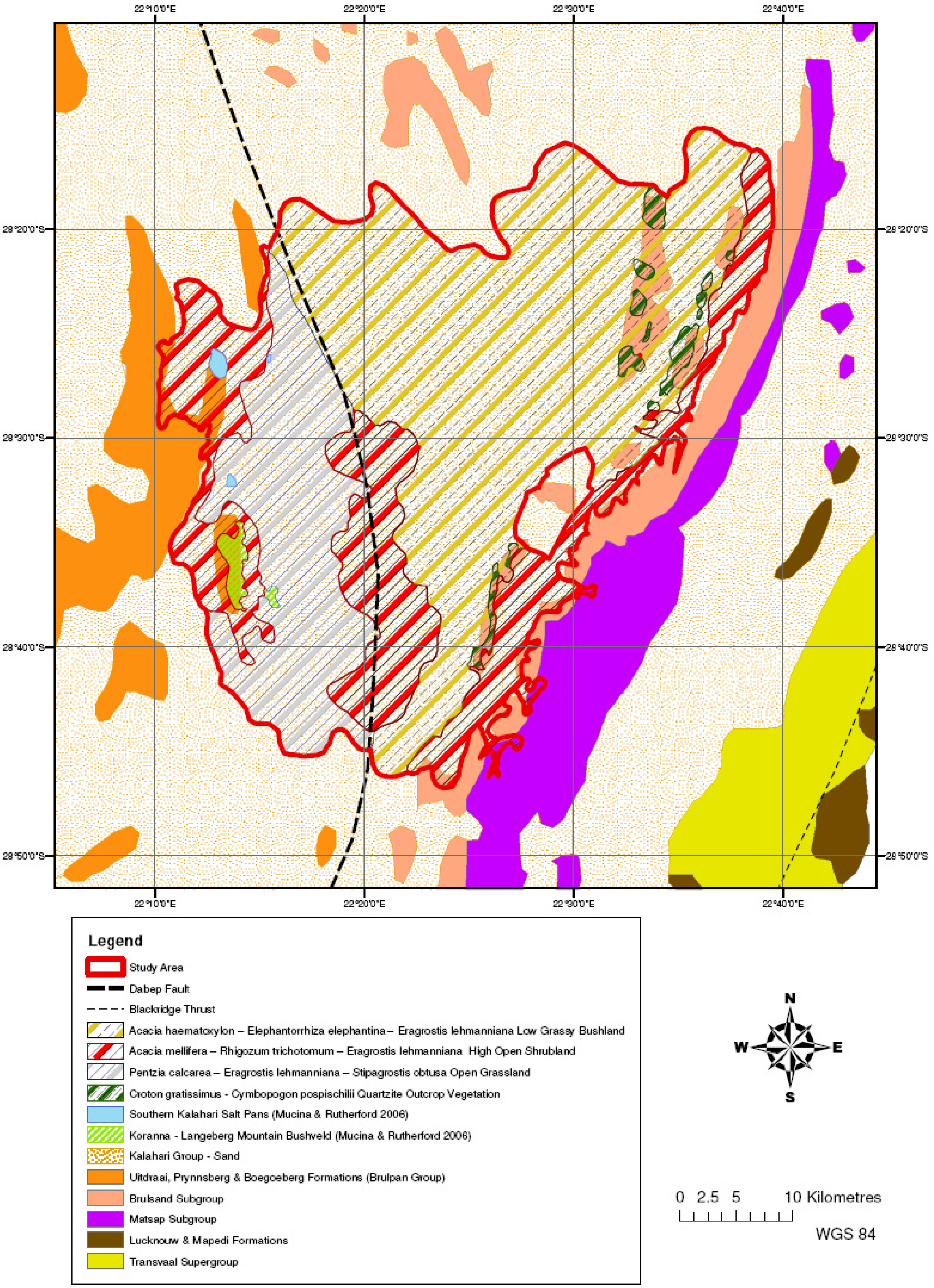


Figure 3.10 Vegetation within the study area compared to the geology map (geology adapted from Cornell *et al.* 2006; Moen 2006).

3.4 Soil

With the exception of limited areas in the south and west, where scrub-dotted boulder plains or limestone-capped plateaux occur, the region is covered with a continuous mantle of sand through which steep-sided mountains project rarely as inselbergs. Over most of the central and southern Kalahari, soils are classified as arenosols in the FAO-UNESCO classification. However, the Kalahari sand is not homogeneous and it differs in colour, texture and depth (Thomas & Shaw 1991).

Upon weathering the strata of the Olifantshoek Supergroup yield medium to coarse-grained sand (Van Rooyen & Verster 1982), containing about 90 percent quartzite (Thomas and Shaw 1991). The aggregated land surface of the plains is composed of reddish and yellowish sand of Quaternary age (Van Rooyen & Verster 1982). Van Rooyen and Verster (1982) stated that there is little doubt that these sands are of aeolian origin (regic sands (Soil Classification Working Group 1991)) and that they were blown in from the northwest during the arid periods of the Pleistocene. The sand is predominantly fine and 65 – 70% of the sand falls in the 0.02 – 0.2 mm fraction (Van Rooyen & Verster 1982), Thomas & Shaw (1991) mention that the fraction size of the sand is between 0.063 and 2 mm. The sand in and around Witsand Nature Reserve, is somewhat coarser, and differs from those of the plains within the study area (Van Rooyen & Verster 1982). These sands are probably a mixture of the aeolian sand and sandy material derived from the Olifantshoek Supergroup formations.

The colour of the Kalahari sand is most often described as red (King 1963), however some can have a yellowish colour (King 1963); but with water it becomes grey or even white (King 1963; Wright 1978).

Deposits of fine, red sand are often arranged in great longitudinal dunes. In the southern part of the region the dunes are fixed by vegetation, except along some dune crests. The height of the dunes seldom exceeds 12 m and the thickness of the sand cover averages only about 5 m (King 1963). The sand cover could reach a depth of more than 400 m in some areas of the Kalahari (Thomas & Shaw 1991), areas on top of calciferous deposits (western part of the study area, west of the Dabep Fault), the sand depth is as shallow as 1 m or less. King (1963) indicated that the main source of the sand can be found in the Kalahari itself where for ages, probably since "Gondwana" time, detritus has been swept in from surrounding regions. Within the area, distribution was mainly by wind and the grain size is exceptionally even over large areas. In places the boundaries of the Kalahari are not definite, for the sand thins away and forms isolated patches on the surrounding plateau. Occasionally a record of its former greater extent is provided by dune patterns in the vegetation. The boundary is sharp only near Marienthal in Namibia and along the Langberg-Korannaberg in the east (Van Rooyen & Verster 1982).

The Witsand Nature Reserve is known for an acoustical phenomenon which occurs in the accumulation of whitish and light yellowish sands with a dune-like appearance. The dunes make a roaring sound when disturbed (Van Rooyen & Verster 1982). The roaring sands (Brulsand) occur at the edge of the dunes with an average angle of 30^{o} and mainly the dunes that face a southerly direction.

The landscape was an aggradational one during the early Tertiary when the Kalahari marls accumulated. Passage of mid-Tertiary calcrete across these, as well as the surrounding country, suggests a very dry regime at that time. Spreading of the Botletle beds shows that sedimentation in and from water was resumed in the late Tertiary, before the Pleistocene spread of red wind-blown sand which today is the universal aspect of the Kalahari (King 1963).

Three types of soil forms were identified in the study area (Soil Classification Working Group 1991):

Mispah form (Ms)

This form of soil is found on the koppies and mountainous areas where the soil is very shallow. Mispah soil compises an orthic A-horizon overlying hard rock. The Koranna-Langeberg Mountain Bushveld and *Cymbopogon pospischilii – Croton gratissimus* Quartzite Outcrop Vegetation are the plant communities found on this type of soil form.

Namib form (Nb)

Most of the study site is covered by sand and is classified as Namib form (Nb). Namib soils comprises an orthic A-horizon overlying regic sands. The orthic A-horizon plus the regic sand must be deeper than 500 mm to classified as a Namib form if a classifiable soil occurs beneath the regic sand.

Three soil families from the Namib form were identified within the study area. These are:

Nortier soil family

The Nortier soils are classified as yellow regic sand (7.5YR - Munsell chart (1971)), with no lime present within 1 500 mm from the soil surface. This soil family is closely associated with the *Acacia haematoxylon – Elephantorrhiza elephantina – Eragrostis lehmanniana* Low Grassy Bushland.

Kalahari soil family

This soil family consists of red regic sand, with a soil colour of 5YR (Munsell chart 1971) and no lime present within 1 500 mm from the soil surface. *Acacia mellifera – Rhigozum trichotomum – Eragrostis lehmanniana* High Open Shrubland vegetation community is closely related to the Kalahari soil family.

Henkries soil family

Henkries soils are red regic sand (5YR - Munsell chart (1971)), containing lime within 1 500 mm from the soil surface. Henkries soils are associated with the *Pentzia calcarea – Eragrostis lehmanniana – Stipagrostis obtusa* Open Grassland.

Coega form (Cg)

The Coega form comprises soils with a shallow (less than 500 mm) orhtic A-horizon overlying a hard carbonate horizon. These soils are found as patches surrounded by Henkries soils, and are also related to the *Pentzia calcarea – Eragrostis lehmanniana – Stipagrostis obtusa* Open Grassland.

3.5 Geohydrology

Van Rooyen & Verster (1983) concluded that the evidence presented at Witsand Nature Reserve and surrounding areas, indicates that the region was subjected to distinct events. These events include: deposition and admixture of sandy parent materials; accumulation of groundwater in two natural dams; pedogenesis (discoloration of sandy deposits by means of hydromorphism and plinthite formation); erosion and subsequent hardening of plinthite into ferricrete due to exposure; at the same time the general reduction of the water table to the present level about 15 m lower; habitation by two Stone Age cultures; recent active dune formation; and recharge of groundwater and peat formation. These events provide information about climatic changes during the

Quaternary and can tentatively be correlated with the record of climatic evolution of this region. In itself the ferricrete represents an irreversible, self-terminating feature and is an indicator of palaeoclimatic conditions much wetter than those of today. It is therefore out of phase with the present climate and thus a paleosol with relict features. The stratigraphy of the ferricrete presents evidence of the extent to which water accumulated during wet periods of the Upper Pleistocene and the periods in which the water table was stationary with seasonal fluctuation (Van Rooyen & Verster 1983).

Owing to the extreme flatness of the landscape, the irregularities of the various reed-margined channels, and the great absorption by the sand, the waters in the cross connections moved slowly first in one direction and then in another as the depressions gradually fill and then dry up. These courses were evidently produced by ponding consequent upon back-tilting during the Tertiary (Van Rooyen & Verster 1983).

3.6 Geomorphology

The underlying hard strata of the Olifantshoek Supergroup, according to Van Rooyen & Verster (1983), form two basins below the sand cover. The study area is between the Langberg in the east and the Skurweberg in the west. The biggest part of the southern Kalahari is flat with a low relief (Figure 3.11). The altitude above sea level ranges from 1 020 – 1 340m. Witsand Nature Reserve is about 3 232 ha whereas the current study area is about 160 000 ha in size.

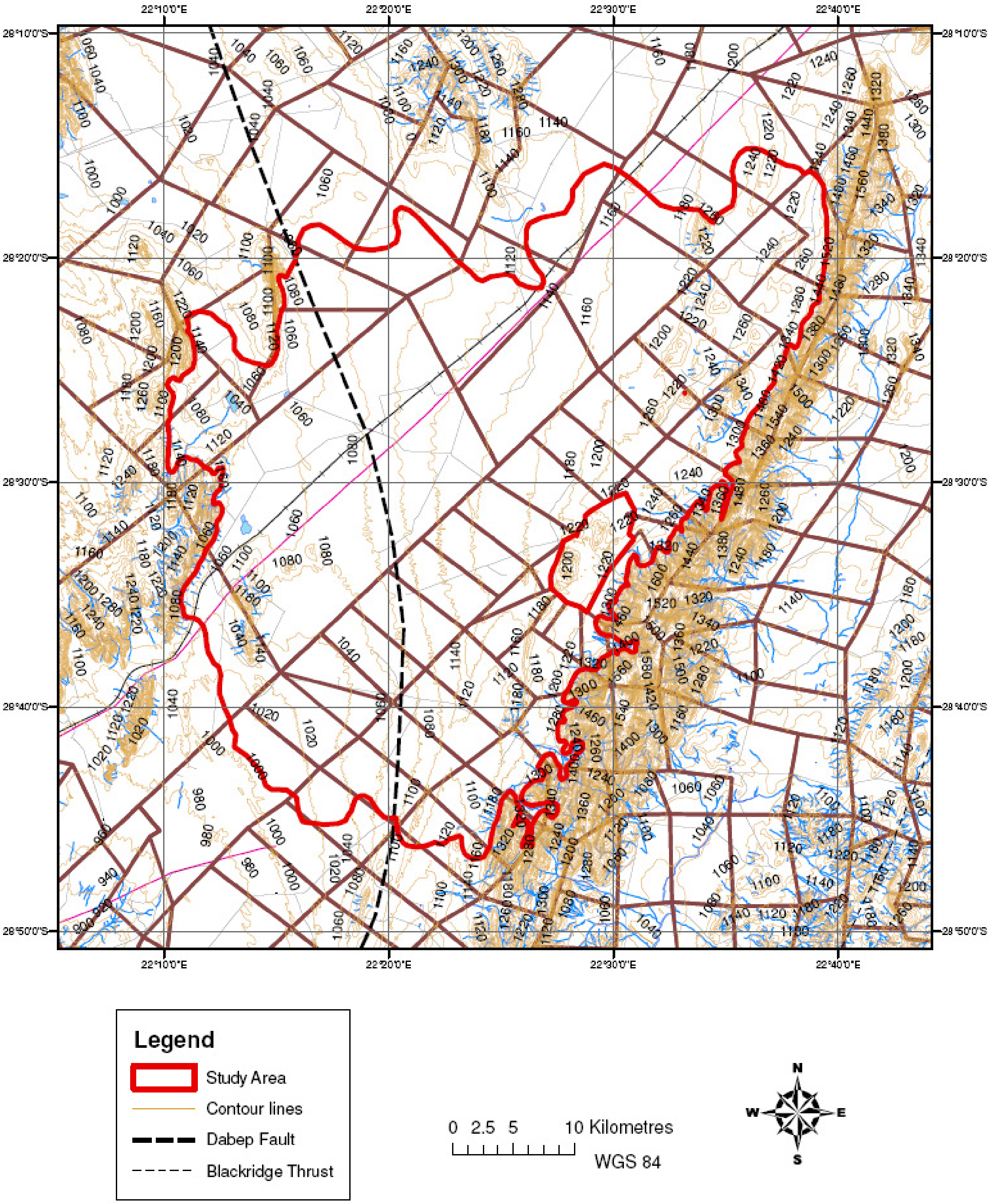


Figure 3.11 Topography of the study area.

3.7 Animals

Apart from the farming of cattle, sheep and goats, game occurs on most of the farms in the study area. A total of 41 mammal species have been recorded on the Witsand Nature Reserve: springbok, gemsbok and red hartebeest, grey duiker, steenbok, aardvark, porcupine, springhare and numerous small mammal species. Up to 170 bird species have been recorded for the Reserve. Several species of reptiles and amphibians have been recorded on the Reserve (39 reptile species and 5 amphibian species) while quite a number of invertebrate species were recorded (Jessnitz 2001).

On the rest of the farms within the study area, springbok and gemsbok are found in abundance, along with several smaller mammals, birds and reptiles.

Chapter 4 Methods

4.1 Introduction

Although a provisional vegetation map of the vegetation of Witsand Nature Reserve had been compiled by Lloyd *et al*. (1997), no classification of the vegetation following the standard Braun-Blanquet procedures, as recommended for South Africa had been produced. The objectives of the study conducted on Witsand Nature Reserve were therefore to classify, describe and map the vegetation of the Reserve.

The vegetation analysis of Witsand Nature Reserve was conducted apart from the current study, and in much more detail. The current study was mainly done to determine the degradation gradient of the perennial grass species of three communities found in the most southern portion of the Kalahari. To be able to determine the degradation gradient, a detailed phytosociological classification, which included the description and mapping of the area, was undertaken.

4.2 Witsand Nature Reserve

4.2.1 Topography and Geology

The topography and geology of Witsand Nature Reserve were studied using 1:50 000 topographic maps 2822CB Witsand (South Africa 1:50 000 sheet 1971a) and 2822DA Plaatjiesdam (South Africa 1:50 000 sheet 1971b); a 1:250 000 geological map and stratigraphical subdivisions (Geological Survey 1977, 1995 & 1998).

4.2.2 Soil

Soil sampling was done at the sample plots for the vegetation surveys by hand collection of sand samples to a depth of 150 mm, using a soil auger. A Munsell chart (1971) was used to determine the colour of the sand. Soil Classification Working Group (1991) was used for the classification of the different soil forms and -families.

4.2.3 Climate

Climate information was obtained from the South African Weather Bureau.

4.2.4 Vegetation classification and description

Preliminary homogeneous areas (units) were selected from aerial photography (Figure 4.1). A reconnaissance survey was conducted over the study area to refine the preliminary homogeneous areas.

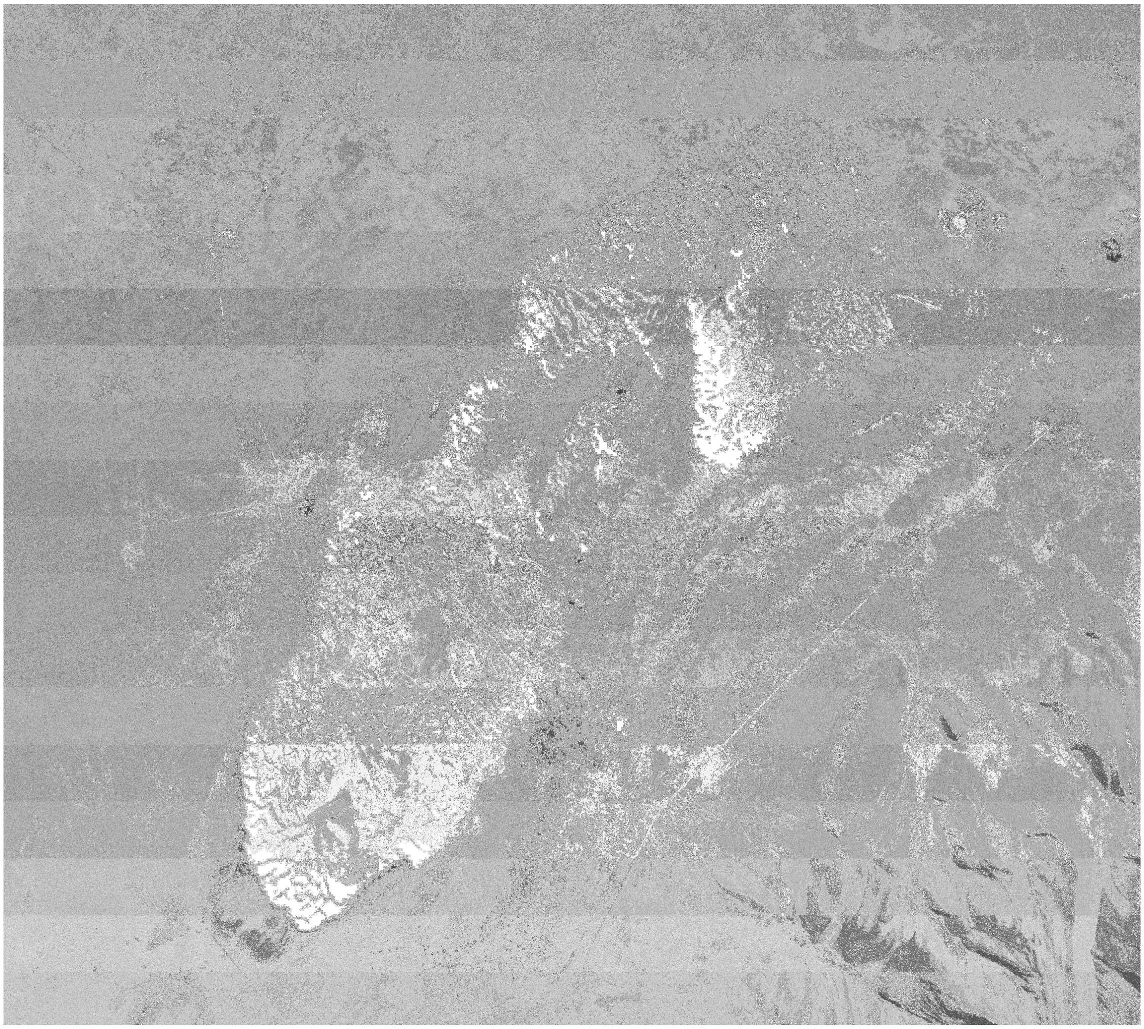


Figure 4.1 Aerial photograph of the Witsand Nature Reserve and surrounding area.

Forty four (44) sample plots were subjectively located within areas that were identified as being homogeneous and representative of a particular physiognomic unit.

4.2.4.1 Vegetation sampling for classification

Each sample plot in a unit was surveyed by means of the Braun-Blanquet method to determine the floristic composition. The sites sampled were 10 x 20 m in size. A geographical positioning system (GPS) reading was taken at every sample plot using a GARMIN MAP 76S, imported into FUGAWI (GPS mapping software) and mapped on ArcGIS Desktop 9.2.

The cover abundance scale of Braun-Blanquet (1932, changed later in 1964), as altered by Werger (1973, 1974) and adapted by Vorster (1982) was used:

r	– Single individual with very low cover;
+	– Individuals that do not occur frequently on the site, ≤ 1 % cover
1	– Individuals that are found frequent on the site, > 1 – 5 % cover
2a	– Individuals with > 5 – 12 % cover;
2b	– Individual with > 12 – 25 % cover;
3	– Individuals with > 25 – 50 % cover;
4	– Individuals with > 50 – 75 % cover;
5	– Individuals with > 75 % cover.

The plant species found in each sample plot were identified either in the field or at base camp using various references, including: Grabandt (1985); Van Wyk & Malan (1988); Van Oudtshoorn (1994); Van Wyk & Van Wyk (1997); Young (1999); Bromilow (2001); Van Rooyen (2001); Palgrave (2002); Van Oudtshoorn (2002). Most of the plant identifications were verified in the HGWJ Schweickerdt Herbarium (PRU) at the University of Pretoria and some unidentified specimens were sent to the National Herbarium (PRE) at the South African National Biodiversity Institute (SANBI) for identification.

4.2.4.2 Data analysis

Ordination of the whole data set is necessary to identify possible sub-data sets (plant communities). The influence of several habitat factors (soil colour, depth of soil and occurrence of lime in the soil) were of importance to the ordination results (Jordaan 1997).

Floristic and habitat data were entered into the TURBOVEG database (Hennekens 1996). After data capturing of the 44 sample plots (floristic as well as habitat data) the data were exported to MEGATAB (Hennekens 1996). A crude classification of the data was derived by the application of TWINSPAN (Hill 1979) to the data set. Cut-levels for TWINSPAN were set at the default value. Three levels of division were applied to the data set. The floristic table was refined by Braun-Blanquet procedures described in Mueller-Dombois & Ellenberg (1974); Werger (1974); and Kent & Coker (2000).

4.2.5 Species list

The species list for the flora encountered in the study area was extracted from the TURBOVEG database. The species list is also combined with the species list from Bosch (1996).

4.3 Current study area – south-eastern Kalahari

4.3.1 Topography and Geology

The topography and geology of the study area were studied using 1:50 000 topographic maps: 2822 AA, 2822 AB, 2822 AC, 2822 AD, 2822 BA, 2822 BB, 2822 BC, 2822 BD, 2822 CA, 2822 CB, 2822 CC, 2822 CD, 2822DA, 2822 DB, 2822 DC and 2822 DD (Chief Directorate); a 1:250 000 geological map (2822 Postmansburg) and stratigraphical subdivisions (Geological Survey 1977 & 1998). The geology was further studied using maps and information from Johnson *et al.* (2006). The following Landsat imagery was also used: S-34-25_2000 (Figure 4.2).

4.3.2 Soil

Soil sampling was done at the sample plots for the vegetation surveys, by hand collection of sand samples to a depth of 150 mm, using a soil auger. A Munsell chart (1971) was used to determine the colour of the sand. Soil Classification Working Group (1991) was used for the classification of the different soil forms and -families.

4.3.3 Climate

Climate information was obtained from the South African Weather Bureau.

4.3.4 Vegetation classification and description

The necessary background information to determine the study area was obtained from: Smit (2000).

Preliminary homogeneous areas (units) were selected from aerial photography and satellite imagery. A reconnaissance survey was conducted over the study area to refine the preliminary homogeneous areas.

One hundred and twenty six (126) sample plots were subjectively located within areas that were identified as being homogeneous and representative of a particular physiognomic unit. The 126 sample plots make up 45 groups. Each group consists of 2-3 sample plots taken several distances away from a watering point.

