THE VEGETATION POTENTIAL OF NATURAL RANGELANDS IN THE MID-FISH RIVER VALLEY, EASTERN CAPE, SOUTH AFRICA:

TOWARDS A SUSTAINABLE AND ACCEPTABLE MANAGEMENT SYSTEM

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ABSTRACT

Desertification is the diminution or destruction of the biological potential of land, and can lead ultimately to desert-like conditions. The vegetation of southern Africa is claimed to have altered over the past 100 years and much of the change is attributed to pastoral practice. In recent years however there has been much debate around the issue of the deterioration and loss of productivity of the natural rangelands, specifically those under communal management. It is one thing to claim that the vegetation has changed but quite another to produce data and analyses to show this unequivocally. Furthermore it is generally difficult to determine the nature and extent of change in natural ecosystems, as one does not know what the optimal base-line conditions should be. For this reason emphasis has been placed on developing models of potential or expected vegetation. By comparing a model of potential or expected vegetation with that of the contemporary vegetation, areas that deviate from expectation can be identified, in so doing providing evidence of the direction of change in the rangelands under various management treatments. The objective of this study was to determine shifts in the vegetation under different land-use treatments, by developing a technique to predict the potential vegetation of an area. In order to explore the nature and extent of degradation at the landscape scale a study site was selected where a range of land-use and rangeland management practices could be studied in parallel. The mid-Fish River valley consists of three markedly different units of land management, namely commercial rangelands, communal rangelands and nature conservation areas. The vegetation within the mid-Fish River valley falls within the Thicket biome and consists of three main vegetation types namely, Short Succulent Thicket, Medium Succulent Thicket and Mesic Bushclump Savanna. The creation of this potential vegetation model was dependent on the direct gradient analysis approach of relating the community patterns with environmental variables. To achieve this, floristic information was collected at sites along a topographical-moisture gradient. A Canonical Correspondence Analysis (CCA) between the environmental variables and the plant communities produced a classification from which the conditions normally associated with the major plant communities were predicted. When projected as a digital map, the qualifying sites provided a testable hypothesis of the potential vegetation. The results of this study showed a definite grazing gradient, which reflects a change from a more mesic environment towards a more arid environment with an increase in utilisation pressure. The predictive vegetation model proved to be useful for predicting the occurrence of the valley thicket communities within the Eastern Cape.

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CHAPTER 1

INTRODUCTION

Rangelands are essentially large tracts of native vegetation used to support livestock production. The context in which the world's rangelands are viewed is rapidly changing. Conflicts in natural resource management are increasing, and there is constant stress between what rangelands can provide and the multiple objectives that people have for them. The increasing demands on the worlds rangelands has led to concern over the sustainability of rangeland uses and the effects on rangeland residents and users.

The concept of desertification with respect to rangelands has been increasingly discussed in the literature over the last 30 years (Olsson 1985). The desertification of rangelands does not refer to the expansion of existing deserts, but to the process of land degradation in these natural ecosystems, and is defined as the destruction of the biological potential, caused by exceeding the carrying capacity of the land. Desertification of rangelands becomes apparent by intricate steps of vegetation and soil deterioration which is usually revealed during periods of drought (United Nations 1992). However, during the last decade the links between overstocking and degradation in arid environments and communal systems has been questioned (Behnke *et al*. 1993). This alternate school of thought emphasises the impact the variability of rainfall has on the livestock mortalities within semi-arid and arid regions, as drought causes a crash in livestock numbers thereby allowing the rangelands a chance to recover while the livestock numbers return to pre-drought levels. In other words, this school of thought suggests that climate has a greater influence on vegetation dynamics than pastoral systems in semi-arid and arid areas.

This perception is central to the new paradigm in rangeland ecology, in which disequilibrium or non-equilibrium has a profound influence over the management and uses of rangeland systems (Behnke *et al* 1993). Based on examples from Africa, it has been argued that livestock do not have a long-term effect on range resources, because intermittent die-offs during extended droughts keep livestock densities below equilibrium. Therefore the risk of environmental degradation in non-equilibrium environments is limited, as livestock numbers rarely reach levels likely to cause irreversible damage (Ellis & Swift 1988, Scoones 1994, Scoones 1996). The traditional view of grazing systems, however, is that animals are in a balance with their resources, and that grazing impacts could be regarded as resulting from the counteracting forces of animal utilisation and primary production coupled with successional forces. The criticism of this traditional approach with respect to rangelands is that environmental variations disturb the balance between animals and resources, resulting in an equilibrium state seldom, if ever being attained (Behnke *et al*. 1993).

The new paradigm is a direct challenge to traditional approaches for managing rangelands and has created a perception that grazing has no effect on the vegetation (de Bruyn & Scogings 1998). The two schools of thought have caused a tremendous amount of debate around the subject of communal livestock farming practices. One point of view suggests that the land under communal management is less productive and is degraded relative to commercial rangelands (Palmer *et al*.1998), while the other suggests that these rangelands are as productive as those under commercial ownership (Behnke *et al*. 1993, Scoones 1994). But what exactly are the arguments surrounding the disequilibrium-equilibrium debate?

The reasons governing the disequilibrium perspective are primarily as follows: firstly, droughts cause the de-coupling of herbivore-plant processes, which reduces the effects of animals on plant species composition and productivity. Typically semi-arid environments have a co-efficient of variation greater than 30% and droughts are therefore common causes of herbivore mortality (Ellis & Swift 1988). This then causes the animal population's dependence on plant abundance, which is affected by animal consumption, to be weakened. Galvin & Ellis (1996) showed that frequent droughts caused mortality of herbivores without having much influence on the vegetation. Studies conducted on the Turkana rangeland in East Africa demonstrated that due to the extreme seasonality it is an example of a non-equilibrium system, with animals having minimal impacts on the vegetation (Ellis & Swift 1988). Secondly, Scoones (1992) argued that the lack of any long-term decline in cattle densities in southern Zimbabwe showed that land degradation must either be minimal, or ineffectual, because it could not have affected the key resources on which livestock depend to survive the dry season. Thirdly, the variation in vegetation can be directly attributed to the variation in rainfall (Scoones 1996).

The equilibrium approach however disputes the concept that the de-coupling of herbivore-plant processes reduces defoliation impacts. The perception that disequilibrium systems are not at risk of being overgrazed as livestock numbers are controlled by climatic variations may not always be valid, as a result of management interventions (Illius & O'Connor 1999). That is if supplemental feeding is implemented during drought conditions, or if drought and disease tolerant breeds of livestock are brought into an area, this may serve to increase animal numbers and impact during a drought instead of these numbers and impact being reduced (Quirk *et al*. 1996). Van de Koppel *et al*. (1997) argue that de-coupled herbivory can trigger irreversible vegetation collapses and soil degradation through positive feedback between reduced vegetation biomass and reduced abundance of resource for plant growth. Illius and O'Connor (1999) maintain that it is difficult to infer changes in animal production potential from long-term changes in stock numbers, because the underlying causes of such trends are usually obscure. Factors that can influence these numbers include changes in economic and social factors, changes in land area available, additional water points and supplemental feeding. These factors can disguise any tendency to show a decline in response to degradation. Finally, although rainfall variability has profound effects on annual variation in species abundance, there are usually no net changes in species composition over the long term. In contrast however, changes as a result of grazing could be substantial over the long term as grazing effects are usually consistent for certain species (O'Connor & Roux 1995).

Very little conclusive evidence on communal grazing systems exists within the sphere of veld management research in South Africa, to be able to either accept or reject any of the above schools of thought. Our knowledge about the relationship between animal numbers and rangelands is actually very limited, as so much of the research to date has focused on trying to understand and improve the beef production system. If disequilibrium is the normal state of rangeland systems, because seasonal and annual climatic variations disrupt that stable equilibrium between animals and plants, the critical question that needs to be addressed is whether these rangelands are showing signs of the impact of grazing on the vegetation under communal management. It is therefore vital to further explore the impacts of grazing in communally grazed areas in order to assess the health and sustainability of these rangelands. Only once these impacts are fully understood should policies relating to communal systems and land management be reviewed.

Rangeland ecosystems are dynamic systems, and fitting rangelands into categories based on ecological criteria is a difficult but an essential task for their assessment. The capacity of the rangelands to meet the demands placed on them depends on the integrity of soils and ecological processes, that is, on their condition. Categorising rangelands as healthy, at risk or unhealthy is an essential step in defining rangeland condition and sustainability. A threshold can be defined as a boundary in space and time between two ecological states. Changes from one state to another across a threshold involves shifts in plant composition; changes in the physical, chemical or biological properties of soils; or changes in basic ecological processes such as nutrient cycles. The threshold of rangeland health is defined as a boundary between ecological states of a rangeland ecosystem that, once crossed, is not easily reversible and results in the loss of productivity and sustainability. The rangeland assessment procedure must therefore provide insight about a rangeland's vulnerability to shift across the threshold of rangeland health. Information on changes in soil or ecological processes that increase the vulnerability of rangelands to a shift across the threshold is essential to assess the effects of land-use on rangeland condition. However, it is one thing to claim that the vegetation has undergone changes, but quite another to produce data and analyses that show this unequivocally. A one time measure of rangeland characteristics is only that – a picture of the situation at the time of measurement. Without a previous measurement with which the current measurement can be compared, the ability to interpret the effect of land utilisation is limited. Personnel, time and budget constraints have limited the capacity to assess rangeland condition, as long intensive studies are no longer viable. For this reason increasing emphasis is being placed on the development of models that can predict the potential of the rangelands and the vegetation responses to land-use. By comparing a model of the potential or expected vegetation with that of the contemporary vegetation, areas that deviate from expectation can be identified (Palmer and van Staden 1992), thereby providing a means of assessing the state of these rangelands and identifying the effect a particular management regime is having on the rangeland.

Models can fulfil two purposes, namely, to test hypotheses or paradigms and secondly to provide assistance in making decisions for effective management by identifying a range of possibilities, which may or may not result in planned actions in the future. There is a need for the development of spatially explicit models to aid in the management and understanding of rangeland systems. Spatially explicit models provide a mechanism by which change can be easily identified, thereby providing a means to explore the effects of land-use on the vegetation (Guisan *et al* 1998), and furthering the understanding of these systems. The creation of a spatially explicit potential vegetation model is dependent on the direct gradient analysis technique of relating community patterns to environmental variables.

The aim of this study was to develop an objective approach to modelling the potential vegetation, in order to provide a means of assessing the contemporary state of natural rangelands in relation to the perceived state of the vegetation under a given land-use practice. In other words, to determine if rangelands under the communal management system conform to the conventional thinking of decreased productivity, sustainability and overall degradation or if there are areas that deviate from expectation and are in a state that equals other land-use practices. This study explores an alternative method of relating the vegetation to the environmental variables, in an attempt to overcome the limitations of the traditional regression methods and to simplify the procedure by using a direct analysis method. The determination of the model's usefulness to be applied in other areas of a similar nature was also considered in this study.

The primary hypotheses for this study therefore are:

1. The communal rangelands are in a more degraded state relative to the commercial rangelands and nature conservation areas that are subjected to the same climatic fluctuations.
2. The potential vegetation of an area can be predicted by correlating the vegetation units and major environmental variables using a direct gradient analysis.

CHAPTER 2

DESCRIPTION OF STUDY SITE

The geographic region defining the study area extends from 32° 50' S, 26° 30' E to 33° 15' S, 27° 15'E. It forms part of the mid-Fish River valley and catchment area, and is both ecologically and socially diverse.

2.1 The Physical Environment

2.1.1 Geology

The geology of the area can be described as predominantly grey/red mudstone and sandstone of the Middleton formation (Adelaide Subgroup: Karoo Supergroup), with sandstone dominating the formation (Johnson and Keyser 1976). The landscape consists of steep river valleys with inter-basin ridges. The river valleys contain the nutrient rich mudstones, which are extremely susceptible to erosion, while the more resistant sandstones occur on the inter-basin ridges.

According to Mountain's (1946) classification, four geological groups are present within the study area. **Sandstone, shale and mudstone of the Ecca series** is the geological group that covers the majority of the study area; 87% of the samples recorded in the study occurred on this series. Seven percent of the sites were sampled on the **sandy mudstone containing boulders and shale of the Dwyka series.** This group covers a small strip at the southern extent of the study area and runs from west to southwest. There is a small section of **mudstone and felspathic sandstone of the Beaufort series**, which lies north of the Great Fish River; only six percent of the sample sites were recorded on the series. Finally, the **dolerite of post Karoo age,** which is found in small isolated patches.

Most of the soils are derived from either shale or mudstone. The soils that are derived from mudstone or sandstone are generally yellow/brown, apedal, sandy clay loams or clay loams. The soils derived from the Beaufort and Ecca sediments are eutrophic, greyish brown and brown, shallow and litholic (Loxton, Hunting & Associates 1979). Generally the soils are dispersive and highly erodible. Most of the soils are on valley slopes and have low infiltration rates. Overgrazing has led to an increase in run-off and a reduction in the content and porosity of the soil (Ainslie *et al* 1994).

In the western region of the study area, slopes are predominantly between 15 and 35 degrees. The soils generally have a low to very low dryland crop potential although the red alluvium soils found at lower elevations have a moderate to low dryland crop potential.

2.1.2 Water

The study area is a water-poor area with regard to surface water resources and the ground water is of low quality. The Fish River flowed inconsistently before the construction of the Orange-Fish tunnel; presently the river is perennial when its flow is not augmented by the water from the Orange River system (Ainslie *et al*. 1994)

Although the mean annual rainfall of the study area is low, ranging from under 400mm in the Great Fish River Valley to over 600mm on the plateau to the east, the effective annual rainfall in the low lying areas is even lower, because of run-off and evaporation, making this area unsuitable to crop production.

2.2 Climate

According to the Köppen classification the climate of the study area may be described as *Cfa,* where
C = warm temperate climate — coldest month 18°C to -3°C; *f* = sufficient precipitation during all months;
a = maximum temperature over 22°C. Mean annual rainfall is 434.3 mm, with peaks in October (spring) and March (autumn) and relatively dry winters.

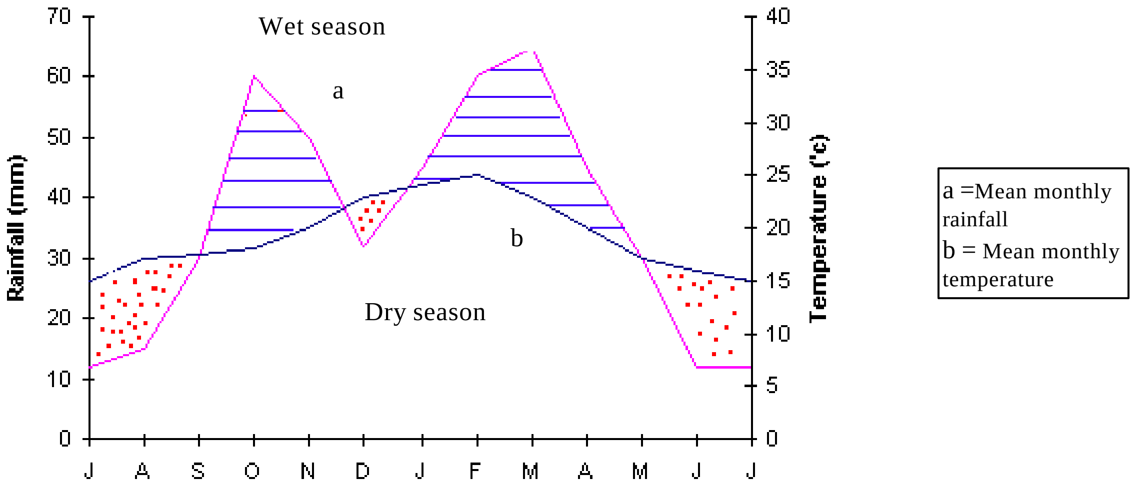

Figure 2.2.1: A Walter-Lieth diagram. Position = 33º 05' 20"S 26º 42' 54"E, rainfall recording years = 30; temperature recording years = 1; elevation = 410m; highest annual rainfall = 612.9mm; mean annual rainfall = 434.3mm; lowest recorded annual rainfall = 225.0mm.

The study area has a complex climatic environment because of its topographical complexity. Elevation ranges from 170m asl at the Great Fish River to over 600m asl on the dividing ridges. This range in elevation has a marked effect on rainfall patterns within the study area. The lower elevation sites experience higher mean annual temperatures as well as lower mean annual rainfall totals, resulting in a hot semi-arid environment. The higher elevation sites have lower mean annual temperatures and higher mean annual rainfall figures, thus resulting in a cooler wetter environment. Aspect and slope result in further variations in the climate as southern slopes experience cooler more moist conditions. Northern facing slopes are characteristically warmer and drier.

2.3 Vegetation

Numerous studies have been conducted in the Thicket Biome of the Eastern Cape, resulting in the vegetation of this area being interpreted in many ways. Black (1901) undertook the earliest descriptive botanical study of this area, describing the vegetation as being more dense and tree-like in the valleys with elevated and level areas more open. Dyer (1937) described the area as Karroid scrub, with grasslands occurring at the top of the ridges between the river valleys.

Acocks (1953) coined the name Valley Bushveld, which implies that this veld type is found in the valleys of rivers. Valley Bushveld, as defined by Acocks (1953), is subdivided as follows:

a) Northern variation of the Valley Bushveld
b) Southern variation of the Valley Bushveld
c) Fish River Scrub
d)(i) The Addo Bush
d)(ii) Sundays River Scrub
e) Gouritz River Scrub

The vegetation of the mid-Fish River Valley falls into the category, Fish River Scrub. Acocks (1953) described the Fish River Scrub in its undamaged state, as an extremely dense, semi-succulent thorny scrub about 2m high. He stated that overgrazing of large areas had opened up this vegetation, resulting in the invasion of *Opuntia* species and *Euphorbia bothae*. Acocks (1953) distinguished four variations of the Fish River Scrub, which he related to a successional gradient: viz.

1. The climax community which is a dense succulent scrub with some grass;
2. The optimum stage of open, useful succulent scrub with much grass;
3. Open succulent scrub with thorny shrubs and with useless succulents invading and/or increasing, and Karoo bushes invading the grassland constituents;
4. Succulent, thorny scrub with Karoo bush and little grass.

Using a phytochorological approach ,White (1983) places this vegetation in the Tongaland-Pondoland phytochoria and calls it Tongaland-Pondoland evergreen and semi-evergreen bushland and thicket.

In a synthesis of the vegetation of the south eastern Cape, Cowling (1984) described the vegetation as Subtropical Transitional Thicket. He produced a classification where he divided Subtropical Transitional Thicket into syntaxonomic and structural units, which produced two orders; Kaffrarian Thicket and Kaffrarian Succulent Thicket. Everard (1987) surveyed different thicket types and formulated a framework for predicting areas of high conservation value. He identified four types in the two orders defined by Cowling (1984), viz. Mesic Succulent Thicket and Xeric Succulent Thicket in the order Kaffrarian Succulent Thicket, and the Mesic Kaffrarian Thicket and the Xeric Kaffrarian Thicket in the order Kaffrarian Thicket. According to Everard (1987), the vegetation of the mid-Fish River Valley can be divided into Xeric Succulent Kaffrarian Thicket and Xeric Kaffrarian Thicket. Rutherford and Westfall (1986) mapped the Subtropical Thicket as part of the savanna biome because it is dominated by plants with phanerophytic and hemicryptophytic life forms, which form the main life forms in savannas. However the predominance of chamaephytes in Valley Bushveld provides grounds for placing it in a separate biome. In a revision of Acocks' veld types, Low and Rebelo (1995) have classified Subtropical Transitional Thicket into the Thicket Biome, which is divided into four types, namely, Dune Thicket, Xeric Succulent Thicket, Mesic Succulent Thicket and Spekboom Succulent Thicket.

Loxton, Hunting and Associates (1987) undertook a broad scale vegetation survey of the catchment area for the Fish River and were able to identify the following vegetation types;

1. Three variations of medium to very short *Scutia-Rhus-Grewia-Maytenus* thickets and shrubland thicket mosaics.
2. Grasslands, wooded grasslands and secondary dwarf shrublands in the higher rainfall areas that shift towards Karroid dwarf shrublands in lower rainfall regions.

In a detailed and quantitative floristic analysis of the Andries Vosloo Kudu Reserve (AVKR), which falls within the study area, Palmer (1981) recognised 13 plant communities. These included the dwarf shrubland characterised by the *Felicia muricata-Walafrida geniculata* association, of which two variations were identified, each with two sub-variations. Also included was the succulent bushclump savannah of the *Portulacaria afra-Barleria obtusa* community, which contained two variations and five subvariations, and lastly, the woodlands of the southern slopes characterised by the *Hippobromus pauciflorus-Schotia latifolia* association.

During a reconnaissance survey of the mid-Fish River Valley, Palmer and Avis (1994) identified five communities based on floristic composition, physiognomy and environmental factors. These five communities are recognisable in the field and include the Tall Succulent Woodlands of the southern slopes, the Short Succulent Thicket, the Medium Succulent Thicket, Mesic Bushclump Savanna and the Riparian Thicket.

2.4 Land-use

The study area consists of three markedly different units of land management and population densities; these are the commercial farming lands, the nature conservation areas and the communal rangelands (Figure 2.4.1).

History of settlement

The history of land occupancy is a major causal factor to this study as it has impacted on the distribution of the people, the distribution and types of settlement, land tenure systems, land management and ultimately the use and abuse of resources. The original division of land into white- and black-owned dates back to 1853 when a section of land in the mid-Great Fish River Valley was allocated for communal rangeland (i.e. the Fingo's Location). The rest of the study area was successively divided up and parcelled out as white farms on either side of the Great Fish River.

With the 1913 Native Land Act, Fingo's Location became a scheduled area, while the 1936 Native Trust and Land Act established the possibility of land being made available for black occupancy beyond the scheduled areas. Black farmers thus become tenants of the SA Native Trust.

The buildup to Ciskei's independence saw the steady incorporation of white-owned farms into the Ciskei, particularly those farms north of the Committee's Drift – Breakfast Vlei road and between the Breakfast Vlei – Peddie road and the Keiskamma River. Some of these incorporated areas were later to form part of the Lennox Sebe Game Reserve (renamed Double Drift Game Reserve only days after the coup that disposed Sebe). By 1982, the South African Government had bought up all the formerly white owned farms between the Great Fish and Keiskamma rivers

The relocation of black people from around the Eastern Cape to Committees's Farm and Glenmore began in 1979. Over 4500 people, with no direct ties to this area, were relocated to this rural township.

Commercial farming areas

Presently the commercial farming lands occur mostly on the western side of the Great Fish River. These are still farmed as natural rangeland but with irrigation of crops, particularly lucerne, on the alluvial terraces of the Great Fish River. A given piece of rangeland within this area may be utilised with either cattle, sheep, goats, indigenous herbivores or various combinations of all of these. The type of management strategy varies between land operators in terms of high or low stocking rate, rotational grazing or continuous grazing and burning or not burning. The overall emphasis of the management strategy within this unit is towards sustainable production of commercial rangelands.