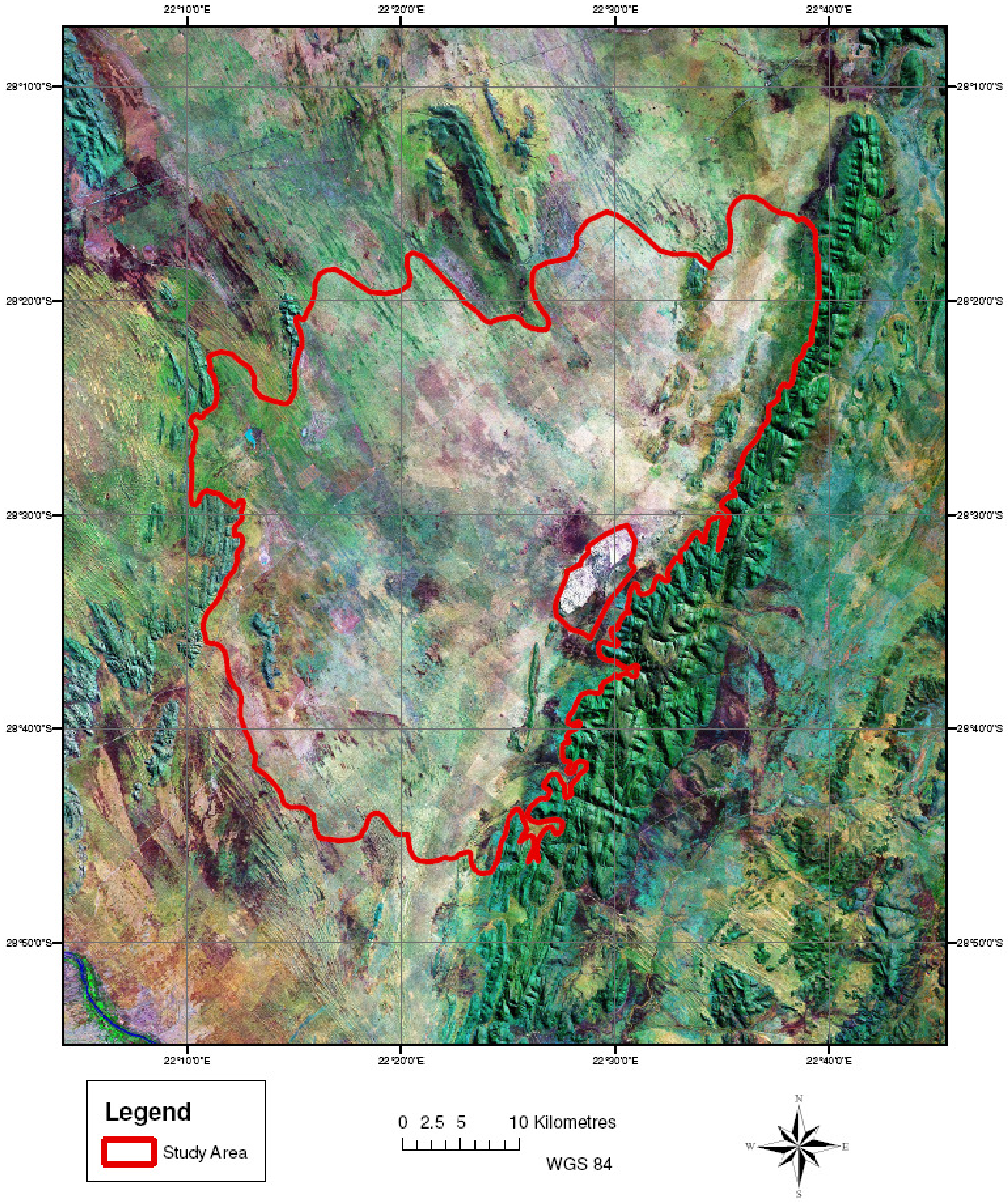


Figure 4.2 Landsat imagery (S-34-25_2000) of the study area.

4.3.4.1 Vegetation sampling for classification

Each sample plot in a unit was surveyed by means of the Braun-Blanquet method to determine the floristic composition. The sites sampled were 10 x 20 m in size. A geographical positioning system (GPS) reading was taken at every sample plot using a GARMIN MAP 76S, imported into FUGAWI (GPS mapping software) and mapped on ArcGIS Desktop 9.2.

The cover abundance scale of Braun-Blanquet (1932, changed later in 1964), as altered by Werger (1973, 1974) and adapted by Vorster (1982) was used:
r – Single individual with very low cover;
\+ – Individuals that do not occur frequently on the site, ≤ 1 % cover
1 – Individuals that are found frequent on the site, > 1 – 5 % cover
2a – Individuals with > 5 – 12 % cover;
2b – Individual with > 12 – 25 % cover;
3 – Individuals with > 25 – 50 % cover;
4 – Individuals with > 50 – 75 % cover;
5 – Individuals with > 75 % cover.

The plant species found in each sample plot were identified either in the field or at base camp using various references, including: Grabandt (1985); Van Wyk & Malan (1988); Van Oudtshoorn (1994); Van Wyk & Van Wyk (1997); Young (1999); Bromilow (2001); Van Rooyen (2001); Palgrave (2002); Van Oudtshoorn (2002). Most of the plant identifications were verified in the HGWJ Schweickerdt Herbarium (PRU) at the University of Pretoria and some unidentified specimens were sent to the National Herbarium (PRE) at the South African National Biodiversity Institute (SANBI) for identification.

4.3.4.2 Grass degradation gradient

In order to construct degradation gradients, the grass species composition that represents different stages of degradation, was sampled at various distances from water points in a particular plant community (Jordaan 1997; Bosch & Booysen 1991; Bosch & Gauch 1991; Bosch *et al*. 1992). These specific sample plots at a site were determined by walking through the area identifying various perceived stages of degradation, based on change in species frequency. Three main types of groups were identified in each community:

- Seriously over-utilised
- Moderately utilised to moderately over-utilised
- Lightly utilised

At each sample point, a 200 m step-point survey (Evans & Love 1957) was done, with a reading every two metre [on the basis of the Wheel-point method (Tidmarsh & Havenga 1955)]. At every step-point the nearest perennial grass species was recorded, if no species occurred within a radius of 0.5 m of the step-point, it was recorded as bare soil. The nearest annual grass-, small shrub species were also recorded (if no shrub available to record, the nearest herbaceous species was recorded). If no herbaceous plant occurred within a radius of 0.5 m of the step-point, it was recorded as bare soil. The shrubs and herbaceous species were recorded, although not used during further data analysis, but could be used in future research.

Habitat information included soil colour, soil depth and if lime is present in the soil.

4.3.5 Data analysis

Data processing and the analysis followed the following steps (Mueller-Dombois & Ellenberg 1974; Werger 1974; Kent & Coker 2000; Bosch & Gauch 1991):

- Identifying the plant community (a homogeneous physiognomic unit)
- Defining the plant community in CANOCO using a Detrended Correspondence Analysis ordination (DCA ordination)
- Defining a degradation gradient for each specific plant community identified by using a Degradation Model Construction (DMOC)
- Analysing the degradation gradient as a veld condition value by species reactions.

4.3.5.1 Identifying the plant community (a homogeneous physiognomic unit)

In the data, vegetation changes as a result of over-utilisation were addressed. It is necessary to divide the data set in such a way that only the vegetation changes remain as the dominant source of variation (Jordaan 1997). Ordination of the whole data set is necessary to identify possible sub-data sets (plant communities). The influence of several habitat factors (soil colour, depth of soil and occurrence of lime in the soil) were of importance to the ordination results (Jordaan 1997).

Floristic and habitat data were entered into the TURBOVEG database (Hennekens 1996). After data capturing of the 126 relevés (Appendix 1) (floristic as well as habitat data) the floristic data were exported to MEGATAB (Hennekens 1996). A crude classification of the data was derived by the application of TWINSPAN (Hill 1979) to the data set. Cut-levels for TWINSPAN were set at the default value. Two levels of division were applied to the data set. The floristic table was refined by Braun-Blanquet procedures described in Mueller-Dombois & Ellenberg (1974); Werger (1974); and Kent & Coker (2000).

4.3.5.2 Refining the plant community in CANOCO using a DCA ordination

The data form all the survey sites were imported into CANOCO as one data set and subjected to a Detrended Correspondence Analysis (DCA) ordination. A DCA is extremely suitable for processing data sets with relatively long gradients (Gauch 1982; Jordaan 1997).

In CANOCO, procedures were followed to confirm the communities identified by Twinspan and the Braun-Blanquet procedures. The DCA ordination procedures are considered as refinement of the classification and confirming the homogeneous units.

Scatter diagrams were compiled for the DCA ordination for each community (by using the CANOCO programme). In these diagrams each site is marked a colour representing the following:

Red – Sample plots 0 to 30 metres away from a watering point
Purple – Sample plots 30 to 100 metres away from a watering point
Green – Sample plots 100 metres or more away from a watering point, some sample plots were several kilometres away.

4.3.5.3 Defining and refining a degradation gradient for each specific plant community identified with the aid of DMOC

The site information and species data collected from the step-point procedures of each community identified were imported into ISPD (Bosch *et al.* 1992; Jordaan 1997). An ordination was done on each community separately. The ordination resulted in the model representing a series of sites in different stages of degradation (Bosch *et al*. 1992).

ISPD consists of different multiple statistical analytical techniques. The Degradation Model Construction (DMOC) (Bosch & Kellner 1991) used the Principal Component Analysis (PCA) technique with a Centred PCA variation (Jordaan 1997; Jordaan 2006). The position on the gradient is therefore an indication of the range condition of the site, while the length of the position on the residual axis is an indication of the model fitting (Jordaan 1997). The residual value on the axis must be a certain minimum [the minimum referred to is comprehensively described by Bosch & Gauch (1991)] and can be defined as the Euclidean distance (an arbitrary 50%) of a monitoring site with regard to the length of the first axis (x-axis). A regression curve of the graph drawn determines a value further used for determining a refined veld condition value of each species in a community (Jordaan 1997).

The formula used to derive the regression curve is (from ISPD software):

$$Y = C * \exp(-1*(X-A)^2/(2*B^2))$$

A = Position of peek
B = Standard Deviation
C = Height of maximum value

The Gaussian models provide the best fit species abundance data on the degradation gradient and key species can be objectively selected (Bosch & Gauch 1991). They classified species with a D-statistic of higher than 0.600 as key species. Species with a low regression (r^2) values show little response to grazing (Van der Westhuizen 2003). In the study the species with a D-statistic (Wilmott 1982) of higher than 0.500 were used as key species.

According to Bosch & Kellner (1991), sites with a residual value more than the arbitrary 50% of the Euclidean distance from the first axis, should be regarded as outliers and removed from the data set. The sites in the data set with such a high residual value were consequently removed.

The degradation gradient value of each site (the values of the first ordination axis) was used as the independent variable, while the species abundance (frequency of occurrence) was used as the subordinate variable for the regression (Bosch & Janse van Rensburg 1987; Janse van Rensburg & Bosch 1990; Jordaan 1997). Species with a low index of low occurrence were left in the data matrix, as they did not change the data set if left out, however a regression curve could not be drawn for these species.

Detailed information with regard to ISPD can be obtained from Bosch *et al.* (1992).

4.3.6 Species list

The species list for the flora encountered in the study area was extracted from the TURBOVEG database. The species list is also combined with the species list from Bosch (1996).

4.3.7 Veld condition

The values obtained from the degradation model are used to determine an ecological value for each species. The position of the peaks of each curve on the first-axis, shown as a percentage value of the veld in an optimal condition of the degradation gradient (Jordaan 1997).

The range condition index was determined with a modification of the veld condition index method (Vorster 1982). The grasses were subjectively classified into ecological index classes, based on degradation gradients. The ecological values as a percentage determine the specific ecological index value (Table 4.1 - Adapted from Van der Westhuizent *et al.* 1999).

Table 4.1 Ecological values as a percentage determine the specific ecological index value (Adapted from Van der Westhuizent *et al.* 1999)

Ecological value		**Ecological index value**
95 – 100 %	=	10
85 – 94 %	=	9
75 – 84 %	=	8
65 – 74 %	=	7
55 – 64 %	=	6
45 – 54 %	=	5
35 – 44 %	=	4
25 – 34 %	=	3
15 – 24 %	=	2
1 – 14 %	=	1

Chapter 5 Vegetation analysis on Witsand Nature Reserve

5.1. Introduction

Witsand Nature Reserve falls within the study area. The Witsand Nature Reserve (WNR) gained nature reserve status on proclamation in April 1994 (Jessnitz 2001) and was established primarily for the conservation of components and processes associated with the dune ecosystem and the biotic communities that converge in that area. The reserve has become renown because of the white sand surrounded by red Kalahari sand. The habitat diversity (Figure 5.1) and variety of endemic plant species offer opportunities to study biological processes. The Witsand Nature Reserve also has a major source of water with a shallow water table which is visible in some parts of the reserve. When the reserve was proclaimed the vegetation was very disturbed by human activity, overgrazing, trampling by animals and the unregulated movement of motor vehicles (Bosch 1996).

Figure 5.1 A view of Witsand Nature Reserve giving the general idea of the diversity of the vegetation.

Although a provisional vegetation map of the vegetation had been compiled by Lloyd *et al.* (1997), no classification of the vegetation following the standard Braun-Blanquet procedures, as recommended for South Africa had been produced. The objectives of this specific study (conducted early 2003) were therefore to classify, describe and map the vegetation of the Witsand Nature Reserve.

5.2 Previous work conducted at Witsand Nature Reserve

A provisional vegetation map for Witsand Nature Reserve was compiled by Lloyd *et al.* (1997) using Landsat Thematic Mapper Imagery. The image was classified on the basis of spectral patterns of various vegetation classes, i.e. it was a computer-assisted interpretation of the remotely sensed image. Ground assessing of sample locations was undertaken in the field and 12 vegetation classes were identified: Quartzite ridges, *Acacia mellifera* - *Prosopis velutina* class, *Acacia haematoxylon* class, *Acacia erioloba* class, Mixed woodland class, *Acacia mellifera* - *Rhigozum trichotomum* class, *Acacia mellifera* class, *Rhigozum trichotomum* class, Sand dune classes, *Rhigozum obovatum* class and Mountain class. The two classes, Vegetated Sand dunes and Sand dunes were taken as a single unit. Some classes were not ground-truthed and only mapped on the provisional vegetation map. Recommendations were made towards management, planning and monitoring on the Witsand Nature Reserve.

Badenhorst *et al.* (1999) conducted a range condition assessment on Witsand Nature Reserve and made recommendations for game introduction. Surveys were done in seven of the classes that were identified by Lloyd *et al.* (1997), namely: *Acacia erioloba* class, *Acacia haematoxylon* class, *Acacia mellifera* class, *Rhigozum trichotomum* class, Sand dunes, Quartzite ridges and Mixed woodland. Soil texture, clay content and free carbonate were determined at each survey site. No free carbonate was found in any of the samples taken.

A provisional plant species list was compiled by Bosch (1996). Between 1923 and 1986 the reserve was visited by various plant collectors and the specimens collected are stored in the McGregor Museum in Kimberley (Bosch 1996).

5.3 Results

5.3.1 Classification hierarchy

The classification revealed the identification of seven plant communities (Table 5.1). A dendrogram showing the hierarchical relationships is provided in Figure 5.2. In addition, these floristically defined communities were categorized according to the physiognomic criteria defined by Edwards (1983) and geographic features. The seven plant communities of Witsand Nature Reserve are the following (Figure 5.2 & 5.3, Table 5.1):

1. *Stipagrostis amabilis – Brachiaria dura* var. *pilosa* Dune Vegetation
2. *Acacia haematoxylon – Eragrostis trichophora* Low Grassy Bushland
3. *Prosopis velutina – Schmidtia kalihariensis* High Closed Shrubland
4. *Acacia erioloba – Acacia karroo* Low Grassy Woodland
5. *Acacia mellifera – Rhigozum trichotomum* Shrubland
6. *Croton gratissimus – Cymbopogon pospischilii* Quartzite Outcrop Vegetation
7. *Cyperus longus* v. *tenuiflorus – Schoenoplectus decipiens* Pan Vegetation

Two broad vegetation categories emerged: namely mesic vegetation and pan vegetation (a marshy type of vegetation) (5.3.2.7 Community 7: *Cyperus longus* v. *tenuiflorus – Schoenoplectus decipiens* Pan Vegetation). The second level of division divided the mesic vegetation into sandy vegetation and quartzite outcrop vegetation (5.3.2.6 Community 6: *Croton gratissimus – Cymbopogon pospischilii* Quartzite Outcrop Vegetation). The outcrop vegetation did not undergo further division. A third division divided the sandy vegetation into vegetation types on light yellow brown to whitish sand and vegetation on reddish sand. The light yellow brown to whitish sand category is divided into dune vegetation (5.3.2.1 Community 1: *Stipagrostis amabilis – Brachiaria dura* var. *pilosa* Dune Vegetation) and sandy plains and dune edges. Areas where the sandy plains and dune edges are undisturbed are classified as 5.3.2.2 Community 2: *Acacia haematoxylon – Eragrostis trichophora* Low Grassy Bushland, but where the area is disturbed, it is classified as 5.3.2.3 Community 3: *Prosopis velutina – Schmidtia kalihariensis* High Closed Shrubland. The reddish sand vegetation category is divided into deep sandy soil vegetation (5.3.2.4 Community 4: *Acacia erioloba – Acacia karroo* Low Grassy Bushland) and shallow sandy soil vegetation with regolith present in some parts (5.3.2.5 Community 5: *Acacia mellifera – Rhigozum trichotomum* Shrubland).

Table 5.1 Phytosociological table for Witsand Nature Reserve

Community no	1								2															3				4					5								6			7
Relevé no	2	2	3	3	2	1	2	2		1	1				1	1	2	3	3	3	4	3	1	3	1	1	1			2	2	3	4	4	3	4				2	4	1	3	2
	7	8	0	3	9	1	3	6	9	8	0	4	7	8	7	9	5	4	8	1	4	2	4	5	6	3	5	3	6	2	0	7	0	3	6	1	2	1	5	1	2	2	9	4
Species Data																																												
Group A																																												
Brachiaria dura v. *pilosa*	b	b	1	a	1	a	.	.	.	.	b	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.
Crotalaria species	1	1	.	1	.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Eragrostis pallens	.	.	.	.	b	a	.	a	.	.	b	.	.	.	.	.	.	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Selago welwitschii	1	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sporobolus fimbriatus	.	.	.	.	b	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Lopholaena coriifolia	.	a	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pterothrix tecta	+	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Group B																																												
Eragrostis trichophora	.	.	.	.	.	.	.	.	.	.	.	+	.	.	3	1	a	1	.	+	b	b	.	1	.	.	.	.	.	.	.	1	.	.	+	b	.	.	.	.	.	.	.	.
Ziziphus mucronata	.	.	.	.	.	.	.	.	a	1	a	r	+	.	.	1	1	a	.	.	.	.	.	1	.	.	.	+	1	b	.	.	.	.	+	.	.	.	.	+	.	.	.	.
Diospyros lycioides	.	.	.	.	.	.	.	.	.	1	a	.	.	.	+	1	a	a	.	1	.	.	.	.	.	.	.	.	a	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Hermannia tomentosa	.	.	.	.	.	.	.	+	.	.	.	.	+	.	+	.	+	+	+	+	+	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.
Elephantorrhiza elephantina	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	a	a	b	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Hermannia quartiniana	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	+	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Acacia hebeclada	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	1	+	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Rhigozum obovatum	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Group C																																												
Stipagrostis amabilis	1	a	3	a	a	.	b	a	1	3	.	.	.	a	1	3	.	.	.	.	.	.	.	+	1	.	.	+	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.
Eragrostis biflora	.	.	.	.	.	.	.	a	.	.	.	.	.	.	.	.	1	.	1	a	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Group D																																												
Prosopis velutina	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	3	a	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sida cordifolia	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	a	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Nolletia arenosa	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	a	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Barleria rigida	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Group E																																												
Acacia haematoxylon	.	.	.	.	.	.	.	1	.	a	1	b	b	a	b	.	a	a	3	3	b	.	1	1	a	.	1	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Tribulus zeyheri	.	.	.	.	.	.	.	.	.	.	.	+	.	.	1	.	.	.	.	.	+	.	a	a	a	.	3	.	.	+	.	.	.	+	.	+	.	.	.	.	.	.	.	.
Lycium hirsutum	.	.	.	.	.	.	.	.	.	.	.	.	+	r	1	.	1	+	+	.	+	.	.	+	1	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.
Group F																																												
Acacia erioloba	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	a	+	a	.	1	r	.	.	.	r	r	r	.	.	.	.	.
Acacia karroo	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	b	.	.	.	.	.	.	.	.	.	.	.	b	3	a	.	.	.	+	.	.	.	.	.	.	.	.	.
Lycium cinereum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	+	.	1	.	.	.	.	.	.	.	.	.	.	.	.
Aptosimum spinescens	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	+	.	.	.	.	.	.	.	+	.	.	.	.	.
Group G																																												
Rhigozum trichotomum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	+	.	.	.	1	b	+	b	3	+	3	.	.	.	.	.	.
Boscia albitrunca	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	a	.	.	.	.	+	r	.	.	1	1	1	.	1	.	+	r	a	1	.	.	.
Schmidtia pappophoroides	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	3	.	.	.	.	.	.	.	.	.
Monechma incanum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	1	a	.	.	.	.	+	.	.	.	.
Chloris virgata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	b	.	.	.	.	.
Solanum capense	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.
Brachiaria nigropedata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	a	.	.	.	.	.
Melinis repens	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
Group H																																												
Acacia mellifera	.	.	.	.	.	.	.	.	.	.	.	+	r	.	1	a	a	.	.	.	.	.	a	.	.	.	1	3	1	.	4	a	3	4	.	b	3	b	1	3	.	.	.	.
Eragrostis lehmanniana	.	.	.	.	.	.	.	.	a	.	.	b	b	a	1	.	.	.	a	a	b	.	+	.	b	a	1	b	1	.	.	b	1	.	+	1	a	a	+	a	.	.	.	.
Schmidtia kalihariensis	.	.	.	.	.	.	.	.	.	.	.	b	+	+	.	.	+	.	+	+	+	.	.	1	a	a	b	1	+	+	.	.	3	.	.	b	.	+	.	.	.	.	.	.
Aristida meridionalis	.	.	.	.	.	.	.	.	1	.	.	+	+	a	.	.	+	+	1	+	b	.	.	1	+	.	.	.	.	.	.	.	+	.	.	.	+	1	b	+	.	.	.	.
Grewia flava	.	.	.	.	.	.	.	.	.	+	+	.	+	r	1	.	1	.	1	.	+	.	1	.	1	.	.	+	a	+	.	b	.	.	+	.	a	.	.	.	.	.	.	.
Asparagus suaveolens	.	.	.	.	.	.	.	.	.	.	.	+	+	+	.	.	.	.	+	+	1	.	+	.	.	.	.	+	+	.	.	+	1	1	+	1	+	+	.	+	.	.	.	.
Aristida congesta	.	.	.	.	.	.	.	.	+	.	.	+	a	1	.	.	1	+	a	1	1	.	.	+	.	.	+	+	a	a	+	1	1	.	.	1	+	1	+	a	.	.	.	.
Hermannia vestita	.	.	.	.	.	.	.	.	.	.	.	.	+	r	.	.	.	.	1	.	1	.	+	.	.	+	.	+	+	1	+	.	+	+	+	.	.	.	+	.	.	.	.	.
Eragrostis bicolor	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	a	3	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	+	+	.	.	.	.
Senna italica	.	.	.	.	.	.	.	.	.	.	.	+	+	+	.	.	.	.	+	.	+	.	.	.	+	.	+	.	+	.	.	.	.	.	+	.	+	+	+	.	.	.	.	.
Tapinanthus oleifolius	.	.	.	.	.	.	.	.	.	+	.	.	.	.	+	.	.	.	.	.	.	.	1	.	.	+	.	.	.	.	.	.	.	.	.	.	+	+	.	+	.	.	.	.
Centropodia glauca	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.
Cadaba aphylla	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.

Community no	1								2															3				4					5								6			7
Relevé no	27	28	30	33	29	11	23	26	9	18	10	4	7	8	17	19	25	34	38	31	44	32	14	35	16	13	15	3	6	22	20	37	40	43	36	41	2	1	5	21	42	12	39	24
Group I																																												
Cymbopogon pospischilii	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	b	b	.
Croton gratissimus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	.	.	.
Digitaria eriantha	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	b	.	1	.
Pollichia campestris	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	1	.
Tarchonanthus camphoratus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	a	.
Euclea undulata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	.
Pegolettia retrofracta	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.
Hermannia grossularifolia	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	+	+	.	.	.
Group J																																												
Eragrostis rigidior	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	+	.	+	a	.	.	.	1	.	a	.	.	.
Euryops multifidus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	+	.	.	.	1	.
Chrysocoma ciliata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	.	.	.	.	.	+	.	+	.	+	+	.	+	.	.	.
Ptycholobium biflorum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	+	.	.	.	.	.	.	+	.	.	.
Psiadia punctulata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	+	.	.	.	.	.	.	+	.	.	.
Group K																																												
Stipagrostis uniplumis	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	3	a	3	.	b	+	.	.	+	+	1	+	.	+	+	a	1	+	.	a	+	+	+	b	.	.	.
Eriocephalus ericoides	.	.	.	.	+	.	.	.	.	.	.	.	+	.	.	.	.	+	.	+	.	+	.	.	.	.	.	.	+	.	.	+	.	+	1	.	.	.	.	+	.	.	1	.
Searsia burchellii	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	a	.
Group L																																												
Cyperus longus v. *tenuiflorus*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	b
Schoenoplectus decipiens	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	b
Juncus exsertus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	a
Senecio angustifolius	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	a
Juncus dregeanus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Fuirena pubescens	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Juncus oxycarpus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+
Xyris capensis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+
Eragrostis gummiflua	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+
Wahlenbergia species	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+
Group M																																												
Lobelia erinus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	b	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	+
Kyphocarpa angustifolia	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	+	.	.	.	.	.	.	.	+	.	.	.	.	.
Vahlia capensis	.	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.	+	.	+	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.	.	.	.	.	.	+

Community no	1								2															3				4					5								6			7
Relevé no	27	28	30	33	29	11	23	26	9	18	10	4	7	8	17	19	25	34	38	31	44	32	14	35	16	13	15	3	6	22	20	37	40	43	36	41	2	1	5	21	42	12	39	24
Pterothrix species	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Trachyandra laxa	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Lebeckia linearifolia	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Thesium strictum	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Stipagrostis ciliata v. *capensis*	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Tricholaena monachne	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Aridarria noctiflora	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Nidorella resedifolia	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pollichia campestris	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Searsia burchellii	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Indigofera damarana	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Indigofera heterotricha	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Andropogon eucomus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Stipagrostis obtusa	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Septulina glauca	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Geigeria brevifolia	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Elionurus muticus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Felicia hyssopifolia	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Melhania rehmannii	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Monechma distichotricha	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sutera burchellii	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Stachys species	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Bulbostylis hispidula	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Gnidia polycephala	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Kleinia longiflora	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.
Anthephora argentea	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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Gazania krebsiana	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
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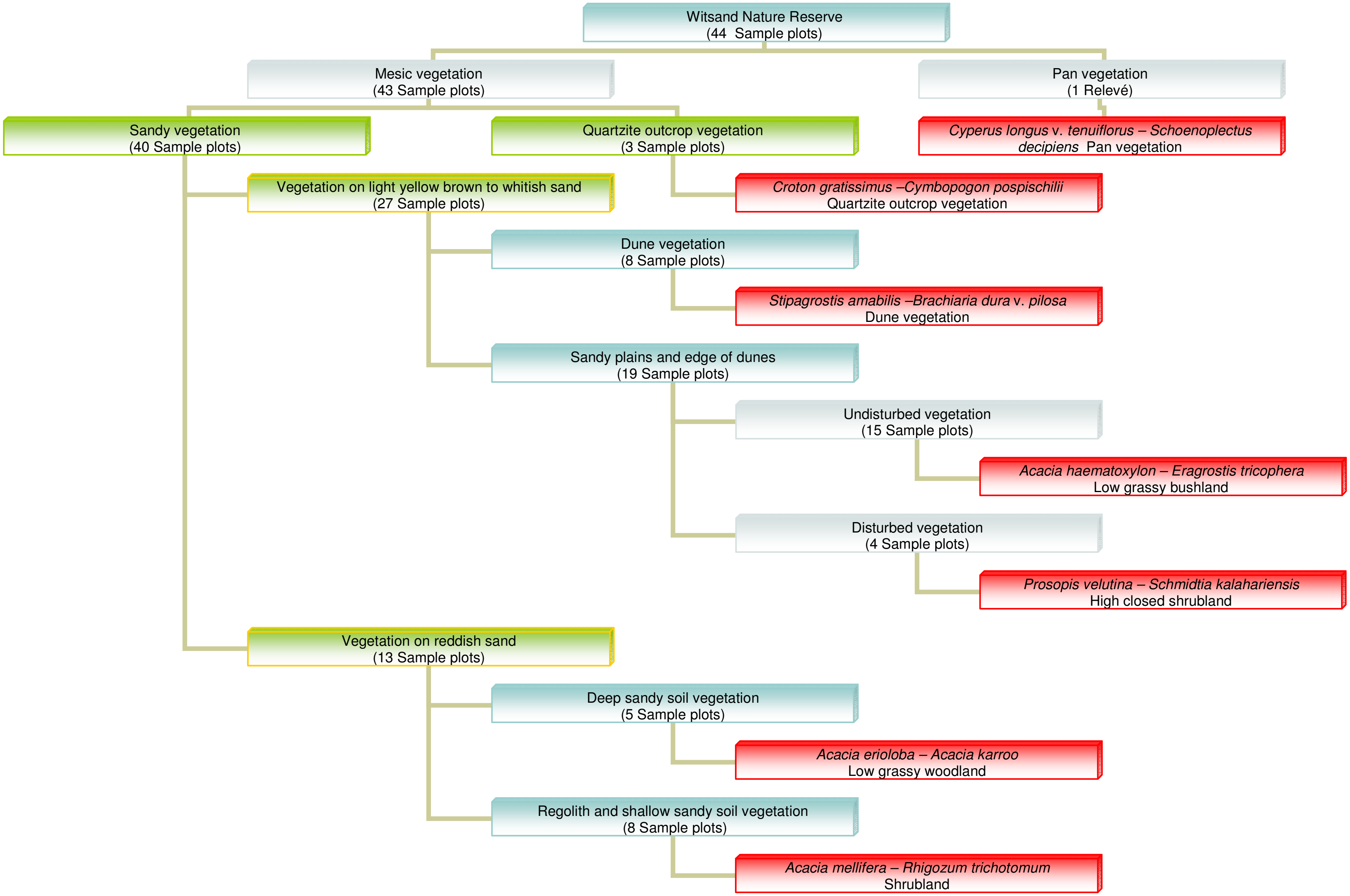

Figure 5.2 TWINSPAN dendrogram of the vegetation communities at Witsand Nature Reserve, based on floristic composition and habitat interpretation.

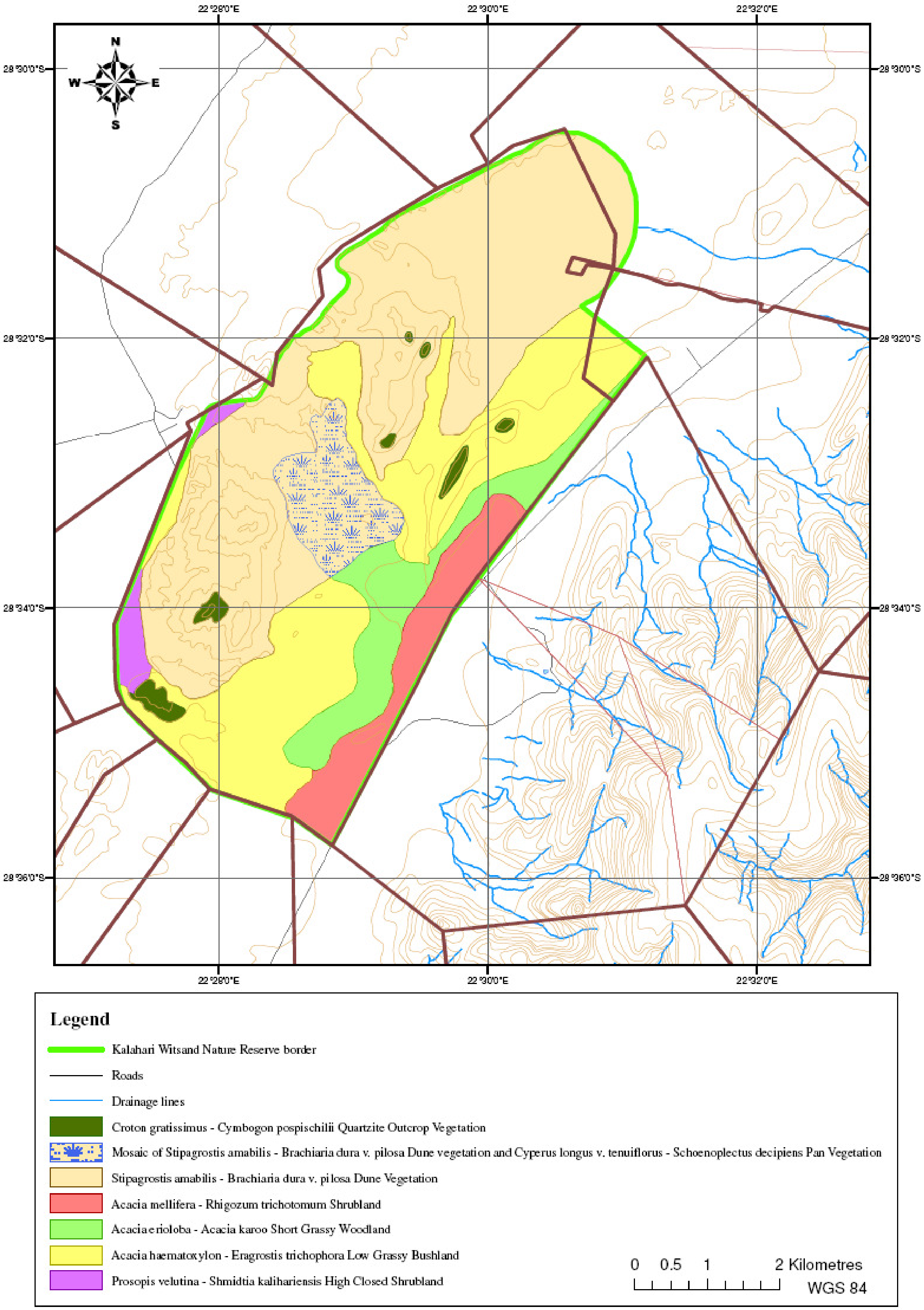

Figure 5.3 Vegetation map of Witsand Nature Reserve**.**

5.3.2 Description of the plant communities on Witsand Nature Reserve

5.3.2.1 Community 1: *Stipagrostis amabilis – Brachiaria dura* var. *pilosa* Dune Vegetation

The vegetation of the dune areas on the Reserve was classified into a single community. Some of the dune areas have very little vegetation cover whereas other parts have a much denser vegetation cover. This community occurs at an altitude of 1 170 – 1 260 m. The sand varies from a light yellow colour to a whitish colour. Badenhorst *et al.* (1999) described the soil of this community as well-drained, pinkish white (7.5YR 8/2) to a very pale brown (10YR 7/4) coloured sand. The sand colour recorded in this study was 7.5YR 7/6 and 10YR 8/3. Different areas on the Reserve have different local names. The soil in the southern part of the community is named Brulsand (roaring sands), the central part is called Witsand (Figure 5.4, 5.5 & 5.6), and the northern part, with some vegetated dunes surrounding it, is called Klein Witsand.

Stipagrostis amabilis – Brachiaria dura var. *pilosa* Dune Vegetation is characterized by Species Group A (Table 5.1) with *Brachiaria dura* var. *pilosa* (Locally to Witsand (Gibbs Russell *et al.* 1990)) as the most prominent diagnostic species, and *Stipagrostis amabilis* (Group C) is the dominant species. Other important species in this community include *Crotolaria* species, *Eragrostis pallens* and *Selago welwitschii*.

The dune vegetation community compares slightly to a vegetation type described by Leistner & Werger (1973): *Stipagrostion amabilis.* Lubbinge (1998) mentions that this alliance mainly occurs on dune crests, and is widely found throughout the southern Kalahari duneveld. The main difference between this vegetation type and the community found at Witsand is that the species *Brachiaria dura* var. *pilosa* occurs on the dunes at Witsand and not at within the Kalahari duneveld.

Figure 5.4 The central part of the *Stipagrostis amabilis – Brachiaria dura* var. *pilosa* Dune Vegetation (Community 1), called Witsand.

Figure 5.5 A view from an outcrop showing the northern part of the Reserve called Klein Witsand with the *Stipagrostis amabilis – Brachiaria dura* v. *pilosa* Dune vegetation (Community 1).

Figure 5.6 The southern part of the *Stipagrostis amabilis – Brachiaria dura* var. *pilosa* Dune Vegetation (Community 1), in the Brulsand area.

5.3.2.2 Community 2: *Acacia haematoxylon – Eragrostis trichophora* Low Grassy Bushland

The community occurs at the edges of the dunes and on the plains adjacent to the dunes. The soil seems to be a mixture between the whitish sand of the dunes and the reddish Kalahari sand. Badenhorst *et al.* (1999) describe the sand as well-drained with a Strong Brown (7.5YR 5/8) soil colour. The soil colours recorded were 7.5YR 5/6, 7.5YR 7/6 and 7/5YR 7/8. The community is situated at an altitude of 1 160 – 1 230 m.

Acacia haematoxylon – Eragrostis trichophora Low Grassy Bushland (Figure 5.7) is characterized by species of Group B (Table 5.1) with *Eragrostis trichophora, Ziziphus mucronata* and *Diospyros lycioides* prominent. *Acacia haematoxylon* (Group E) is often dominant, and forms a characteristic feature of the vegetation community. Other important species that are found in this community are *Hermannia tomentosa, Elephanthorrhiza elephantia* and *Stipagrostis amabilis* (Group C) and *Eragrostis lehmanniana, Aristida meridionalis, Aristida congesta, Grewia flava* and *Stipagrostis uniplumis* (Group E) occur widely in this community.

The presence of Species Group H indicates that this community is floristically (and therefore ecologically) related to other plant communities on sandy plains and dunes (see Figure 5.2). Species Group C indicates the close relationship of this plant community to the *Stipagrostis amabilis – Brachiaria dura* var. *pilosa* Dune Vegetation. Community 2 represents undisturbed natural vegetation.

The species composition at the edge of the dunes compares to a community described by Lubbinge (1998): *Acacia haematoxylon – Stipagrostetum amabilis*, associated with dune crests (ranging from very high dunes to undulating sand flats). Lubbinge (1998) further mentions that this vegetation type occurs on loose non-calceferous sand.

Figure 5.7 The *Acacia haematoxylon – Eragrostis trichophora* Low grassy Bushland showing *Acacia haematoxylon* surrounded by a herbaceous layer consisting mainly of *Eragrostis trichophora*.

5.3.2.3 Community 3: *Prosopis velutina – Schmidtia kalihariensis* High Closed Shrubland

In contrast to the previous community that was undisturbed this community shows signs of disturbance and invasion of the alien tree *Prosopis velutina.* This species, originally from USA (Arizona, western New Mexico), Mexico (Sonora) (Faucon 1998-2005) is a serous problem in this area (Figure 5.7). In some parts of this community attempts have been made to eradicate the *Prosopis*, but range degradation has already occurred as can be seen by the grass and pioneer species growing in these cleared areas. The species found in the cleared area are *Tribulus zeyheri* and *Schmidtia kalihariensis*. The soil characteristics are similar to that of 5.3.2.2 Community 2. The soil colour recorded was 7.5YR 6/6.

Prosopis velutina – Schmidtia kalihariensis High Closed Shrubland is characterized by *Prosopis velutina* and less abundant species such as *Sida cordifolia* and *Nolletia arenosa* (Group D). Other important species found in this community are *Tribulus terrestris* (Goup E) and *Schmidtia kalihariensis* (Group H), which are indicators of disturbance. Less common species are *Eragrostis lehmanniana* and *Lycium hirsutum.*

Figure 5.8 *Prosopis velutina – Schmidtia kalihariensis* High Closed Shrubland (Community 3). Dense stands of *Prosopis velutina* occur in this community.

5.3.2.4 Community 4: *Acacia erioloba – Acacia karroo* Low Grassy Woodland

This woodland is found on the reddish Kalahari sand. The sand, however, is much deeper than the sand on which Community 5 occurs. There is no regolith visible in this community. The colour of the sand is 7.5YR 5/8, 7.5YR 5/6 and 7.5YR 6/8. Badenhorst *et al.* (1999) describe the soil as strong brown (7.5YR 5/8). The altitude where the community occurs is 1 160 – 1 230 m.

Acacia erioloba – Acacia karroo Low Grassy Woodland (Figure 5.8) is characterized by Species Group F (Table 5.1) with species such as *Acacia erioloba* and *Acacia karroo* prominent. Other species that also occur in this community are *Acacia mellifera*, *Boscia albitrunca, Eragrostis lehmanniana, Grewia flava, Diospyros lycioides, Aristida congesta, Hermannia vestita* (Species Group H) and *Stipagrostis uniplumis* (Species Group K). These two Species Groups indicate the floristic relationship with other sandy plains vegetation on the Reserve.

Lloyd *et al.* (1997) recorded several other species such as *Acacia haematoxylon*, *Schmidtia kalihariensis*, *Indigofera alternans*, *Lycium cinereum* and *Stipagrostis obtusa* in parts of this community.

Figure 5.9 The *Acacia erioloba – Acacia karroo* Low Grassy Woodland (Community 4) showing most of the prominent woody species such as *Acacia erioloba, Acacia karroo, Acacia mellifera*, *Boscia albitrunca, Grewia flava, Diospyros lycioides* and *Acacia haematoxylon*.

5.3.2.5 Community 5: *Acacia mellifera – Rhigozum trichotomum* Shrubland

This community occurs on shallow red Kalahari sand with a 5YR 5/8 colour, with no calciferous material present in the soil. Badenhorst *et al.* (1999) classify the soil colour as strong brown (7.5YR 5/8). The community occurs at an altitude of 1 160 – 1 250 m. There are areas where quartzite is visible in the community. It is not always certain whether the quartzite belongs to outcrops or are loose pieces (regolith).

Acacia mellifera – Rhigozum trichotomum Shrubland is characterised by Species Group G (Table 5.1) but also contains species from Group H. The most conspicuous species are *Rhigozum trichotomum* (Figure 5.9)*, Acacia mellifera* and *Boscia albitrunca.* Other important species are *Eragrostis lehmanniana, Monechma incanum, Asparagus suaveolens, Schmidtia kalihariensis* and *Stipagrostis uniplumis.*

Species Group H indicates the floristic relationship of this community to the other sandy plains vegetation on the Reserve.

The species composition of this community compares to a community described by Lubbinge (1998): *Acacia mellifera – Rhigozum trichotomum* calciferous terraces. The main difference is that the community described by Lubbinge is associated with calciferous terraces near rivers and pans where the calcrete outcrops.

Figure 5.10 The *Acacia mellifera – Rhigozum trichotomum* Shrubland (Community 5) showing *Acacia mellifera* and *Rhigozum tricotomum* as prominant.

5.3.2.6 Community 6: *Croton gratissimus – Cymbopogon pospischilii* Quartzite Outcrop Vegetation

This community is associated with the quartzite outcrops (Figure 5.10). On Witsand Nature Reserve there are only limited areas where the quartzite outcrops are visible, but only as small hills. The soil colours recorded in this community are 7.5YR 5/4, 7.5YR 6/6 and 7.5YR 5/8.

The species that characterize this community are classified into Species Group I, *Cymbopogon pospischilii , Croton gratissimus, Digitaria eriantha* and *Pollichia campestris.* Other species that are found are *Tarchonanthus camphoratus, Euclea undulata*, *Eragrostis rigidior, Aloe hereroensis*, *Crassula* species. Lloyd *et al.* (1997) also recorded species, such as *Melinis nerviglumis*, *Digitaria eriantha* and *Enneapogon cenchroides*.

The total herbaceous plant cover according to Lloyd *et al.* (1997) was 57.2%, the woody vegetation cover 14.8% and the rock cover 38.0%. Lloyd *et al.* (1997) also indicated that that the rock cover and shallow (0 – 30 cm) soil of this community were distinctive. All other vegetation types had little or no rock cover and deep soils (>100 cm) (Lloyd *et al.* 1997).

The species composition compares slightly to that of the Koranna-Langeberg Mountain Bushveld (SVk 15) vegetation unit (Mucina & Rutherford 2006), but differs enough to classify separately. It however has been noticed that there are several other species occurring on the adjacent Langberg.

Figure 5.11 The *Cymbopogon pospischilii* – *Croton gratissimus* Quartzite Outcrop Vegetation (Community 6). The quartzite is a visible characteristic of this community.

5.3.2.7 Community 7: *Cyperus longus* var. *tenuiflorus – Schoenoplectus decipiens* Pan Vegetation

This community is found as small local patches scattered within 5.3.2.1 Community 1. These patches are concentrated in the central part of 5.3.2.1 Community 1 and the area is known as the white sands of Witsand Nature Reserve. This community consists mainly of species of the Cyperaceae and is found associated with the patches of surface water. The pans are formed in parts where the water table reaches the surface (Figure 5.11).

This community is characterized by species of Group L with species such as *Cyperus longus* var. *tenuiflorus, Schoenoplectus decipiens, Juncus exsertus, Senecio angustifolius* and *Juncus dregeanus*.

Lubbinge (1998) described several vegetation types occurring around rivers and pans in the southern Kalahari duneveld, but none of them compares to the pan vegetation occurring on Witsand.

Figure 5.12 One of the pans showing *Cyperus longus* var. *tenuiflorus – Schoenoplectus decipiens* Pan Vegetation (Community 7). Some of the pans have no visible surface water, but the occurrence of sedges show that the soil is water logged.

5.4 Species occurring at Witsand Nature Reserve:

Acacia erioloba E.Mey.
Acacia erioloba E.Mey. x *A. haematoxylon* Willd.*
Acacia haematoxylon Willd.
*Acacia heb*eclada DC.
Acacia karroo Hayne
Acacia mellifera (Vahl) Benth.
Acrotome inflata Benth.
Albuca species
Aloe hereroensis Engl.
Alternanthera pungens H.B.K.*
Amaranthus dinteri Schinz*
Andropogon eucomus Nees
Anthephora argentea Gooss.
Aptosimum junceum (Hiern) Philcox*
Aptosimum pubescens Weber*
Aptosimum spinescens (Thunb.) F.E.Weber
Argemone ochroleuca Sweet*
Aridaria noctiflora (L.) Schwantes
Aristida congesta Roem. & Schult.
Aristida meridionalis Henrard
Aristida stipitata Hack.
Aristida stipitata Hack. ssp. *graciliflora* (Pilg.) Mield.
Asclepia fruticosa L.*
Asparagus suaveolens Burch.
Azima tetracantha Lam.*
Barleria lichtensteiniana Nees*
Barleria rigida Nees
Blepharis mitrata C.B. Cl.*
Boerhavia cordobensis Kuntze*
Boophone disticha (L.f.) Herb.
Boscia albitrunca (Burch.)
Brachiaria dura Stapf var. *pilosa* J.G. Anderson
Brachiaria nigropedata (Ficalho & Hiern) Stapf.
Bryum capilare Hedw.*
Bulbostylis hispidula (Vahl) R.W. Hains
Cadaba aphylla (Thunb.) Wild
Cenchrus ciliaris L.
Centropodia glauca (Nees)
Chascanum pinnatifidum (L.f.) E. Mey
Chenopodium album L.
Chloris virgata Sw.
*Chrysocoma ciliat*a L.
Chrysocoma species
Cleome gynandra L.*
Cleome kalachariensis (Schinz) Gilg & Ben.*
Cleome rubella Burch.*
Conyza albida Spreng.*
Crotalaria orientalis Burtt Davy ex I. Verb.
Crotalaria sphaerocarpa Perr. ex DC.*

Croton gratissimus Burch.
Cucumis africanus L.F.*
Cymbopogon pospischilii (K.Schum.) C.E. Hubb
Cynodon dactylon (L.) Pers.*
Cyperus longus L. var. tenuiflorus (Rottb.) Boeck.
Cyperus margaritaceus Vahl
Dicoma schinzii O. Hoffm.
Digitaria eriantha Steud.
Dimorphotheca polyptera DC.
Diospyros lycioides Desf.
Dipcadi marlothii Engl.*
Dipcadi papillatum Oberm.*
Ehretia rigida (Thunb.) Druce*
Elephantorrhiza elephantina (Burch.) Skeels
Elionurus muticus (Spreng.) Kuntze
Enneapogon cenchroides (Roem. & Schult.) C.E. Hubb*
Enneapogon desvauxii P. Beauv.
Eragrostis bicolor Nees
Eragrostis biflora Hack. Ex Schinz
Eragrostis echinochloidea Stapf*
Eragrostis gummiflua Nees
Eragrostis lehmanniana Nees
Eragrostis nindensis Fical. & Hiern*
Eragrostis pallens Hack.
Eragrostis rigidior Pilg.
Eragrostis trichophora Coss. & Durieu
Eriocephalus ericoides (L.f.) Druce
Eriospermum confusum V. Poelln.*
Euclea undulata Thunb.
Euphorbia gariepina Boiss.*
Euryops multifidus (Thunb.)
Euryops species
Euryops subcarnosus DC. subsp. *vulgaris* B. Nord.*
Evolvulus alsinoides (L.)
Felicia fascicularis DC.
Felicia hyssopifolia (P.J. Berguis) Nees
Felicia muricata (Thunb.) Nees*
Felicia namaquana (Harv.) Merxm.*
Fuirena coerulescens Steud.*
Fuirena pubescens (Poir.) Kunth
Galenia namaensis Schinz*
Garuleum schinzii O. Hoffm.*
Gazania krebsiana Less.
Geigeria brevifolia (DC.)
Geigeria onativa O. Hoffm.*
Gisekia pharnacioides L.*
Gnidia polycephala (C.A. Mey.) Gigly
Grewia flava DC.
Grielum hmifusum Thunb.*
Harpagophytum procumbens (Burch.) DC. ex Meisnn.*
Helichrysum argyrosphaerum DC.*
Helichrysum zeyheri Less.