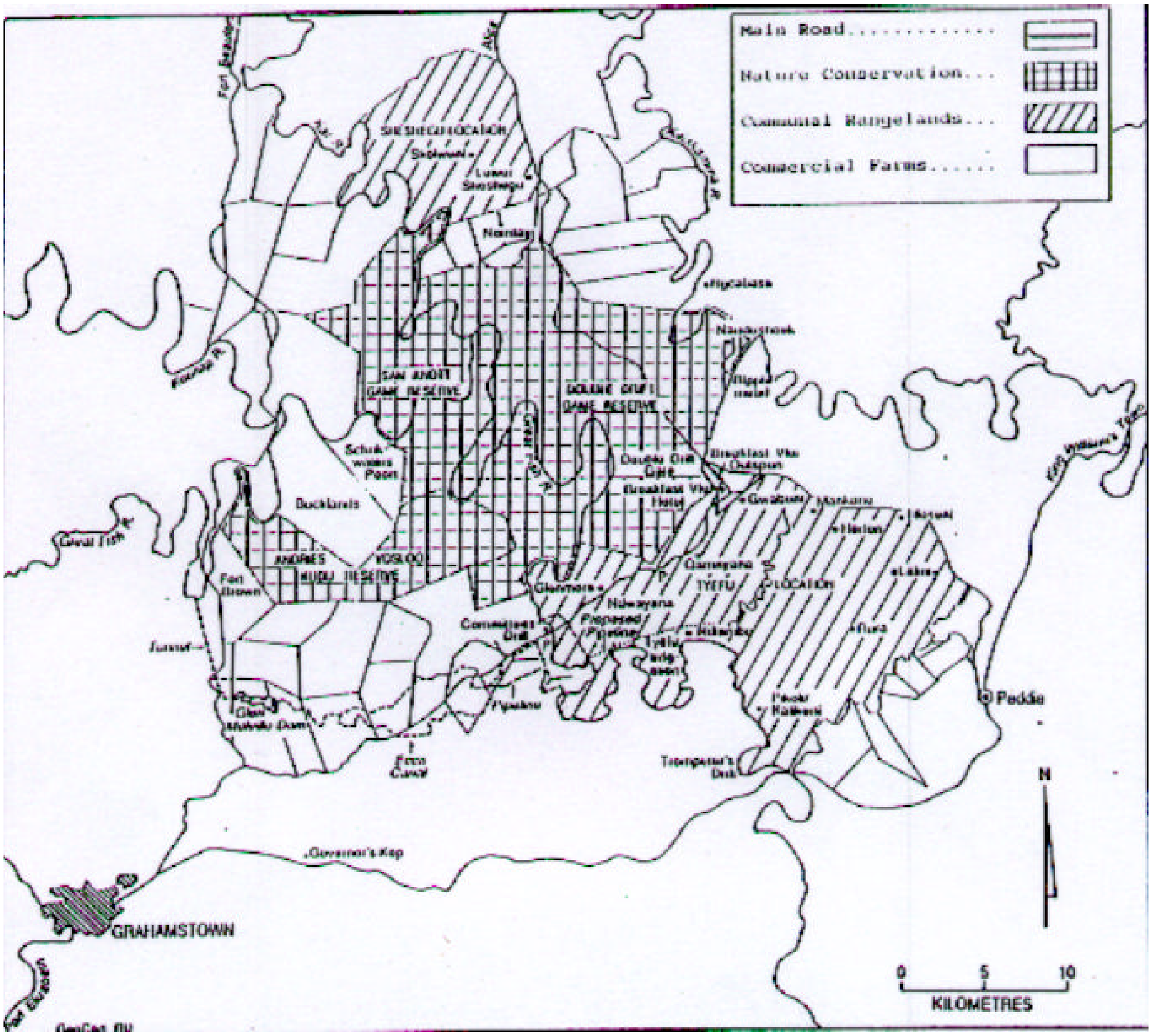

Figure 2.4.1: A map of the study site showing the three land-use classes present within the area.

Nature conservation areas

The second division of land utilisation is that of the nature conservation areas. This unit falls roughly in the centre of the study area and is referred to as the Great Fish River Reserve complex. This complex comprises the Andries Vosloo Kudu Reserve, the Sam Knott Nature Reserve and the Double Drift Nature Reserve. In total these three reserves have an approximate size of 45 000ha.

The Andries Vosloo Kudu Reserve, representing 6 500ha, was established in 1973 as a stronghold for the Greater Kudu (*Tragelaphus strepsiceros*) in the Eastern Cape and to conserve an area of Valley Bushveld. The area is rich in historical background and a number of forts, signalling towers, barracks and graves are locate within the reserve. In 1987, 15 000ha of land adjoining the Andries Vosloo Kudu Reserve was added as a bequest of the late Mr M.T. (Sam) Knott. The domestic cattle were removed before incorporating it into the reserve complex. The Double Drift Nature Reserve was established in 1983 and totals approximately 23 000ha. This reserve lies to the east of the Andries Vosloo Kudu and Sam Knott Reserves with part of the northern region fenced off to form a smaller enclosed game viewing camp.

The wildlife populations on these reserves include Eland (*Taurotragus oryx*), Kudu (*Tragelaphus strepsiceros*), Red Hartebeeste (*Alceplaphus buselaphus*), Steenbok (*Raphicerus campestris*), Springbok (*Antidorcas marsupialis*), Duiker (*Sylvicapra grimmia*), Cape Buffalo (*Syncerus caffer*), Black Rhinoceros (*Diceros bicornis*), Hippopotomus (*Hippopotamus amphibius*), Warthog (*Phacochoerus aethiopicus*), Leopard (*Panthera pardus*), African Rock Python, Flightless Dung Beetle, and Red-Billed Oxpecker. The separate game viewing camp on Double Drift Nature Reserve includes additional species such as White Rhinoceros (*Ceratotherium simum*), Giraffe *(Giraffa camelopardis*), Zebra (*Equus zebra*), Bontebok (*Damaliscus dorcas*), Waterbuck *(Kobus ellipsiprymnus*), Gemsbok (*Oryx gazella*), Blue Wildebeest (*Connochaetes taurinus*), Impala (*Aepyceros melampus*), Nyala (*Tragelaphus angassi*), Southern Reedbuck (*Redunca fulvorufula*) and Elephant (*Loxodonta africana*).

Communal Rangelands

Tyefu Location and Sheshegu are areas where the land is used as subsistence rangeland with limited dryland cultivation practised on land allocated on a communal basis (Ainslie *et al*. 1994). Tyefu has an irrigation scheme, utilising the alluvial terraces along the Fish River and water made available from the Orange-Fish River Scheme. Glenmore is the other main population concentration; it is located adjacent to Tyefu and is a resettlement community on a released white farm (Ainslie *et al*. 1994).

The people are very unequally distributed within the study area, with a huge imbalance between the former black and white areas. Of the 18 500 people in the study area, 16 500 live in 25 percent of the area (Tyefu and

Glenmore) and the remaining 2000 are spread through the white farms and nature reserves (there is a density of 71 persons per square kilometre in Tyefu Location but only 3-6 persons in the rest of the study area).

The areas inhabited by Xhosa-speaking people (mainly Tyefu and Sheshegu area) have distinct patterns of concentration, the most distinct being the Glenmore settlement, where the villages are adjacent to the cultivated lands stretching along the Fish River Valley, while the remaining villages snake along the higher-lying ridges on the plateau above the valley. The western side of the Fish River includes the majority of the commercial farms found in the study site. Here the population is more clustered around sites where farm buildings occur and where cultivation in valley bottoms is possible.

CHAPTER 3

VEGETATION DESCRIPTION

3.1 Introduction

The Thicket Biome is the broad term used by Low and Rebelo (1995) to describe the semi-succulent thorny scrub of the river valleys of the eastern seaboard of South Africa. It is characterised by dense, sometimes impenetrable thickets of thorny and succulent shrubs. Unlike fynbos, it has not been the focus of intensive research and at present only about ten percent of the total extent of this vegetation type is conserved (Everard 1990, La Cock *et al*. 1990).

The Thicket Biome occupies a tension zone at the meeting point of five phytochoria (White 1983). It has variable proportions of trees, shrubs, succulents and herbaceous species. Arid forms generally have a sparse field layer consisting of succulents, dwarf shrubs and geophtyes while the more mesic forms usually have a herbaceous field layer of grasses and forbs. Floristically,Valley Thicket is relatively species rich with high alpha diversity (37.3 species/100m^2) but is low in beta diversity (Everard 1987).

The Thicket Biome in the Eastern Cape occupies a broad belt of undulating terrain between the great escarpment and the coastal belt (Marker 1990) and is the product of interacting variables such as geology, topography, climate, soils and present and past land-use. It is suggested that one of the most significant variables is elevation which correlates closely with rainfall totals (Marker 1990). Increasing elevation inland and drainage to the coast results in the dissection of the landscape, which together with the added influence of slope and aspect result in a variety of micro-environments. The mosaic pattern of the vegetation is a reflection of the effects of this variable topography and water availability.

Much of plant community ecology is and has been involved with describing the distribution of species along environmental gradients (Gauch 1982, Munchin 1987). In an attempt to describe this distribution, vegetation responses to the spatial variations of environmental factors such as elevation, moisture or exposure must be measured. Gradient analysis is one technique whereby this variation may be measured (Austin *et al*. 1984), and includes direct and indirect approaches. Indirect gradient analysis displays community samples along axes of variation in composition that can subsequently be interpreted in terms of environmental gradients (Ter Braak & Prentice 1988). Attention is first focused on the major pattern of variation in community composition, and the environmental basis of this pattern is only established later. The disadvantage of indirect gradient analysis is that the axes derived from the ordination technique may be hard to interpret or are sometimes uninterpretable (Hill 1973). If the environmental variables are easily distinguishable, the direct approach is likely to be more effective than the traditional indirect approach

(Palmer 1993). Direct gradient analysis relates species presence or abundance directly to environmental variables on the basis of species and environmental data from the same set of sample plots. The advantage of direct gradient analysis is that it allows for the study of part of the variation in community composition that can be explained by a particular set of environmental variables. In order to undertake a direct gradient analysis the dominant environmental variables need to be identified prior to sampling. That is, a prior hypothesis is needed about what environmental variables are relevant (Ter Braak & Prentice 1988). Once these have been identified, sampling can be carried out along the environmental gradient.

A noticeable feature of the mid-Fish River Valley is the tremendous range in elevation over relatively short distances, owing to the undulating nature of the terrain. As elevation is closely correlated with rainfall totals (Marker 1990), the most significant environmental variables affecting plant community distribution within the mid-Fish River Valley are easily identified as elevation and rainfall (Palmer & Avis 1994). Therefore, in order to investigate the vegetational pattern within the area, a direct gradient analysis is the best option, owing to the easy identification of the dominant environmental variables.

In order to manage an area effectively the representative plant communities within the ecosystem must be well managed to maintain genetic diversity and productivity. Maintaining an area to deliver a high production potential is vital given the land-use demands of an ever-increasing human population (Taggart 1994). The objective of this chapter was to identify the representative communities within an area and to understand the effect of the dominant environmental variables on vegetation patterns. To achieve this objective a detailed vegetation survey was required to investigate what plant species are present and which factors influence their distribution within the study area.

3.2 Methods

3.2.1 Selection of representative samples

The studies undertaken on the Thicket Biome have been based upon the indirect and direct gradient analysis approach (Cowling 1984, Everard 1987, Palmer *et al*. 1988, Cowling & Campbell 1983 and Hoffman and Cowling 1991). For this study the direct approach was taken, the vegetation was sampled along the pre-defined topo-moisture gradient.

To overcome the problems of subjective sampling, such as lack of repeatability and the tendency to only sample areas representative of "good" vegetation, a stratified random sampling technique was employed. In order to stratify the study area, the region was first divided into the three land-use classes and then further subdivided into a number of topographic-moisture classes (Whittaker 1973). Sampling was then carried out within each defined class. Rainfall, elevation and the land-use practice were used to define these classes, based on the assumption that the chief factors affecting the composition of the vegetation are rainfall and elevation. Median annual rainfall values were extracted from a surface response model for southern Africa (Dent *et al*. 1989). Elevation values were obtained from a digital terrain model produced by recording spot heights at a 200m spatial resolution. This information is converted from ASCII text data to a digital image in IDRISI. The digital image may then be geo-referenced to produce a geographical projection. This information was then used to prepare a cross tabulation of rainfall class against elevation class. This cross tabulation produced 12 topographical-moisture classes, which ranged from low elevation, low rainfall sites to high elevation, high rainfall sites (Table 3.2.1). Relevé sites were recorded in each of the 12 classes. The topo-moisture classes did not occur with equal frequency throughout the study area and were therefore not sampled equally. Classes with greater area had a greater number of relevés recorded within them.

	Elevation		
Rainfall	0-200m	201-400m	401->600m
<400mm	23(11%)	12(2%)	2(0.7%)
400-500mm	17(9%)	123(38%)	53(21%)
500-600mm	1(0.06%)	16(5%)	26(12%)
>600mm	1(0.04%)	1(0.2%)	11(1%)

Table 3.2.1: Relevés sampled within the topo-moisture classes present in the study area. The classes that occupied a greater area within the study site have a higher number of relevés recorded for that class. The figures in parentheses represent the percentage area for each class within the study site.

3.2.2 Vegetation sampling

The aims and methods of the Zürich-Montpellier school of phytosociology were employed for the vegetation survey Werger (1974). A total of 286 sites were sampled using a 10x10m quadrant. A total floristic list was compiled for each sample plot and each species was allocated a cover abundance score using the scale of Werger (1974). The 100m^2 plot size has been shown to be optimal for this vegetation type (Palmer 1981, Everard 1987, Palmer *et al*. 1988). Soil texture and colour were determined in the field. The height of the vegetation strata were recorded in order to gain an indication of the vegetation structure. Table 3.2.2 is a summary of all the information collected at each sample site. A reference collection of plant species found in the study area was established by A. R. Palmer, and is housed at the Schönland Herbarium in Grahamstown.

3.2.3 Data analysis

3.2.3.1 Classification of vegetation data:

Two-way tables were generated for each land-use class using two-way indicator species analysis (TWINSPAN, Hill 1979). The two-way tables were used to produce a first approximation of the plant communities present in each land-use class. These communities were identified at the third level of division in a manner that produced an interpretable classification scheme with respect to underlying environmental variables. The program was run using default options. TWINSPAN is a polythetic divisive classification technique that uses the cover of indicator species selected at each division to arrange sites into two distinct groups along the first axis of a reciprocal averaging ordination. In addition to classifying sites on the basis of their compositional similarity, TWINSPAN simultaneously generates a separate classification of species on the basis of their distributional similarity (Hill 1979). TWINSPAN is dependent on a predominant primary gradient. Problems arise if secondary or subsequent gradients exist and if the primary gradient has been incorrectly identified. If the primary gradient is not accurately detected, separation between groups on this gradient is lost, resulting in groups being incorrectly split (Belbin and McDonald 1993).

INFORMATION COLLECTED	METHOD
Location	Recorded longitude and latitude co-ordinates using a GPS
Elevation	Values obtained from a digital elevation model (Director-General, Surveys and Mapping)
Rainfall	Values obtained from surface response model for South Africa (Dent *et al*. 1989)
Aspect	Values obtained from the digital elevation model using the SURFACE module in IDRISI for Windows Version 2
Slope	Values obtained from the digital elevation model using the SURFACE module in IDRISI for Windows Version 2
Soil colour	Determined using a standard Munsell soil colour chart
Soil texture	Measured percentage clay content using sausage method
Vegetation strata	Measured height in metres of various strata
Vegetation cover abundance values	Recorded using Braun-Blanquet scale

Table 3.2.2: Summary of information collected at each sample site.

Although TWINSPAN has received some criticism, Parker (1991) and Allen *et al*. (1991) have shown that when the environmental variables are clearly defined and exert a major influence on vegetation patterns, such as topography and rainfall in this study area, TWINSPAN can be used quite successfully to define community groups, up to the third level of division. Subsequent levels of division were not considered in the identification of community groups for this study.

3.2.3.2 Ordination of vegetation data:

The elevation, rainfall, aspect and slope angle values were determined by overlaying relevé site maps to surface response models, using the Geographical Information System GRASS 4.0. (USA-CERL 1991) and the GPS (Global Positioning System) reading for each site. The aspect values were converted to reflect an energy regime These values comprised the environmental variables for each sample site.

The data set was split into the three land-use categories for analysis, in order to investigate within land-use class variation of vegetation pattern in response to environmental variables. Canonical correspondence analysis (CCA) was performed on all three of the data sets, using the computer program CANOCO version 2.1 (Ter Braak 1988) with all the program defaults. CANOCO (Canonical Community Ordination) is a computer program designed for data analysis in community ecology. Canonical ordination is a class of techniques for relating the composition of plant communities directly to their environment (Ter Braak 1988). The solution of canonical correspondence analysis can be displayed in an ordination diagram with site and species represented by points and environmental variables represented by arrows (Ter Braak 1987). The species and site points jointly represent the dominant pattern in community composition, and these patterns can be explained by environmental gradients. The use of canonical ordination greatly improves the power to detect the specific effects of environmental variables (Ter Braak 1988). The ordination of these data produced three separate ordination diagrams where the axes were constrained to be linear combinations of the environmental variables.

3.2.3.3 Environmental distribution of plant communities:

To investigate a distributional pattern of the communities along the environmental gradient, a one-way analysis of variance test (ANOVA) was run to determine whether the elevation and rainfall values differed significantly. A Bonferroni Multiple Range Test was subsequently run to determine which values were significantly different.

3.3 Results & Discussion

3.3.1. Classification of vegetation data

Commercial Rangelands:

In total, 119 relevés were collected in commercial rangelands. Using TWINSPAN, the samples were divided into four groups, based on total floristic composition, physiognomy and environmental factors (Fig 3.3.1). These communities included the **Short Succulent Thicket** (SST) which is generally restricted to flat or north facing slopes. The soils can be described as sandy clay on mudstone. The average height of the vegetation is between 1m and 2m, forming a dense, sometimes impenetrable thicket, with *Euphorbia bothae* and *Rhigozum obovatum* being a major component of the species composition. Other common species are listed in Figure 3.3.1.

The **Medium Succulent Thicket** (MST) is distinguished from SST in both species composition and structure. The height of this vegetation type ranges between 2m and 2.5m and the soils are nutrient rich sandy clay to clay. This community is mainly present on north facing slopes, but also occurs on west and south facing slopes. The common species include *Portulacaria afra, Euclea undulata, Maytenus capitata* and *Grewia robusta*. The most common grass species found within this vegetation type was *Tragus berteronianus*.

The **Mesic Bushclump Savanna** (MBS) is generally found on flat to north facing slopes. The soils can be described as shallow sandy clays on sandstone. The average height of the vegetation is generally greater than 2.5m. Dense bushclumps characterised by species such as *Scutia myrtina* and *Acacia karroo* are separated by small patches of open grasslands dominated by *Sporobolus fimbriatus*. Other common species are listed in Figure 3.3.1.

The **Grasslands of the Mesic Bushclump Savanna** (GMBS) are characterised by having a high percentage cover (e.g. 70-80%), with the grasslands comprising most of the cover and shrubs scattered throughout the community. This community may be distinguished from the MBS as the number and size of the bushclumps are greatly reduced. Although the species composition of these bushclumps are the same, the bushclumps in the Grasslands of the Mesic Bushclump Savanna are smaller in diameter and consist of only two or three species, whereas the bushclumps in the MBS may contain as many as eight different shrub or tree species. This community is found on flat areas, mostly in paddocks which have been subjected to moderate or high herbivory.

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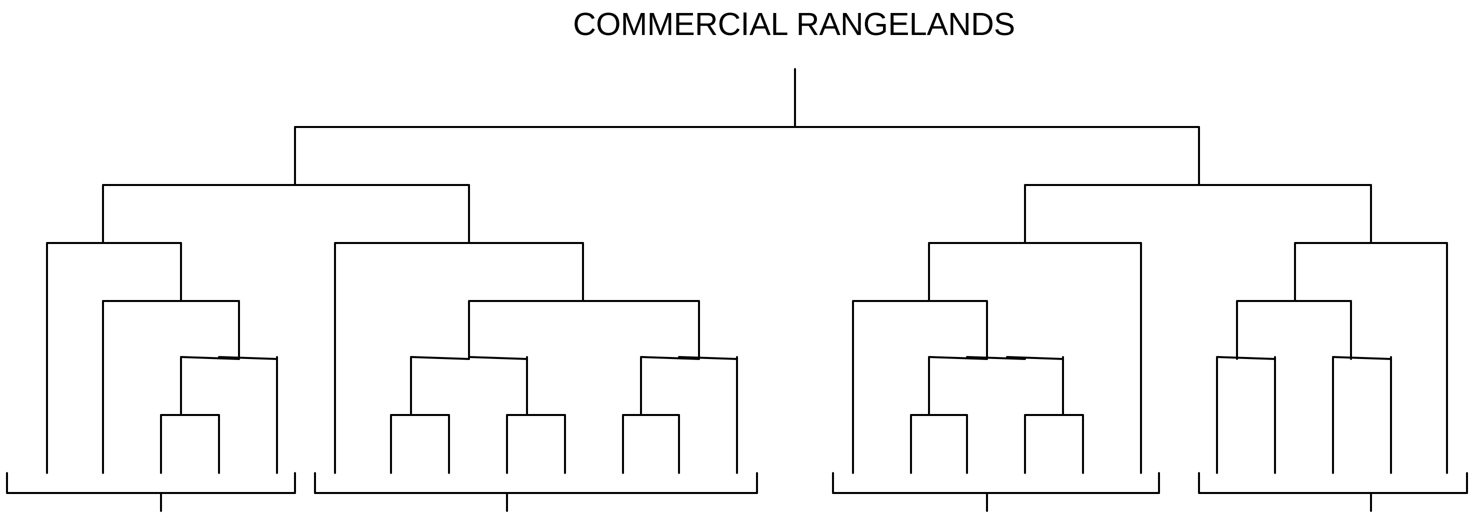


Short succulent thicket	Medium succulent thicket	Grasslands of mesic bushclump savanna	Mesic bushclump savanna
Rhigozum obovatum	*Portulacaria afra*	*Acacia karroo*	*Scutia myrtina*
Euphorbia bothae	*Grewia robusta*	*Digitaria eriantha*	*Rhus refracta*
Delosperma calycinum	*Euclea undulata*	*Eragrostis obtusa*	*Sporobolus fimbriatus*
Portulacaria afra	*Schotia afra*	*Sporobolus fimbriatus*	*Eragrostis obutsa*
Jatrophra capensis	*Tragus berteronianus*	*Scutia myrtina*	*Helichrysum dregeanum*

Figure 3.3.1: The TWINSPAN dendrogram for the commercial rangelands showing the four community groups at the third level of division, with the most commonly occurring species listed below.

Nature Conservation:

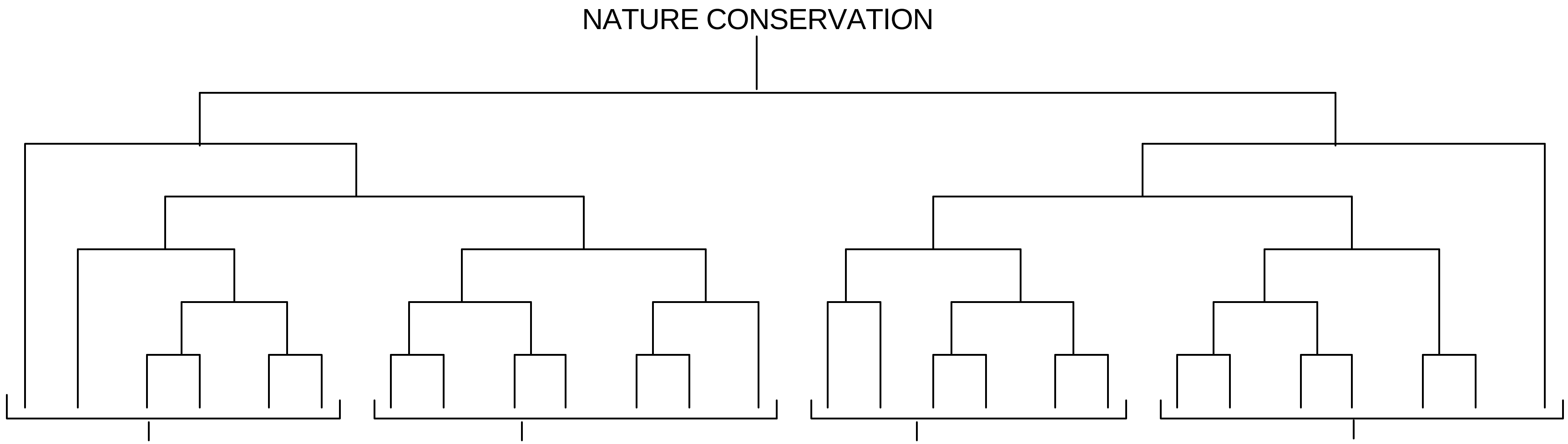
There were 111 relevés collected in nature conservation areas. TWINSPAN generated four community groups at the third level of division (Fig 3.3.2). Three of these communities were also found in commercial farming areas, namely Medium Succulent Thicket (MST), Mesic Bushclump Savanna (MBS) and the Grasslands of the Mesic Bushclump Savanna (GMBS). Although floristically similar they differ from the commercial rangeland communities in the following respects:

The **Medium Succulent Thicket** (MST) community is strongly associated with termitaria (of *Microhodotermes*), which are more evident in the nature conservation areas than in the commercial rangelands. Furthermore, the percentage grass cover is lower in the nature reserves and there is a higher percentage of forbes.

The **Mesic Bushclump Savanna** (MBS) differed from that found in the commercial rangelands, as the size of the bushclumps in the nature reserves appeared to be larger and the distance between the bushclumps appeared to be smaller. Thus the proportion of grassland for this community was less in the nature conservation areas.

The **Grasslands of the Mesic Bushclump Savanna** (GMBS) community in the nature reserves, as in the commercial rangelands, occurred in flat areas. However, the high incidence of *Walafrida geniculata* and *Panicum maximum* in the nature reserves and the complete absence of *Euphorbia tetragona*, distinguished this community from that occurring in the commercial rangelands.

The fourth community, **Succulent Bushclump Savanna** (SBS), occurs on blue shale and is mostly restricted to north facing slopes. The average height of this vegetation is between 1m and 2m. There was little or no ground cover between the bushclumps which were spaced approximately 1m to 1.5m apart. *Portulacaria afra* and *Euphorbia tetragona* are the dominant species forming the bushclumps, with other smaller succulents such as *Kalanchoe rotundifolia* and *Crassula* species found within the bushclumps (Fig 3.3.2).