Heliotropium ciliatum Kaplan
Heliotropium steudnere Vatke*
Hermannia burchelli (Sweet) Verdoorn*
Hermannia comosa Burch. ex DC.
Hermannia grandiflora Aiton
Hermannia grossularifolia L.
Hermannia modesta (Ehrenb.) Mast*
Hermannia quartiniana A.Rich.
Hermannia tomentosa (Turcz.) Schinz ex Engl.
Hermannia vestita Thunb.
Hermbstaedtia odorata (Burch.) T. Cooke var odorata*
Hertia species
Heteropogon contortus (L.) Roem. & Schult.*
Hibiscus micranthus L. f. var. *micranthus*
Hirpicium echinus Less.*
Hypericum lalandii Choisy*
Indigofera alternans DC.*
Indigofera damarana Merxm. & A Scfreib.
Indigofera daleoides Benth. ex Harv. var *daleoides*
Indigofera heterotricha DC
Ipomoea bolusiana Schinz
Ipomoea magnusiana Schinz var. *eenii* (Rendle) A. Meeuse*
Isolepis cernua (Vahl) Roem. & Schult.
Jamesbrittenia argentea (L.f.) Hilliard
Jamesbrittenia integerrima
Juncus dregeanus Kunth
Juncus exsertus Buchenau
Juncus oxycarpus E.Mey. ex Kunth
Juncus rigidus Desf.*
Justicia thymifolia (Nees)
Kalanchoe brachyloba Welw. ex Britten
Kalanchoe paniculata Harv.*
Kleinia longiflora DC.
Kyllinga alata Nees*
Kyphocarpa angustifolia (Moq.) Lopr.
Lantana rugosa Thunb.*
Lebeckia linearifolia E. Mey.
Lebeckia spinescens Harv.*
Lessertia macrostachyta DC.*
Limeum argute-carinatum Wawra & Peyr.*
Limeum fenestratum (Fenzl) Hiemerl*
Limeum viscosum (Gay) Fenzl subsp. *nummulifolium* (H. Walter) Friedr.*
Limeum viscosum (Gay) Fenzl subsp. *viscosum* var. *macrocarpum* Friedr.*
Lobelia erinus L.
Lophiocarpus polystachyus Turcz*
Lopholaena cneorifolia (DC.) S. Moore*
Lopholaena coriifolia (Son.) E. Phillips & C.A. Sm.
Lotononis anthyllopsis B.-E. van Wyk
Lotononis listii Polhill*
Lycium bosciifolium Schinz
Lycium cinereum Thunb.
Lycium hirsutum Dunal

Megaloprotachne albescens C.E. Hubb
Melhania rehmannii Szyszyl.
Melinis nerviglumis (Franch.) Zizka
Melinis repens (Willd.) Zizka
Melolobium microphyllum (L.f.) Eckl. & Zeyh.*
Merremia tridentata (L.) Hallier f. subsp. *angustifolia* (Jacq.) Van Ooststr. var. *angustifolia**
Merremia verecunda Rendle*
Mollugo cerviana (L.) Ser. ex DC.*
Monechma distichotrichum (Lindau) P.G. Mey
Monechma incanum (Nees) C.B. Clarke
Monechma spartioides (T. Anders.) C.B. Cl.*
Monsonia glauca Knuth*
Moquinella rubra (Spreng.f.) Balle*
Nidorella resedifolia DC.
Nolletia arenosa O.Hoffm.
Ornithogalum seineri (Engl. & Krause) Oberm.*
Ornithogalum tenuifolium Delaroche subsp. *aridum* Oberm.*
Ornithoglossum viride (L.f.) Ait.
Oxalis haedulipes Salter*
Oxygonum alatum Burch. var. *alatum**
Panicum kalaharense Mez*
Panicum schinzii Hack*
Pavonia burchelli (DC.) R.A. Dyer*
Pegolettia retrofracta (Thumb.) Kies
Pellaea calomelanos (Sw.)
Pentzia incana (Thunb.) Kuntze*
Persicaria limbata (Meisn.) Hara*
Pharnaceum elongatum (DC.) Adamson*
Phyllanthus parvulus Sond.*
Plexipus pinnatifidus (L.f.) R. Fernandes*
Plexipus pumilus (E. Mey.) R. Fernandes*
Plinthus sericeus Pax
Pogonarthria squarrosa (Roeom. & Schult.) Pilg.
Pollichia campestris Aiton
Pollichia species
Polygala leptophylla Burch.*
Portulaca kermesina N.E. Br.*
Prosopis velutina Wooton
Pseudognaphalium luteo-album (L.) Hilliard & Burtt*
Pseudognaphalium undulatum (L.) Hilliard & Brutt*
Psiadia punctulata (DC.) Oliva. & Hiern ex Vatke
Pteronia cylindracea DC.*
Pterothrix species
Pterothrix tecta Brusse
Ptycholobium biflorum (E. Mey.) Brummitt
Pupalia lappacea (L.) A. Juss.*
Rhigozum obovatum Burch.
Rhigozum trichotomum Burch.
Salsola aphylla L.f.*
Salsola kali L.*
Schmidtia kalihariensis Stend
Schmidtia pappophoroides Stend

Schoenoplectus decipiens (Nees) J. Raynal
Schoenoplectus littoralis (Schrad.) Palla*
Searsia burchellii Sond. ex Engl.
Searsia erosa Thunb.
Searsia tridactyla Burch.
Selago welwitschii Rolfe
Senecio angustifolius (Thunb.) Wild.
Senecio arenarius Thunb.*
Senecio burchelli DC.*
Senecio consanguineus DC.*
*Senecio vimineus**
Senna italica Mill.
Septulina glauca (Thunb.)
Sericocoma avolans Fenzl*
Sesamum capense Burm. f.*
Setaria verticillata (L.)Beauv.
Sida cordifolia L.
Solanum capense L.
Sporobolus fimbriatus (Trin.) Nees
Stachys species
Stipagrostis amabilis (Schweick.) De Winter
Stipagrostis ciliata (Desf.) De Winter
Stipagrostis obtusa (Delile) Nees
Stipagrostis species
Stipagrostis uniplumis (Licht.) De Winter
Sutera argentea (L.f.) Hiern*
Sutera griquensis Hiern
Sutera integerrima (Benth.) Hien*
Sutherlandia frutescens (L.) R. Br.*
Talinum species
Tapinanthus oleifolius (J.C. Wendl.) Danser
Tarchonanthus camphoratus L.
Tavaresia barklyii (T-Dyer) N.E. Br.
Tetragonia arbuscula Fenzl*
Tetragonia calycina Fenzl*
Thesium lineatum L.f.
Thesium strictum P.J.Bergius
Trachyandra laxa (N.E.Br.) Oberm
Tragus racemosus (L.) All.*
Tribulus terrestris L.
Tricholaena monachne (Trin.) Stapf & C.E. Hubb.
Triraphis purpurea (Hack)*
Turbina oenotheroides (L.f.) A. Meeuse*
Typha capensis (Rohrb.) N.E. Br.*
Utricularia arenaria A. DC.
Vahlia capensis (L.f.) Thunb.
Vahlia capensis (L.f.) Thunb. subsp. *ellipticifolia* Bridston*
Verbesina encelioides (Cav.) Benth. & Hook.*
Viscum rotundifolium (L.f.)
Wahlenbergia ecklonii H.Buek
Wahlenbergia species
Waltheria indica L.

Xyris capensis Thunb.
Ziziphus mucronata Willd.

* Species added to list, adapted from Bosch (1996)

Chapter 6 Vegetation Description of the study area

6.1 Classification hierarchy

One hundred and twenty six (126) sample plots, making up 45 sites, were used for the TWINSPAN classification of the plant communities (Figure 6.1). The classification resulted in the identification of three plant communities (Annexure 1). A dendrogram showing the hierarchical floristic relationships and a habitat interpretation is provided in Figure 6.2. In addition, these floristically defined communities were described according to geographic features and physiognomic criteria defined by Edwards (1983). The three plant communities of the study area are the following (Figure 6.3):

1. *Acacia haematoxylon* – *Elephantorrhiza elephantina* – *Eragrostis lehmanniana* Low Grassy Bushland
2. *Acacia mellifera* – *Rhigozum trichotomum* – *Eragrostis lehmanniana* High Open Shrubland
3. *Pentzia calcarea* – *Eragrostis lehmanniana* – *Stipagrostis obtusa* Open Grassland

The first division of TWINSPAN revealed two broad vegetation types linked to the depth of the soil and the presence of calciferous material. These types are 1st: communities containing woody (trees and large shrubs) species (on the deeper soils) and 2nd: a community not containing woody (trees and large shrubs) species (on shallow soils containing calciferous material) consisting of small shrubs, grasses and herbaceous species (Community 3: *Pentzia calcarea* – *Eragrostis lehmanniana* – *Stipagrostis obtusa* Open Grassland). The second level of division divided the Woody communities into bushland vegetation found on the deep sandy soils with a colouration of 7.5 YR (Community 1: *Acacia haematoxylon* – *Elephantorrhiza elephantina* – *Eragrostis lehmanniana* Low Grassy Bushland) and High Shrubland vegetation found on deep and shallow sandy soils with a colouration of 5YR (Community 2: *Acacia mellifera* – *Rhigozum trichotomum* – *Eragrostis lehmanniana* High Open Shrubland).

The following comments on the interpretation of this identification should be made:

- It is a regional classification attempting to identify and define broad attempts to identify broad plant communities, not fine-scale detailed plant communities on the local level.
- Various stages of degradation within the broad communities should indicate degradation patterns within the plant communities. Although these stages of degradation could be interpreted as smaller degraded plant communities this level of detail was not the aim of

the study and not included in this classification. The total data set of these broader plant communities was used for the degradation gradient analysis, to determine the reaction of grass species to the degradation gradient (Chapter 7).

- Several of the described plant communities identified in the more detailed vegetation classification of the Witsand Nature Reserve, could therefore be included in a single broader plant community of this classification.

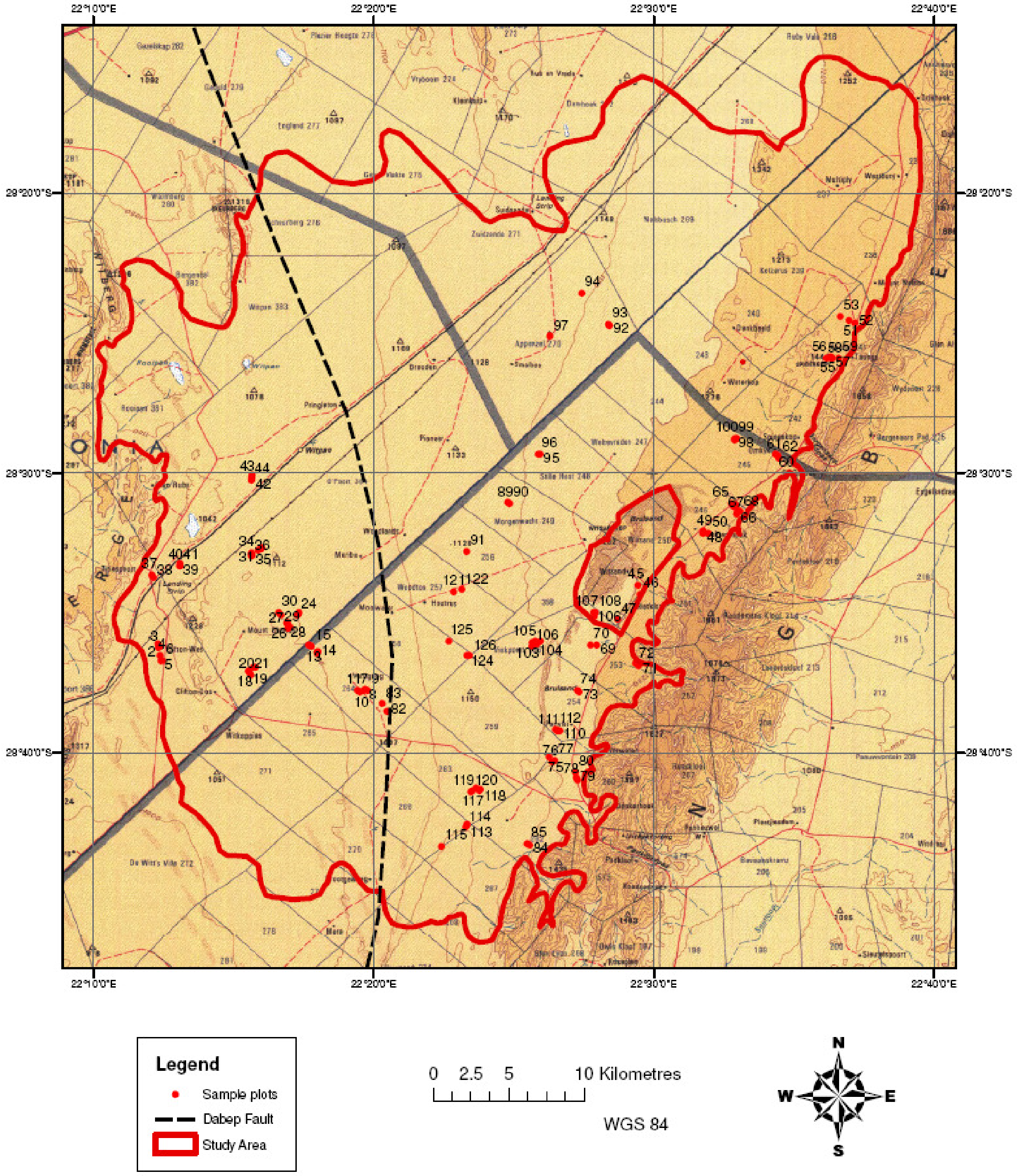

Figure 6.1 Location of sample plots [One hundred and twenty six (126) sample plots].

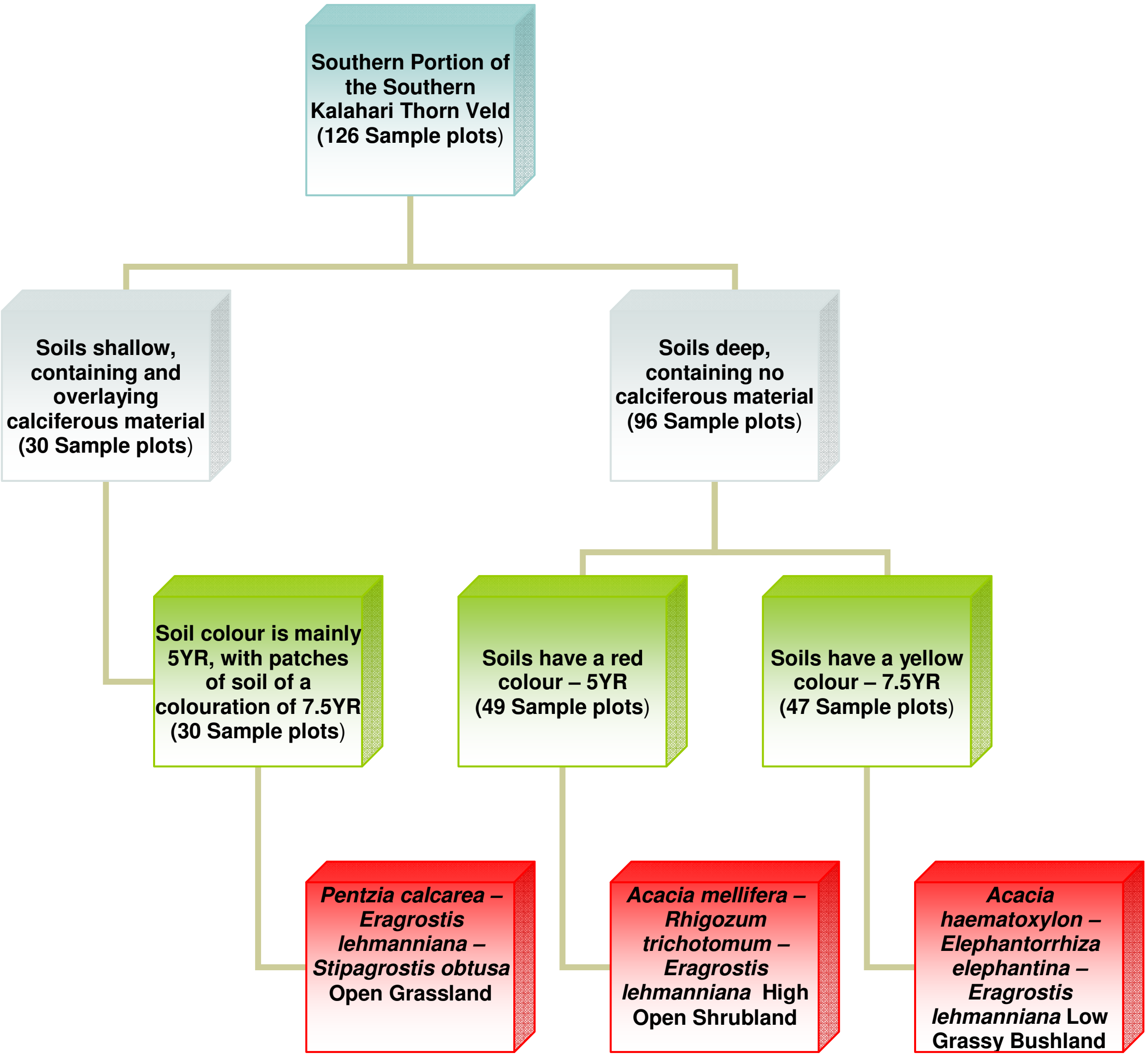

Figure 6.2 A dendrogram showing the hierarchical relationships and broad habitat interpretation between the three plant communities identified in the study area.

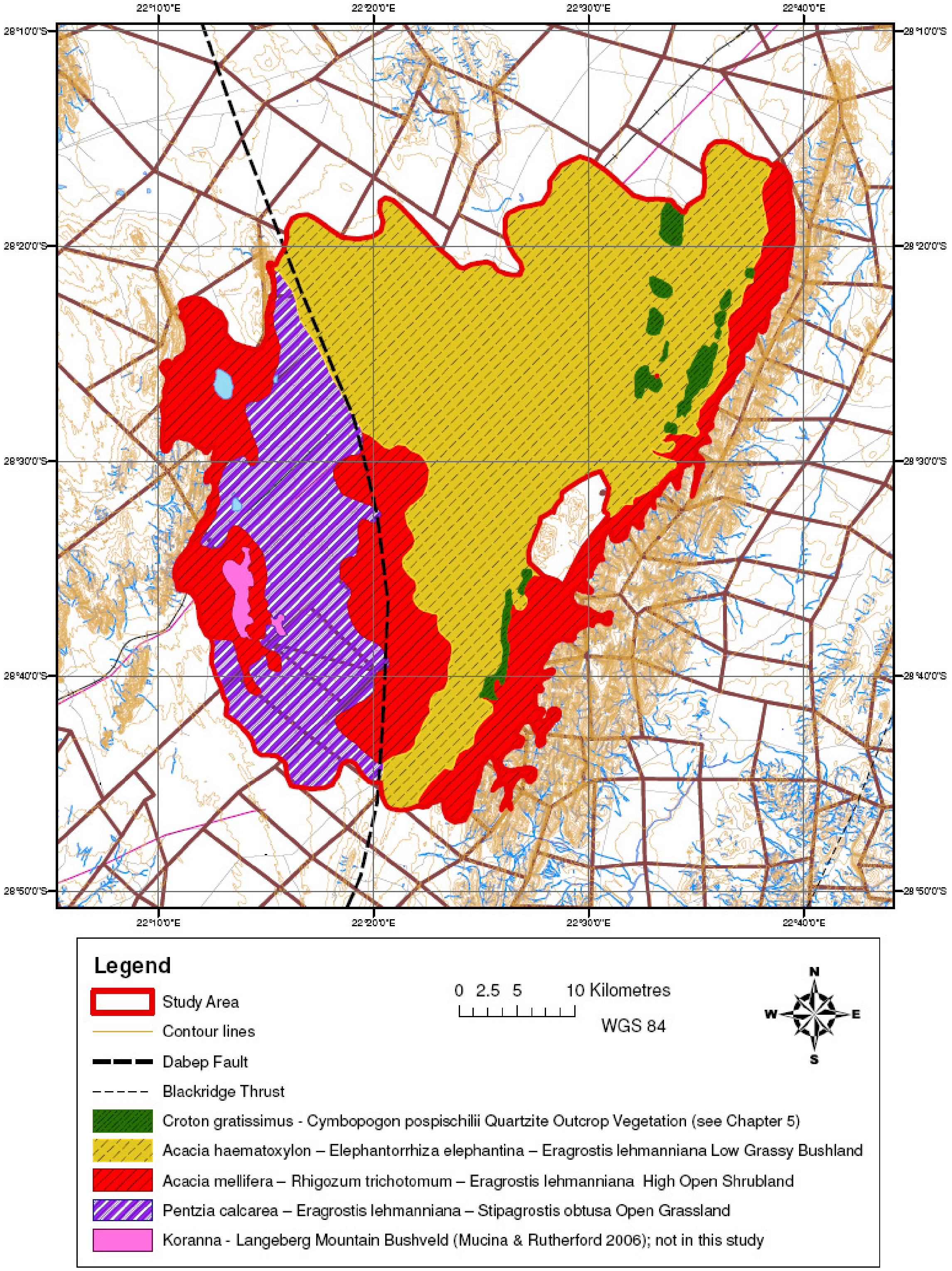

Figure 6.3 Vegetation map of the study area.

6.2 Description of plant communities from the study area

6.2.1 *Acacia haematoxylon – Elephantorrhiza elephantina – Eragrostis lehmanniana* Low Grassy Bushland

A few large dunes occur stretching almost from the main road between Olifantshoek and Upington in a north-south direction all the way down to the Orange River. These dunes are large with a very wide flat structure, flowing gradually into the surrounding sandy plains. This area consists of a very deep sandy soil, with a soil colouration of 7.5YR with no calciferous material present in the profile. Badenhorst *et al.* (1999) describe the sand as well-drained with a Strong Brown (7.5YR 5/8) soil colour. Typical soil colours recorded were 7.5YR 5/6, 7.5YR 7/6 and 7/5YR 7/8. The community lies at an altitude of 1 100 – 1 320 m. This is the area and habitat of *Acacia haematoxylon – Elephantorrhiza elephantina – Eragrostis lehmanniana* Low Grassy Bushland (Figure 6.4, 6.5).

Plant communities 2-3, described in the detailed vegetation classification of the Witsand Nature Reserve (see Chapter 5) are included in the *Acacia haematoxylon – Elephantorrhiza elephantina – Eragrostis lehmanniana* Low Grassy Bushland. The *Acacia haematoxylon – Eragrostis tricophora* Low Grassy Bushland community on Witsand Nature Reserve (Chapter 5) is representative of this community. This Witsand Nature Reserve community is however a small, well protected area, therefore the grassy layer is somewhat different than that of the widely distributed *Acacia haematoxylon – Elephantorrhiza elephantina – Eragrostis lehmanniana* Low Grassy Bushland. Furthermore, the sample pots in the bigger community were selected to represent a degradation gradient, causing the differences in the grassy layer.

The community is characterized by Species Group A (Annexure 1) and includes *Acacia haematoxylon, Elephanthorrhiza elephantia, Hermannia tomentosa, Diospyros lycioides, Anthephora pubescens, Eragrostis bicolor, Eragrostis biflora, Eragrostis pallens* and *Panicum kalaharense*.

Species in Group C (Annexure 1) are shared with Community 2. Prominent species shared between Community 1 and 2 are: *Tribulus zeyheri, Aristida stipitata, Lycium hirsutum, Acacia erioloba, Grewia flava, Aristida meridionalis, Indigofera alternans, Boscia albitrunca,* and *Asparagus suaveolens*.

Group E (Annexure 1) contain species that are shared among Communities 1, 2, and 3 of which, *Eragrostis lehmanniana, Eragrostis trichophora, Aristida congesta, Stipagrostis hirtigluma, Schmidtia kalihariensis, Schmidtia pappophoroides, Senna italica, Crotalaria orientalis* and

Hermannia vestita occur widely in this community. These are widespread species from the Kalahari region.