Succulent bushclump savanna	Medium succulent thicket	Mesic bushclump savanna	Grasslands of mesic bushclump savanna
Portulacaria afra	*Portulacaria afra*	*Digitaria eriantha*	*Acacia karroo*
Kalanchoe rotundifolia	*Flueggea verrucosa*	*Rhus refracta*	*Panicum maximum*
Delosperma calycinum	*Grewia robusta*	*Scutia myrtina*	*Eragrostis obtusa*
Euphorbia tetragona	*Euclea undulata*	*Panicum maximum*	*Digitaria eriantha*
Grewia robusta	*Ptaeroxylon obliquum*	*Themeda triandra*	*Hermannia althaeoides*

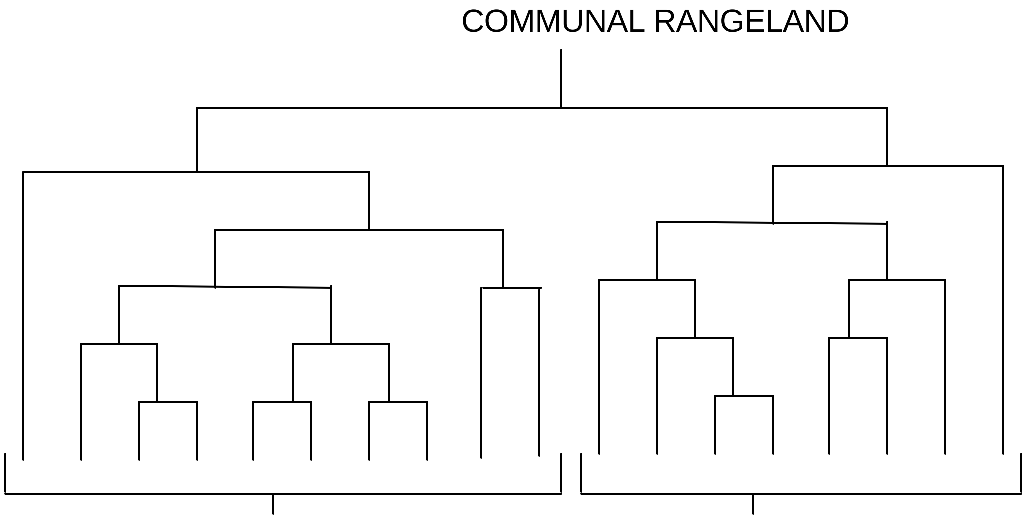
Figure 3.3.2: The TWINSPAN dendrogram under nature conservation showing the four community groups at the third level of division, with the most commonly occurring species listed below.

Communal Rangelands:

The 56 relevés collected from communal rangelands were divided into only two distinct communities by TWINSPAN, namely, Dwarf Shrubland (DS) and Grasslands of the Mesic Bushclump Savanna, (Fig 3.3.3).

The average height of the vegetation in the **Dwarf Shrubland** is less than 1m. It is commonly found in close proximity to human settlements and is dominated by dwarf shrubs such as *Pteronia incana* and *Chrysocoma ciliata*. The percentage cover in this community is very low and large areas of the sandy clay soils are exposed. Extensive erosion is evident throughout this community type.

The **Grasslands of the Mesic Bushclump Savanna** (GMBS) in this land-use class displayed an increase in the amount and number of species of *Aloes* and the dominance of *Pteronia incana*.



Grasslands of mesic bushclump savanna	Dwarf shrubland
Acacia karroo	*Pteronia incana*
Scutia myrtina	*Chrysocomma ciliata*
Sporobolus fimbriatus	*Pentzia incana*
Aloe teniour	*Aristida congesta*
Eragrostis obtusa	*Azima tetracantha*

Figure 3.3.3: The TWINSPAN dendrogram for the communal rangelands showing the two community groups at the third level of division, with the most commonly occurring species listed below

Plate 3.3.1: The Medium Succulent Thicket community (MST) where the vegetation is over 2m tall

Plate 3.3.2: Within the Medium Succulent Thicket Community *P. afra* is commonly found and vegetation can form impenetrable thickets

Plate 3.3.3: The Short Succulent Thicket Community where the vegetation is between 1 and 2m tall

Plate 3.3.4: A Short Succulent Thicket (SST) community within a commercial rangeland that has been invaded by *Euphorbia bothae*

Plate 3.3.5: The Succulent Bushclump Savanna (SBS) community occurs on blue shale, and there is little or no ground cover between the small succulent shrubs

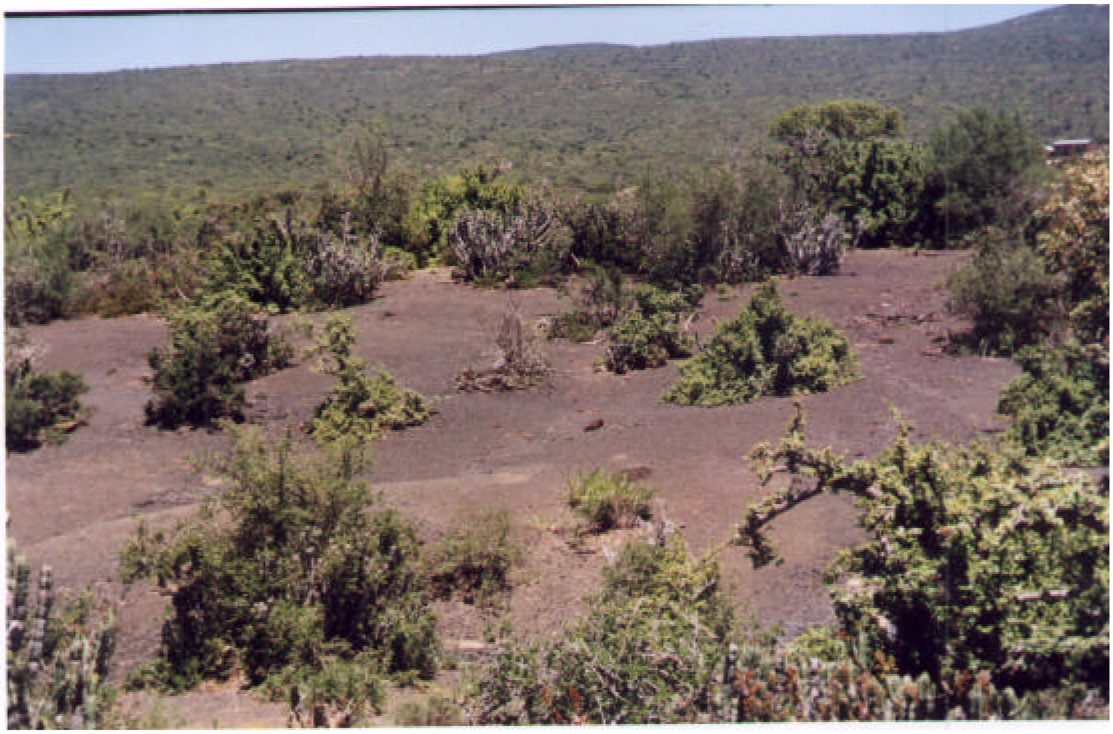


Plate 3.3.6: The Succulent Bushclump Savanna vegetation type is highly prone to erosion as the lack of ground cover results in a high runoff.

Plate 3.3.7: The Mesic Bushclump Savanna (MBS) community is comprised of dense bushclumps surrounded by small patches of grassland.

Plate 3.3.8: Within the Mesic Bushclump Savanna (MBS) community the bushclumps often contain *Opuntia ficus-indica* which is an alien invasive species to this vegetation.

Plate 3.3.9: An example of the Grasslands of the Mesic Bushclump Savanna (GMBS) community in a commercial rangeland where grass comprises most of the vegetation cover and the bushclumps are reduced in size.

Plate 3.3.10: The Grasslands of the Mesic Bushclump Savanna (GMBS) within a communal area, the number and size of the bushclumps is greatly reduced and there is a high incidence of *Acacia karroo*.

3.3.2. Comparative Studies*:*

These results compare favourably with other studies conducted in the mid-Fish River Valley. Most of the vegetation falls into Acocks'(1953) veld type, Valley Bushveld, either Southern variation or Fish River Scrub variation. Acocks (1953) maintained that this vegetation had been opened up by overgrazing of large areas, resulting in the invasion of *Opuntia* species and *Euphorbia bothae*. In his study of the vegetation of the divisions of Albany and Bathurst, Dyer (1937) recognised nine main vegetation types or formations, namely Low Forest, Bush, Scrub (Inland), Scrub (Littoral), Fynbos (heath), Psammophilous macchic, Karroid Scrub (semi-arid scrub), Karroid veld (semi-arid steppe) and Grassland. Although he does not clearly define his classes, the vegetation of the mid-Fish River Valley is best described by the following three classes; Scrub, Karroid scrub and Karroid veld. Martin and Noel (1960) produced a more detailed description of the vegetation of these divisions, which contain five main formations, namely Temperate rainforest forest formation, Succulent woodland formation, Dwarf shrub steppe formation, Savanna formation and the Temperate grassland formation. Loxton, Hunting and Associates (1979) described most of the vegetation as medium to very short *Scutia-Rhus-Grewia-Maytenus* thickets and shrubland thicket mosaics. In the study by Palmer (1981) 13 plant communities were recognised. His gradient extended from the Dwarf Shrubland, through the Succulent Bushclump Savanna to the Woodlands of the Southern Slopes. The study conducted by Palmer and Avis (1994) distinguished six different communities, four of which were described in this study. Low and Rebelo (1995) recognised four distinct variations within the Thicket Biome, including the Xeric Succulent Thicket, Spekboom Succulent Thicket, Valley Thicket and Eastern Thorn Bushveld, which floristically matched the communities identified in this study. Tanser (1997) used a structural approach based on Edward's (1983) structural classification system to produce his vegetation classification. He described nine categories for the mid-Fish River Valley, some of which can be combined as they fall into a single vegetation community for this study.

Most of the plant communities described in this study had been described previously (Table 3.3.1). In the matching plant communities the most common plant species were very similar, but the dominant species varied. There are gaps in the table as not all the plant communities identified in previous studies could be adequately matched to those identified in this study. For instance, the SST and MST communities identified in this study were listed as sub-variations of the Xeric Succulent Bushclump Savanna community by Palmer (1981). Acocks (1953) did not distinguish between the SST and the MST communities, although species common to both communities are given in his description of the Dense Succulent Scrub. Acocks (1953) did not identify a separate grouping for SBS, however the common species from this community were found in his description of Open Succulent Scrub and hence this community has been compared with the SBS community. The two communities which were not strongly floristically similar to those identified in this study and other studies were the Dry Forest community identified by Palmer (1981) and the Tall Succulent Thicket community identified by Palmer and Avis (1994). However, some of the tree species present in these communities were found in the MBS and the MST communities. The Eastern Thorn Bushveld community described by Low and Rebelo (1995) includes the Mesic Bushclump Savanna and the Grasslands of the Mesic Bushclump Savanna of this study, as they described this vegetation type as ranging from a densely vegetated area to a more open community. Their description includes species common to both communities. Martin and Noel (1960) described the Dry temperate savanna as intermediate between *Acacia* grasslands and Dwarf shrubland. This feature is particularly noticeable in the GMBS communities within the communal areas, as single trees occur in a more or less continuous stratum of small sub-shrubs. Martin and Noel (1960) stated that much of the grasslands occurring within the Albany and Bathurst area are a result of land-use regimes and agricultural practices as most of these areas contain bushclumps, suggesting that they were not former grasslands.

Following these floristic classifications it is clear that three major plant communities predominate in the study area, namely Short Succulent Thicket, Medium Succulent Thicket and Mesic Bushclump Savanna. Within these major communities a number of variations are present the nature of these variations being dependent on local climatic conditions and type of management strategy implemented (Evans *et al*.1997).

THIS STUDY	**Short succulent thicket** *Rhigozum obovatum* *Euphorbia bothae*	**Medium succulent thicket** *Portulacaria afra* *Euclea Undulata*	**Succulent bushclump savanna** *Portulacaria afra* *Kalanchoe rotundifolia*	**Mesic bushclump savanna** *Rhus-Scutia-Themeda*	**Grasslands of the Mesic bushclump savanna** *Digitaria eriantha* *Sporobolus Fimbriatus*	**Dwarf shrublands** *Pteronia incana* *Chrysocomma ciliata*	
TANSER (1997)	**Succulent thicket** Abundance of *P. afra* *R. obovatum*	**Dry Forest** Shrubs 5-8m high *E. triangularis* *P. capensis*	**Succulent shrublands** underlying Ecca shales *P afra*	**Open shrubland** *Scutia, Themeda, Digiteria*	**Marginal shrublands & Grasslands** *E. obtusa* *A. ferox*	**Open and sparse dwarf shrublands** *karroid dwarf shrubs degradation*	**Riparian forest** *O. europaea* *H.arborescens E. tetragona,* *E triangularis*
PALMER AND AVIS (1994)	**Short succulent thicket** *Rhigozum obovatum* *Euphorbia bothae*	**Medium succulent thicket** *Portulacaria afra* *Euclea undulata*		**Mesic bushclump savanna** *Rhus-Scutia-Themeda*		**Very short succulent thicket** *Chrysocomma ciliata,* *Jatrophra capensis*	**Tall succulent thicket** *Hippobromus pauciflorus* *Euphorbia triangularis*
PALMER (1981)			**Xeric succulent bushclump savanna** *Portulacaria afra/Barleria obtusa* bushclumps	**Non-succulent bushclump savanna** *Eragrostis-Walafrida - Barleria*	**Mesic thicket** *Walafrida geniculata/ Barleria obtusa* community		**Dry forests** *Hippobromus pauciflorus/ Schotia latifolia*
LOXTON HUNTING (1979)	**Short to very short xeric thicket** *Grewia-Maytenus-Rhus*	**Medium semi-succulent thicket** *Euphorbia* species present in high numbers		**Short thicket** *Scutia-rhus-maytenus (Acacia* species present)	**Wooded grasslands** *Acacia-Themeda-Elyonurus*	**Open shrubland**	**Short semi-succulent thicket** *Portulacaria* present in bushclumps
MARTIN & NOEL (1960)	**Low succulent scrub sub-formation** *P.afra* *E.bothae*	**Sub succulent woodland, dry** *E triangularis, P obliquum*	**Sub-succulent woodland sub-formation** *E. Gradidens, E. triangularis*	**Bushclump savanna** *densely interwoven clumps*	**Acacia grassland & dry temperate savanna**	**Dwarf shrub steppe formation**	
ACOCKS (1953)	**Climax community** dense succulent scrub with	**The optimum stage** of open, useful succulent	**Open succulent scrub** with thorny shrubs and useless	**False thornveld** thorny scrub with weedy karoo bushes			

	some grass	scrub with much grass	succulents invading - Karoo bushes invading the grasslands	and grass

Table 3.3.1: A summary of the plant communities identified for the vegetation of the mid-Fish River Valley.

3.3.3 Ordination

In the CANOCO analysis the four arrows indicating environmental variables on the ordination diagrams (Figures 3.3.4 – 3.3.6) accounted for 87% of the variance in the weighted averages of the relevés with respect to the four environmental variables.

The arrangement of sites on the CCA ordination for the nature conservation areas (Fig 3.3.4) reflected the influence of gradients representing elevation, rainfall, aspect and slope factors on compositional patterns. Sites were ordered along axes one and two from high elevation, mesic flats to lower elevation, dry, steep slopes. The sites occurring in the commercial rangelands (Fig 3.3.5) were ordered from lower elevation, dry steep slopes to higher elevation sites occurring on mesic flats. For the communal rangelands, the two communities, Dwarf Shubland (DS) and Grasslands of Mesic Bushclump Savanna (GMBS) are clearly defined in the ordination diagram. The gradient runs from high elevation, high rainfall, where sites predominantly classified as GMBS occurred to low elevation, low rainfall sites, which were mainly classified into the community Dwarf Shrubland.

In all three of the ordination diagrams rainfall and elevation were shown to be the dominant environmental variables affecting plant community distribution. Table 3.3.2 is a summary of the canonical coefficients and interset correlations produced by the CANOCO ordination solution. The canonical coefficients define the ordination axes as linear combinations of the environmental variables, and the interset correlations are the correlation coefficients between the environmental variables and these ordination axes (Ter Braak 1988). By looking at the relative magnitudes[1] of the interset correlations and the canonical coefficients, one may infer the relative importance of each variable for predicting the community composition (Ter Braak 1986). The canonical coefficients give the same information as the interset correlations in cases when the environmental variables are mutually uncorrelated. However, they may provide rather different information when the environmental variables are correlated with each other, as they usually are in field data (Ter Braak 1986).

Both values indicate that for all three ordinations rainfall and elevation were the dominant factors affecting plant community distribution. None of the three ordination diagrams reflected optimum performance, as the two dominant variables should be represented perpendicular to one another, although the nature conservation areas were close to displaying optimum performance. The reason for CCA not performing optimally may be attributed to the extremely high level of noise in the data, however CCA is a robust and powerful technique and thus gives reliable results in spite of the high noise level (Palmer 1993).

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[1] The sign of the value is not considered, as the sign only determines the value's position either side of the origin.

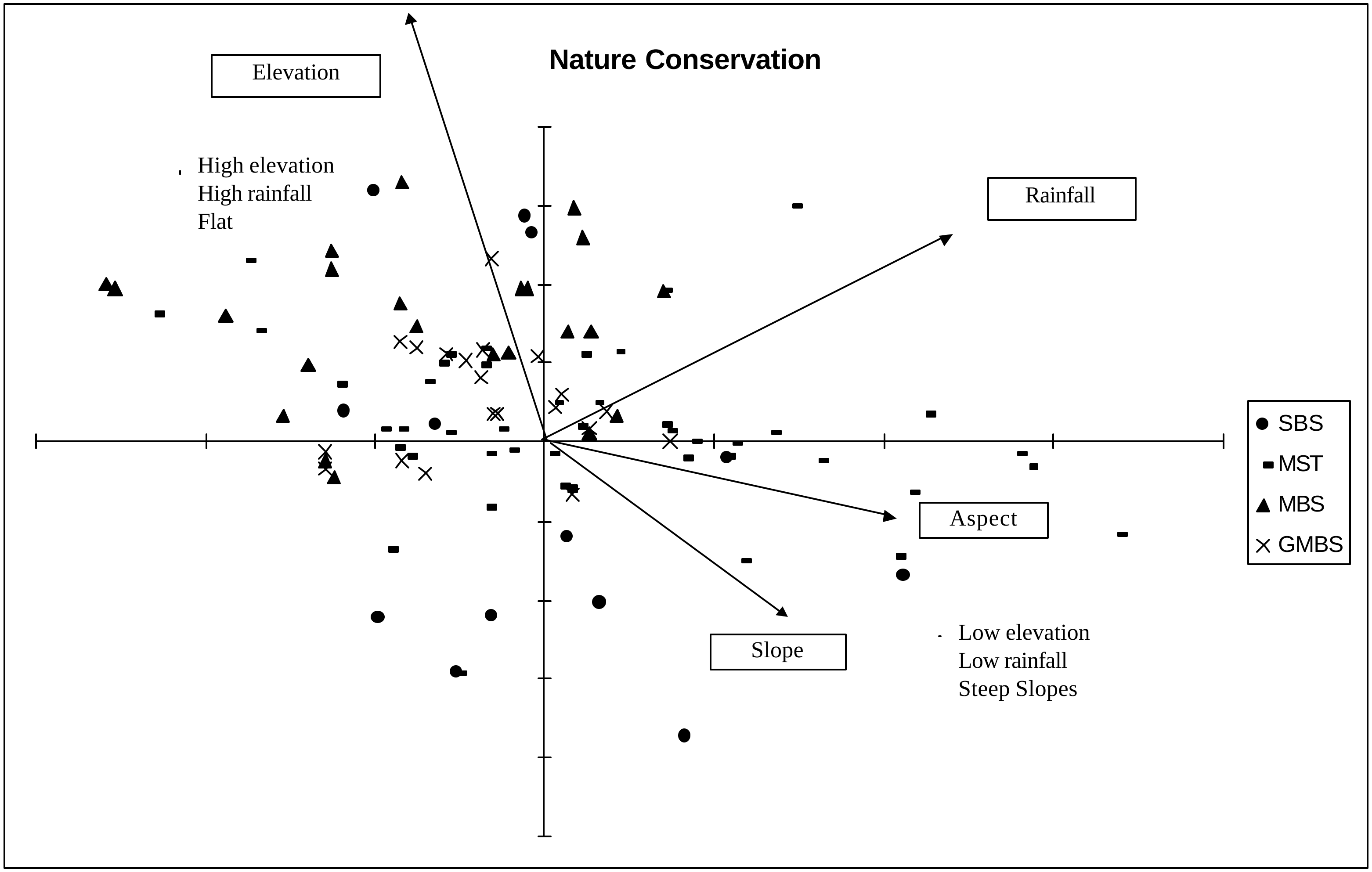


Figure 3.3.4: The distribution of the vegetation communities of nature conservation areas in the mid-Fish River Valley along the first two axes in the CCA ordination. The first axis is horizontal, the second vertical. Also included is an overlay of the biplot scores for the environmental variables (arrows). MST = Medium succulent thicket; MBS = Mesic bushclump savanna; GMBS = Grasslands of the mesic bushclump savanna; SBS = Succulent bushclump savanna.

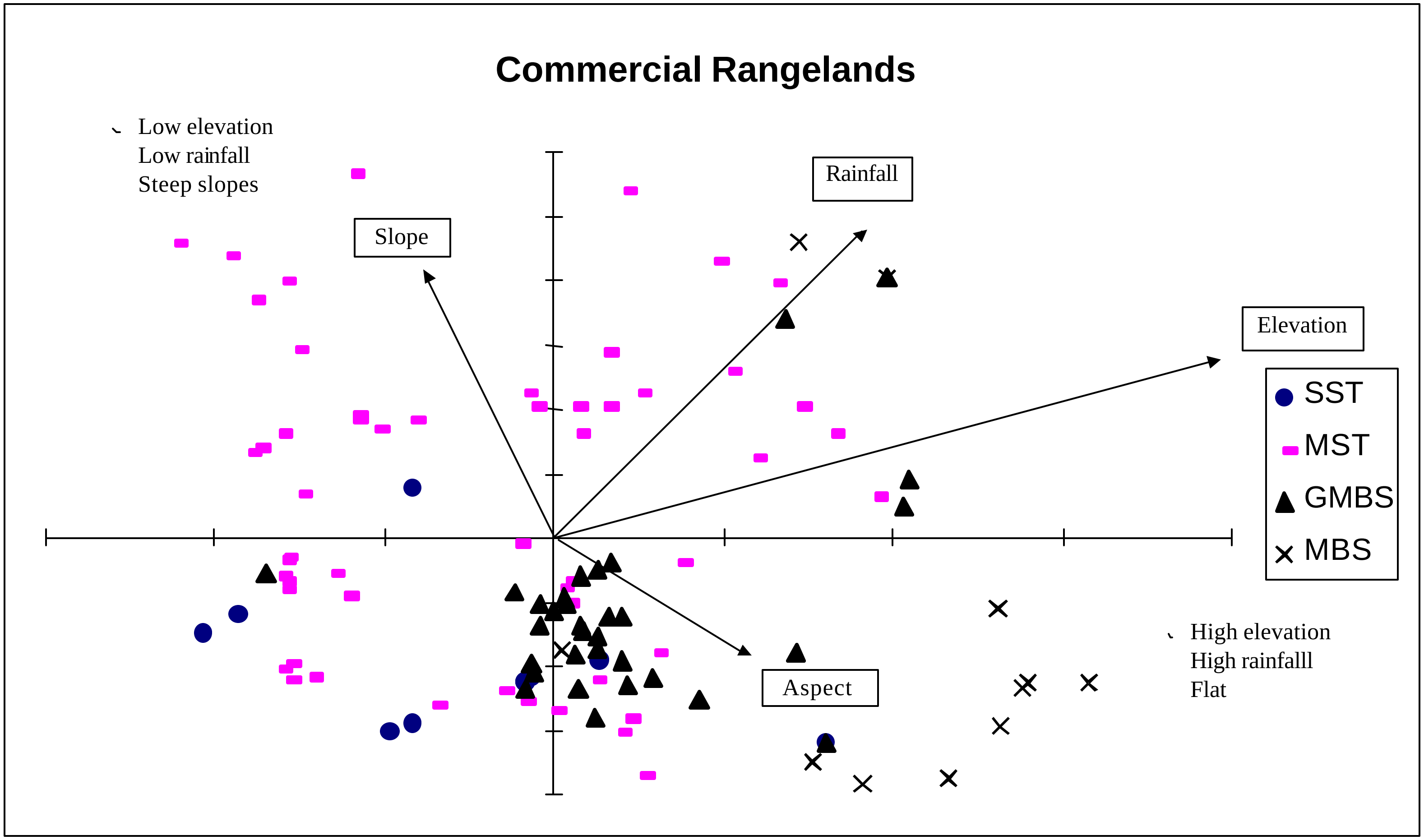


Figure 3.3.5: The distribution of the vegetation communities of the commercial rangelands in the mid-Fish River Valley along the first two axes in the CCA ordination. The first axis is horizontal, the second vertical. Also included is an overlay of the biplot scores for the environmental variables (arrows). MST = Medium succulent thicket; MBS = Mesic bushclump savanna; GMBS = Grasslands of the mesic bushclump savanna; SST = Short succulent thicket

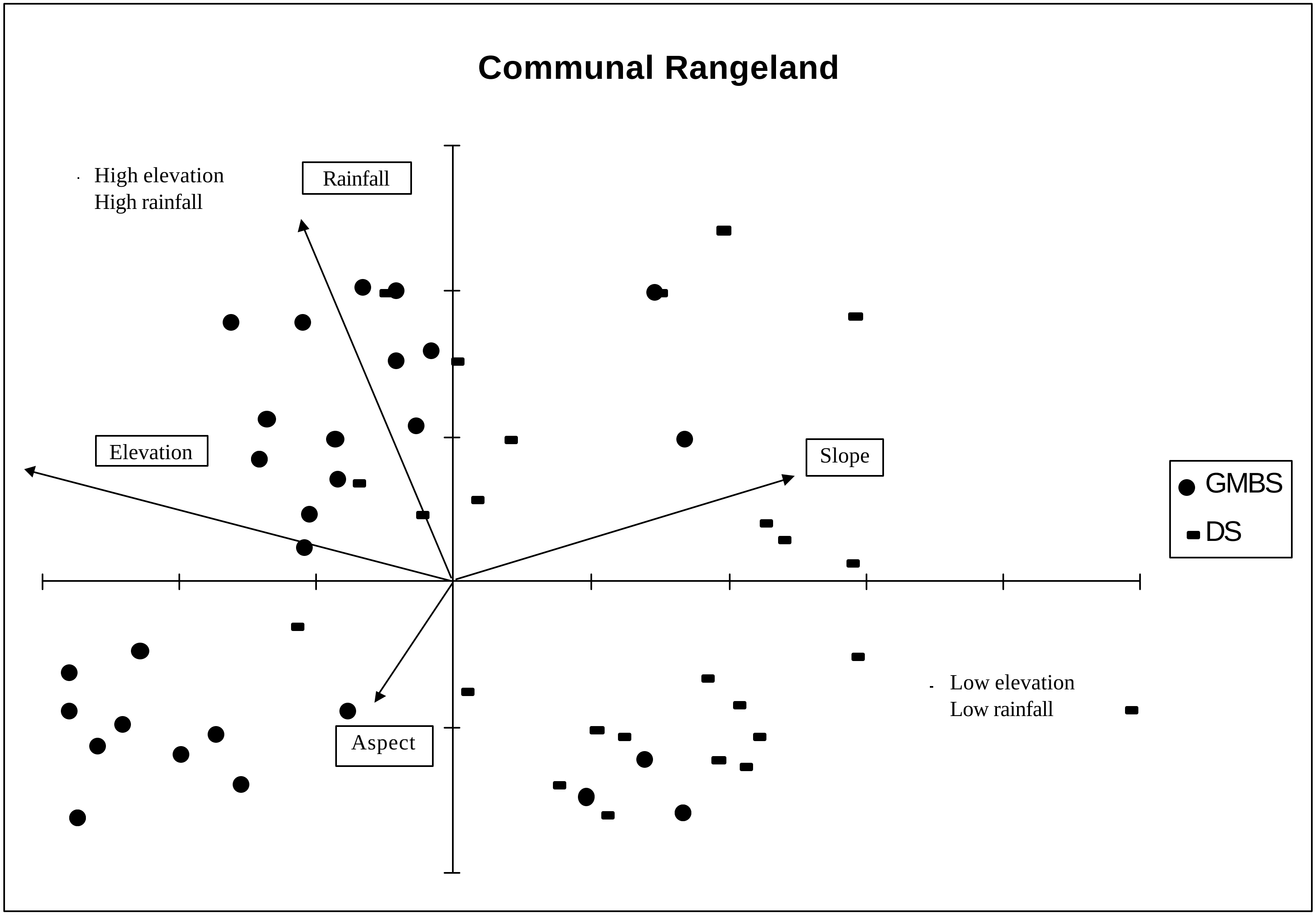


Figure 3.3.6: The distribution of the vegetation communities of the communal rangelands in the mid-Fish River Valley along the first two axes in the CCA ordination. The first axis is horizontal, second vertical. Also included is an overlay of the biplot scores for the environmental variables (arrows). GMBS = Grasslands of the mesic bushclump savanna; DS = Dwarf shrublands.

Variable	Nature conservation				Commercial Rangelands				Communal Rangelands			
	Canonical coeffecient		Interset correlation		Canonical coeffecient		Interset correlation		Canonical coeffecient		Interset correlation	
	Axis 1	Axis 2	Axis 1	Axis 2	Axis 1	Axis 2	Axis 1	Axis 2	Axis 1	Axis 2	Axis 1	Axis 2
Aspect	-47	105	-121	38	-2	-45	80	-87	-218	-106	-102	-116
Elevation	**-667**	51	**-717**	357	**781**	-234	**753**	229	**-792**	-455	**-754**	21
Rainfall	263	**424**	67	**735**	-236	**543**	337	**658**	-43	**782**	-465	**620**
Slope	178	91	226	261	-65	94	-39	368	333	34	270	54

Table 3.3.2: The canonical coefficients and interset correlations produced by the CANOCO ordination solution, for the first two ordination axes for each of the three land-use classes. Bold values indicate highest value.

3.3.4 Environmental distribution of plant communities

There was a significant difference in the elevation and rainfall values for the respective communities within the three land-use classes (Table 3.3.3). However not all of the communities showed a significant difference in rainfall and elevation values within a particular land-use category.

	Community	Elevation			Rainfall		
		Mean	F ratio	P value	Mean	F ratio	P value
Nature Conservation	SBS	373.94	4.266	0.0688	456.55	2.37	0.0743
	MST	341.74			437.78		
	MBS	405			435.91		
	GMBS	345.60			429.4		
Commercial Rangelands	SST	259.14	12.51	3.98E-07	408	5.11	0.0023
	MST	304.4			495.56		
	GMBS	367.87			469.75		
	MBS	478.2			489.33		
Communal Rangelands	GMBS	413.87	27.045	3.14E-06	469.75	12.32	0.0009
	DS	220.87			423.87		

Table 3.3.3: Mean elevation and rainfall values for vegetation communities classed in different land-use categories. F. ratio and P. values are results of one-way ANOVA.

The expectation is that the rainfall and elevation characteristics of a specific plant community should be then same across the land-use classes and when the rainfall and elevation characteristics of plant communities in different land-use categories are compared, a pattern should be evident. This pattern should show communities that are adapted to low rainfall occurring at low rainfall, low elevation sites, and communities adapted to more mesic conditions at high rainfall, high elevation sites. This environmental gradient is not clearly defined for the nature conservation areas (Figure 3.3.7). The communities tend to display moderate elevation and rainfall values, indicating the range in elevation and rainfall is not as great as expected in the nature conservation areas. Here the only community that exhibited a significantly different elevation value when compared to the other communities was MBS (Bonferroni test = 0.0003 when compared with SBS Bonferroni test = 0.00001 when compared with MST and Bonferroni test = 0.0002 when compared with GMBS; p<0.001111 at 95% significant level). MBS is the only community to occur in a high elevation class. All four of the communities fell under the moderate rainfall category, however Succulent Bushclump Savanna (SBS) showed a significant difference in rainfall when compared with GMBS since they occur at the upper and lower limits of the moderate rainfall class (Bonferroni test = 0.0006; p< 0.001111 at 95% significance level). Comparing the relative rainfall and elevation classes for this land-use category, SBS occurs in a higher than expected rainfall class. Owing to the large percentage of succulents in the community it would appear to be more suited to a lower rainfall class.

The communities of the commercial rangelands (Fig 3.3.7) show a clear environmental gradient, with Short Succulent Thicket (SST) occurring at low elevation, low rainfall and Mesic Bushclump Savanna (MBS) occurring at high elevation, high rainfall. SST, which occurs in a low elevation class, has a mean elevation value which is significantly different from GMBS and MBS communities that occur at moderate and high elevations respectively (Bonferroni test = 0.0005 when compared with GMBS and Bonferroni test = 0.00001 when compared with MBS; p < 0.001111 at 95% significance level). It did not show a significant difference with MST although they occur in different elevation classes (Bonferroni test = 0.1104; p < 0.001111 at 95% significance level). This is due to SST occurring at the upper limits of the low elevation class while MST occurs in the lower limits of the moderate elevation class. MBS, which was the only community to occur in the high elevation class, showed a significant difference in mean elevation value to the other three communities (Bonferroni test = 0.00001 when compared with SST; Bonferroni test = 0.00001 when compared with MST and Bonferroni test = 0.0009 when compared with GMBS; p < 0.001111 at 95% significance level). SST showed a significant difference in mean rainfall value compared with all three other communities, as it was the only community to occur in a low rainfall class (Bonferroni test = 0.00001 for MST; Bonferroni test = 0.00001 for GMBS and Bonferroni test = 0.0006 for MBS; p < 0.001111 at 95% significance level). The other communities within this land-use category all occurred in the high rainfall class and consequently did not show any significant difference in mean rainfall values.

Medium Succulent Thicket (MST) occurs at moderate elevation but in a higher than expected rainfall class, when compared to the other communities within this land-use class. It is also true for this community in the nature conservation areas.

The communal rangelands also show a clearly defined environmental gradient (Figure 3.3.7), with the DS communities being found at low elevation low, rainfall sites and the GMBS communities found at high elevation and rainfall sites. DS and GMBS have significantly different elevation and rainfall values (Bonferroni test = 0.00001 for elevation and Bonferroni test = 0.0008 for rainfall; $p < 0.001111$ at 95% significance level).

These results indicate that the variation on the species composition of the mid-Fish River Valley is complex and multidimensional. Dominant compositional gradients are related to elevation and rainfall, and to a lesser extent, slope and aspect. Environmental factors not measured, such as the physical properties of the soil also explain a portion of this variation in the vegetation.

The results show that the communities within the land-use classes are restricted to certain positions along the topo-moisture gradient. In broad terms the higher elevation sites, which receive a higher annual rainfall, are characterised by communities such as the MBS and GMBS. The plant communities found at lower elevation and rainfall sites such as MST are characterised by having a high percentage of succulent and plants adapted to xeric conditions.

The geographical distribution of these communities is not controlled simply by moisture and elevation. In many cases the conspicuous importance of elevation and rainfall may obscure the less dramatic yet still important role of slope, aspect and substrate in determining compositional variation in vegetation (Peet 1988). Austin *et al*. (1984) described elevation as an indirect environmental variable, and stated that it was the location specific correlation of elevation to rainfall, wind and temperature which is responsible for changes in vegetation performance with elevation. Thus, although elevation and rainfall were the dominant observable environmental variables affecting plant community distribution in the mid-Fish River Valley, one cannot discount the importance of other factors such as aspect, slope and soil. This is evident in the results, where SBS and MST occurred in a higher than expected rainfall class. These communities are however associated with steep north facing slopes. These steep slopes result in a high degree of evaporation and run off of water, hence the amount of effective water is greatly reduced. For the SBS community this effect is enhanced by the presence of the shale substrate as it further decreases the amount of available water owing to its low water holding capacity (Ainslie *et al*.1994). Thus a community may occur in a rainfall and elevation class that differs from expectation, owing to slope, aspect and substrate conditions.

Parker (1991) showed that soil texture as well as slope aspect exerted a large influence over the vegetational distribution within the Sonoran Desert. She concluded that variations in slope aspect affects soil moisture availability, as different aspects experience differences in heat stress, resulting in different rates of evaporation. The texture of the soil alters the infiltration rates of water, with coarse textured soils allowing a more rapid infiltration of water and holding the water at higher potentials than fine textured soils. Brown *et* *al*.(1993) found that the minor importance of geology was mostly overshadowed by the effects of elevation, precipitation and oceanicity. However, they did find some strong geological associations for certain communities in their study area of the Scottish uplands. They stated that although the overall effect of geology was small, they could not discount it in their description of environmental variables affecting plant community distribution.

These results show that the major compositional gradients in the mid-Fish River Valley were related to rainfall and elevation. However slope, aspect and substrate play an important role in determining the distribution of the plant communities along this environmental gradient.

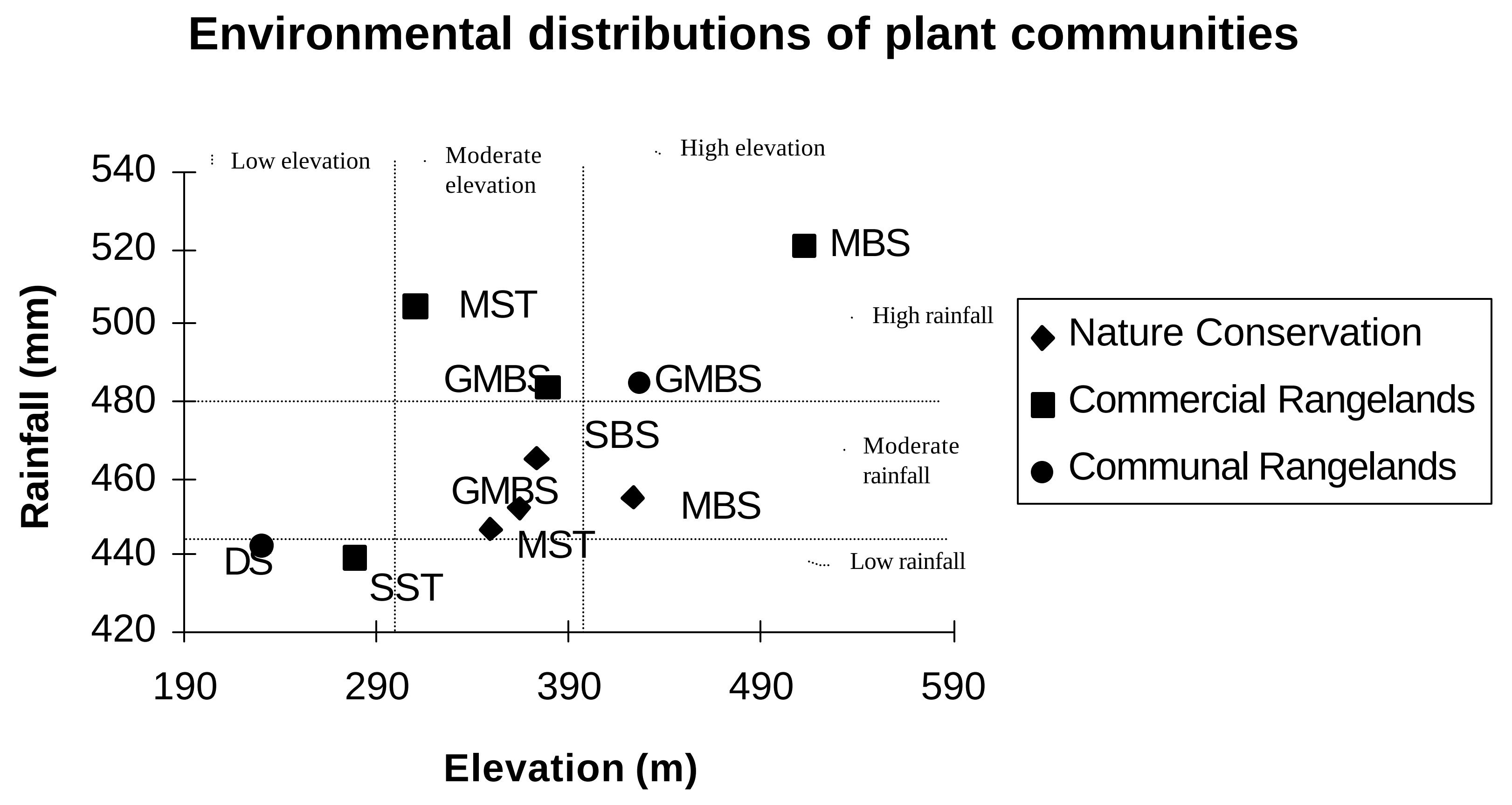


Figure 3.3.7: Rainfall and elevation characteristics of different vegetation communities according to their land-use category. MST = Medium succulent thicket; MBS = Mesic bushclump savanna; GMBS = Grasslands of the mesic bushclump savanna; SBS = Succulent bushclump savanna; SST = Short succulent thicket; DS = Dwarf shrubland.

CHAPTER 4

CHANGES IN THE VEGETATION COMMUNITIES IN RESPONSE TO LAND-USE

4.1 Introduction

All land utilisation involves change in some attribute of the land (Pickard 1991). Natural ecosystems are in a dynamic state, responding to variations in the extrinsic factors (climate and grazing) imposed upon them (Dankwerts and Teague 1989). The distinction between changes that are within the bounds of the dynamic equilibrium of an ecosystem and those that constitute a permanent change is vital to the management of that ecosystem. An understanding of the impacts of heavy grazing on biodiversity and ecosystem processes is thus important from both a conservation and economic perspective (Taggart 1994), given the land-use demands of an ever-increasing human population. It therefore becomes important to understand the vegetation pattern of an area and how a particular land-use practice will affect this pattern.

All species occur within a characteristic, limited range of habitat and within their range, they tend to be most abundant around their particular environmental optimum (Ter Braak and Prentice 1988). Thus, successive species replacements occur as a function of variation in the environment (Brown 1994). Much of the environmental variability controlling the vegetation patterns in the mid-Fish River Valley may be attributed to the topographic factors and their influence on climate (Palmer and Avis 1995). However, disturbance regimes can cause vegetation patterns to deviate from those predicted by the natural environment (Brown 1994), resulting in communities occurring in different positions along an environmental gradient under different management classes.

In South Africa the key indices for appraising veld condition are herbaceous cover and species composition (Tainton 1981). The basis of these indices is secondary production (to sustain particular live weight gains by livestock). Other objectives include protecting soil, biodiversity and the resilience of the grazing lands (Shackleton 1998). In communal situations however emphasis is placed on animal survival rather than on production economics. If there are long-term declines in survival rates, independent of rainfall or drought, this is seen as degradation. Whereas, commercial farmers view range degradation as a process by which either the productive capacity or the ability to conserve the resources of soil and water, are reduced below the potential indicated by the environment of the area concerned. The consequence of range degradation is a reduction in the productive capacity of the range.

Shackleton (1998) listed a set of measurable indices by which to appraise change, as a foundation by which to reach a positive or negative judgement on the basis of the direction and magnitude of change. There are essentially two components of concern; namely those dealing with the resource base for its intrinsic value, and those pertaining to the risk of reduced secondary production, and therefore lower economic returns from the land.

<u>Intrinsic value of the resource base</u>

- Loss of biodiversity
- Increased soil erosion
- Irreversibility of changes (owing to the land being too damaged)

<u>Productive value of the resource base directly affecting potential secondary production</u>

- Loss of palatable species in favour of less palatable species
- Loss of woody and herbaceous biomass
- Reduction in soil nutrient pools
- Decrease plant production due to changes in species and reduced soil nutrients
- Decreased animal production due to all of the above
- Sub-optimal economic returns because of reduced animal production

Although secondary production has been included in this assessment, the indices provide a basis by which to compare the condition of rangelands under various management regimes. The challenge to scientists now is to determine the sustainability of communal land-use and, if necessary, to then develop land-use options acceptable to the local communities.

The objective of this chapter was to investigate the impact domestic and wild herbivores have had on the species composition and production of the mid-Fish River Valley, by determining whether a shift in plant communities' distribution, composition and productivity could be detected along the topo-moisture gradient under different land-use practices. To determine a change in the vegetation, a number of questions must be addressed; i) How do the plant communities of the land-use classes differ in terms of floristic composition, structure and percentage cover? ii) Does the land-use treatment affect the distribution of the plant communities along the environmental gradient? iii) Are species restricted to certain ranges along the environmental gradient? iv) If so, how does the land-use treatment affect this distribution? v) Does species diversity change across the three land-use classes at different altitudes? vi) How is the productivity of the rangelands affected by land-use treatments along the topo-moisture gradient?

4.2 Methods

The plant communities described for the study area were compared across the land-use classes, in terms of floristic composition, structure and percentage cover. The TWINSPAN tables were used to divide the data set into a number of structural categories, namely palatable grasses, non-palatable grasses, forbs, succulents, karroid shrubs and other shrubs. Palatable grasses consisted of those species readily selected by grazing animals, such as *Themeda triandra* and *Digitaria eriantha*. Non-palatable grasses included those species that are not initially selected but will be eaten under heavy grazing pressure, as well as those species that are avoided by most animal species, such as *Eragrostis plana* and *Cymbopogon plurinodis*. The plant species that were included into the category forbs, were small herbaceous species, generally readily selected by grazers. Succulents included both stem and leaf succulents, while the category dwarf karroid shrubs included species such as *Chrysocoma ciliata* and *Felicia muricata,* which are species that commonly occur in the karroid vegetation type. The other shrubs included all shrub and tree species ranging in height from 1m to over 3m that did not fall into the other categories. Dansereau (1951) suggests that these life form categories can provide insight into the variation in structure of communities in response to various environmental variables. Pie charts of the percentage cover for each category were drawn for easy comparison and to aid in the identification of shifts in vegetation composition and structure under the different land-use treatments.

To determine whether shifts of these communities occur along the environmental gradient under different management regimes, the elevation and rainfall values for a specific community under the different land-use treatments were compared. An ANOVA and Bonferroni multiple range test was run on these values to determine if they differed significantly.

The percentage similarity of the plant species present in the different communities of the area was calculated using Sorensen's Index of Similarity, (Mueller-Dombois and Ellenberg 1974). Species richness and species diversity, using Shannon's diversity index, was calculated for each land-use class along the topo-moisture gradient. Biomass data for the mid-Fish River Valley was obtained by converting canopy volume as determined by Danckwerts and Teague (1989) to biomass using a regression analysis technique as described by Rutherford (1979). However, it must be stressed that the biomass values are derived from a conversion of data and therefore should not be accepted as an accurate measurement of the biomass in the study site but rather a means of assessing relative changes in biomass across the land-use classes.

Assessing productivity changes over a time period presents certain difficulties as no long-term productivity studies have been conducted for each land-use class along the topo-moisture gradient within the study area. It is therefore difficult to determine if the rangelands under communal management have suffered any loss in productivity relative to the other two land-use classes. In order to gain some insight into the productivity and sustainability of communal rangelands, the ARTEMIS (African Real Time Environment Monitoring Information System) image archive was used to extract NDVI data for the study area over a period of 10 years. The ARTEMIS archive contains 10 years of NOAA Vegetation index images. The NDVI (Normalized Difference Vegetation Index) data from NOAA's AVHRR sensor is used to establish annual and seasonal variations in surface reflectance. Vegetation has low reflectance at the red wavelength and maximal reflectance in near infrared. Photosynthetically active plants reflect more light in the near infra-red part of the spectrum than less active plants. Sites having a higher NDVI value are actively greener (Tucker *et al*. 1985), assimilate more CO_2, and are more productive than sites with lower NDVI values (Sannier *et al*. 1998). The seasonal integration of NDVI values is closely associated with primary production of grazing, agricultural and forested areas. NDVI is the most widely used satellite derived indicator of vegetation activity (Sannier *et al*. 1998), and several studies have used it to assess crop yields or primary production (Kennedy 1989, Prince 1991 and Rasmussen 1992). The limitation of NDVI image maps is that they can be difficult to interpret as the relationship between NDVI and vegetation condition may vary between vegetation types (Sannier *et al*. 1998). In order to aid in the interpretation of the NDVI values as a measure of productivity, NDVI values can be related to biomass accumulation with a system. Areas with high biomass and NDVI values can be interpreted as high production areas, thus providing a means of assessing the changing trends in productivity.

The time series profiles already corrected for sensor degradation were extracted for the 10-year period covered by the ARTEMIS data set (August 1981 to June 1991). Time series profiles were extracted for each land-use class within the various elevation and rainfall categories. The parts of the time series affected by cloud cover were then removed from the data set ensuring that each data set contained the same time series points. A one-way ANOVA test was run on the mean NDVI values to determine if there was a significant difference between land-use classes. To investigate instability of the rangelands under different land-use classes, the standard deviation for the NDVI values over the 10-year period was calculated for each land-use class within each topo-moisture category.

4.3 Results

4.3.1 Floristic, structural and cover changes

Figure 4.3.1 shows the structural composition of the species found in each land-use class. Six categories were defined Figure 4.3.1 shows the structural composition of the species found in each land-use class. Six categories were defined.