Schmidtia kalihariensis is recognised as an indicator species of disturbance. These disturbances can either be because of trampling or exposed areas due to drought. It is abundant usually after good rains following a long period of drought. Occurrence of this species is generally in pure stands and is believed to have allelopathic properties (Van Rooyen *et al.* 1991b).

Figure 6.4 *Acacia haematoxylon – Elephantorrhiza elephantina – Eragrostis lehmanniana* Low Grassy Bushland.

Figure 6.5 The *Acacia haematoxylon – Elephantorrhiza elephantina – Eragrostis lehmanniana* Low Grassy Bushland showing *Acacia haematoxylon* surrounded by a herbaceous layer consisting mainly of *Eragrostis trichophora*.

Species that occur within this community:

Trees

Acacia erioloba E.Mey.

Acacia haematoxylon Willd.

Boscia albitrunca (Burch.) Gilg & Gilg-Ben.

Prosopis velutina Wooton

Ziziphus mucronata Willd.

Shrubs

Acacia hebeclada DC.

Acacia mellifera (Vahl) Benth.

Diospyros lycioides Desf.

Grewia flava DC.

Lycium bosciifolium Schinz

Lycium cinereum Thunb. sensu lato

Lycium hirsutum Dunal

Rhigozum obovatum Burch.
Rhigozum trichotomum Burch.

Dwarf Shrubs

Aptosimum marlothii (Engl.) Hiern
Aptosimum spinescens (Thunb.) Weber
Asparagus nelsii Schinz
Asparagus suaveolens Burch.
Crotalaria orientalis Burtt Davy ex I.Verd.
Elephantorrhiza elephantina (Burch.) Skeels
Eriocephalus ericoides (L.f.) Druce
Geigeria ornativa O.Hoffm.
Monechma divaricatum (Nees) C.B.Clarke
Monechma incanum (Nees) C.B.Clarke
Solanum capense L.
Solanum incanum L.
Solanum supinum Dunal

Grasses and sedges

Anthephora pubescens Nees
Aristida congesta Roem. & Schult.
Aristida meridionalis Henrard
Aristida stipitata Hack.
Cenchrus ciliaris L.
Centropodia glauca (Nees) Cope
Cynodon dactylon (L.) Pers.
Enneapogon cenchroides (Roem. & Schult.) C.E.Hubb.
Enneapogon scoparius Stapf
Eragrostis bicolor Nees
Eragrostis biflora Hack. ex Schinz
Eragrostis cilianensis (All.) F.T.Hubb.
Eragrostis lehmanniana Nees
Eragrostis pallens Hack.
Eragrostis plana Nees
Eragrostis trichophora Coss. & Durieu
Panicum kalaharense Mez
Pogonarthria squarrosa (Roem. & Schult.) Pilg.

Schmidtia kalihariensis Stent
Schmidtia pappophoroides Steud.
Setaria sphacelata (Schumach.) Moss
Setaria verticillata (L.) P.Beauv.
Sporobolus rangei Pilg.
Stipagrostis amabilis (Schweick.) De Winter
Stipagrostis ciliata (Desf.) De Winter
Stipagrostis hirtigluma (Trin. & Rupr.) De Winter
Stipagrostis obtusa (Delile) Nees
Stipagrostis uniplumis (Licht.) De Winter

Bulbostylis hispidula (Vahl) R.W.Haines ssp. *pyriformis* (Lye) R.w. Haines
Bulbostylis species
Cyperus margaritaceus Vahl
Kyllinga alba

Herbaceous plants

Acanthosicyos naudinianus (Sond.) C.Jeffrey
Acrotome inflata Benth.
Argemone ochroleuca Sweet
Citrullus lanatus (Thunb.) Matsum. & Nakai
Cleome gynandra L.
Crinum minimum Milne-Redh.
Cucumis africanus L.f.
Cullen obtusifolia (DC.) C.H.Stirt.
Euryops multifidus (Thunb.) DC.
Gisekia africana (Lour.) Kuntze
Hermannia tomentosa (Turcz.) Schinz ex Engl.
Hermannia vestita Thunb.
Indigofera alternans DC.
Indigofera auricoma E.Mey.
Indigofera species
Ledebouria undulata (Jacq.) Jessop
Limeum arenicolum G.Schellenb.
Limeum argute-carinatum Wawra & Peyr.
Limeum sulcatum (Klotzsch) Hutch.
Limeum viscosum (J.Gay) Fenzl

Lotononis leptoloba Bolus

Lotononis platycarpa (Viv.) Pic.Serm.

Mesembryanthemum longipapillosum Dinter

Nolletia arenosa O.Hoffm.

Phyllobolus congestus (L.Bolus) Gerbaulet

Portulaca kermesina N.E.Br.

Requienia sphaerosperma DC.

Senecio angustifolius (Thunb.) Willd.

Senecio laevigatus Thunb.

Senna italica Mill.

Sesamum triphyllum Welw. ex Asch.

Sida cordifolia L.

Tapinanthus oleifolius (J.C.Wendl.) Danser

Tephrosia burchelli Burtt Davy

Trachyandra laxa (N.E.Br.) Oberm.

Trianthema parvifolia E.Mey. ex Sond.

Tribulus zeyheri Sond.

6.2.2 ***Acacia mellifera – Rhigozum trichotomum – Eragrostis lehmanniana*** **High Open Shrubland**

This broad plant community occurs in three large but isolated areas within the study area (Figure 6.3). It (Figure 6.6, 6.7, 6.8) occurs 1st: following a line in a north-south direction between the large yellowish sandy dunes and the Langberg all the way down to the Orange River, 2nd: small areas occur (west of the large yellowish dunes) between Community 1 and Community 3 (large areas of calciferous shallow sandy soils), 3rd: Stretching North-south along the eastern part of the Korannaberg and 4th: along the Dabep Fault. This community occurs on shallow to deep red Kalahari sand with a 5YR colouration. The most prominent colour found throughout the community is 5YR 5/8 colour. The community occurs at an altitude of 1 040 – 1 340 m.

Acacia mellifera – Rhigozum trichotomum Shrubland community of Witsand Nature Reserve is included in the broader community.

The most conspicuous diagnostic species in this community are *Acacia mellifera, Rhigozum trichotomum* (Species Group B – Annexure 1), *Eragrostis lehmanniana* (Species Group E – Annexure 1). Other diagnostic species within the community that occurs in high frequency are *Euryops multifidus* and *Stipagrostis uniplumis* (Species Group B – Annexure 1)

Species Group C (Annexure 1) contains species shared by Communities 1 and 2, species shared between the two communities with prominent occurrence are *Boscia albitrunca, Acacia erioloba, Lycium hirsutum, Grewia flava, Asparagus suaveolens, Aristida stipitata, Aristida meridionalis, Tribulus zeyheri,* and *Indigofera alternans*.

Other species that occur widely over the Kalahari region are *Eragrostis trichophora, Aristida congesta, Stipagrostis hirtigluma, Schmidtia kalihariensis, Schmidtia pappophoroides, Senna italica, Crotalaria orientalis, Hermannia vestita, Requienia sphaerospermum, Monechma incanum, Eriocephalus ericoides, Stipagrostis ciliata, and Stipagrostis obtusa.* These species are shared between Community 1, 2, and 3 (Species Group E – Annexure 1).

Figure 6.6 *Acacia mellifera – Rhigozum trichotomum – Eragrostis lehmanniana* High Open Shrubland. *Acacia erioloba* is present in the community. The Skurweberg in the background.

Figure 6.7 The *Acacia mellifera – Rhigozum trichotomum – Eragrostis lehmanniana* High Open Shrubland showing *Acacia mellifera* and *Rhigozum tricotomum* as prominant.

Figure 6.8 *Acacia mellifera – Rhigozum trichotomum – Eragrostis lehmanniana* High Open Shrubland with *Rhigozum trichotomum* bush encroachment.

Species that occur within this community:

Trees

Acacia karroo Hayne

Acacia haematoxylon Willd.

Prosopis velutina Wooton

Searcia species

Shrubs

Acacia hebeclada DC.

Acacia mellifera (Vahl) Benth.

Cadaba aphylla (Thunb.) Wild

Lycium cinereum Thunb. sensu lato

Rhigozum trichotomum Burch.

Dwarf shrubs

Aptosimum elongatum Engl.

Aptosimum species

Aptosimum spinescens (Thunb.) Weber

Asparagus nelsii Schinz

Barleria rigida Nees

Chrysocoma obtusata (Thunb.) Ehr.Bayer

Crotalaria orientalis Burtt Davy ex I.Verd.

Elephantorrhiza elephantina (Burch.) Skeels

Eriocephalus ericoides (L.f.) Druce

Hermannia burchellii (Sweet) I.Verd.

Hirpicium echinus Less.

Monechma incanum (Nees) C.B.Clarke

Plinthus cryptocarpus Fenzl

Solanum capense L.

Solanum supinum Dunal

Grasses and sedges

Anthephora pubescens Nees

Aristida congesta Roem. & Schult.

Brachiaria dura Stapf f. *pilosa* J.G Anders.

Cenchrus ciliaris L.

Centropodia glauca (Nees) Cope

Eragrostis bicolor Nees

Eragrostis biflora Hack. ex Schinz

Eragrostis brizantha Nees

Eragrostis echinochloidea Stapf

Eragrostis lehmanniana Nees

Eragrostis trichophora Coss. & Durieu

Melinis repens (Willd.) Zizka

Panicum kalaharense Mez

Pogonarthria squarrosa (Roem. & Schult.) Pilg.

Schmidtia kalihariensis Stent

Schmidtia pappophoroides Steud.

Setaria sphacelata (Schumach.) Moss

Setaria verticillata (L.) P.Beauv.

Stipagrostis amabilis (Schweick.) De Winter

Stipagrostis ciliata (Desf.) De Winter
Stipagrostis hirtigluma (Trin. & Rupr.) De Winter
Stipagrostis obtusa (Delile) Nees
Stipagrostis uniplumis (Licht.) De Winter
Tragus racemosus (L.) All.

Bulbostylis species
Cyperus margaritaceus Vahl

Herbaceous plants

Acanthosicyos naudinianus (Sond.) C.Jeffrey
Acrotome inflata Benth.
Ammocharis coranica (Ker Gawl.) Herb.
Arctotis venusta Norl.
Boophane disticha (L.f.) Herb.
Cleome angustifolia Forssk.
Crinum species
Cucumis africanus L.f.
Dicerocaryum eriocarpum (Decne.) Abels
Euryops multifidus (Thunb.) DC.
Geigeria ornativa O.Hoffm.
Gisekia africana (Lour.) Kuntze
Harpagophytum procumbens (Burch.) DC. ex Meisn.
Hermannia species
Hermannia tomentosa (Turcz.) Schinz ex Engl.
Hermannia vestita Thunb.
Hoodia species
Indigofera species
Kleinia longiflora DC.
Lapeiroudia littoralis Baker ssp. *caudata* (Schinz) Goldblatt
Limeum viscosum (J.Gay) Fenzl
Mesembryanthemum longipapillosum Dinter
Mollugo cerviana (L.) Ser. ex DC.
Oxygonum delagoense Kuntze
Pelargonium leucophyllum Turcz.
Portulaca kermesina N.E.Br.
Pupalia lappacea (L.) A.Juss.

Requienia sphaerosperma DC.
Ruschia canonotata (L.Bolus) Schwantes
Senna italica Mill.
Sesamum triphyllum Welw. ex Asch.
Tribulus terrestris L.
Verbesina encelioides (Cav.) Benth. & Hook.

6.2.3 *Pentzia calcarea – Eragrostis lehmanniana – Stipagrostis obtusa* Open Grassland

This community (Figure 6.9, 6.10) is associated with calciferous soils. It occurs west of the Dabep Fault. The soil depth varies from very shallow (areas where the calciferous material form a hard bank that outcrops) to a mere 2 metres (the sand is underlain with a hard calciferous bank. Fine calciferous material is present throughout the soil profile. The soil colour is mainly a reddish colour (5YR), but can become yellowish (7.5YR) closer to the boundary of Community 1. The absence of trees and large shrubs in this community is rather conspicuous. This could be due to unpenetrateable hard calciferous layer below the sand. The community occurs at altitudes ranging from 1 020 – 1 100 m.

The species that characterize this community are classified into Species Group D (Annexure 1), *Pentzia calcarea, Felicia burkei, Eragrostis echinochloidea* and *Jamesbrittenia huillana.* However other diagnostic species that are very prominent within this community are *Plinthus sericeus* (Species Group D – Annexure 1), *Eragrostis lehmanniana* and *Stipagrostis obtusa* (Species Group E – Annexure 1).

Several other species that are shared among Communities 1, 2, and 3 (Species Group E – Annexure 1), of which, *Eragrostis trichophora, Aristida congesta, Stipagrostis hirtigluma, Stipagrostis ciliata, Schmidtia kalihariensis, Schmidtia pappophoroides, Requienia sphaerospermum, Monechma incanum* and *Eriocephalus ericoides* occur widely in the Kalahari region.

Figure 6.9 *Pentzia calcarea – Eragrostis lehmanniana – Stipagrostis obtusa* Open Grassland.

Figure 6.10 *Pentzia calcarea – Eragrostis lehmanniana – Stipagrostis obtusa* Open Grassland showing degraded area.

Species that occur within this community:

Trees

Acacia erioloba E.Mey.
Acacia haematoxylon Willd.
Boscia albitrunca (Burch.) Gilg & Gilg-Ben.

Shrubs

Acacia mellifera (Vahl) Benth.
Grewia flava DC.
Lycium cinereum Thunb. sensu lato
Lycium hirsutum Dunal
Rhigozum trichotomum Burch.

Dwarf shrubs

Aptosimum lineare Marloth & Engl.
Aptosimum marlothii (Engl.) Hiern
Aptosimum species
Aptosimum spinescens (Thunb.) Weber
Asparagus nelsii Schinz
Asparagus suaveolens Burch.
Chrysocoma sparsifolia Hutch.
Crotalaria orientalis Burtt Davy ex I.Verd.
Elephantorrhiza elephantina (Burch.) Skeels
Eriocephalus ericoides (L.f.) Druce
Hermannia grossularifolia L.
Monechma incanum (Nees) C.B.Clarke
Pentzia calcarea Kies
Plinthus cryptocarpus Fenzl
Plinthus sericeus Pax
Solanum capense L.
Solanum supinum Dunal

Grasses and sedges

Aristida congesta Roem. & Schult.
Aristida meridionalis Henrard
Centropodia glauca (Nees) Cope

Eragrostis echinochloidea Stapf

Eragrostis lehmanniana Nees

Eragrostis trichophora Coss. & Durieu

Panicum kalaharense Mez

Pogonarthria squarrosa (Roem. & Schult.) Pilg.

Schmidtia kalihariensis Stent

Schmidtia pappophoroides Steud.

Setaria verticillata (L.) P.Beauv.

Stipagrostis amabilis (Schweick.) De Winter

Stipagrostis ciliata (Desf.) De Winter

Stipagrostis hirtigluma (Trin. & Rupr.) De Winter

Stipagrostis obtusa (Delile) Nees

Bulbostylis species

Herbaceous plants

Acanthosicyos naudinianus (Sond.) C.Jeffrey

Acrotome inflata Benth.

Boophane disticha (L.f.) Herb.

Citrullus lanatus (Thunb.) Matsum. & Nakai

Cucumis africanus L.f.

Felicia burkei (Harv.) L.Bolus

Gisekia africana (Lour.) Kuntze

Hybanthus enneaspermus (L.) F.Muell.

Hermannia tomentosa (Turcz.) Schinz ex Engl.

Hermannia vestita Thunb.

Indigofera alternans DC.

Indigofera auricoma E.Mey.

Jamesbrittenia huillana (Diels) Hilliard

Kohautia cynanchica DC.

Limeum viscosum (J.Gay) Fenzl

Melolobium macrocalyx Dummer

Mesembryanthemum longipapillosum Dinter

Moraea polystachya (Thunb.) Ker Gawl.

Peliostomum leucorrhizum E.Mey. ex Benth.

Phyllobolus congestus (L.Bolus) Gerbaulet

*Portulaca ker*mesina N.E.Br.

Requienia sphaerosperma DC.

Senna italica Mill.
Striga gesnerioides (Willd.) Vatke ex Engl.
Zygophyllum pubescens Schinz

Chapter 7 Degradation gradients and ecological index values

7.1 Introduction

Three plant communities were identified by the TWINSPAN classification technique (Chapter 6).

1. *Acacia haematoxylon – Elephantorrhiza elephantina – Eragrostis lehmanniana* Low Grassy Bushland
2. *Acacia mellifera – Rhigozum trichotomum – Eragrostis lehmanniana* High Open Shrubland
3. *Pentzia calcarea – Eragrostis lehmanniana – Stipagrostis obtusa* Open Grassland

A DCA ordination was further conducted on the total data set. The results are shown in a scatter diagram (Figure 7.1). The Eigen values for the different Axes are:
Axis 1: 0.351
Axis 2: 0.176
Axis 3: 0.145
Axis 4: 0.111

The cumulative percentage variance of the species data is as follows:
Axis 1: 35.1 %
Axis 2: 52.7 %
Axis 3: 67.3 %
Axis 4: 78.4 %

Most of the points that were closest to the water points in all three communities seemed to group in the centre of the scatter diagram, though the three communities tend to stretch out in three different directions, confirming the result of the classification (Chapter 6).

To identify the possible degradation gradients within each of the identified plant communities a DCA ordination was conducted on each identified community separately (Figure 7.3, 7.5, 7.7). The DCA ordination were used to refine the communities (identify the vegetation:habitat groups (Jordaan 1997)).

The outliers identified within each community were removed from the data set, and placed within one of the other data sets to see if they fit within the DCA ordination of those communities. This process was repeated several times until all the sites fit into a dataset. It was not necessary to remove any site out of the total dataset.

No habitat data were used for further ordination, only species composition and frequency.

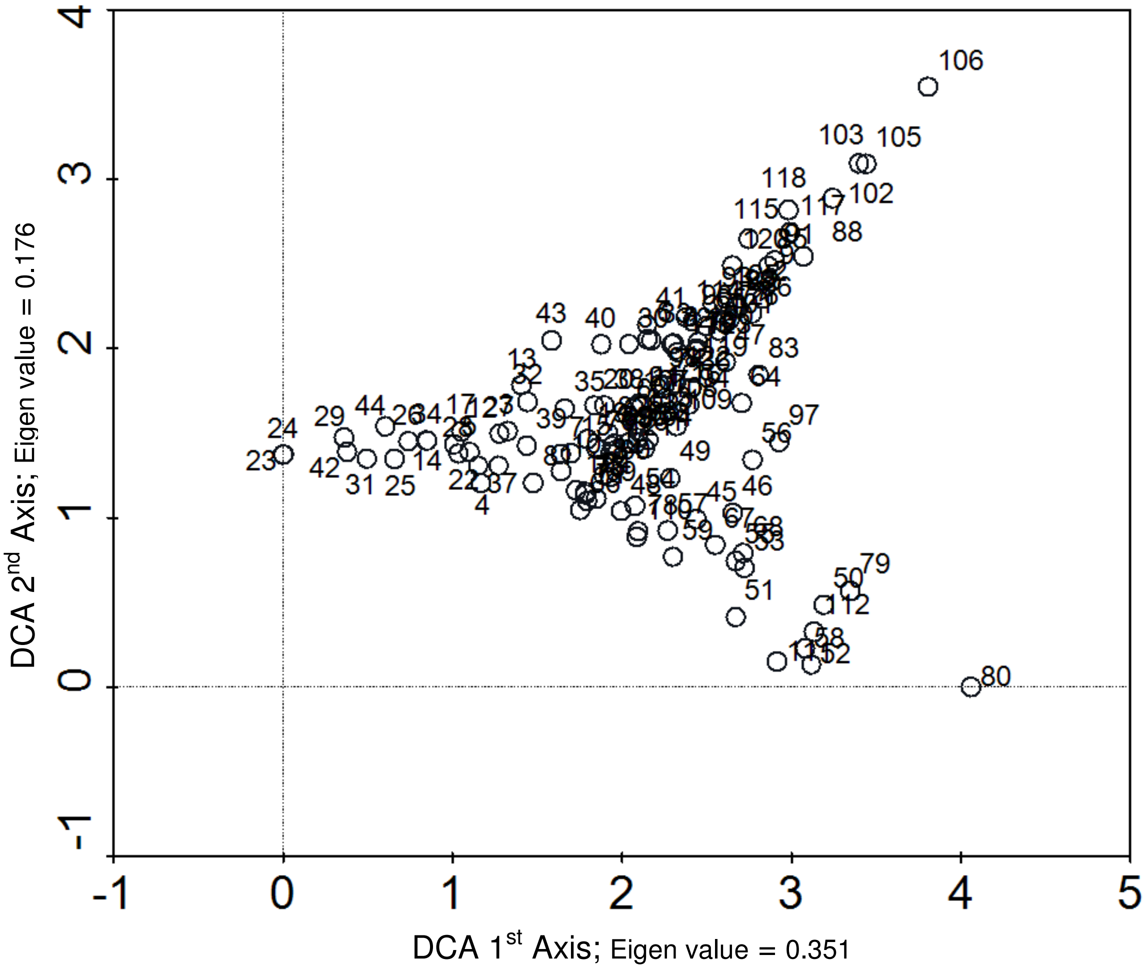

Figure 7.1 DCA-ordination for all the sites together of the three plant communities. Sites closest to the water points clutter together in the centre, while three main groups can be identified.

Gaussian regression curves were compiled to test the individual grass species reaction to degradation (Bosch and Gauch 1991; and Jordaan 1997) within each community separately. Key species were objectively identified (Bosch & Gauch 1991). According to Van der Westhuizen 2003, species with a D-statistic of higher than 0.600, are classified as a key species and species with a low regression (r^2) values show little response to grazing. Species in arid areas has a very sparse vegetation distribution, and the system is very dynamic (climatic changes from year to year – event driven). Therefore in this study, species with a D-statistical value of more than 0.500 were used as key species. According to Jordaan (1997) species that cannot be identified as key species, may be regarded as non-significant (especially species that no regression value were determined for, due to a very low r^2-value) or non-responsive species.

Species are classified into five categories (Janse van Rensburg & Bosch 1990; Bosch & Gauch 1991, Van Rooyen *et al.* 1991a), according to their frequency curves on the grazing intensity gradients within each of the three communities (Figure 7.2)

Category 1: Species characteristic of under utilised veld (ungrazed vegetation (Janse van Rensburg & Bosch 1990)), which decline in frequency along the grazing gradient. These species normally are absent in veld that is moderately to over-grazed (Van Rooyen *et al.* 1991a) – Increasers 1 (Janse van Rensburg & Bosch 1990; Bosch & Gauch 1991).

Category 2: Species rare or low in frequency in under utilised veld (abundant in lightly grazed veld (Janse van Rensburg & Bosch 1990)), but will increase when the veld is lightly grazed. If the veld is moderately to heavily grazed, the frequency of occurrence of these species will decrease (Van Rooyen *et al.* 1991a) – Decreasers (Janse van Rensburg & Bosch 1990; Bosch & Gauch 1991).

Category 3: The species are rare or have a low abundance in lightly grazed veld, but increase in frequency when the veld is moderately or selectively grazed (Janse van Rensburg & Bosch 1990; Van Rooyen *et al.* 1991a) – Increasers 2 (Janse van Rensburg & Bosch 1990; Bosch & Gauch 1991).

Category 4: Species are rare in lightly to moderately grazed veld, but increase when the vegetation is fairly heavily grazed (Janse van Rensburg & Bosch 1990; Van Rooyen *et al.* 1991a) – Increasers 3 (Janse van Rensburg & Bosch 1990; Bosch & Gauch 1991).

Category 5: The species in this category are absent in lightly grazed vegetation and become dominant in veld that is severely (very heavily) overgrazed (Janse van Rensburg & Bosch 1990; Van Rooyen *et al.* 1991a) – Increasers 4 (Janse van Rensburg & Bosch 1990; Bosch & Gauch 1991).

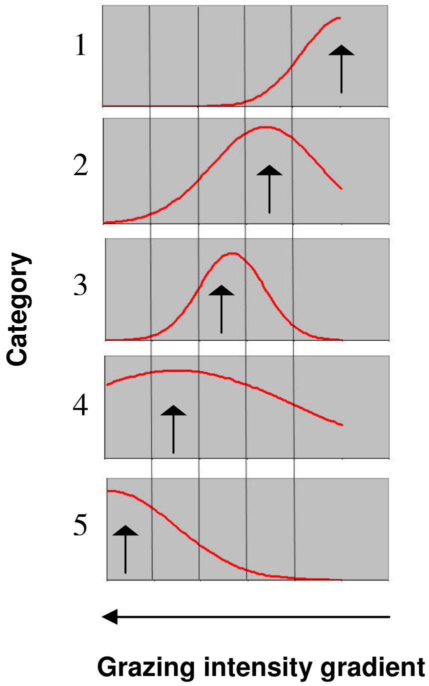

Figure 7.2 Schematic presentation of the five categories defined along a grazing intensity gradient (adapted from Van Rooyen *et al.* 1991a).