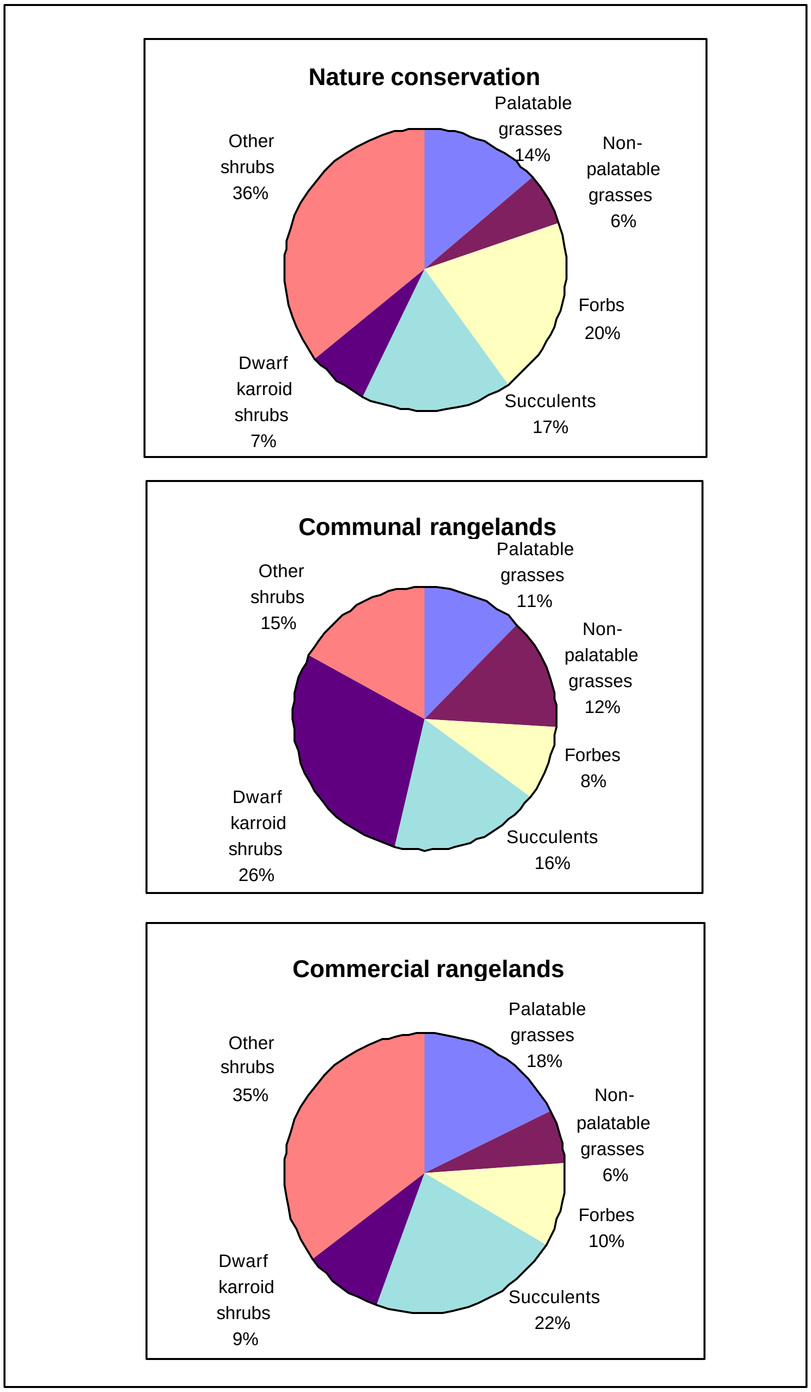


Figure 4.3.1: A comparison of vegetation composition for three land-use classes, namely nature conservation, commercial rangelands and communal rangelands.

Figure 4.3.1 shows that the overall percentage grass cover was higher in the commercial farming areas, which also had the highest proportion of palatable grass species (18% for commercial rangelands, while nature conservation and communal rangelands had values of 14% and 11% respectively). This is in accordance with the management objective of the landowner, which is towards a high percentage cover of palatable grasses, resulting in an increase in the production potential of the rangelands.

The communal rangelands contained double the percentage of non-palatable grass species when compared to the commercial farming and nature conservation areas (12% as opposed to 6% for nature conservation and commercial rangelands). Twenty percent of the nature conservation species composition consisted of forbs (Figure 4.3.1), indicating a lesser amount of selective grazing for forbs by wild herbivores. The commercial rangelands and communal rangelands showed a decrease in the percentage cover of forbs (10% and 8% respectively) when compared to the nature conservation areas.

The percentage cover of succulents was similar in all three land-use classes (Figure 4.3.1), but the composition of the succulents differed between the land-use treatments. In the nature conservation areas most of the succulents were *Crassula* species, while in the commercial farming lands *Euphorbia* species were the most common succulents. *Portulacaria afra* occurred with high incidence in both these land-use classes, but was virtually absent from the communal rangelands, where *Aloe* species constituted the majority of the succulents. Karroid dwarf shrubs were the largest group of plants found in the communal rangelands, constituting 26% of the total species composition (Figure 4.3.1). This percentage cover was substantially higher than that found in the nature reserves or the commercial rangelands, which were 7% and 9% respectively. The percentage cover of the other shrubs decreased quite dramatically in the communal rangelands but was virtually the same in the nature conservation and commercial farming areas (36% and 35% respectively), where it formed the greatest portion of the floristic composition.

4.3.2 Shift in environmental distributions of plant communities

A definite shift occurred in the placement of Grasslands of the Mesic Bushclump Savanna (GMBS) along the topo-moisture gradient (Figure 4.3.2). With a change from nature conservation to commercial rangeland, the GMBS community showed a shift into a higher rainfall class but remained in the moderate elevation class as this value was not significantly different to the mean elevation value under nature conservation (Bonferroni test = 0.0022 for elevation & Bonferroni test = 0.0001 for rainfall; $p < 0.001111$ at 95% significance level). Comparing the mean values of the commercial and communal rangelands (Table 4.3.1), GMBS shows a significant shift into a higher elevation class but remained in the same rainfall class (Bonferroni test = 0.0005 for elevation & Bonferroni test = 0.9996 for rainfall; $p < 0.001111$ at 95% significance level). Medium Succulent Thicket (MST) was only found in the nature conservation and commercial farming areas and it also showed a shift in position along the gradient, owing to a change in management regime. This shift was from a lower rainfall class in nature conservation areas to a higher rainfall class in commercial rangelands. The Mesic Bushclump Savanna (MBS) community showed a shift towards a higher elevation and rainfall, with a change from nature conservation to commercial rangelands.

		Elevation			Rainfall		
	Land-use class	Mean	F ratio	P value	Mean	F ratio	P value
GMBS	Nature conservation	345.6	2.73	0.071	429.4	4.64	0.0123
	Commercial Rangelands	367.87			469.75		
	Communal Rangelands	413.87			469.75		
MST	Nature conservation	341.74	4.089	0.0457	437.78	21.73	9.41E-06
	Commercial Rangelands	304			495.56		
MBS	Nature conservation	405	5.53	0.024	435.91	5.08	0.0302
	Commercial Rangelands	478.2			486.33		

Table 4.3.1: Mean elevation and rainfall values for a specific vegetation community classed in different land-use categories. F. ratio and P. value are results of one-way ANOVA.

4.3.3 Floristic similarity between individual communities

The results of the Sorensen's Similarity Index (Table 4.3.2) showed a high degree of floristic similarity (> 60%) between the communities within the three land-use classes. Mueller-Dombois and Ellenberg (1974) describe a percentage similarity above 60% as showing good floristic similarity. This indicated that there was only a small amount of floristic differentiation between the communities along the environmental gradient. In the commercial rangelands, SST and MBS showed the lowest number of shared species with only 62 percent of the species common to both communities. MST and GMBS showed the highest degree of similarity between the two communities (93%).

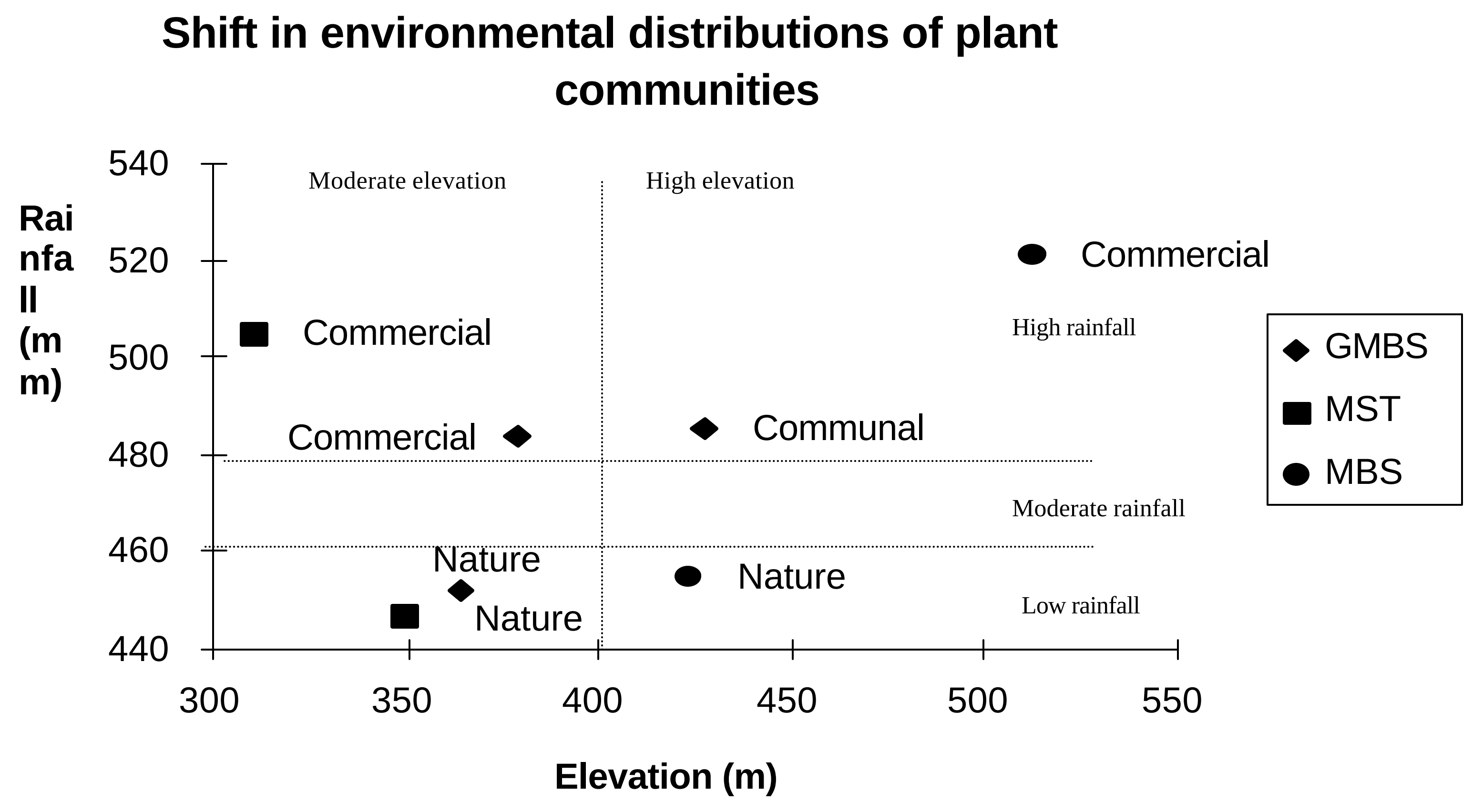


Figure 4.3.2: Changes to rainfall and elevation characteristics of different vegetation communities under different land-use categories. MST = Medium succulent thicket; MBS = Mesic bushclump savanna; GMBS = Grasslands of the mesic bushclump savanna.

	Nature Conservation			Commercial Rangelands			Communal Rangelands
	MST	**MBS**	**GMBS**	**MST**	**MBS**	**GMBS**	**GMBS**
SST				67	62	67	
SBS	89	85	78				
DS							80
MST		79	93		93	80	
MBS			81			83	

Table 4.3.2: Sorensen's Index of Similarity showing percentage floristic similarity of the species between the communities within each of the three land-use classes.

In the nature conservation areas, SBS and GMBS showed the lowest similarity (78 percent). The other communities in the nature conservation areas had a similarity of over 80 percent, which indicated only a slight difference in floristic composition along the gradient. The DS and the GMBS communities in the communal rangelands were highly similar (Table 4.3.2).

4.3.4 Diversity and Productivity

The productivity time series graph (Figure 4.3.3) revealed a difference in the overall productivity of the rangelands under the different land-use classes. The mean NDVI values over the 10-year period showed a significant difference between the communal areas and those of the nature conservation and commercially managed areas (F=0.036; P=0.00674 at 95% significance level, when compared with nature conservation & F=0.016; P=0.00125 when compared with commercial rangelands). The NDVI values for nature conservation areas and those of the commercial rangelands were not significantly different (F=0.72; P=0.81).

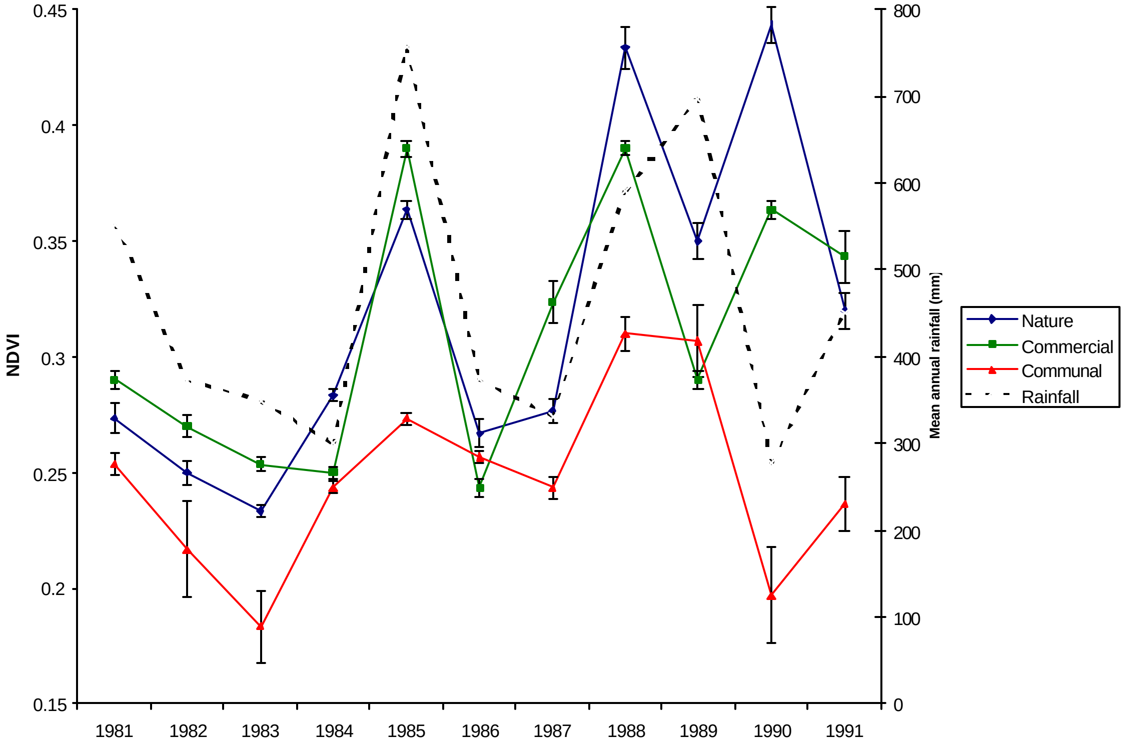


Figure 4.3.3: Productivity time series graph of the mean NDVI values for the three land-use classes within the mid-Fish River Valley for a 10-year period from 1981 to 1991.

The rangelands exhibited differences at the various points along the topo-moisture gradient according to the type of management employed (Figure 4.3.4). Palmer and Avis (1995) identified the high elevation, high rainfall sites as high potential production areas and the low elevation, low rainfall sites as lower potential production areas, i.e. they identified a potential production gradient which increased up the topo-moisture gradient. This increase in production up the gradient is consistent with the increase of NDVI and biomass values (Figure 4.3.4) under nature conservation and communal rangelands. However, the commercial rangelands showed a decrease in NDVI and biomass values, indicating a decrease in productivity in the high elevation, high rainfall category. This decrease may be a result of over utilisation of these highly productive areas under commercial farming. The decrease in diversity and species richness for this category further attested to changes taking place. The low standard deviation values reveal relatively stable productivity levels over the 10-year period for all three land-use classes. However the high elevation, high rainfall category under commercial management showed an increase in the standard deviation of the NDVI values, indicating that the productivity of these rangelands varied slightly more over the 10-year period when compared to the other categories under this land-use class. This greater instability indicated that under extreme conditions such as drought the ability of the rangelands to cope with the conditions have been somewhat undermined and consequently the resiliency of these rangelands have changed.

The diversity, as measured by species richness and Shannon's Diversity Index for species, displayed the same trend as the productivity levels in the nature conservation areas, that is, one of increasing up the topo-moisture gradient (Figure 4.3.4). The species richness, diversity and biomass were the highest under nature conservation at all points along the gradient. The standard deviation values remained constant along the topo-moisture gradient, denoting stable productivity levels.

The diversity and species richness for the communal rangelands was consistently lower than that of the other two land-use classes along the topo-moisture gradient. The productivity under the communally managed areas showed a large increase from the low elevation, low rainfall areas to the high elevation, high rainfall areas. The standard deviation values were higher than the other two land-use classes for both the low and medium topo-moisture categories. The communal rangeland standard deviation values showed a peak in the low elevation, low rainfall category, denoting a greater fluctuation in productivity levels within this category. Under communal management the vegetation of these low-lying areas has been transformed into the Dwarf Shrublands, which are dominated by a few individual species and have large bare patches of soil exposed. The instability of the productivity levels for this vegetation community indicated that the ability to cope with extreme conditions is variable.

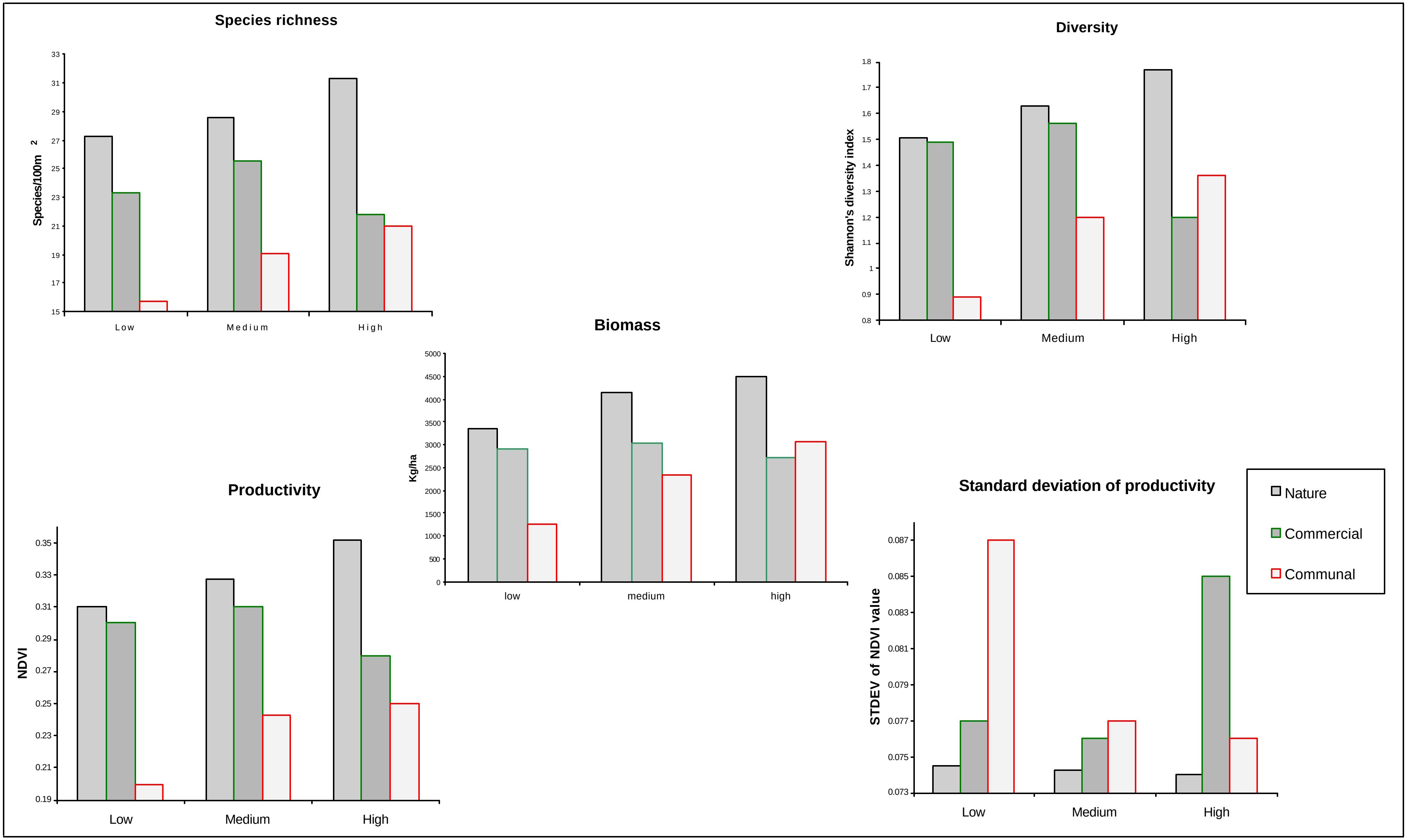


Figure 4.3.4: Species richness, diversity, biomass, productivity and standard deviation in productivity at low elevation and rainfall, medium elevation and rainfall and high elevation and rainfall for the three land-use classes within the mid-Fish River Valley.

4.4 Discussion

The extent of vegetation degradation in the Thicket Biome is significant and has resulted in a large-scale reduction in production potential (Hoffman and Everard 1987). In the absence of adequate management strategies, severe overstocking of the rangelands has occurred, resulting in the replacement of palatable species by weedy unpalatable invaders (O'Reagain and Grau 1995).

The results of this study show a definite grazing gradient within the Thicket Biome, where changes in vegetation pattern occurs according to the type of land-use. In commercial rangelands vegetation is under controlled moderate grazing by domestic livestock. Under nature conservation there is light continuous grazing by wild herbivores, while in the communal rangelands the vegetation is subjected to continuous moderate to heavy grazing pressure. If the grazing intensity of the three land-use treatments are compared, the nature conservation areas can be described as having the least intensive grazing (stocking rate = 60-80 ha/LSU), while the communal rangelands are under the heaviest grazing pressure (10-20 ha/LSU).
These different grazing strategies have resulted in a difference between the structural composition of the community groups described for the study area. Comparing the change in vegetational composition, structure and position along the environmental gradient from nature conservation to commercial rangelands through to the communal rangelands, a pattern becomes evident. The succulent components in the understorey are the first elements to disappear, and are initially replaced by annual species, which include annual succulents as well as annual grasses.

Intensive grazing pressure leads to a change in spatial and temporal heterogeneity of water, nitrogen and other soil resources (Schlesinger *et al*. 1990). Heterogeneity of soil promotes the invasion of karroid shrubs, which leads to a further localisation of soil resources under shrub canopies. The invasion of the area by karroid shrubs has the effect of increasing floristic patchiness (Hoffman and Cowling 1990). Karroid shrubs are able to invade as they exploit the soil moisture more effectively (Schlesinger *et al*. 1990). The decrease in ground cover results in an increase in the effective energy of raindrops (Schlesinger *et al*. 1990) and consequently less rain filters into the soil. Soil compaction owing to trampling further reduces infiltration rates. This has the effect of increasing run off rates and erosion, which is most evident in the bare patches between the shrubs. The net effect of these changes is to reduce the availability of soil moisture and nutrients in the landscape and to increase soil temperature (Schlesinger *et al*. 1996). Karroid elements, such as *Pentzia incana* and *Chrysocoma ciliata*, which are able to tolerate the increased evaporation and higher temperature levels, invade available habitats and become dominant. This is apparent in the communal rangelands, where the percentage of karroid shrubs is significantly greater than that of the other two land-use treatments (Figure 4.3.1). This alteration in species composition and loss of cover causes a radical change in germination microclimate, as the soils become hot and dry. Consequently, new seedlings of the subtropical trees, such as *Portulacaria afra, Pappea capensis, Euclea undulata* and *Grewia robusta*, cannot establish. If the older individuals of these trees are removed by excessive browsing or fuel collection by local populations, the transformation to a karroid, semi-desert landscape is complete. This is particularly visible in areas surrounding human settlements, where the vegetation has become a Dwarf Shrubland and the percentage cover has been drastically reduced.

The grazing gradient is therefore a transformation from a mesic environment towards a more arid environment with an increase in grazing and browsing pressure. This gradient also results in a decrease in vegetal complexity from good condition rangelands to poor condition rangelands. The species diversity decreases and the area becomes dominated by a few individual species. For instance, in the nature conservation areas there are a high percentage of forbs, which increase the overall species diversity under this land-use treatment. Whereas under commercial and communal management the combined effect of selective grazing and trampling by domestic stock result in a decline in the percentage of forbs (Tainton 1981). Therefore as the grazing and browsing pressure increases the diversity decreases and the area becomes dominated by a few karroid species, resulting in a decrease in the overall species diversity.

Although specific plant communities occurred at certain positions along the environmental gradient, the species did not show a definite restriction of range, as the percentage similarity of species at low elevation, low rainfall sites was high when compared with the species at high elevation, high rainfall sites. This is not the result one would expect, owing to the difference in climate from low elevation to high elevation sites. However, this high percentage similarity of the species from the various communities along the gradient is a consequence of the vegetation having low beta diversity (La Cock *et al*. 1990). Although the communities are comprised of similar species, the dominant species are different at either end of the gradient. Species adapted to low rainfall are dominant in the more arid environments, while more mesic adapted plants are found in greater numbers at the higher rainfall sites.

This is in accordance with results obtained from other studies along grazing gradients. Barker *et al*. (1989) conducted a study along a grazing gradient within the coastal grassland of central Somalia and concluded that species diversity and percentage cover increased from very poor to good condition rangelands. In a study of fence line contrasts in the lower Sundays River Valley, Hoffman and Cowling (1990), found that the vegetation cover decreased along a gradient from slightly more than 100% cover in an ungrazed site to about 45% in a heavily grazed site. It was also noted that there was a structural distinction between the two sites studied. Hoffman and Cowling (1991) showed that under sustained, continuous grazing, many common low shrubs which are characteristic of mesic environments are replaced by widespread karroid dwarf shrubs and herbs. They further stated that the longer-lived tree component may persist during the early phases of degradation, forming an open savanna. Hoffman and Cowling (1991) concluded that many of the endemic species occupied specialised habitats, often protected by other shrubs. The large-scale destruction of these shrubs may lead to the extinction of these endemics.

Their findings correlate well with the results obtained in this study, which also reflects a change in vegetational cover as grazing intensity increases. The bush was opened up by grazing, resulting in a change in vegetation from a densely vegetated community towards an open bush community. As grazing pressure increased, the size of the bushclumps decreased and the grassy areas between the bushclumps expanded, resulting in the formation of a grassland within the bushclump savanna i.e. the Grassland of Mesic Bushclump Savanna community. The changes that are reflected in the data are not only a product of different grazing intensities, but may also be a result of varying animal combinations. Under commercial farming the number of cattle present generally exceed that of sheep and goats, whereas in communal areas goats and sheep tend to occur in greater numbers. The foraging behaviour of goats and sheep result in a concentration of grazing within a small area, especially around water points (Noss 1994). This has the effect of increasing the impact of grazing within localised areas, which is evident around the homesteads. Rangeland stocked predominantly with cattle is usually less closely and more evenly grazed than veld stocked with sheep (Brown & McDonald 1995). The introduction of browsers such as goats causes a decrease in bush density (Trollope 1984) which results in the opening up of the dense bush thereby producing a larger grassy area for grazing. The poor water quality and the scarcity of the livestock water points within the communal rangelands (Ainslie *et al*. 1994) further impacts on the condition of the vegetation. Studies on domestic herbivore water use-efficiency and their subsequent choice of food shows that under conditions where insufficient water or water of poor quality is available to livestock, they tend to focus their foraging on succulent plant species (Vega-Villasante *et al.* 1997). Succulent species have a high water and nutritional content and therefore serve as an important feed under dry conditions. Thus the utilisation of a plant such as *Portulacaria afra* is intensified under these conditions. *P. afra* propagates to a large extent vegetatively, its branches reach down onto the ground where they take root and become new individuals. Under conditions where elephants are the dominant defoliating agents, the *P. afra* is grazed from the top downwards and this contrasts with goats that browse *P. afra* from the side inwards. The browsing habit of elephants would allow the lower-side branches to root and propagate, while goats defoliated these branches and thereby prevent new individuals establishing (Stuart-Hill et al. 1986). This can ultimately result in this species being eliminated across the entire landscape, which is the case in the communal rangelands of the mid-Fish River Valley.

The grazing gradient from good condition rangelands to poor condition rangelands can therefore be followed from the nature conservation areas to the commercial rangelands through to the communal rangelands, which experience the highest intensity of utilisation pressure. Along this gradient varying degrees of degradation can be distinguished. It ranges from marginal degradation where the bushclump savanna communities have been opened up, resulting in a higher percentage of grass cover, to degraded rangelands where karroid shrubs have invaded but where subtropical trees are still present. At this stage of degradation there is still potential for the rangelands to revert to a more productive state as the germination microclimate has not been destroyed. This stage is evident in the GMBS community present in the communal rangelands. The community Dwarf Shrubland can be classified as severely degraded. Under these conditions the rangeland has been transformed into a karroid shrubland, where there has been a substantial decrease in production potential with the invasion of many unpalatable species and the removal of the established trees and shrubs. The germination microclimate has been destroyed, therefore there is little or no chance of these rangelands recovering to a more productive state.

Along with the change in vegetation from valley thicket to a karroid dwarf shrubland, there is another less visually dramatic effect of increased grazing and browsing pressure. This effect is a shift in community position along the environmental gradient, towards a higher elevation and rainfall class with increased grazing pressure. The results of this study indicate that as the communities are subjected to an increase in grazing pressure, they tend to occur in less arid environments. Consequently these communities are then found in areas where the rainfall is higher and because rainfall is highly correlated to elevation this usually results in the communities moving into a higher elevation class. As grazing intensity increases, the pressure leads to a change in the soil water, nitrogen and other soil resources (Hoffman and Cowling 1990). This change causes communities to occur in a higher than expected rainfall class, as the relative amount of water available to the plants is less and so the transformation from a mesic environment to a more arid environment alters the position of the communities along the environmental gradient. Thus, a community usually found at low elevation and rainfall under nature conservation would be found at a moderate elevation and rainfall in the commercial rangelands and at high elevation and rainfall under the communal rangeland system.

This ecosystem transformation that occurs along the grazing gradient is not only evident in vegetation changes but is also evident in changes to the invertebrate, bird and small mammal assemblages (Seymour & Dean 1999, Todd *et al*. 1998 and Joubert & Ryan 1999). A study by Fabricius and Burger (1997) in the succulent thicket revealed changes in invertebrate species composition between nature conservation and communally managed areas. They reported that between 23% and 45% of the arthropod species were unique to a specific land-use treatment, with the more arid adapted species occurring more commonly in the communally managed areas. The changes in birds and small mammals are usually in response to the changes in vegetation structure that occurs along the grazing gradient (Joubert & Ryan 1999).

The underlying assumption concerning productivity is that healthy rangelands are less variable than degraded rangelands. Healthy, well functioning rangelands show high productivity levels and are able to accumulate biomass in good seasons for use in periods of shortages, whereas poor condition rangelands show high productivity levels during good seasons (equal to those of good condition rangelands) but are unable to simultaneously accumulate biomass and consequently during periods of extreme conditions the productivity of the rangelands declines drastically. It is at this point where the question of sustainability becomes relevant. Are rangelands that show large declines in productivity under extreme conditions managed in a sustainable manner? The philosophy behind good veld management is to provide the land-user with adequate food reserves in order to sustain utilisation throughout periods of extreme conditions without detrimentally affecting the quality and productivity of the vegetation (van Rooyen *et al*. 1996). The results reveal some differences in productivity levels for the three land-use treatments, as well as a relationship between areas that have undergone a change in species composition and structure, and areas that are showing greater deviations in the productivity levels over time (the low elevation, low rainfall category under communal management). These results suggest that when changes in species composition and structure occur as a result of heavy grazing and browsing pressure, the productivity of these rangelands begin to fluctuate. Consequently these rangelands cannot be regarded as sustainable, owing to the decline in productivity.

Considering the indices listed by Shackelton (1998) to appraise veld condition, the communal rangelands comply to some degree with the conventional interpretation of degradation. That is, there has been a loss of biodiversity, increased soil erosion, an inability to reverse the changes that have taken place, loss of palatable species, replacement by less palatable species, loss of biomass, reduction in soil nutrients and a change in plant productivity.

CHAPTER 5

A PREDICTIVE VEGETATION MODEL FOR THE MID-FISH RIVER VALLEY

5.1 Introduction

Over the last two decades, models of environmental systems have grown in importance for theoretical and applied research. There is an increasing demand on resource managers to maintain productivity levels and restore damaged ecosystems without direct experimentation, owing to financial and/or time constraints. Ecological models are able to provide useful insights of vegetation responses to varying management schemes (van de Rijt *et al*. 1996). Various models are available, each having specific data requirements, as well as different potentials and limitations.

5.1.1 The theory of vegetation modelling

There exists a wide range of the impact of man's actions on natural ecosystems. When impact is limited, the ecosystem tends to retain most of its original attributes, but when impacts are severe, the natural system is often replaced. As the degree of habitat modification increases and as natural communities are altered or replaced by communities composed largely of exotic species, a knowledge of structural and functional relationships provides the most sound basis for effective long-term management, consistent with both conservation and maintenance of productivity.

In recent years, the application of powerful modelling procedures to ecological processes has stimulated research into the relationship that exists between plants/vegetation types and the environmental variables, for the possibility of providing a sound ecological basis for the development of management strategies for natural and semi-natural ecosystems. These techniques have potential application to a wide spectrum of ecological problems and to the management of rangelands.

In general a search for change in ecological systems will be directed by hypotheses about mechanisms which govern and induce changes. Only rarely will methods of detecting changes that are totally unspecified be devised, even more rarely will models be developed that are capable of predicting changes that are completely unspecified (Jeffers 1988). Nevertheless, models may frequently predict changes that are unexpected (van de Rijt *et al*.1996). It is these unexpected changes which provide an insight into ecosystem responses to utilisation.

The models for predicting vegetation change have a wide range of applications. Obviously, they are especially relevant to many kinds of fundamental research in ecology, especially to describe the complex interrelationships between organisms and between organisms and the physical and chemical factors of their environment. Modelling and the prediction of vegetation change is essential in the assessment of environmental impacts and management decisions.

Species-environmental relationships

The concept of vegetation composition changing along environmental gradients arose in antithesis to the community-unity theory, which stated that plant communities are natural units of coevolved species populations forming homogeneous, discrete and recognisable units (Austin 1985). The distribution of plants is affected by a wide variety of environmental and biotic factors, however the ultimate deterministic pattern of vegetation distributions according to Brown (1994) is the variation in the physical environment. Austin (1980) and Austin and Cunningham (1981) divided environmental gradients into three types – indirect, direct and resource gradients. An indirect gradient such as altitude has an indirect influence on plant growth; a direct gradient such as pH has a direct physiological effect on plant growth; while a resource gradient, for example nitrogen, is one where the factor is directly used as a resource for plant growth. These environmental gradients interact and determine the availability of resources for plants. It is these interactions which cause species, populations and community characteristics to change along environmental gradients (Whittaker 1975). The study of such changes, that is, the measurement and interpretation of vegetation response to spatial variation of an environmental factor such as elevation, moisture or exposure, is termed gradient analysis. Essentially gradient modelling is the application of gradient analysis and ordination techniques.

Gradient analysis allows the environmental variables that have the greatest influence over plant distribution to be identified. Although the environmental influences on vegetation were often thought to be too numerous and complicated to be represented by gradient analysis, Whittaker (1975) demonstrated that in some environments, two or three indirect environmental gradients may summarise much of the observed variation in species distribution. Austin *et al.* (1984) found that in a study of *Eucalyptus* species, only a limited number of environmental gradients (mean annual rainfall, mean annual temperature, radiation index and geology) accounted for a major proportion of the variability in vegetation composition. Landscape studies have shown that the use of elevation and moisture gradients are effective in creating models to predict the distribution of vegetation (Austin *et al*. 1984, Palmer 1991, Palmer and Van Staden 1992 and Palmer and Avis 1994).

Relating vegetation composition to environmental gradients

Various statistical methods are available for relating vegetation composition to environmental gradients. The following provides a summary of a few well-known statistical methods.

Simple linear regression:

The term simple regression refers to the fact that only two variables are being considered. Data amenable to simple regression analysis will consist of a dependent variable that is a random effect factor and an independent variable that is either a fixed effect or a random effect factor. The simplest method of direct gradient analysis involves plotting each species' abundance values against values of an environmental variable, or drawing isopleths for each species in a space of two environmental variables (Ter Braak 1987). The analysis of relationships between three or more variables however requires the procedures of multiple regression.

Multiple regression analysis:

More elaborate models use multiple regression methods (Austin *et al*. 1984) and are useful in simultaneously studying the effects of more than one environmental variable. The problem facing the user of multiple regression analysis relates to the determination of which of the independent variables have a significant effect on the population sampled. The step-wise method can be used to conclude which is the best regression. Step-wise multiple regression consists of two methods. The step-up method begins with the smallest possible regression model, i.e. with one independent variable (a simple regression), and gradually works up the multiple regression model incorporating the largest number of significantly important independent variables. The second method is that of the step-wise elimination of variables (the step-down method). However, despite some successful applications, Boer *et al*. (1996) and Austin (1972), multiple regression has never become popular in vegetation science. Reasons for this include: 1) Each species requires separate analysis, so regression analysis may require an unreasonable amount of effort. Furthermore, separate analysis cannot be combined easily to get an overview of how community composition varies with the environment. 2) Vegetation data are often qualitative, or when quantitative, the data may contain many zero values (plots where species are absent). In both cases the data does not satisfy the assumption of normal error distribution that is implicit in ordinary multiple regression. 3) Relationships between species and environmental variables are generally non-linear. 4) Environmental variables are often highly correlated, and it can therefore be impossible to separate their independent effects. Generalised linear modelling (GLM), however, provides a solution for points 2 and 3.

Generalised linear modelling (GLM):

Significant advances in statistical theory have allowed the development of a class of models very similar in structure to linear regression but without the constraint of assuming a normal distribution of the errors, and with a greater range of relationships between the response and explanatory variables. These classes of statistical models are referred to as Generalised Linear Modelling. Logistic regression, one of the family of Generalised Linear Modelling (GLM), uses a linear combination of independent variables to explain the variance in a dependent variable having only two states. Logistic regression assumes that a species occurrence relates to an environmental gradient in a logistic rather than a linear manner. This makes good biological sense because a species might be expected to exhibit tolerance over part of the gradient, decreasing tolerance once a threshold has been reached, and then intolerance over the remainder, thus prescribing a sigmoid–type curve (Osborne and Tigor 1992). Logistic regression is well suited to analyse presence-absence data, and generates a value constrained between 0 and 1 which may be regarded as the probability of occurrence. It thus has an advantage over techniques such as discriminant function analysis, which generates expected frequencies beyond 1 in both positive and negative direction and hence pose difficulties of interpretation. Although GLM is able to overcome the problems of qualitative vegetation data and non-linearity (Ter Braak 1987), problems with separating the effects of highly correlated environmental variables and separate species analysis still remain. Therefore it becomes difficult to put results for several species together so as to obtain an overall graphical summary of species-environment relationships. A simple method is thus needed to analyse and visualise the relationships between many species and many environmental variables. Canonical correspondence analysis (CCA) is designed to fulfil this need. Guisan *et al*. (1999) compared the predictive power of GLM with that of CCA modelling. They showed that although GLM models gave better species specific models, CCA provided a better overview of multiple species diversity and plant communities.

Canonical Correspondence Analysis

CCA is an eigenvector ordination technique that produces a multivariate direct gradient analysis (Ter Braak 1986). CCA aims to visualise a pattern of community variation, as in standard ordination, and also to visualise the main features of species' distributions along the environmental variables. In other words, it detects the pattern of variation in community composition that can be explained best by environmental variables. The rationale of the technique is derived from a species packing model wherein species are assumed to have Gaussian (bell-shaped) response surfaces with respect to compound environmental gradients. These gradients are assumed to be linear combinations of the environmental variables.

- **Theory of CCA**

Suppose a survey of n sites lists the abundances or occurrences (presence scored as 1, absence as 0) of m species and the values of q environmental variables ($q < n$). Let y_{ik} be the abundance or presence /absence (1/0) of species k ($y_{ik} > 0$), and z_{ij} the value of the environmental variable j at site i.

The first step in indirect gradient analysis is to summarise the main variation in the species data by ordination (Eq 1)

$$E(y_{ik}) = c_k \exp[(\tfrac{1}{2}x_i - u_k)^2/t_k^2] \qquad (1)$$

Where $E(y_{ik})$ denotes the expected (average) value of y_{ik} at site i that has score x_i on the ordination axis. The parameters for species k are c_k, the maximum of that species response curve; u_k, the mode or optimum and t_k, the tolerance, a measure of ecological amplitude.

The second step of indirect gradient analysis is to relate the ordination axis to the environmental variable (Eq 2).

$$x_i = b_o + \sum_{j=1}^{q} b_j \, z_{ij} \qquad (2)$$

CCA simultaneously estimates the species optima, the regression coefficients and hence the site scores using Eq. 1 in conjunction with Eq.2. Simultaneous estimation turns the technique into a direct gradient analysis method. CCA uses the following iteration algorithm of reciprocal averaging and multiple regression to investigate the species-environment correlation.

Step 1) Start with arbitrary, but equal, initial site scores.

Step 2) Calculate species scores by weighted averaging of the site scores (Eq. 3).

$$\lambda U_k = \sum_{i=1}^{n} y_{ik} x_i / y_{+k} \qquad (3)$$

Step 3) Calculate new site scores by weighted averaging of the species scores (Eq. 4).

$$x_i^* = \sum_{k=1}^{m} y_{ik} u_k / y_{i+} \qquad (4)$$

Step 4) Obtain regression coefficients by weighted multiple regression of the site scores on the environmental variables (Eq. 5). The weights are the site totals (y_{i+}).

$$b = (Z'RZ)^{-1} Z'Rx^* \qquad (5)$$

Step 5) Calculate new site scores by Eq.6 or equivalently, Eq.2. The new site scores are in fact the fitted values of the regression of the previous step.

$$x = Zb \qquad (6)$$

[where y_{+k} and y_{i+} are species and site total, respectively, R is a diagonal n x n matrix with y_{i+} as the (i, i)-th element ; Z = {Z_{ij}} is an n x (q + 1) matrix containing the environmental data and a column of ones and b, x and x^* are column-vectors: $b = (b_o, b_i, \ldots, b_q)'$, $x = (x_i, \ldots, x_n)'$, and $x^* = (x_i^*, \ldots, x_n^*)'$.]

Step 6) Centre and standardise the site scores to zero mean.

Step 7) Stop on convergence, i.e. when the new site scores are sufficiently close to the site scores of the previous iteration; otherwise go back to step 2.

This procedure is similar to the reciprocal averaging algorithm of correspondence analysis, but steps 4 and 5 are additional. The final regression coefficients will be called canonical coefficients and the multiple correlation coefficient of the final regression will be called the species-environment correlation. The species-environment correlation is a measure of how well the extracted variation in community composition can be explained by the environmental variables and is equal to the correlation between the site scores $\{x_i^*\}$, which are weighted mean species scores (calculated by Eq.4), and the site scores $\{x_i\}$, which are a linear combination of the environmental variables (calculated by Eq. 2 or Eq.6). Second and additional axes can be extracted as in correspondence analysis by adding a step to the algorithm after step 5, that makes the trial site scores uncorrelated with the previous axes (Ter Braak 1987). For interpreting the ordination axes one can use the canonical coefficients and the interset correlations. The canonical coefficients define the ordination axes as linear combinations of the environmental variables, and the interset correlations are the correlation coefficients between the environmental variables and these ordination axes (Ter Braak 1988). Both relate to the rate of change in community composition per unit change in the corresponding environmental variable.

Model validation

Validation can be described as a process that results in an explicit statement about the behaviour of a model. Validation is a demonstration that a model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model (Rykiel 1996). Validation indicates that the model is acceptable for use, not that it embodies any absolute truth. The process involves a comparison of simulated data with data obtained by observation and measurement of the real system. Validation demonstrates that a model meets some specified performance standard under specified conditions. That is, a model is declared validated within a specific context, which is an integral part of certification.

Ecological literature however reveals considerable confusion about the process of validation. For example, validation is sometimes considered essential and sometimes considered impossible. Some authors suggest that models can be validated (Kirchner *et al*.1996), while others contend that models can only be invalidated (Law and Kelton 1991). Universally applicable test procedures are difficult to prescribe, given the diversity of modelling approaches and the many uses for models. Because of these conflicting ideas, some modellers are prompted to avoid using the terms verification and validation. Mankin *et al*. (1977) suggested that the problems surrounding the terms of valid and realistic could be overcome by using the concept of model usefulness, where a useful model simulates all (or at least some) of the system behaviour needed to solve a specific research problem. By definition models represent only a portion of system behaviour; there will always be system behaviour that is not included in the model and there will always be unrealistic model behaviour (Cale *et al*. 1983). The concept of model usefulness permits redefinition of the validation problem in terms of a domain of applicability, that is the range of conditions for which the model simulates system behaviour. The term implies that there are some conditions for which the model is useful and others for which it is useless. The critical information is whether a model's domain of applicability is adequate for the task at hand.

In order for an ecological model to be desirable it must be applicable over a range of specific problems, and produce few nonsense results over the range of conditions expressed. A desirable model must have both algebraic formulation, which follows ecological principles, and parameters that can be defined ecologically and measured directly. It must have been tested to estimate its parameters and finally a desirable model must treat the common properties of ecological phenomena rather than the special properties of a specific case (Cale *et al*. 1983). That is, the model is more likely to be desirable if the class of phenomena covered by the model is more general.

The value of models can be expressed in reduced cost and effort in collecting samples. Ecosystem science may not be ready to claim that models are completely valid over all possible circumstances (Kirchner *et al*. 1996), but models that have adequacies over 50% can be successfully incorporated into research programs (Cale *et al*. 1983). Improving ecosystem models will require setting higher standards for model testing and evaluation. It must however be remembered that a model's usefulness extends to providing insights into the effects of a particular defined set of circumstances, with the result that a model's prediction may not necessarily be a true reflection of a contemporary state, owing to a different set of circumstances being present. This phenomena needs consideration when testing model adequacy.

5.1.2 The vegetation model for the mid-Fish River Valley

The structure and floristic composition of the rangelands in the mid-Fish River Valley is claimed to have been altered owing to pastoral practice. However, it is one thing to claim that the vegetation has changed but quite another to produce data and analyses that show this unequivocally. In order to modify the contemporary vegetation towards a preferred or initial state, this state must be determined before treatments can be applied to the vegetation. By comparing a model of the potential or expected vegetation with that of the contemporary vegetation, areas that deviate from expectation can be identified and the management policies of such areas investigated. The determination of a preferred state may be achieved through the process of gradient modelling.

Elevation is an indirect environmental factor (Austin 1980), which influences plant growth through correlated changes in direct variables and can be partitioned into several direct environmental factors (Austin *et al*. 1984). These factors change with latitude and longitude, resulting in latitudinal factors being location specific (Austin *et al*. 1983). If latitude and altitude are kept within strict limits, it provides a valuable opportunity for testing the effects of changing other environmental factors (Palmer 1991).

Rainfall, which has an effect on plant distribution, is a direct environmental gradient (Austin 1980) and can be measured using median annual rainfall (MAR). This is a better measure of rainfall than the more conventional mean (Palmer 1991), as it provides an index of aridity in semi-arid areas, and has been used successfully in direct gradient analysis (Austin and Cunningham 1981). The relationship between plant communities and precipitation has traditionally been difficult to model. This is because sample sites are seldom near rainfall recording stations, resulting in precipitation data not being available. However, with the development of interpolated rainfall models (Dent *et al*. 1989) and the associated digital elevation models there is now a basis for associating total floristic samples with rainfall and elevation (Palmer 1991).

Much of the environmental variability controlling vegetation patterns in the mid-Fish River Valley may be attributed to topographical factors and their influence on climate. The differences in plant composition and relative abundance in this area can be explained by two major environmental factors: elevation and rainfall (Evans *et al*. 1997). The use of elevation and moisture gradients is an effective means by which to create models of predictive vegetation distribution (Palmer and Van Staden 1992).

The majority of the vegetation modelling procedures in the literature involve a form of regression analysis. Generalised linear modelling has proved to be a popular method to provide a means of predicting distributions along gradients (van Etten 1999, van de Rijt *et al*. 1996, Brown 1994, Osborne and Tigar 1992, Parker 1991 and Austin *et al*. 1983). This modelling procedure generally first involves the classification of the vegetation data followed by the ordination of the data to identify dominant environmental variables. The integration of the classification results with the ordination results, to describe probability of occurrence, is achieved through Generalised linear modelling. The method proposed for the development of a predictive vegetation model for the mid-Fish River Valley is a more direct approach in that the scores generated by the CCA are used to weight the environmental variables according to their importance of influencing the distribution of the vegetation, thereby describing the predictive distribution of the vegetation along the environmental gradient.