7.2 Community 1: *Acacia haematoxylon – Elephantorrhiza elephantina – Eragrostis lehmanniana* Low Grassy Bushland

7.2.1 Degradation Gradient

The data on the species composition of this community were collected from 47 sample points (16 sites). The spatial distribution of the sample plots along the first and second axes of the DCA ordination is shown in a scatter diagram (Figure 7.3).

The Eigen values for the different Axes are:
Axis 1: 0.397
Axis 2: 0.219
Axis 3: 0.130
Axis 4: 0.085

The first axis of the scatter diagram (Figure 7.3) shows that there is an association with a gradient (degradation gradient), sample plots with lower x-values were usually closer to watering points (sample plots marked in red). It was assumed during the field survey that sample plots closer to the watering points were much more degraded than sample plots further away from the watering points. It is observed from the scatter diagram (Figure 7.3) that sample plots surveyed further away from watering points have higher (veld condition) values (x-axis) (sample plots marked in green).

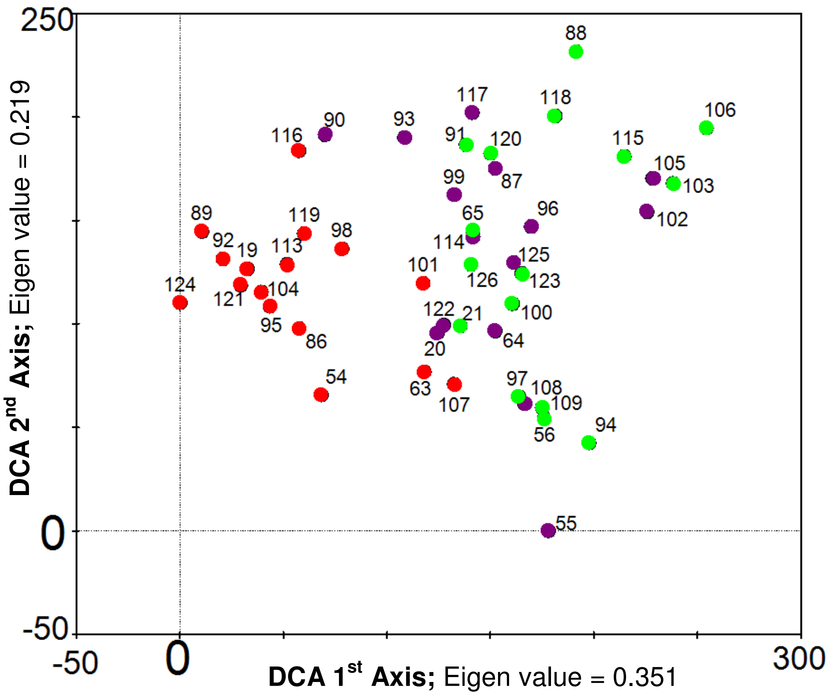

Figure 7.3 Spatial distribution of the sample plots from Community 1: *Acacia haematoxylon – Elephantorrhiza elephantina – Eragrostis lehmanniana* Low Grassy Bushland, on the first and second axes of the DCA ordination. Red – sample plots 0 to 30 metres away from a watering point; Purple – sample plots 30 to 100 metres away from a watering point; Green – sample plots 100 metres or more away from a watering point, some sample plots were several kilometres away.

7.2.2 Categorization of grass species

Regression values (Table 7.1) were determined for eleven (11) of the eighteen (18) grass species researched from the twenty six (26) grass species found within the community. The species where no regression values were determined were species with very low frequency of occurrence within the community. These 11 species are: *Anthephora pubescens, Aristida congesta, Aristida meridionalis, Aristida stipitata, Eragrostis bicolor, Eragrostis lehmanniana, Eragrostis pallens, Eragrostis trichophora, Stipagrostis ciliate, Stipagrostis hirtugluma, Stipagrostis obtusa.*

The following 6 species were included for the DMOC ordination procedures, but the frequency of occurrence was too low to determine any regression value: *Enneapogon cenchroides, Eragrostis cilianensis, Eragrostis biflora, Pogonarthia squarosa, Sporobolus rangei* and *Stipagrostis uniplumis.*

Table 7.1 Regression value and D-statistic for the indicator species in Community 1: *Acacia haematoxylon – Elephantorrhiza elephantina – Eragrostis lehmanniana* Low Grassy Bushland

Responsive species		
Name	**r^2**	**D**
Anthephora pubescens	0.305	0.710
Aristida stipitata	0.153	0.500
Eragrostis bicolor	0.872	0.956
Eragrostis pallens	0.185	0.540
Stipagrostis ciliata	0.283	0.677
Stipagrostis hirtugluma	0.963	0.990
Non-responsive species		
Name	**r^2**	**D**
Aristida congesta	0.086	0.456
Aristida meridionalis	0.066	0.334
Eragrostis lehmanniana	0.016	0.125
Eragrostis tricophora	0.024	0.151
Stipagrostis obtusa	0.140	0.460

The Gaussian distribution curves were used to determine the ecological values. The position of the peak of every curve (Figure 7.4) on the x-axis expressed as a percentage of the length of the degradation gradient was used to allocate ecological values (Van der Westhuizen *et al.* 1999) for all 11 species. The species were then classified into ecological index classes (adapted from Van der Westhuizent *et al.* (1999) (Table 7.2).

Table 7.2 The ecological value, ecological index value and categorization of grass species determined by the Degradation Model Construction method for Community 1: *Acacia haematoxylon – Elephantorrhiza elephantina – Eragrostis lehmanniana* Low Grassy Bushland

Species	**Ecological Value**	**Ecological Index value**	**Category**
Anthephora pubescens	100	10	1
Eragrostis bicolor	72	7	2
Eragrostis pallens	68	7	2
Eragrostis tricophora	62	6	3
Aristida meridionalis	61	6	3
Eragrostis lehmanniana	59	6	3
Aristida congesta	54	5	3
Stipagrostis obtusa	42	4	4
Aristida stipitata	37	4	4
Stipagrostis ciliata	1	1	5
Stipagrostis hirtugluma	1	1	5

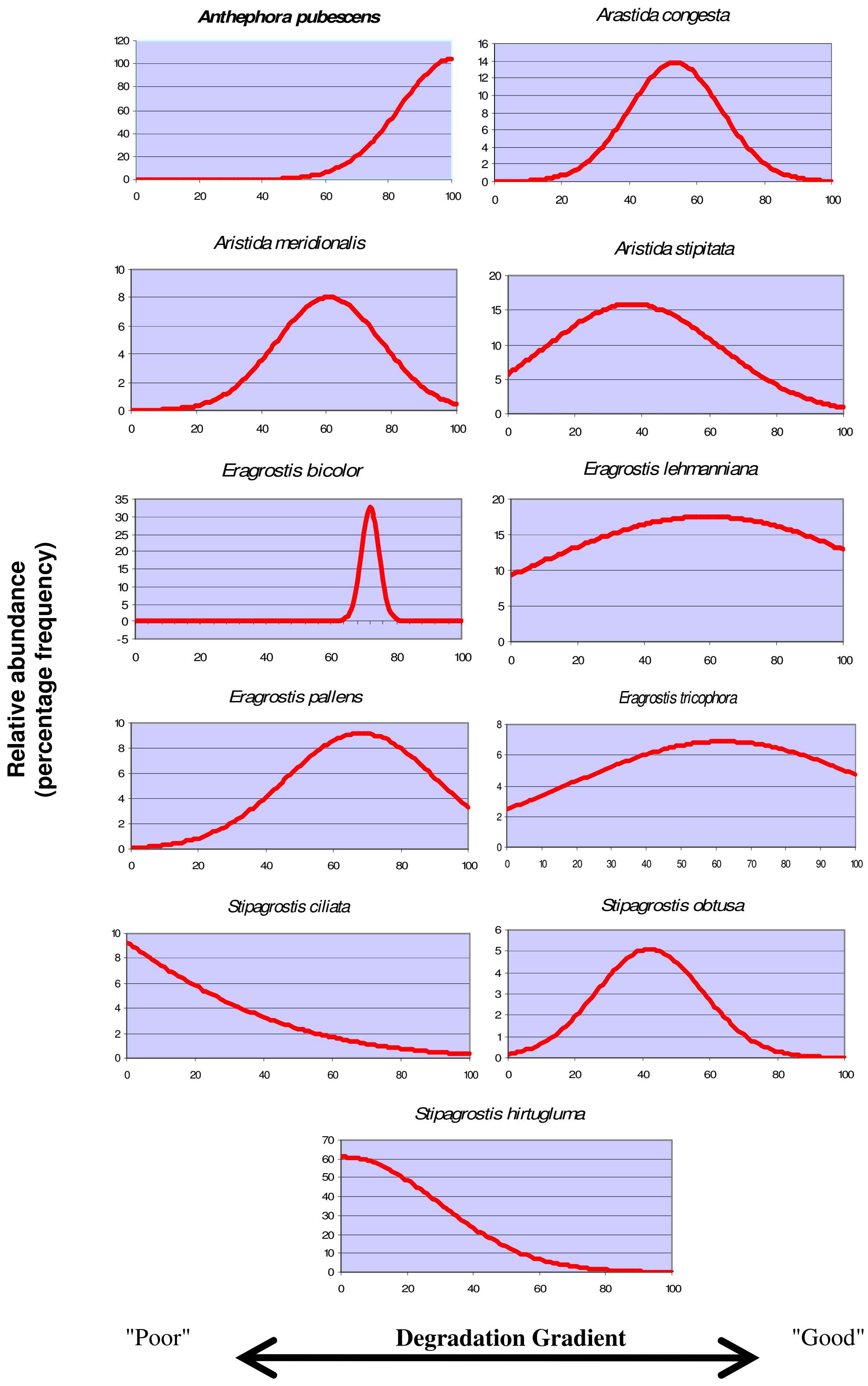

Figure 7.4 The response of individual grass species on a degradation gradient in Community 1: *Acacia haematoxylon – Elephantorrhiza elephantina – Eragrostis lehmanniana* Low Grassy Bushland**.**

7.2.3 Categorization of the 11 indicator species within Community 1: *Acacia haematoxylon – Elephantorrhiza elephantina – Eragrostis lehmanniana* Low Grassy Bushland, and their reaction to grazing.

Category 1

Anthephora pubescens decreases when veld is moderately grazed, and increases when veld is under utilised.

Category 2

Eragrostis bicolor is highly influenced by grazing and increases only with lightly grazed veld. This species decreases when veld is under utilised and when moderate to high grazing occurs. *Eragrostis pallens* increases with light grazing of the veld and decreases when moderate grazing occurs.

Category 3

Aristida meridionalis increases with light to moderate grazing within this community, but decreases when the veld is heavily grazed. *Eragrostis lehmanniana* and *Eragrostis trichophora* show little reaction to grazing pressures. Both species decrease in frequency when the veld is under utilized or heavily grazed. All three of the species are however classified as non-responsive species within this community (Table 7.1). *Aristida congesta* rarely occur in under utilised- and heavily grazed veld. The species increases when veld is moderately or selectively grazed.

Category 4

Stipagrostis obtusa increases in frequency when the veld is moderately to fairly heavily grazed. Both these two species are classified as non-responsive species within this community (Table 7.1). *A. congesta and S. obtusa* will slowly replace *A. pubescens* and *E. bicolor* within this community as the grazing intensity increases. *Aristida stipitata* occurs in veld that is fairly heavily grazed.

Category 5

Stipagrostis ciliata and *Stipagrostis hirtugluma* increases when the veld is fairly heavily grazed and become even more abundant when the veld is seriously overgrazed within this community. *A. stipitata, S. ciliata* and *S. hirtugluma* will, when the veld is heavily grazed, start to replace species such as *A. meridionalis, E. lehmanniana* and *E. trichophora.*

7.3 Community 2: *Acacia mellifera – Rhigozum trichotomum – Eragrostis lehmanniana* High Open Shrubland

7.3.1 Degradation Gradient

Forty nine (49) sample plots (18 sites) were surveyed and species composition data collected. The spatial distribution of the sample plots along the first and second axes of the DCA ordination is shown in a scatter diagram (Figure 7.5).

The Eigen values for the different Axes are:
Axis 1: 0.486
Axis 2: 0.319
Axis 3: 0.205
Axis 4: 0.131

The first axis shows that a degradation gradient exists, except for plots 79 and 80. Sample plots with lower x-values, were closer to watering points (sample plots marked in red). It was assumed during the field survey that sample plots closer to the watering points was much more degraded than sample plots further away from the watering points. It is observed from the scatter diagram that sample plots surveyed further away from watering points generally have higher values on the x-axis (sample plots marked in green). A second environmental factor may also be influencing the ordination.

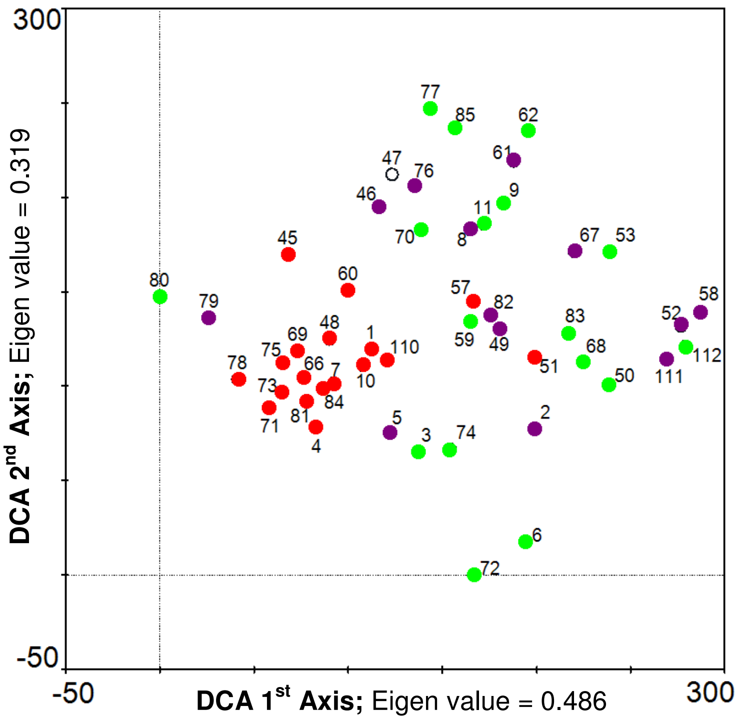

Figure 7.5 Spatial distribution of the sample plots from Community 2: *Acacia mellifera – Rhigozum trichotomum – Eragrostis lehmanniana* High Open Shrubland, on the first and second axes of the DCA ordination. Red – sample plots 0 to 30 metres away from a watering point; Purple – sample plots 30 to 100 metres away from a watering point; Green – sample plots 100 metres or more away from a watering point, some sample plots were several kilometres away.

Sample plots 78, 79 and 80 are within one group. Due to the species composition these sample plots are classified within this community. The reason for the position of plot 80 so far to the left on the first axis could be because of another environmental factor. This sample plot is situated close to the foot of the Langberg Mountains. Although the condition of the grass layer of this sample plot was considered to be good, at the time of the survey, the frequency of occurrence (taken from the Braun-Blanquet table surveys) of *Rhigozum trichotomum* and *Acacia mellifera* within this area and lower occurrence of grass and herbaceous species, bush encroachment might be the reason why this sample plot is ordinated so far left on the first axis.

7.3.2 Categorization of grass species

Regression values were determined for nine (9) (Table 7.3) of the twenty (20) grass species researched from the twenty five (25) species recorded within the community. The species where no regression values were determined were species with very low frequency of occurrence within the community.

The following species were included in the DMOC ordination procedures, but the frequency of occurrence was to low to determine any regression value: *Anthephora pubescens, Brachiaria dura var. pilosa, Cenchrus ciliaris, Centropodia glauca, Eragrostis bicolor, Eragrostis biflora, Eragrostis brizantha, Eragrostis echinochloida, Eragrostis pallens, Pogonarthia squarosa* and *Stipagrostis amabilis.*

Table 7.3 Regression values and D-statistic for the indicator species in Community 2: *Acacia mellifera – Rhigozum trichotomum – Eragrostis lehmanniana* High Open Shrubland

Responsive species		
Name	**r^2**	**D**
Aristida congesta	0.542	0.835
Aristida stipitata	0.715	0.909
Eragrostis lehmanniana	0.738	0.924
Stipagrostis ciliata	0.186	0.555
Stipagrostis hirtugluma	0.695	0.991
Stipagrostis obtusa	0.184	0.574
Stipagrostis uniplumis	0.252	0.677
Non-responsive species		
Name	**r^2**	**D**
Arastida meridionalis	0.074	0.0361
Eragrostis trichophora	0.012	0.163

The 9 species in Table 7.3 were identified as key species within the community. The Gaussian distribution curves were used to determine the ecological values. The position of the peaks of every curve (Figure 7.6) on the x-axis expressed as a percentage of the length of the degradation gradient was used to allocate ecological values (Van der Westhuizen *et al.* 1999) for all 9 species. The species were subjectively classified into ecological index classes (adapted from Van der Westhuizen *et al.* 1999) (Table 7.4), and status assigned.

Table 7.4 The ecological values, ecological index values and categorization of grass species determined by the Degradation Model Construction method for Community 2: *Acacia mellifera – Rhigozum trichotomum – Eragrostis lehmanniana* High Open Shrubland

Species	**Ecological Value**	**Ecological Index value**	**Category**
Eragrostis lehmanniana	100	10	1
Stipagrostis uniplumis	100	10	1
Aristida stipitata	69	7	2
Stipagrostis obtusa	58	6	3
Stipagrostis ciliata	54	5	3
Eragrostis tricophora	30	3	4
Aristida meridionalis	1	1	5
Stipagrostis hirtugluma	1	1	5

Disregarded species:

Aristida congesta	100	10	1

Aristida congesta is a perennial species associated with poor veld conditions (Van Oudtshoorn 2002), such as the other two communities described within this study. *A. congesta* also occur as an annual species (Van Oudtshoorn 2002) (pioneer species). Because this study was conducted during a wet season, the possibility that a large amount of *A. congesta* seed germinated during this period in the less degraded veld. It is very unlikely to use this species as an indicator of good veld conditions because of its known relation with degraded veld. Further research is needed on this species within this community to establish its reaction to grazing and to be able to categorize the species.

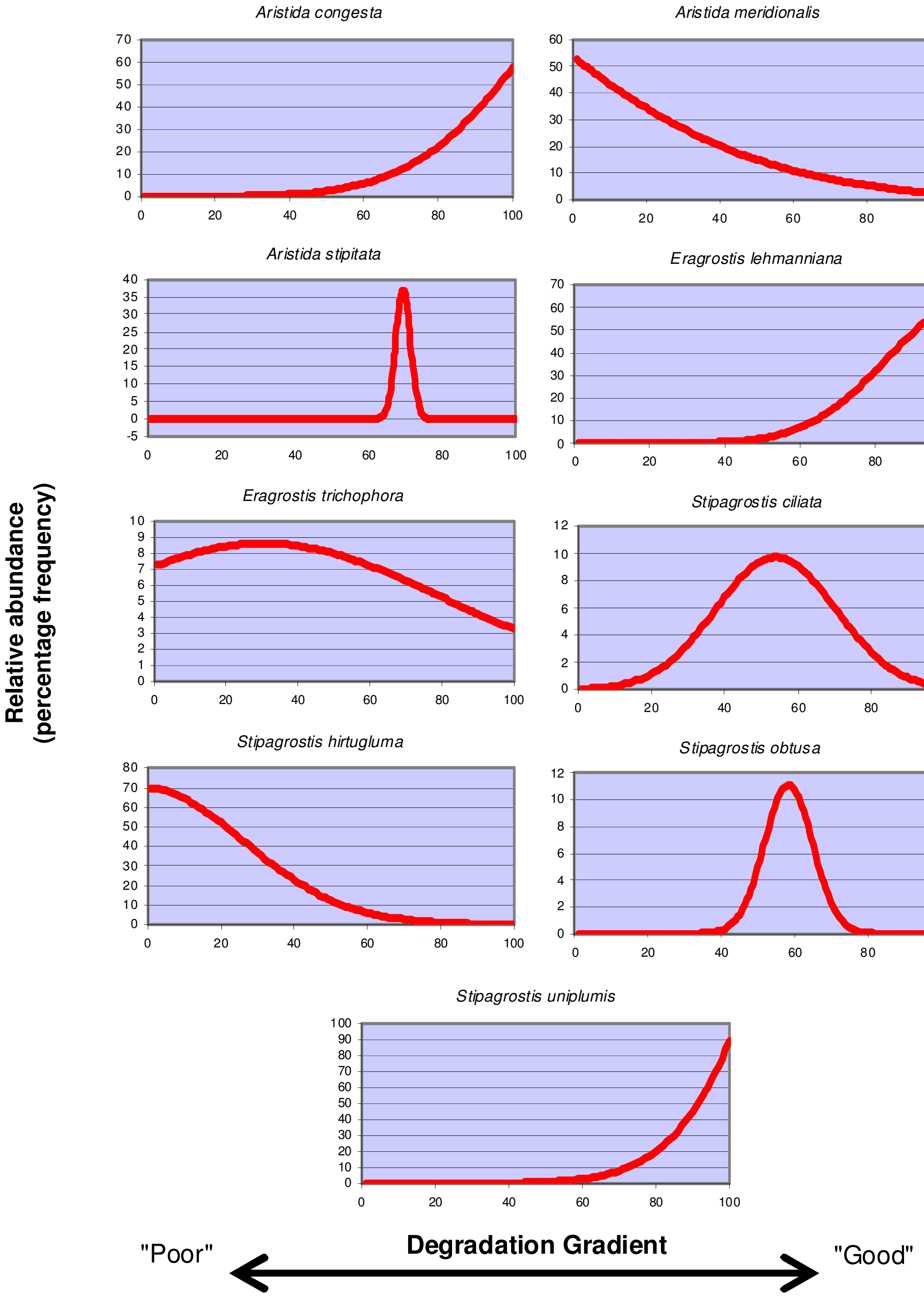

Figure 7.6 The response of individual grass species on a degradation gradient in Community 2: *Acacia mellifera – Rhigozum trichotomum – Eragrostis lehmanniana* High Open Shrubland**.**

7.3.3 Categorization of the 9 indicator species within Community 2: *Acacia mellifera – Rhigozum trichotomum – Eragrostis lehmanniana* High Open Shrubland.

Category 1

Stipagrostis uniplumis increases when veld is under utilized, and will decrease when veld is lightly grazed. The species will be very rare in veld that is moderately to heavily grazed. *Eragrostis lehmanniana* increases when veld is lightly grazed to under utilized. Within this community these species are usually absent in moderately grazed to heavily grazed veld.

Category 2

Aristida stipitata occurs mainly in veld that is lightly grazed and reacts easily to changing grazing intensity. The species occurrence is rare in veld that is under utilized and moderately to overgrazed veld.

Category 3

Stipagrostis obtusa react easily to change in grazing intensity within this community. The species occur mainly within veld that is lightly to moderately grazed. *A. stipitata* will start to displace *S. uniplumis* within this community. *Stipagrostis ciliata* occurs within moderately grazed veld, the species will decrease when the veld is under utilized or heavily grazed. When the veld is being grazed moderately, *S. ciliata* will start to replace species such as *S. uniplumis, A. congesta* and *E. lehmanniana* in this community.

Category 4

Eragrostis trichophora increases when veld is moderately to heavily grazed. The species does not react too much to grazing changes within the community, thus classified as non-responsive species (Table 7.3).

Category 5

Aristida meridionalis is classified as non-responsive species (Table 7.3). This species increases in frequency in veld that is moderately grazed and is abundant in heavily grazed veld. *Stipagrostis hirtugluma* increases in veld that is moderately grazed and is abundant in heavily grazed veld. *S. hirtugluma* will start to replace species such as *S. obtusa* and *S. ciliata* when the veld is being heavily grazed.

7.4 Community 3: *Pentzia calcarea – Eragrostis lehmanniana – Stipagrostis obtusa* Open Grassland

7.4.1 Degradation Gradient

Species composition data were collected within this community from 30 sample plots (11 sites). The spatial distribution of the sample plots with regard to the first and second axes of the DCA ordination is shown in a scatter diagram (Figure 7.7).

The Eigen values for the different Axes are:
Axis 1: 0.456
Axis 2: 0.195
Axis 3: 0.094
Axis 4: 0.054

Most of the sample plots with lower x-values, were sample plots closer to watering points (sample plots marked in red). It was assumed during the field survey that sample plots closer to the watering points was much more degraded than sample plots further away from the watering points (Figure 7.8). It is observed from the scatter diagram that sample plots surveyed further away from watering points have higher values on the x-axis (sample plots marked in green), except for a few sites that might have another environmental factor influencing them.