The objective of this chapter therefore was to develop a predictive vegetation model for the mid-Fish River Valley using a direct gradient analysis approach in order to detect areas that have undergone changes in species composition and productivity. As there is currently much debate over the sustainability and productiveness of communal rangelands, a predictive vegetation model could provide a useful means by which to identify areas within the communal rangelands that are currently in a state that is better than predicted. If such areas exist, it may provide proof that natural rangelands can be utilised by communal management without detrimental effects. Intensive research can then be carried out within these areas to ascertain why they are less degraded than surrounding areas, thus enhancing our knowledge of communal rangeland systems.

5.2 Methods

5.2.1 Modelling procedure

To produce a model of expected or potential vegetation, two sources of information were used. Firstly, the environmental elements potentially important for plant distribution were obtained from overlaying relevé site maps to surface response models using the Geographical Information System GRASS 4.0. (USA-CERL 1991) and a GPS (Global Positioning System) reading for each site. These values were used to represent the environmental variables. Secondly, the regression/canonical coefficients obtained from the CCA were used as a means to weight the importance of a specific environmental variable in determining the plant community distribution.

For each relevé site recorded, a Z score was calculated to enable allocation of the plant communities described for the study area into a range of values. These values were then used to predict the location of the community on a prepared Z surface. The Z scores were calculated as follows:

$$Z = [(X_a \text{ x } Y_a) + (X_e \text{ x } Y_e) + (X_r \text{ x } Y_r) + (X_s \text{ x } Y_s)] \text{ x } E$$

Where X represents the value derived from the surface response model for each relevé, for the four environmental variables, namely aspect (a), elevation (e), rainfall (r) and slope (s), and Y represents the regression/canonical coefficient for each of the environmental variables. E, which is a constant, is the eigenvalue score for axis one. The eigenvalues produced by CCA measures the distribution of species along an environmental gradient.

Once the Z scores were allocated to each relevé, a range per community could be determined. The range for a particular community was established by determining which community had the highest number of occurrences within a certain range. These ranges therefore depicted where that community’s highest probability of occurrence was within the Z surface.

The Z surface was prepared in IDRISI (Eastman 1990) by multiplying the pixels in each of the environmental surface images by the constant for the variable (Y). These environmental surface maps were then overlayed to produce a Z surface for each of the three land-use classes. Using the RECLASS procedure in IDRISI, the plant communities present were defined within the image of each land-use class. The three land-use class images were then overlayed in IDRISI to provide a map of the predicted vegetation of the mid-Fish River Valley for the three zones of land-use management (Figure 5.2.1)

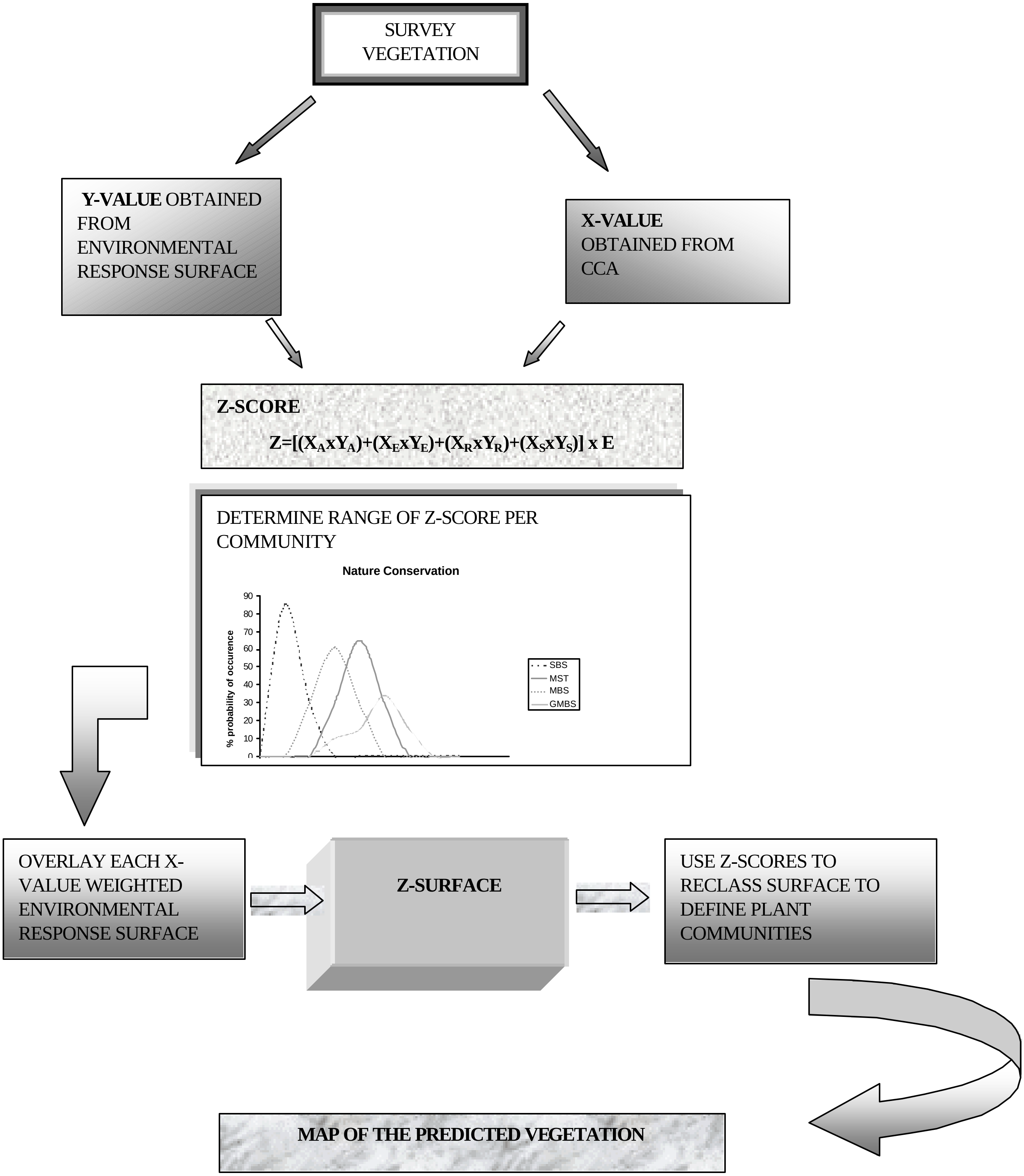


Figure 5.2.1: Flow diagram showing the steps for building the map of the predicted vegetation

5.2.2 Contemporary Vegetation Map

A map of the contemporary vegetation for the mid-Fish River Valley was prepared by Tanser (1997). This map was produced using remote sensing techniques. Spectral bands 3, 4 and 5 were obtained from the satellite image for the study area and were geo-referenced in GRASS version 4.1. Tanser (1997) performed an unsurpervised classification using these spectral bands to produce classes for the area. Where classes were too broad and contained more than one class, or where it was necessary to delineate a small vegetation class, a surpervised classification was performed. Tanser (1997) produced a map showing ten vegetation classes. Where necessary classes were combined using the RECLASS module in IDRISI to reflect the six vegetation communities described in this study. An error matrix was prepared as a means of assessing the classification accuracy. The vegetation samples collected for the vegetation survey were used as reference points in the error matrix table. To further interpret classification accuracy, the k (KHAT) statistic (Aronoff 1985) was used as a measure of the difference between the actual agreement of the sample data and the contemporary vegetation map, and the chance agreement between the two sets of data. The k statistic was calculated as follows:

$$k = \frac{N \sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} (x_{i+} . x_{+i})}{N2 - \sum_{i=1}^{r} (x_{i+} . x_{+i})}$$

This statistic serves as an indicator of the extent to which the percentage of correct values of an error matrix are due to true agreement versus chance agreement. As true agreement approaches 1 and chance agreement approaches 0, k approaches 1. In cases where chance agreement is large, k can take on negative values, which is an indication of a very poor classification performance.

The contemporary vegetation map and the predictive vegetation map were compared using the OVERLAY module in IDRISI. The areas of correct classification (where the vegetation community in the prediction matched the vegetation community in the contemporary vegetation map) and areas of misclassification were identified. The areas of misclassification were divided up into areas of over-prediction and areas of under-prediction. Areas of over-prediction were defined as those areas where the vegetation on the contemporary vegetation map was in a more degraded state than what was predicted on the map of expected vegetation. Areas of under-prediction were defined as areas where the contemporary map showed the vegetation to be in a better state than what was predicted.

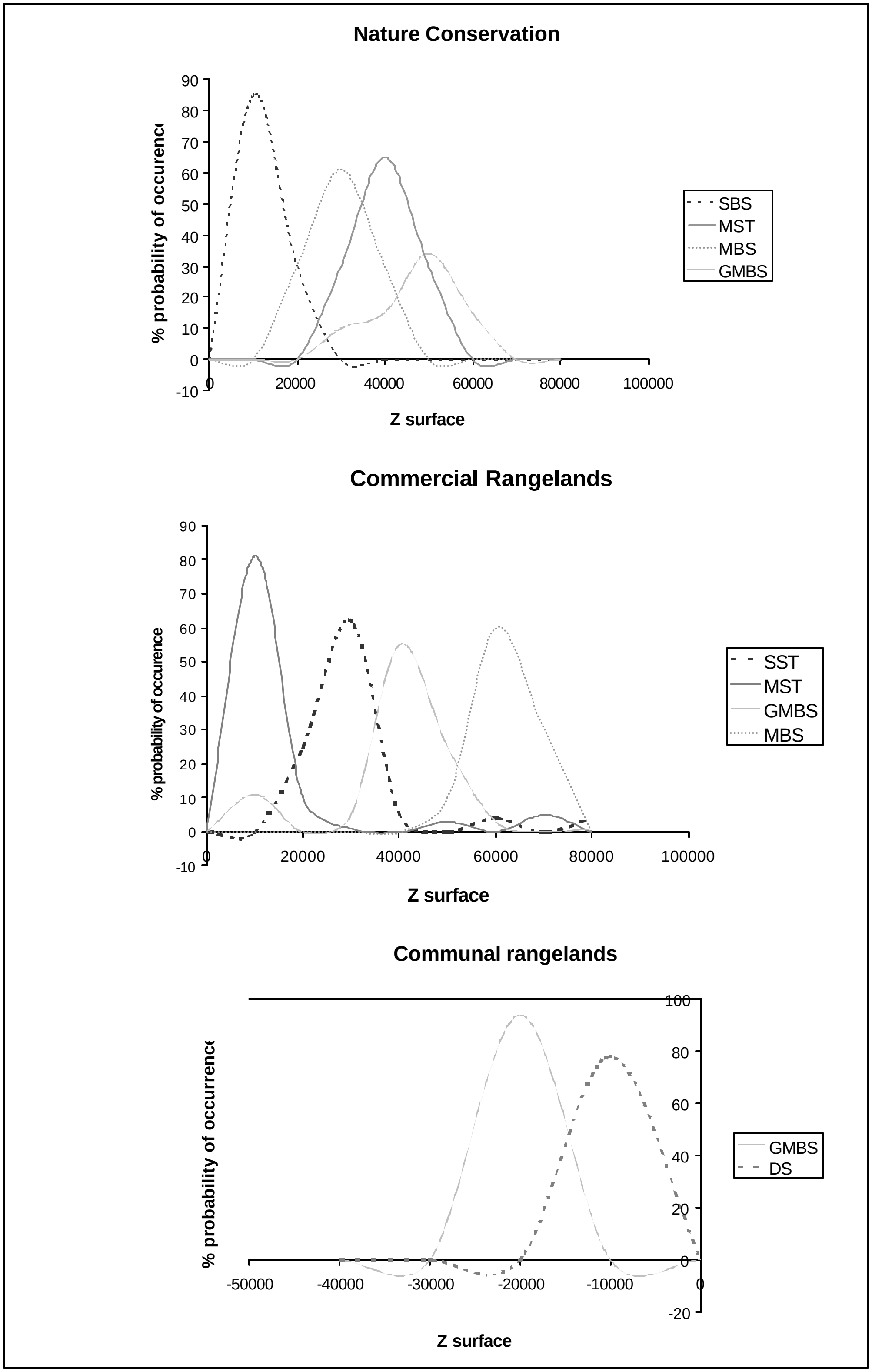
5.3 Results

5.3.1 The predictive vegetation model

The predictive vegetation map is shown in digital form in Figure 5.3.1. The area within the boundaries of the study site where no colour is shown indicates regions of high overlap between the communities, that is, an area where two or more communities occur with equal probability. A prediction was not made for such an area and therefore no colour (indicating a community) has been placed in those regions. Figure 5.3.2 is the topographical moisture classes present in the mid-Fish River Valley, that have been reclassified to represent the three main categories, namely low elevation and rainfall, medium elevation and rainfall and high elevation and rainfall. The MBS community is predicted to occur on the high lying areas that receive a higher rainfall, while the MST and SST communities are restricted mostly to the lower elevation and rainfall areas. The GMBS community occurs mainly within the medium elevation and rainfall regions, although it is also present in the lower elevation and rainfall area. The community SBS is predicted to occur in two patches, in medium to lower elevation and rainfall regions. The DS community is restricted to the lower elevation and rainfall areas. The percentage probability of occurrence for the various communities differed quite substantially within the land-use classes, resulting in certain communities being predicted with a higher degree of confidence than other communities (Figure 5.3.3). Although the four environmental variables accounted for a large percentage of variation in the vegetation (87%), other variables, such as the grazing gradient, are affecting the distribution of these communities and are consequently resulting in the communities occurring with a greater overlap of ranges.

Within the nature conservation areas the GMBS community occurs with a high degree of overlap with the MST community (Figure 5.3.3). The prediction probability for GMBS under nature conservation was the lowest for all vegetation communities occurring in the mid-Fish River Valley. It is therefore the only community that is not adequately presented in this model. The reason for not accurately predicting the occurrence of this vegetation type is largely due to the fact that the presence of the GMBS community is usually a result of increased grazing pressure, thus increasing the difficulty of predicting the occurrence of this community, as its presence is not solely dictated by the environmental variables.

Overall the percentage probability of correctly predicting the occurrence of communities was slightly higher for the commercial rangelands than for the nature conservation areas (65% and 61% respectively). The commercial rangelands displayed a more distinct separation of ranges per community within the Z surface, thus resulting in an increase in the predictive probability for this land-use class. Under communal management the predictive vegetation map displays only two vegetation types, namely Dwarf Shrubland, which may be classified as severely degraded (where the production potential is low and there is little chance of recovery), and the Grasslands of the Mesic Bushclump Savanna, which may be classified as moderately degraded (where the production potential is significantly reduced but potential for improvement exists). The DS communities were predicted mainly for the lower elevation, lower rainfall areas that are less productive than the higher elevation, higher rainfall areas. For the higher elevation, higher rainfall areas GMBS communities were predicted (figure 5.3.1). Since the higher elevation, higher rainfall areas have a greater productivity than the lower elevation, lower rainfall sites, they are better able to cope with the heavy utilisation pressure and consequently are in a less degraded state. The two communities displayed distinct separation, with GMBS showing 94% probability of occurrence within its Z score range and the DS community showing a percentage probability of occurrence of 78% (Figure 5.3.3).


Nature Conservation

Commercial Rangelands

Communal rangelands

Figure 5.3.3: The predicted probability of occurrence within the ranges of the prepared Z surface for the three land-use classes of the mid-Fish River Valley.

5.3.2 The contemporary vegetation map

The contemporary vegetation map for the mid-Fish River Valley is shown in Figure 5.3.4. One of the most common methods of expressing classification accuracy is the preparation of a classification error matrix (Table 5.3.1). Several characteristics about classification performance are expressed by using an error matrix. These include the errors of omission (exclusion) and commission (inclusion), the overall accuracy and the producer's and user's accuracy as well as the *k* statistic.

Vegetation survey classification	**Spectral classification**						
	MST	MBS	GMBS	SST	SBS	DS	Row total
MST	82	0	0	1	0	1	84
MBS	0	55	5	0	0	1	61
GMBS	2	5	76	0	1	1	85
SST	1	1	0	12	0	0	14
SBS	2	0	0	0	10	6	18
DS	2	0	1	0	0	21	24
Column total	89	61	82	13	11	30	286

Producer's Accuracy	**User's Accuracy**
MST = 82/84 = 98%	MST = 82/89 = 92%
MBS = 55/61 = 90%	MBS = 55/61 = 90%
GMBS = 76/85 = 89%	GMBS = 76/82 = 93%
SST = 12/14 = 86%	SST = 12/13 = 92%
SBS = 10/18 = 56%	SBS = 10/11 = 91%
DS = 21/24 = 88%	DS = 21/30 = 70%
Overall accuracy = 90%	**k** = 0.86

Table 5.3.1: Error matrix classification table for the mid-Fish River Valley contemporary vegetation map, to express the classification accuracy of the six plant communities shown in the map.

The error matrix indicates that 98 percent of the MST areas were correctly identified as MST (producer's accuracy) and 92 percent of the areas identified within this classification are truly of this category (user's accuracy). In other words, MST is a highly reliable category associated with this classification from both a producer's and user's perspective. MST displayed an omission error of 2 samples (2%) and a commission error of 7 samples (8%). All the communities except SBS displayed reliable classification categories for both user's and producer's accuracy (above 85%). SBS displayed only a 56% producer's accuracy, that is, it had an omission error of 44% (8 samples were incorrectly classified as other vegetation communities). However this community showed a high user's accuracy (91%) as only one sample was incorrectly included into the community of SBS (commission error). This indicates that from a user's perspective there is a high reliability that the SBS community will be identified correctly but from a producer's perspective the classification of this community is unreliable. That is, 56% of the time SBS will be classified as SBS, while 91% of the time an area visited on the ground classified as SBS will actually be SBS. The overall accuracy of the contemporary vegetation map was high (90%) and the *k* statistic was also high (0.86), indicting good overall classification performance for the contemporary vegetation map.

5.3.3 Deviations from expectation

A comparison of the contemporary vegetation map and the predictive vegetation map reveals a large portion of the vegetation that differs from expectation. Figure 5.3.5 reflects a comparison between the predicted vegetation map and the contemporary vegetation map by indicating areas where the prediction and the contemporary vegetation maps agree and areas where deviations have occurred.

Within the communal rangelands the model predicts a large area as DS. The contemporary vegetation map however shows that within this area MST, SST, GMBS and MBS communities are all present, indicating that the extent of the degraded DS community is not as great as expected. However, there are areas within this land-use class that are in a worse condition than what was predicted. There were some areas where the model predicted GMBS community to occur, but the contemporary vegetation map shows the presence of the DS community, indicating that certain higher productive areas within the communal rangelands are more degraded than expected and these areas need to be monitored closely to determine the reason for the degradation.

The communal rangelands were not the only land-use class to display deviations from expectation; both the commercial rangelands and the nature conservation areas displayed regions of over and under predictions. Within the commercial rangelands the northern sections of the model shows a large area of over prediction. For this area the predictive vegetation model shows that MST, MBS and small patches of SBS should be present. However, the contemporary vegetation map shows that although the MST and the MBS communities are present, they cover a smaller area, and other communities such as DS and GMBS constitute the rest of the vegetation cover. SBS community was absent from this area in the contemporary vegetation map. The southern section of the commercial rangelands displays areas of under prediction; here the model has predicted the presence of GMBS but the contemporary vegetation map reveals the presence of MST instead of grassland. Under nature conservation, areas of under prediction are as a result of the model predicting the occurrence of GMBS, but the contemporary vegetation map shows MST and MBS communities. The model predicted MBS for some regions but the contemporary map shows DS and GMBS occurring within these regions, resulting in an over prediction within the nature conservation areas.

Certain areas of the contemporary vegetation map showed the presence of MBS when MST was predicted. This situation presents certain problems as it cannot be classified as either an under or an over prediction, since both vegetation types are considered original vegetation types i.e. not altered by grazing practices or described as degraded. A common practice of commercial farmers in the valley bushveld vegetation has been to bulldoze an area of dense thicket in order to increase the amount of grazing for their cattle. The bulldozing created strips of open grassland between patches of dense thicket. The spectral reflectances from this pattern of disturbed vegetation could be similar to those that were used to classify MBS. Therefore, although the vegetation may not be MBS, the patchiness of the bulldozed vegetation has resulted in the vegetation being interpreted as bushclump savanna.

5.4 Discussion

The controversy surrounding communal rangeland management stems from a lack of knowledge on communal grazing systems (Meyer *et al*. 1998). Studies on communal rangelands have revealed an array of results of the effects communal grazing is having on the vegetation. Shackelton *et al*. (1998) found that communal grazing systems failed to comply with conventional methods of assessing degradation and therefore there remains a great deal of uncertainty about the overall status of these rangelands and their sustainability. Questions remain as to whether all communal areas are severely degraded or if certain areas remain productive under this management scheme.

The results presented here suggest that the state of the vegetation in some areas is better than predicted, indicating that the spread of the DS is not as extensive as its potential distribution under communal land-use. However the occurrence of DS, which is a degraded vegetation type, in the other land-use areas is a cause for concern as it was only predicted for areas under very heavy utilisation pressure. This indicates that the management policies within the commercial rangelands in some areas are having an adverse effect on the vegetation and that the carrying capacity for such areas needs to be addressed. The presence of the DS community in the nature conservation areas is likely to be a result of the area once having been stocked with domestic livestock, thus giving insight into the low restoration potential of valley bushveld after sever overgrazing to revert to its natural state after disturbance. Only the GMBS community was predicted for the higher productivity areas within the communal rangelands, but the contemporary vegetation map shows the presence of DS within this region, denoting that those areas have a higher utilisation pressure than the surrounding high elevation and rainfall areas and are experiencing severe degradation.

This model provides an expected vegetation type under strict conditions; that under a particular management regime a fixed stocking rate is applied and a fixed composition of animals utilised. It presents a picture of “worse case” scenario for the communal areas by only taking into account the state of the vegetation under heavy utilisation pressure and projecting the consequences of this grazing pressure across the entire expanse of the communal rangelands, in so doing providing a means of comparing the expected state of the vegetation under communal management to the vegetation condition at present. The model thus provides a method by which land-use practices can be evaluated and their effects on the vegetation determined against a source of reference. If areas occur in a better state than expected, it provides evidence that the rangelands are in a better condition than what conventional thinking would anticipate. Such areas can then be investigated to identify reasons for this better state, such as possible local management differences. This model can also provide useful information on the density distributions of cattle, as areas with higher than expected cattle concentrations are more likely to be in a worse state than predicted.

Model Validation and Error Recognition

In reality, models are rarely valid or invalid, validity being defined as adequacy for a specific purpose, rather than as absolute truth in every respect (Rykiel 1996). Instead they are valid to varying degrees, in various ways, for various purposes. All models simplify reality and therefore are unrealistic to some degree (Kirchner *et al*. 1996). Most models are based on a predetermined set of assumptions and these assumptions need to be highlighted during interpretation in order to avoid misinterpretation. It is also important to identify possible sources of error to enable the usefulness of the model to be assessed.

For this model the underlying assumption is that within each land-use class the utilisation intensity is constant. That is, under nature conservation there is light selective grazing by wild herbivores, under commercial farming there is moderate utilisation pressure from domestic livestock, whilst under communal management there is heavy utilisation by domestic stock. This assumption is an over simplification of what is occurring in reality. There are differences in the utilisation pressure between landowners and even differences in utilisation pressure within one land-owner’s boundaries, i.e. it will differ from camp to camp. Within the communal areas the stocking density will differ according to the density of human settlements, with an increase in stock numbers around villages. However, for the purpose of this model it became necessary to consider each land-use class with a uniform utilisation pressure. This assumption however results in an over simplification of the predicted distribution of the communities, as areas that deviate from the predetermined stocking rate will not be highlighted within the prediction, but they will be identified when a comparison is made with a contemporary vegetation map. Therefore if one’s objective is to locate such areas, then the model proves to be valid under these conditions.

The modelling process produced communities with a high degree of overlap, this overlap occurs as the ends of the Z-score ranges of the different communities have not separately clearly causing two communities to occur within the same Z-score range. In order to further refine the distribution ranges, and increase the degree of confidence of a predicted more environmental variables are required. For example the occurrence of the community GMBS is a direct result of the grazing gradient, and its distribution is therefore not determined solely by the defined environmental variables but by utilisation pressure, both historically and currently. This can cause a decrease in the prediction accuracy for this community as not all the factors influencing its distribution have been incorporated into the model, thereby creating areas of misclassification and introducing a degree of error into the model.