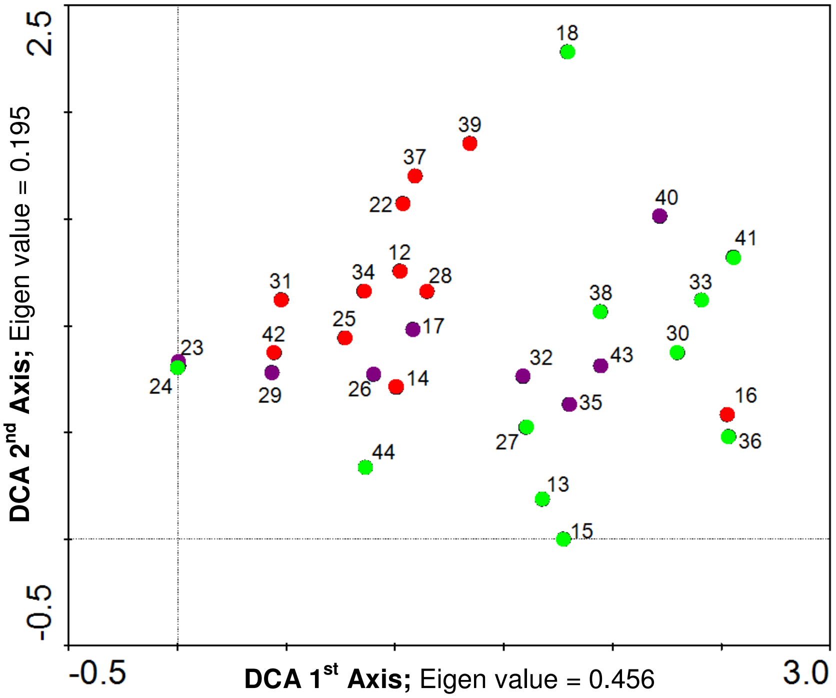

Figure 7.7 Spatial distribution of the survey sample plots from Community 3: *Pentzia calcarea – Eragrostis lehmanniana – Stipagrostis obtusa* Open Grassland, on the first and second axes of the DCA ordination. Red – sample plots 0 to 30 metres away from a watering point; Purple – sample plots 30 to 100 metres away from a watering point; Green – sample plots 100 metres or more away from a watering point, some sample plots were several kilometres away.

Figure 7.8 An example of how the vegetation changes from bare soil, and very degraded near a watering point, to a grass cover consisting of mainly *Stipagrostis obutsa, Eragrostis lehmanniana* and *Stipagrostis ciliata*.

7.4.2 Categorization of grass species

Regression values were determined for eight (8) (key species) of the eleven (11) grass species researched from the fourteen (14) species recorded within the community (Table 7.5). The species where no regression values were determined were species with very low frequency of occurrence within the community.

The following species were used within the data set during the DMOC ordination procedures, but the frequency of occurrence was to low to determine any regression value: *Aristida meridionalis, Pogonarthia squarosa* and *Stipagrostis amabilis.*

The Gaussian distribution curves were used to determine the ecological values. The position of the peaks of every curve (Figure 7.9) on the x-axis expressed as a percentage of the length of the degradation gradient was used to allocate ecological values (Van der Westhuizen *et al.* 1999) for all 8 species. The species were classified into ecological index classes (adapted from Van der Westhuizen *et al.* 1999) (Table 7.6).

Table 7.5 Regression values D-statistic for the indicator species within Community 3: *Pentzia calcarea – Eragrostis lehmanniana – Stipagrostis obtusa* Open Grassland

Responsive species		
Name	**r^2**	**D**
Aristida congesta	0.170	0.536
Eragrostis echinochloidea	0.394	0.758
Eragrostis lehmanniana	0.244	0.595
Eragrostis tricophora	0.271	0.644
Stipagrostis ciliata	0.327	0.685
Stipagrostis hirtugluma	0.893	0.971
Stipagrostis obtusa	0.881	0.968
Non-responsive species		
Name	**r^2**	**D**
Centropodia glauca	0.029	0.254

Table 7.6 The ecological values, ecological index values and categorization of grass species determined by the Degradation Model Construction method for Community 3: *Pentzia calcarea – Eragrostis lehmanniana – Stipagrostis obtusa* Open Grassland

Species	**Ecological Value**	**Ecological Index value**	**Category**
Stipagrostis obtusa	100	10	1
Centropodia glauca	71	7	2
Stipagrostis ciliata	66	7	2
Eragrostis echinochloida	52	5	3
Eragrostis lehemaniana	41	4	4
Aristida congesta	38	4	4
Eragrostis tricophora	1	1	5
Stipagrostis hirtugluma	1	1	5

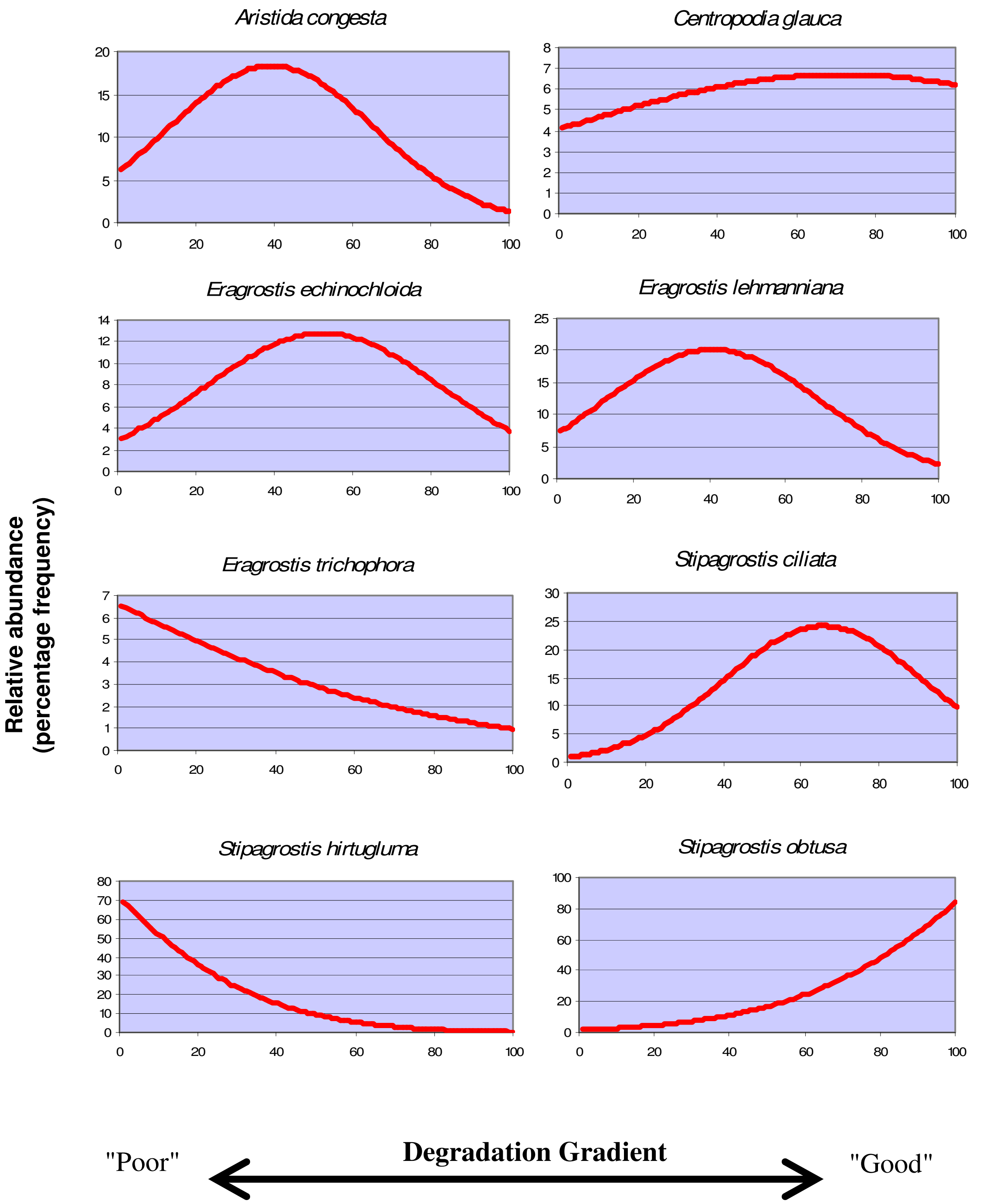

Figure 7.9 The response of individual species on a degradation gradient in Community 3: *Pentzia calcarea – Eragrostis lehmanniana – Stipagrostis obtusa* Open Grassland**.**

7.4.3 Categorization of the 8 indicator species within Community 3: *Pentzia calcarea – Eragrostis lehmanniana – Stipagrostis obtusa* Open Grassland.

Category 1

Stipagrostis obtusa is mostly abundant when the veld is under utilized. The species starts to decrease when the veld is being lightly to moderately grazed. The species is rare in heavily grazed veld.

Category 2

Stipagrostis ciliata occur mainly within lightly grazed veld. The species decreases when the veld is under utilized and also when moderate to heavy grazing occurs. *Centropodia glauca* is a non-responsive species (Table 7.5). The species does not show much of a reaction towards grazing, it only starts to decrease when the veld is heavily grazed.

Category 3

Eragrostis echinochloida is mostly abundant in moderate grazed veld. It decreases when grazing is heavy and also when grazing decreases (light grazing – under utilized). *E. echinochloida* will start to replace species such as *S. obtusa* and *S. ciliata* when grazing intensity increases from under utilized to moderate grazing.

Category 4

Aristida congesta and *Eragrostis lehmanniana* are both species that increase with moderate to heavy grazing within this community. Their frequency lowers with light grazing and under utilized veld.

Category 5

Eragrostis trichophora starts to increase with light grazing and is most abundant within veld that is seriously ovder grazed. *Stipagrostis hirtugluma* increases when the veld is heavily grazed. *E. trichophora* and *S. hirtugluma* will replace species such as *C. glauca, E. echinochloida* within this community, when heavy grazing occurs.

Chapter 8 Conclusions and Recommendations

An ecological assessment of the vegetation was conducted in the south-eastern corner of the Kalahari, south of Olifantshoek within the vicinity of Witsand Nature Reserve. One hundred and twenty six (126) sample plots, making up 45 groups, were used for the TWINSPAN classification, refined by Braun-Blanquet procedures. Results illustrated in a dendrogram, revealed three communities:

1. *Acacia haematoxylon – Elephantorrhiza elephantina – Eragrostis lehmanniana* Low Grassy Bushland
2. *Acacia mellifera – Rhigozum trichotomum – Eragrostis lehmanniana* High Open Shrubland
3. *Pentzia calcarea – Eragrostis lehmanniana – Stipagrostis obtusa* Open Grassland

In the period when the study was done (January – June 2005), the rainfall was 199.5 mm, which was the start of a wet cycle in that area. In comparison with the previous years the rainfall over the same period was much lower. The rainfall during the study period was even higher than the average total (150 mm) over the same period measured from 1951 – 2007.

The western part of the study area is situated on the Kaaien Terrane which for the *Pentzia calcarea – Eragrostis lehmanniana – Stipagrostis obtusa* Open Grassland. The Dabep Thrust forms the boundary between the Brulpan Group of the Kaaien Terrane (Namaqua-Natal Province) and the Volop Group of the Olifantshoek Supergroup. (Cornell *et al.* 2006). The Dabep Thrust runs almost through the middle of the study area from north to south. The Dabep Thrust also coincides with the boundary line between two of the vegetation communities (*Pentzia calcarea – Eragrostis lehmanniana – Stipagrostis obtusa* Open Grassland, occurring the Brulpan Group, and *Acacia haematoxylon – Elephantorrhiza elephantina – Eragrostis lehmanniana* Low Grassy Bushland, occurring the Volop Group). *Acacia mellifera – Rhigozum trichotomum – Eragrostis lehmanniana* High Open Shrubland occur on the areas close to the mountains (outcrops) and on the Dabep Thrust (Figure 3.10).

Three types of soil forms were identified in the study area (Soil Classification Working Group 1991). There is a correlation between the soils and the three different plant communities. Most of the study site is covered by sand and is classified as Namib form (Nb). Three soil families from the Namib form were identified within the study area. The Nortier soils are classified as yellow regic sand (7.5YR - Munsell chart (1971)), with no lime present within 1 500 mm from the soil surface. This soil family is closely associated with the *Acacia haematoxylon – Elephantorrhiza* *elephantina – Eragrostis lehmanniana* Low Grassy Bushland vegetation community. This Kalahari soil family consists of red regic sand, with a soil colour of 5YR (Munsell chart 1971) and no lime present within 1 500 mm from the soil surface. *Acacia mellifera – Rhigozum trichotomum – Eragrostis lehmanniana* High Open Shrubland vegetation community is closely associated with the Kalahari soil family. Henkries soils are red regic sand (5YR - Munsell chart (1971)), containing lime within 1 500 mm from the soil surface. Henkries soils are associated with the *Pentzia calcarea – Eragrostis lehmanniana – Stipagrostis obtusa* Open Grassland vegetation community. The Coega soils comprise of soils with a shallow (less than 500 mm) orhtic A-horizon overlaying a hard carbonate horizon. These soils are found as patches surrounded by Henkries soils and are also associated with the *Pentzia calcarea – Eragrostis lehmanniana – Stipagrostis obtusa* Open Grassland vegetation community.

A study of the vegetation of Witsand Nature Reserve was conducted to classify, describe and map the vegetation of the Witsand Nature Reserve following the standard Braun-Blanquet procedures, as recommended for South Africa. Several of the described plant communities identified in the more detailed vegetation classification of the Witsand Nature Reserve, could therefore be included in a single broader plant community of the vegetation classification done in this study.

The classification revealed the identification of seven plant communities (Table 5.1). A dendrogram showing the hierarchical relationships is provided in Figure 5.2. In addition, these floristically defined communities were categorized according to the physiognomic criteria defined by Edwards (1983) and geographic features:

1. *Stipagrostis amabilis – Brachiaria dura* var. *pilosa* Dune Vegetation
2. *Acacia haematoxylon – Eragrostis trichophora* Low Grassy Bushland
3. *Prosopis velutina – Schmidtia kalihariensis* High Closed Shrubland
4. *Acacia erioloba – Acacia karroo* Low Grassy Woodland
5. *Acacia mellifera – Rhigozum trichotomum* Shrubland
6. *Croton gratissimus – Cymbopogon pospischilii* Quartzite Outcrop Vegetation
7. *Cyperus longus* v. *tenuiflorus – Schoenoplectus decipiens* Pan Vegetation

In the broader communities, 200 meter step-point data were collected at each sample plot, gathered in such a way that different successional stages (degradation stages) could be identified. An ordination technique (multivariate analytical procedures) was used to define the grazing gradient. The plant communities were refined by using a DCA ordination. The degradation gradient was determined and key grass species within each community with the aid of a DMOC. Species abundance curves were statistically fitted to the grazing gradient and used to classify the species into decreaser and increaser categories. Ecological index values were determined for each of the significant species within each community.

Long-term grazing trials would be ideal for the purpose of interpreting condition assessments (Bosch & Kellner 1991), but studying vegetation changes by using single sampling periods was found by Bosch & Janse van Rensburg (1987) to be relatively successful. Van Rooyen *et al.* (1991a) found that veld degradation trends at watering points in the Kalahari, observed by monitoring long term changes over a period of decreasing rainfall and increasing grazing pressure, were similar to observations of a single sampling period. This study was done over one season (a single sampling period).

The degradation gradient method is described by Hurt & Bosch (1991) as one of the most accurate methods for calculating rangeland condition. The multivariant techniques on which this method is based can only be applied with the assistance of a computer (Van der Westhuizen *et.al.* 1999), and the most effective programme to this analysis (ISPD), software is out of date with the current existing computers.

Bosch & Janse van Rensburg (1987) found that the approach to use only a few species which are significantly associated with different degradation stages could be useful for determining veld condition. Janse van Rensburg & Bosch (1990) found that the same species often react differently to grazing in different topographical localities as well as between sub-habitats of the same topographical unit. They found from their study in the Free State that broad standardized grouping of species in ecological groups (Decreasers and Increasers) is scientifically wrong and of little practical value. Therefore in this study key grass species were classified into ecological categories.

It is important to note that the annual grass species – *Schmidtia kalihariensis,* has not been included in the data set. The year the field study was conducted (January – June 2005) (Table 3.3; Figure 3.6), the rainfall was higher than usual, and so was the frequency of occurrence of *Schmidtia kalihariensis* during this period. The occurrence of *Schmidtia kalihariensis* is not only an indicator of degraded or heavily grazed veld (Van Rooyen 2001; Van Oudtshoorn 2002), but is also event driven, for instance when the rain starts after a dry period (Van Oudtshoorn 2002).

If *Schmidtia kalihariensis* was included in the data set, the results would have been influenced by it and could then not be used to develop an ecological index value for the perennial grass species that is subjective (not influenced by major weather changes such as rainy and dry seasons). This however does not mean that the frequency of the perennial species will stay the same during wet or dry periods, but a more realistic value is determined.

The DCA ordination was used to refine the communities (identify the vegetation:habitat groups (Jordaan 1997)). The outliers identified within each community were removed from the data set, and placed within one of the other data sets to see if they fit within the DCA ordination of those communities.

Gaussian regression curves were compiled to test the individual grass species reaction to degradation (Bosch and Gauch 1991; Jordaan, 1997) within each community separately. Key species were objectively identified (Bosch & Gauch 1991). According to Van der Westhuizen 2003, species with a D-statistic of higher than 0.600, are classified as a key species and species with low regression (r^2) values show little response to grazing. Species in arid areas have a very sparse vegetation distribution, and the system is very dynamic (climatic changes from year to year – event driven). In this study, species with a D-statistical value of more than 0.500 were used as key species. According to Jordaan (1997) species that cannot be identified as key species, may be regarded as non-significant (especially species that no regression value were determined for) or non-responsive species.

Species are classified into five categories (Janse van Rensburg & Bosch 1990; Bosch & Gauch 1991, Van Rooyen *et al.* 1991a), according to their frequency curves on the grazing intensity gradients within each of the three communities. The species within each community separately, were subjectively classified into ecological index classes (adapted from van der Westhuizent *et al.* (1999)). The categories of the key grass species within each of the broader communities are summarised in Table 8.1.

Table 8.1 Summary of the key grass species within each of the broader communities

Species	**Community 1: *Acacia haematoxylon – Elephantorrhiza elephantina – Eragrostis lehmanniana* Low Grassy Bushland**	**Community 2: *Acacia mellifera – Rhigozum trichotomum – Eragrostis lehmanniana* High Open Shrubland**	**Community 3: *Pentzia calcarea – Eragrostis lehmanniana – Stipagrostis obtusa* Open Grassland**
Anthephora pubescens	1	-	-
Aristida congesta	3	1?	4
Aristida meridionalis	3	5	-
Aristida stipitata	4	2	-
Centropodia glauca	-	-	2
Eragrostis bicolor	2	-	
Eragrostis echinochloida	-	-	3
Eragrostis lehmanniana	3	1	4
Eragrostis pallens	2	-	-
Eragrostis tricophora	3	4	5
Stipagrostis ciliata	5	3	2
Stipagrostis hirtugluma	5	5	5
Stipagrostis obtusa	4	3	1
Stipagrostis uniplumis	-	1	-

Aristida congesta is a perennial species associated with poor veld conditions (Van Oudtshoorn 2002), such as the other two communities described within this study. *A. congesta* also occur as an annual species (Van Oudtshoorn 2002) (pioneer species). Because this study was conducted during a wet season, the possibility that a large amount of *A. congesta* seed germinated during this period in the less degraded veld. It is very unlikely to use this species as an indicator of good veld conditions because of its known relation with degraded veld. Further research is needed on this species within this community to establish its reaction to grazing and to be able to categorize the species.

The ecological index value could be refined even more if this research is repeated over several years, and compared to weather changes. These ecological values determined for each species should be compared to a grazing value (production value) (Van der Westhuizen *et al.* 2001), defined as the potential genetic ability of a plant species to produce forage production (Van Oudtshoorn 1994), to give better relationship between veld condition and grazing capacity (Van der Westhuizen *et al.* 2001) but is a more financial and time consuming exercise. The ecological index values determined for each specific area are relevant for determining veld condition values. These values could be used on the farms to determine the condition of the veld in each camp and from there an ecological- and economical grazing capacity for each camp can be derived. Based on the calculated grazing capacities recommendations could be made on the stocking density for each camp (Large Stock Units – LSU).

The range condition of the major plant communities was assessed and the ecological grazing and browsing capacities of these communities determined.

The vegetation description of the Langberg and Skurweberg should be refined.

It is recommended that the ISPD software should be upgraded to be able to work on newer versions of Microsoft Windows. Furthermore, a programme must be developed that is more user friendly, especially farmers. Milton *et el.* (1998) started a rangeland health assessment – practical guide for ranches in the arid Karoo shrublands. Something similar could be developed for the farmers in the southern Kalahari, using the veld condition index values derived from degradation gradients, as the backbone of the guides.

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Summary

An ecological assessment of the vegetation was conducted in the south-eastern corner of the Kalahari, south of Olifantshoek within the vicinity of Witsand Nature Reserve. One hundred and twenty six (126) sample plots, making up 45 groups, were used for the TWINSPAN classification, refined by Braun-Blanquet procedures. Results illustrated in a dendrogram, revealed three communities:

1. *Acacia haematoxylon – Elephantorrhiza elephantina – Eragrostis lehmanniana* Low Grassy Bushland
2. *Acacia mellifera – Rhigozum trichotomum – Eragrostis lehmanniana* High Open Shrubland
3. *Pentzia calcarea – Eragrostis lehmanniana – Stipagrostis obtusa* Open Grassland

A study of the vegetation of Witsand Nature Reserve was conducted to classify, describe and map the vegetation of the Witsand Nature Reserve following the standard Braun-Blanquet procedures, as recommended for South Africa. Several of the described plant communities identified in the more detailed vegetation classification of the Witsand Nature Reserve, could therefore be included in a single broader plant community of the vegetation classification done in this study.

The classification revealed the identification of seven plant communities and the results illustrated in a dendrogram. In addition, these floristically defined communities were categorized according to the physiognomic criteria defined by Edwards (1983) and geographic features:

1. *Stipagrostis amabilis – Brachiaria dura* var. *pilosa* Dune Vegetation
2. *Acacia haematoxylon – Eragrostis trichophora* Low Grassy Bushland
3. *Prosopis velutina – Schmidtia kalihariensis* High Closed Shrubland
4. *Acacia erioloba – Acacia karroo* Low Grassy Woodland
5. *Acacia mellifera – Rhigozum trichotomum* Shrubland
6. *Croton gratissimus – Cymbopogon pospischilii* Quartzite Outcrop Vegetation
7. *Cyperus longus* v. *tenuiflorus – Schoenoplectus decipiens* Pan Vegetation

In the broader communities, 200 meter step-point data were collected at each sample plot, gathered in such a way that different successional stages (degradation stages) could be identified. An ordination technique (multivariate analytical procedures) was used to define the grazing gradient. The plant communities were refined by using a DCA ordination. The

degradation gradient was determined and key grass species within each community with the aid of a DMOC. Species abundance curves were statistically fitted to the grazing gradient and used to classify the species into decreaser and increaser categories. Ecological index values were determined for each of the significant species within each community. Gaussian regression curves were compiled to test the individual grass species reaction to degradation (Bosch and Gauch 1991; Jordaan 1997) within each community separately. Key species were objectively identified (Bosch & Gauch 1991).

Species are classified into five categories (Janse van Rensburg & Bosch 1990; Bosch & Gauch 1991, Van Rooyen *et al.* 1991a), according to their frequency curves on the grazing intensity gradients within each of the three communities. The species within each community separately, were subjectively classified into ecological index classes (adapted from van der Westhuizent *et al.* (1999)).

Annexure 1 Phytosociological table for the study area

Communities																								**1**																							
Sites		A			B			C			D			E			F			G			H			I			J			K			L			M		N			O			P	
Sample plots	19	20	21	54	55	56	63	64	65	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	113	114	115	116	117	118	119	120	121	122	123	124	125	126
Species Data																																															
Group A																																															
Acacia haematoxylon	+	+	+	.	+	.	a	1	a	1	b	a	b	.	3	b	b	b	a	1	1	a	1	.	a	a	a	b	a	b	b	b	3	3	b	a	b	3	3	3	b	a	a	a	b	b	b
Elephantorrhiza elephantina	.	.	.	+	3	a	1	b	3	3	3	b	.	.	.	+	a	a	.	.	+	.	.	+	.	.	b	.	.	+	.	.	.	.	+	3	b	3	3	a	3	.	.	a	.	.	.
Hermannia tomentosa	.	+	.	.	.	.	+	.	+	+	+	b	+	.	+	.	.	+	1	.	.	+	1	+	.	1	1	.	+	+	b	.	1	+	b	+	+	b	a	b	b	+	1	1	.	a	a
Anthephora pubescens	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	a	a	+	3	b	+	.	.	+	b	.	+	a	a	+	a	.	.	.	.	.	.
Eragrostis bicolor	.	.	.	.	.	.	1	.	.	+	+	+	.	.	.	.	.	.	+	1	.	1	a	1	a	b	a	+	+	b	+	+	.	.	.	.	.	+	+	.	+	.	.	.	.	.	.
Diospyros lycioides	.	.	.	.	.	a	.	.	.	.	.	.	.	.	.	.	.	1	.	.	1	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Eragrostis biflora	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	+	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	+	+	+	.	.	.	.	.	.	.	.
Eragrostis pallens	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	+	+	.	.	.	.	+	a	.	a	b	.	.	.	.	+	b	.	b	a	.	.	+	.	.	.	.	.
Panicum kalaharense	.	.	.	.	.	.	.	.	.	1	+	+	.	.	.	.	.	.	.	.	.	.	.	.	+	1	.	.	.	a	.	.	.	.	.	+	.	.	+	.	.	.	.	.	.	.	+
Pogonarthria squarrosa	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	a	.	.	.	.	.	.	+	.	.	+	+
Stipagrostis amabilis	.	.	.	.	.	.	.	.	.	1	a	a	.	.	.	.	.	.	+	.	1	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	+	.	.	.	.	.	.	.	.	.
Trachyandra laxa	.	.	.	.	.	.	.	.	.	a	b	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cyperus margaritaceus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.
Monechma divaricatum	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Lycium bosciifolium	.	.	.	.	+	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sporobolus rangei	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Bulbostylis hispidula	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Enneapogon cenchroides	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Group B																																															
Acacia mellifera	+	.	+	.	+	a	+	1	1	.	.	.	.	.	.	.	.	.	.	+	.	.	.	1	.	+	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	1	+	.	1	.
Rhigozum trichotomum	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Lycium cinereum	.	+	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Euryops multifidus	.	.	.	.	+	1	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Stipagrostis uniplumis	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	a	.	.	.	.	.	.	.	.
Cenchrus ciliaris	.	.	.	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Geigeria ornativa	.	.	.	+	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Chrysocoma obtusata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Indigofera species	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
Prosopis velutina	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cadaba aphylla	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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Tribulus terrestris	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Harpagophytum procumbens	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sesamum triphyllum	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Barleria rigida	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Limeum argute-carinatum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Lotononis furcata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Plinthus cryptocarpus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Portulaca kermesina	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Setaria sphacelata	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ammocharis coranica	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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Pelargonium leucophyllum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Kleinia longiflora	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cleome angustifolia	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Eragrostis brizantha	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Group C																																															
Tribulus zeyheri	.	.	.	3	1	.	3	1	1	4	1	1	1	.	.	a	+	.	4	.	1	3	b	.	b	1	.	3	a	1	b	b	.	b	+	.	.	.	.	.	.	+	1	+	+	a	.
Aristida stipitata	.	.	+	+	+	1	1	b	b	b	+	+	+	1	1	1	a	b	+	+	+	+	1	a	1	1	1	+	a	+	+	+	+	1	b	+	+	a	1	a	1	+	b	+	.	a	a
Lycium hirsutum	.	.	.	+	+	.	1	.	1	1	+	.	+	.	.	.	.	.	1	.	.	+	1	.	b	1	.	b	b	a	a	.	b	.	a	.	.	.	.	.	.	1	1	1	a	a	1
Acacia erioloba	.	.	.	+	1	.	a	1	1	.	.	1	.	.	.	.	.	.	.	1	1	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Grewia flava	1	1	1	.	+	1	1	a	1	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	a	+	.	.	.	.	.	.	.	.	.	a	1	.	.	.
Aristida meridionalis	.	.	.	.	.	.	.	.	+	1	3	3	+	.	.	.	.	.	.	.	.	.	.	.	.	a	+	.	.	.	+	.	.	+	1	+	1	+	a	1	a	.	.	.	.	.	a
Indigofera alternans	.	.	+	+	+	1	.	.	+	.	+	.	.	1	.	.	.	+	+	1	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Asparagus suaveolens	.	.	.	.	.	+	+	+	.	.	.	+	1	.	.	.	+	1	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.
Boscia albitrunca	.	.	.	.	.	1	.	1	.	+	.	.	.	.	.	.	.	.	1	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.
Aptosimum marlothii	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Citrullus lanatus	+	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cleome gynandra	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Senecio laevigatus	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Nolletia arenosa	.	.	.	.	.	.	.	.	.	b	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Asparagus species	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Tapinanthus oleifolius	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Limeum arenicolum	.	.	.	+	.	.	.	.	.	.	.	.	.	.	1	.	.	.	+	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Solanum incanum	.	.	.	.	+	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	1	.
Limeum sulcatum	.	.	.	+	.	.	+	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Eragrostis plana	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.
Ledebouria undulata	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Limeum species	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ziziphus mucronata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Communities																									**2**																								
Sites		Q			R			S		T			U			V			W			X			Y			Z		AA		BB		CC			DD			EE			FF		GG			HH	
Sample plots	1	2	3	4	5	6	7	8	9	10	11	45	46	47	48	49	50	51	52	53	57	58	59	60	61	62	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	110	111	112
Species Data																																																	
Group A																																																	
Acacia haematoxylon	.	1	+	1	.	1	1	1	1	1	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	.	.	.	.	.	.	1	a	.	.	.
Elephantorrhiza elephantina	.	a	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	a
Hermannia tomentosa	.	.	.	.	.	.	.	.	+	+	+	.	.	+	.	.	.	.	.	.	.	.	.	+	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	.	.
Anthephora pubescens	+	a	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Eragrostis bicolor	.	.	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.
Diospyros lycioides	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Eragrostis biflora	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.
Eragrostis pallens	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Panicum kalaharense	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pogonarthria squarrosa	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.
Stipagrostis amabilis	.	.	.	.	.	.	.	.	.	.	.	.	.	a	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Trachyandra laxa	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cyperus margaritaceus	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Monechma divaricatum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Lycium bosciifolium	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sporobolus rangei	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Bulbostylis hispidula	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Enneapogon cenchroides	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Group B																																																	
Acacia mellifera	.	1	+	.	.	.	.	1	1	1	.	3	3	3	a	b	a	.	b	b	1	.	.	b	1	a	a	1	b	+	1	b	b	3	b	a	b	1	4	3	a	a	b	3	b	a	.	.	.
Rhigozum trichotomum	1	a	a	.	b	.	.	.	1	b	b	b	+	.	.	+	+	1	4	.	.	.	.	.	.	.	3	3	b	4	b	b	4	.	+	.	.	.	3	3	b	b	.	1	.	.	b	b	a
Lycium cinereum	1	1	.	b	.	b	1	+	.	.	.	.	+	1	+	+	1	.	.	.	.	.	.	+	.	.	.	.	.	.	a	+	b	1	+	.	.	.	a	+	+	a	.	.	.	.	.	.	.
Euryops multifidus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	+	1	1	b	b	b	+	b	.	.	.	+	.	.	.	.	.	+	b	a	.	.	.	.	.	a	b	1
Stipagrostis uniplumis	.	.	.	.	.	.	.	.	.	.	.	1	b	.	+	1	1	.	+	1	.	.	.	.	.	.	.	b	a	.	.	.	.	.	.	.	.	.	a	a	3	.	.	.	.	.	.	.	.
Cenchrus ciliaris	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	b	b	+	.	.	.	.	a	+	.	.	.	.	.	.	.	.	.
Geigeria ornativa	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	3	.	1	a	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Chrysocoma obtusata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	1	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	+	.	.
Indigofera species	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	a	.	a	1	.	.	.	.	.	.	.	.
Prosopis velutina	.	.	.	b	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cadaba aphylla	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	+	+	.	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.
Acacia hebeclada	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Tribulus terrestris	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	b	.	.	.	.	.	.	.
Harpagophytum procumbens	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sesamum triphyllum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.
Barleria rigida	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.
Limeum argute-carinatum	.	.	.	.	.	.	1	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Lotononis furcata	.	.	.	.	.	.	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Plinthus cryptocarpus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	+	.	.	.	.	.	.	.	.	.
Portulaca kermesina	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.
Setaria sphacelata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.
Ammocharis coranica	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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Pelargonium leucophyllum	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Kleinia longiflora	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cleome angustifolia	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Eragrostis brizantha	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.
Group C																																																	
Tribulus zeyheri	3	.	a	1	.	.	.	.	.	.	.	+	+	1	b	+	.	1	.	.	3	.	1	b	.	.	3	.	.	b	1	.	.	b	1	3	.	.	b	1	.	.	.	.	+	.	a	.	.
Aristida stipitata	+	a	a	.	.	.	+	b	b	.	+	.	.	.	+	a	.	.	.	.	.	.	.	.	1	a	1	+	1	.	.	.	.	.	+	+	b	b	.	.	.	.	.	.	+	b	.	.	1
Lycium hirsutum	.	.	.	.	a	.	a	.	.	.	1	.	1	.	1	.	+	.	.	.	1	+	.	+	.	.	.	.	a	.	+	a	+	b	.	.	.	.	.	+	.	.	.	.	+	.	.	.	.
Acacia erioloba	+	+	.	a	1	1	.	+	.	.	+	1	.	.	1	1	1	.	.	.	1	+	1	3	1	1	+	.	.	r	1	+	r	.	1	b	a	a	1	.	.	.	1	1	1	1	1	1	a
Grewia flava	.	.	.	.	.	.	.	a	a	.	.	.	.	.	+	+	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	a	.	.	a	1	a	b	.	.	.
Aristida meridionalis	.	.	.	.	.	.	+	3	3	1	a	.	1	b	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	a	.	.	.	.	+	1	+	a	.	.	.
Indigofera alternans	.	.	.	.	.	+	.	+	+	.	.	.	.	.	.	.	+	+	.	.	.	+	1	.	.	.	.	.	.	.	+	.	.	+	+	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Asparagus suaveolens	.	.	.	.	.	.	.	.	.	.	.	1	+	1	1	+	+	+	+	.	.	.	.	.	+	1	+	+	+	.	.	1	.	1	a	.	.	.	+	1	+	1	.	1	a	+	.	.	.
Boscia albitrunca	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1	1	1	.	.	1	.	.	1	1	.	1	1	1	a	.	.	a	.	1	.	.	.	.	.	a	a	.	1	.	.	a	.	.	.
Aptosimum marlothii	.	.	.	.	.	.	.	.	.	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	1	1
Citrullus lanatus	.	.	.	.	.	.	.	.	+	.	+	.	.	.	.	.	.	+	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	+	+	.	.	.	1	.	.	.	.	.	.	.	.	.	.
Cleome gynandra	.	.	.	.	.	+	.	.	.	.	.	.	.	.	+	.	r	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	+	.	.	.	.
Senecio laevigatus	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Nolletia arenosa	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	a	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Asparagus species	.	.	+	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Tapinanthus oleifolius	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Limeum arenicolum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	+	+	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Solanum incanum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	1	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Limeum sulcatum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Eragrostis plana	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ledebouria undulata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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Ziziphus mucronata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.

Communities															**3**															
Sites	II		JJ			KK			LL			MM			NN			OO			PP		QQ			RR			SS	
Sample plots	12	13	14	15	16	17	18	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
Species Data																														
Group A																														
Acacia haematoxylon	.	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.
Elephantorrhiza elephantina	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	1	.	.	+	.	.	.	.	.	.	.	.
Hermannia tomentosa	.	+	.	+	+	+	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	+	.	.	.	.	.	.	.	.
Anthephora pubescens	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Eragrostis bicolor	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Diospyros lycioides	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Eragrostis biflora	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Eragrostis pallens	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Panicum kalaharense	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pogonarthria squarrosa	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.	.	.	.	.
Stipagrostis amabilis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.
Trachyandra laxa	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cyperus margaritaceus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Monechma divaricatum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Lycium bosciifolium	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sporobolus rangei	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Bulbostylis hispidula	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Enneapogon cenchroides	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Group B																														
Acacia mellifera	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	+	.	.	.
Rhigozum trichotomum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.
Lycium cinereum	.	+	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Euryops multifidus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Stipagrostis uniplumis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cenchrus ciliaris	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Geigeria ornativa	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Chrysocoma obtusata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Indigofera species	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Prosopis velutina	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cadaba aphylla	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Acacia hebeclada	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Tribulus terrestris	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Harpagophytum procumbens	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sesamum triphyllum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Barleria rigida	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Limeum argute-carinatum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Lotononis furcata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Plinthus cryptocarpus	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Portulaca kermesina	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Setaria sphacelata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ammocharis coranica	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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Pelargonium leucophyllum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Kleinia longiflora	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cleome angustifolia	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Eragrostis brizantha	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Group C																														
Tribulus zeyheri	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Aristida stipitata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Lycium hirsutum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Acacia erioloba	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Grewia flava	.	.	.	.	1	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Aristida meridionalis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	1	.	.	.	.	.	.	.	.	.	.	.
Indigofera alternans	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.
Asparagus suaveolens	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.
Boscia albitrunca	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.
Aptosimum marlothii	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Citrullus lanatus	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cleome gynandra	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Senecio laevigatus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Nolletia arenosa	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Asparagus species	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Tapinanthus oleifolius	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Limeum arenicolum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Solanum incanum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Limeum sulcatum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Eragrostis plana	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ledebouria undulata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Limeum species	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ziziphus mucronata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Communities	1																																															2																																																	3																													
Sites	A			B			C			D			E			F			G			H			I			J			K			L			M			N		O			P			Q			R			S			T		U			V			W			X			Y			Z			AA		BB		CC		DD			EE			FF			GG		HH			II		JJ		KK			LL			MM			NN			OO			PP			QQ		RR			SS		
Sample plots	19	20	21	54	55	56	63	64	65	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	113	114	115	116	117	118	119	120	121	122	123	124	125	126	1	2	3	4	5	6	7	8	9	10	11	45	46	47	48	49	50	51	52	53	57	58	59	60	61	62	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	110	111	112	12	13	14	15	16	17	18	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
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Pentzia calcarea	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	a	a	b	.	+	.	.	.	1	+	.	.	1	1	.	1	.	1	+	+	.	.	.	.	+	+	.	+	+
Felicia burkei	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	a	.	.	.	3	3	3	+	1	+	3	b	.	.	1	1	+	+	+	.	.	+	.	+	+	+	1
Eragrostis echinochloides	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	1	.	1	.	.	+	+	+	+	+	.	.	.	a	1	.	.	.	.	+	.	.	+	.	+	+	.	+	.	.
Jamesbrittenia huillana	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	+	+	+	.	+	.	.	+	.	+	+	.	+
Plinthus sericeus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	+	.	.	.	.	.	+	+	+	.	.	+	+	+
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Zygophyllum pubescens	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Chrysocoma sparsifolia	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	b	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Group E																																																																																																																																							
Eragrostis lehmanniana	3	a	b	a	a	a	1	+	b	a	a	a	+	+	1	.	.	+	+	1	+	1	a	1	+	a	a	+	a	a	a	3	3	+	a	a	.	.	a	.	+	+	b	b	+	a	b	a	1	1	+	a	+	+	+	a	a	+	+	b	a	+	1	+	.	1	a	+	a	1	+	a	b	1	a	a	1	+	+	+	+	+	1	+	a	.	+	+	1	+	a	1	a	1	+	1	+	1	+	1	a	a	1	1	a	+	1	1	a	1	+	1	+	1	a	+	1	a	1	b	1	+	+	+	+	+
Eragrostis trichophora	.	.	.	.	a	+	1	+	b	.	1	b	+	+	+	.	.	.	+	1	.	+	+	1	1	1	a	+	a	1	a	b	+	+	a	b	.	+	a	.	+	+	+	1	.	+	a	1	1	a	.	.	+	+	1	b	+	+	.	.	a	+	.	.	.	.	+	+	+	.	.	.	.	.	+	.	.	+	.	.	.	.	.	+	b	+	+	.	+	+	+	1	a	.	.	1	.	1	.	1	1	.	.	.	.	.	.	.	.	.	+	1	.	1	1	.	1	1	+	+	.	.	.	+	+	.
Aristida congesta	.	b	a	+	1	1	+	+	a	+	1	+	.	+	1	+	1	+	+	1	a	+	+	1	.	1	.	+	+	+	+	b	b	1	b	a	+	1	1	a	b	+	b	a	+	a	1	1	1	a	+	+	.	+	b	b	1	a	+	a	1	+	1	.	.	+	+	+	.	+	+	a	a	.	a	1	a	a	+	+	+	1	1	a	a	.	.	.	.	b	a	.	b	+	.	+	+	1	+	1	1	+	.	.	.	.	+	+	.	.	+	.	1	b	b	b	b	+	1	1	1	+	.	.	+	.
Stipagrostis hirtiglum	1	a	b	.	+	b	.	1	a	a	.	+	+	b	a	1	b	b	.	a	a	1	3	3	.	.	.	+	1	.	.	.	.	+	a	.	a	b	b	1	b	+	a	3	+	1	b	.	b	b	.	a	3	.	a	+	.	a	.	.	.	.	b	3	.	.	.	.	+	.	+	.	1	.	a	+	+	.	a	b	+	a	+	1	+	.	+	+	.	a	3	1	a	.	.	3	.	a	.	a	b	b	a	.	.	.	.	.	1	.	+	b	+	1	b	.	b	b	.	+	1	b	3	+	3	.
Schmidtia kalihariensis	b	+	1	+	.	.	a	a	a	+	.	+	1	+	+	b	1	.	1	+	.	.	.	.	1	+	.	+	.	.	b	a	a	a	1	.	.	.	.	.	+	3	1	1	4	a	+	a	1	a	b	b	1	3	a	.	3	1	a	a	1	+	+	.	a	.	.	+	.	1	1	+	+	4	+	+	3	3	4	b	a	3	4	b	a	.	a	1	3	+	1	3	1	b	+	.	b	.	1	.	1	a	b	.	.	.	b	+	.	1	b	.	b	1	+	3	b	+	a	+	3	b	a	.	.	.
Schmidtia pappophoroides	+	1	+	1	3	a	+	b	+	+	.	.	.	.	1	.	+	b	+	+	1	.	1	+	1	+	.	.	.	.	.	a	+	.	.	.	.	.	.	.	.	.	+	+	.	+	a	+	1	a	.	.	b	.	1	a	.	a	.	.	.	+	1	b	1	3	b	+	a	a	.	a	b	+	b	a	+	.	.	.	.	+	.	+	.	.	.	+	.	b	b	1	a	1	3	3	.	1	+	a	a	.	.	.	.	.	.	.	+	.	.	+	.	+	1	.	a	b	.	+	.	.	+	.	.	.
Senna italica	.	.	+	+	+	1	+	a	1	+	+	+	1	1	1	.	.	.	+	+	+	+	1	1	b	a	.	1	a	1	1	a	.	a	+	+	.	.	.	.	.	.	+	1	+	+	.	+	.	.	+	.	.	.	.	.	.	+	+	.	.	1	+	1	b	.	.	.	1	1	+	a	1	+	a	a	a	a	.	.	.	+	.	b	b	+	1	.	.	.	.	.	.	3	1	a	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	+	.	.	.	+	.	.	.	.
Crotalaria orientalis	+	+	+	+	+	a	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	+	1	a	.	.	a	.	.	.	1	+	a	b	a	.	.	.	.	.	.	.	.	.	.	.	.	b	a	.	+	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	1	+	.	+	.	.	.	.	.	.	+	b	+	+	a	.	.	.	.	.	.	+	.	1	1	1	.	.	.	.	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.
Stipagrostis ciliata	1	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	+	+	.	.	.	.	1	.	.	.	.	.	.	.	b	1	+	.	.	.	.	.	.	+	1	+	+	.	.	a	a	+	1	a	+	a	1	.	1	1	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	+	.	b	.	.	.	.	.	a	.	.	.	.	.	.	a	b	1	+	.	.	.	+	1	b	1	b	1	1	.	.	.	.	+	1	b	1	+	b	1	1	1	+	+	1	+	+	.	.	.	a	1	b
Stipagrostis obtusa	+	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	+	.	.	1	.	.	.	.	.	.	.	.	.	.	+	.	.	a	.	b	1	a	+	a	.	.	a	1	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	+	+	a	1	+	+	.	1	.	+	.	+	.	.	.	a	a	.	+	.	.	+	+	1	1	1	a	.	1	+	a	b	3	1	b	1	b	1	+	a	+	.	+	1	.	+	1	1	+	1	b	1	b
Limeum viscosum	+	+	+	.	+	1	+	.	+	1	.	.	+	+	1	.	.	.	1	+	+	+	+	.	.	.	.	.	.	.	.	.	.	a	.	.	.	.	.	+	+	.	.	.	.	.	.	+	.	+	b	a	a	.	1	.	+	1	.	.	.	1	+	.	+	1	+	+	+	1	+	1	.	1	.	.	.	.	+	.	+	1	+	.	.	a	.	.	b	.	.	1	a	+	.	.	+	.	+	.	+	.	1	.	.	.	b	+	+	+	.	.	1	+	+	.	.	.	.	.	+	.	.	.	.	.
Eriocephalus ericoides	.	a	b	+	+	a	+	b	.	.	+	.	.	1	.	.	.	.	+	b	3	.	.	+	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	a	b	b	.	.	.	.	.	+	.	.	.	.	.	.	.	+	.	1	a	+	+	1	.	.	.	.	a	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	a	b	b	.	.	.	.	a	b	1	.	.	+	.	.	.	.	+	+	1	a	1	.	1	a	+	+	+	.	.	.	.	1
Requienia sphaerosperm	+	.	+	.	.	.	.	.	.	.	.	.	+	1	.	+	+	.	.	.	.	.	.	.	+	.	.	.	+	+	.	.	.	+	1	+	.	.	.	+	a	+	b	+	+	.	1	.	+	.	.	a	b	.	+	1	+	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	+	+	.	+	+	+	.	1	.	a	+	a	a	.	.	.	+	1	.	+	+	.	+	.	.	.	.	+	.	.	.	+	+	+	+	.	+	+	.	+	.	+	+	.	+	.
Monechma incanum	.	1	+	+	1	+	+	.	.	.	.	.	.	.	.	.	.	.	+	1	+	.	.	.	.	.	.	.	.	.	.	b	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	1	b	.	+	.	.	+	+	.	.	.	.	.	+	+	+	1	1	+	.	.	.	.	.	.	a	.	.	.	+	.	1	a	+	b	b	a	1	.	.	.	.	+	b	a	+	.	+	.	.	.	.	.	.	+	.	.	.	1	+	.	+	+	1	+	.	.	a	b	.	+	1	.	.	.
Centropodia glauca	.	1	1	.	+	1	.	.	+	+	+	+	.	.	.	.	.	b	.	+	.	+	1	a	+	1	1	.	.	.	.	.	+	.	+	b	.	1	+	.	+	.	.	.	.	.	.	.	.	.	.	+	a	.	.	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	1	.	1	.	a	.	+	.	.	.	.	.	.	.	.	.	+	.	.	.	.	1	1	.	+	.	.	.	.	1	+
Centropodia glauca																																																																																																																																						
Bulbostylis species	.	.	.	+	1	.	.	+	+	.	.	.	.	.	.	.	.	+	+	+	.	.	+	+	.	.	.	.	.	+	.	.	.	.	+	.	.	1	+	.	+	.	+	.	.	.	.	.	.	.	.	.	.	.	+	+	.	+	.	.	.	.	.	.	.	.	.	.	.	+	.	+	+	+	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	+	+	.	+	.	+	+	+	+	+	+	.	.	.	.	.	.	.	.	.	.	+	+	.	+	+	.	+	+	.	.	.	+	.	.	.	.
Acrotome inflata	.	.	.	.	.	.	1	.	1	+	.	+	.	+	.	.	.	.	.	.	.	.	.	.	+	.	.	+	a	.	.	.	.	.	.	.	.	.	.	.	.	1	+	.	+	.	.	+	.	.	.	+	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	+	.	.	+	b	1	.	.	.	.	+	1	.	.	.	+	.	.	.	.	.	1	.	.	3	a	+	.	.	+	+	b	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	.	.	.	.	+	+	.	.
Solanum capense	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	+	.	+	+	.	.	.	.	+	.	.	.	.	.	.	.	.	.	+	.	+	+	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	+	.	.	.	.	+	.	.	.	.	+	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.
Solanum supinum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	+	1	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.
Cucumis africanus	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	+	1	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	a	b	.	.	.	.	.	+	+	.	.	+	a	.	.	.	.	.	.	+	.	.	.	+	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.
Asparagus nelsii	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	+	+	+	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.
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Enneapogon scoparius	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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Senecio angustifolius	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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Mollugo cerviana	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pupalia lappacea	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Arctotis venusta	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Searsia species	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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Moraea polystachya	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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Melolobium macrocalyx	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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Kohautia cynanchica	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Peliostomum leucorrhizum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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