Another source of error within this modelling technique is the use of the GPS. The magnitude of error in the collection of location data using a Global Positioning System (GPS) is a common source of debate in the remote sensing community (Tanser 1997). The GPS system is owned by the United States Department of Defence. The system comprises a constellation of 24 satellites that orbit the earth every 12 hours. Each satellite transmits two carrier signals termed L1 and L2 respectively. Modulated into the L1 signal are two pseudo-random binary code sequences known as the Coarse Acquisition (C/A) code and the precise (P) code. The C/A code is intended for civilian use and provides approximate measurements, whereas the P code is intended for military use and provides more precise measurements. The maximum error encountered using the C/A coding system has been demonstrated to be 44m from a known fixed point using a single GPS (Tanser 1997). An error of 44m can have a dramatic effect on the slope angle and aspect of a point, as well as the altitude reading. These errors can then be transferred into the model, which in turn causes errors to be recorded for a specific vegetation community, further reducing the reliability of correctly predicting its presence. In an attempt to reduce this error, a trigonometric beacon of known geographic position was visited frequently during the field survey to determine errors in the GPS reading. Although this method does help to reduce the error, it does not completely eliminate the problem. Incorrect GPS readings could result in misclassifications of communities with respect to environmental variables, ultimately decreasing the predictive capabilities of the model. All sources of error unfortunately influence the accuracy of the end product. Although it may not be feasible or practical, given current data collection and analysis limitations, to eliminate errors, identifying where and how the errors affect the model is a vital attribute in model validation.

Although the predictive vegetation model for the mid-Fish River Valley has limitation in its predictive capabilities, it achieved the original objective, which was to identify areas that deviate from expectation. The predictive probability of this model was above the 50% recommended by Kirchner *et al*. (1996) and can therefore be considered valid under its conditions of use. Whether or not the model will prove to be valid under a wider set of conditions must still be determined.

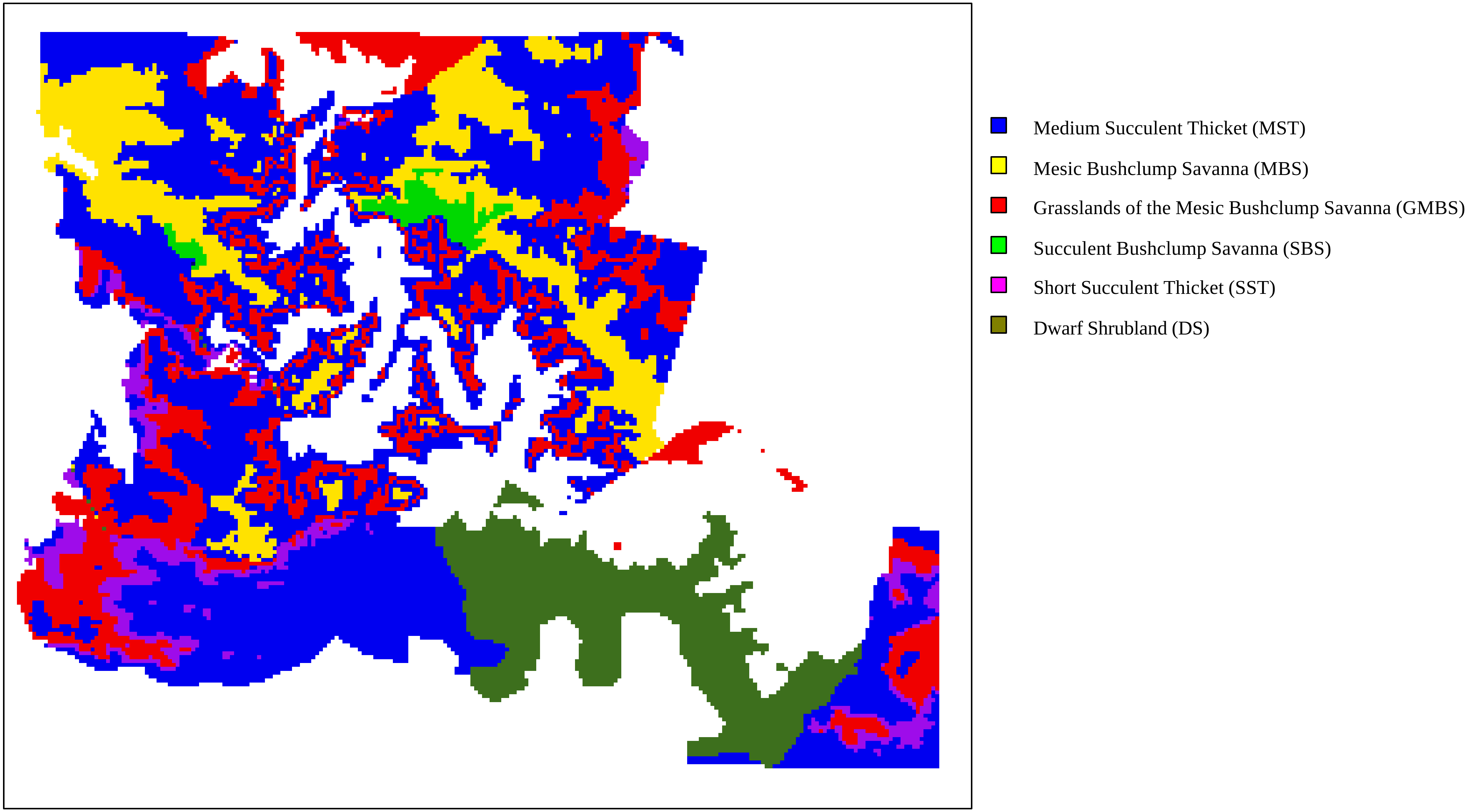


Figure 5.3.1 The expected plant community distribution, as predicted by the vegetation model for the mid-Fish River Valley.

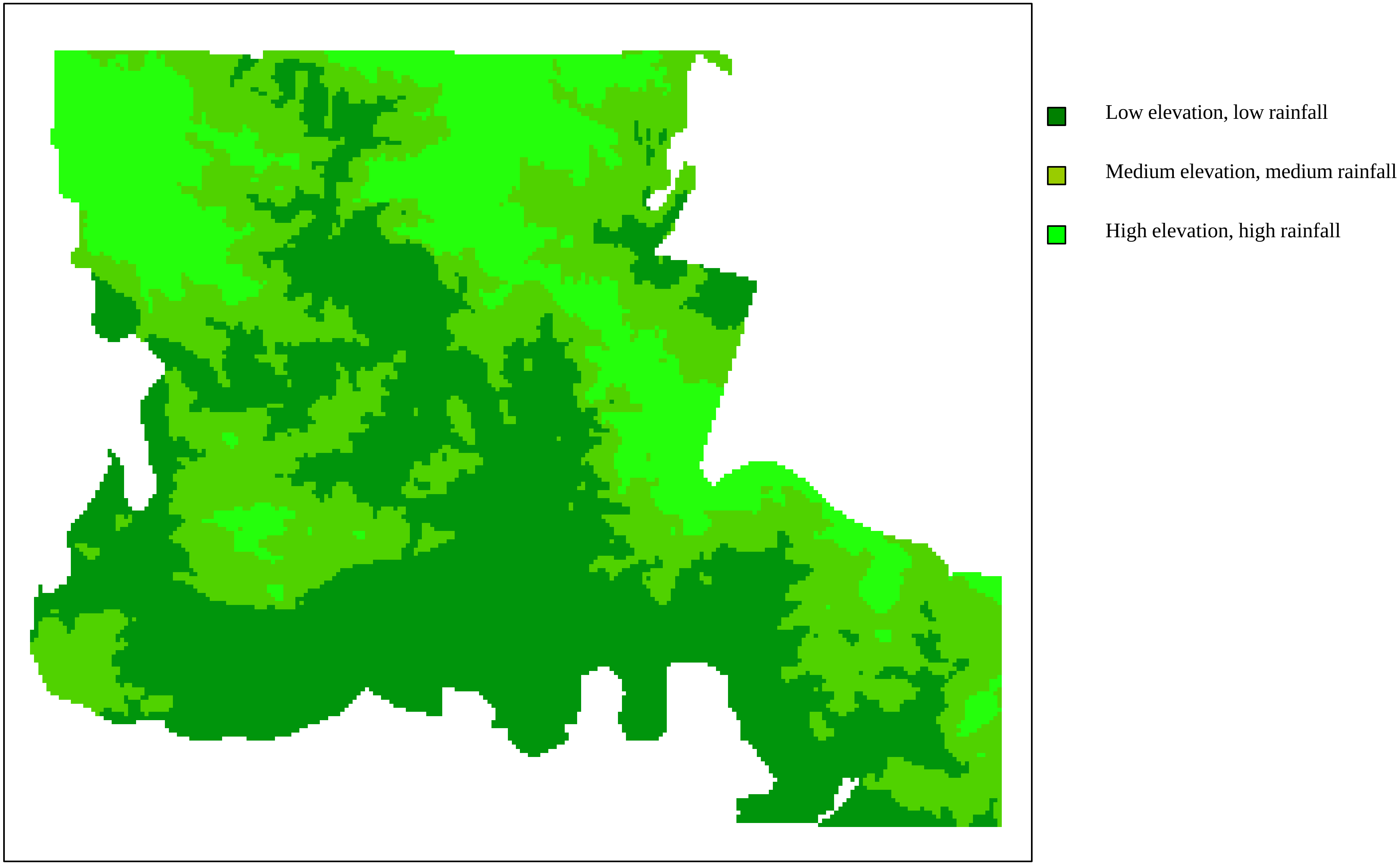


Figure 5.3.2 The distribution of the three principal topographical moisture classes present within the mid-Fish River valley

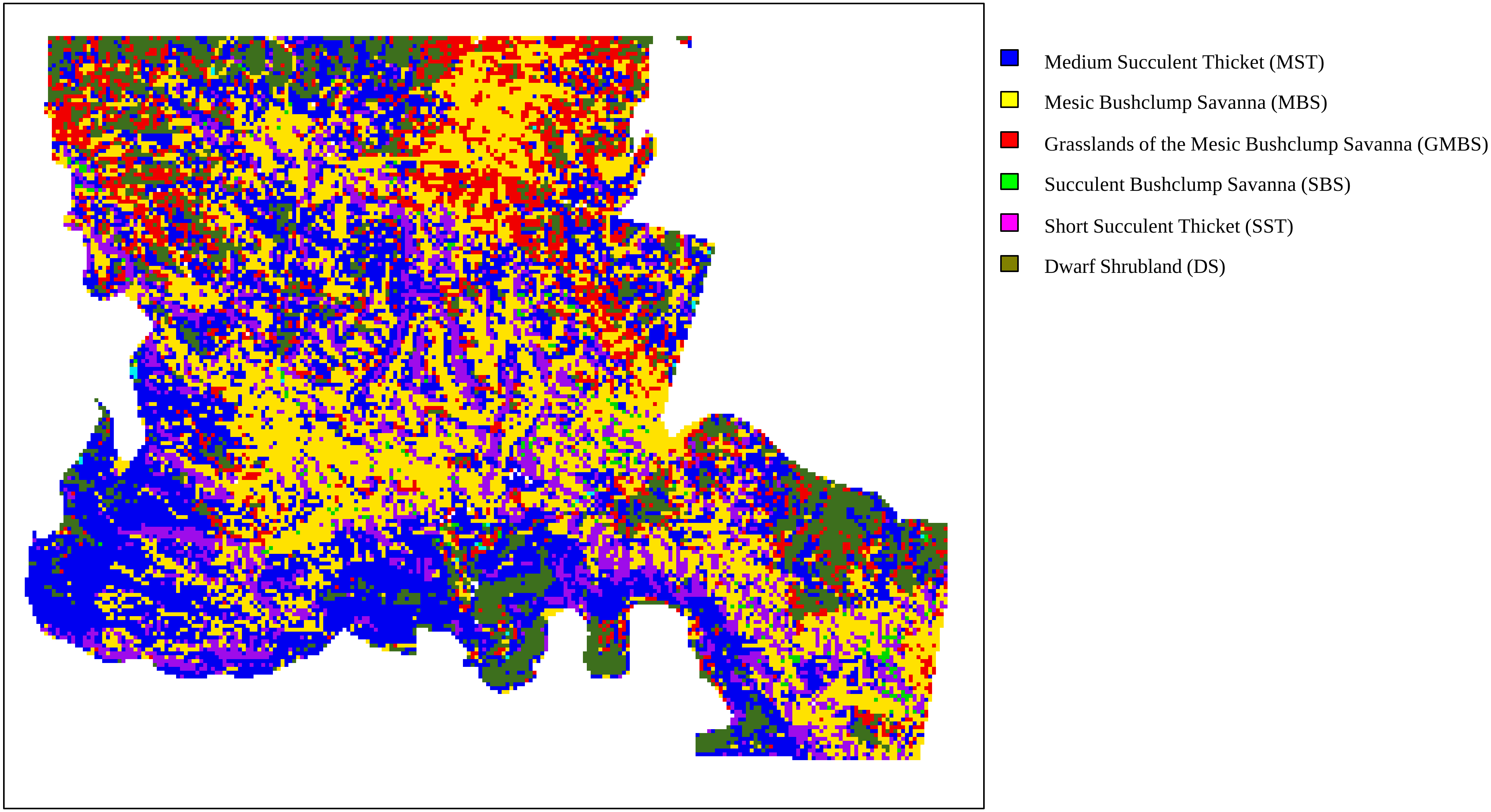


Figure 5.3.4 The contemporary vegetation distribution within the mid-Fish River Valley

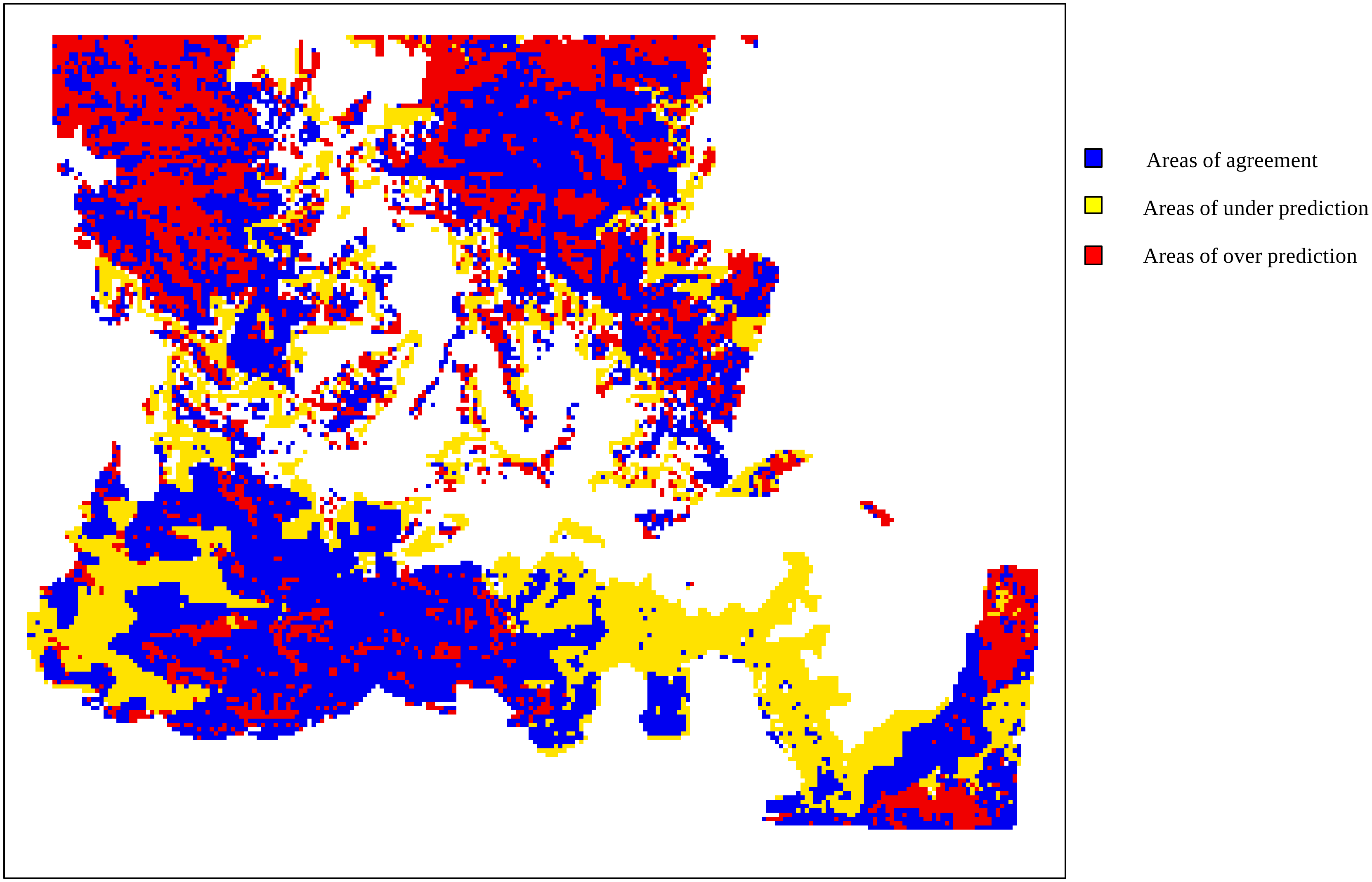


Figure 5.3.5 Areas of agreement and disagreement resulting from a comparison between the predicted vegetation and the contemporary vegetation of the mid-Fish River Valley.

CHAPTER 6

APPLICATION OF THE PREDICTIVE VEGETATION MODEL

6.1 Introduction

Vegetation classifications are commonly used to describe and improve the understanding of the variations in vegetation types present in an area (van Etten 1999). Accurate maps of vegetation units enable spatial extent and exact positions of vegetation units to be determined and this information can then be used to assess the conservation status and land management of an area. However, with time and financial constraints it is not always possible to conduct the detailed vegetation surveys required to obtain the necessary information in order to make sound management recommendations. It is under these circumstances that models are being increasingly used.

The value of a model therefore depends on its range of applications that translates into gaining knowledge into effective management systems (Parton 1999). The various means of applying a model depend on the users objective, that is, it may be necessary to extrapolate the model into many different areas or simply to use the model to examine the projected vegetation changes under an array of changing conditions, from a change in management policies to changes in $C0_2$ concentrations.

The objective of this chapter was to examine the application properties of the predictive vegetation model, formulated for the mid-Fish River Valley. To achieve this objective the model was assessed as a tool to examine changes in vegetation with a change in land-use practice. The model was then assessed in terms of its usefulness for predicting vegetation communities in other regions that have a similar topo-moisture classification to the mid-Fish River Valley.

6.2 Predicting vegetation changes under different land-use practices

6.2.1 Method

The Z surface prepared in IDRISI for each of the three land-use classes was used to prepare vegetation maps for the entire study area under a single land-use class. Using the RECLASS module in IDRISI, the Z surfaces were redefined to project only those communities described for a single land-use class, resulting in three separate maps, one for each land-use class.

6.2.2 Results & Discussion

Three potential vegetation maps were produced, one for each of the three land-use regimes within the study area. The predictive vegetation maps (Figure 6.2.1 – 6.2.3) show the likely distribution of the plant communities over the entire study area when placed under a single management scheme. The black area indicates regions of high overlap between the communities, that is, an area where any one of the communities could occur with an equal probability. Therefore a prediction is not made for such an area. The predictive vegetation maps show a change in the vegetation pattern according to the type of land-use. The vegetation distribution under nature conservation (Figure 6.2.1) reflects the topo-moisture gradient within the mid-Fish River Valley. The lower elevation, lower rainfall areas contain the MST community while the high elevation, high rainfall areas are vegetation by the MBS community. Under commercial management (Figure 6.2.2) there is a decrease in the distribution of the MBS. Some of the areas previously containing this vegetation type are now covered by the GMBS community, and hence GMBS community displays an increase in its distribution. The most noticeable change is however reflected in the predictive vegetation map of communal rangelands (Figure 6.2.3), where only two communities are present. The change in the plant communities show that under sustained, continuous grazing, the bush is opened up, which is reflected in the increased distribution of the grassland community. If the grazing pressure continues to increase, the common low shrubs are eventually replaced by karroid dwarf shrubs and herbs. This is evident by the presence of the Dwarf Shrubland (DS) community in the communal rangelands, where the grazing intensity is the greatest. Therefore the change is from a mesic thicket to a more open bush and grassland, which is finally degraded into a karroid shrubland.

The results shown by the predictive vegetation maps display the same pattern of grazing gradient and changes to the vegetation that the detailed vegetation survey revealed (Chapter 4). The advantage of this style of predictive vegetation map is that it provides a visual means of identifying potentially sensitive areas to proposed management policies. It gives an overview of the extent to which change can take place under certain management conditions.

6.2.3 Conclusion

The predictive vegetation model has been shown to be effective in predicting vegetation changes under different land-use practices, for the mid-Fish River Valley. This has important consequences for future land-use planning in this area as it provides a tool to explore the outcome of various forms of land management for the region.

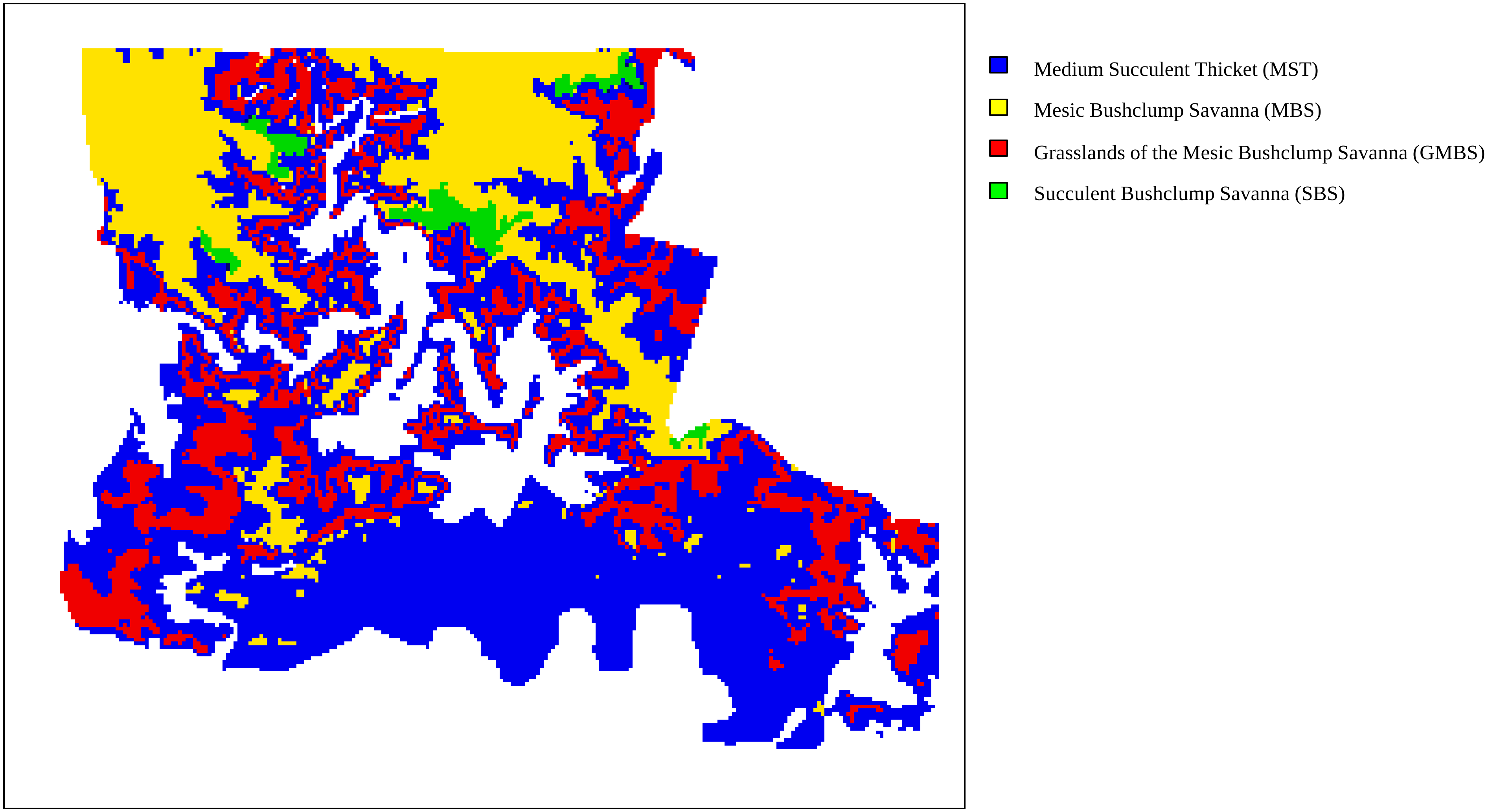


Figure 6.2.1 Predicted distribution of the vegetation communities under nature conservation within the mid-Fish River Valley

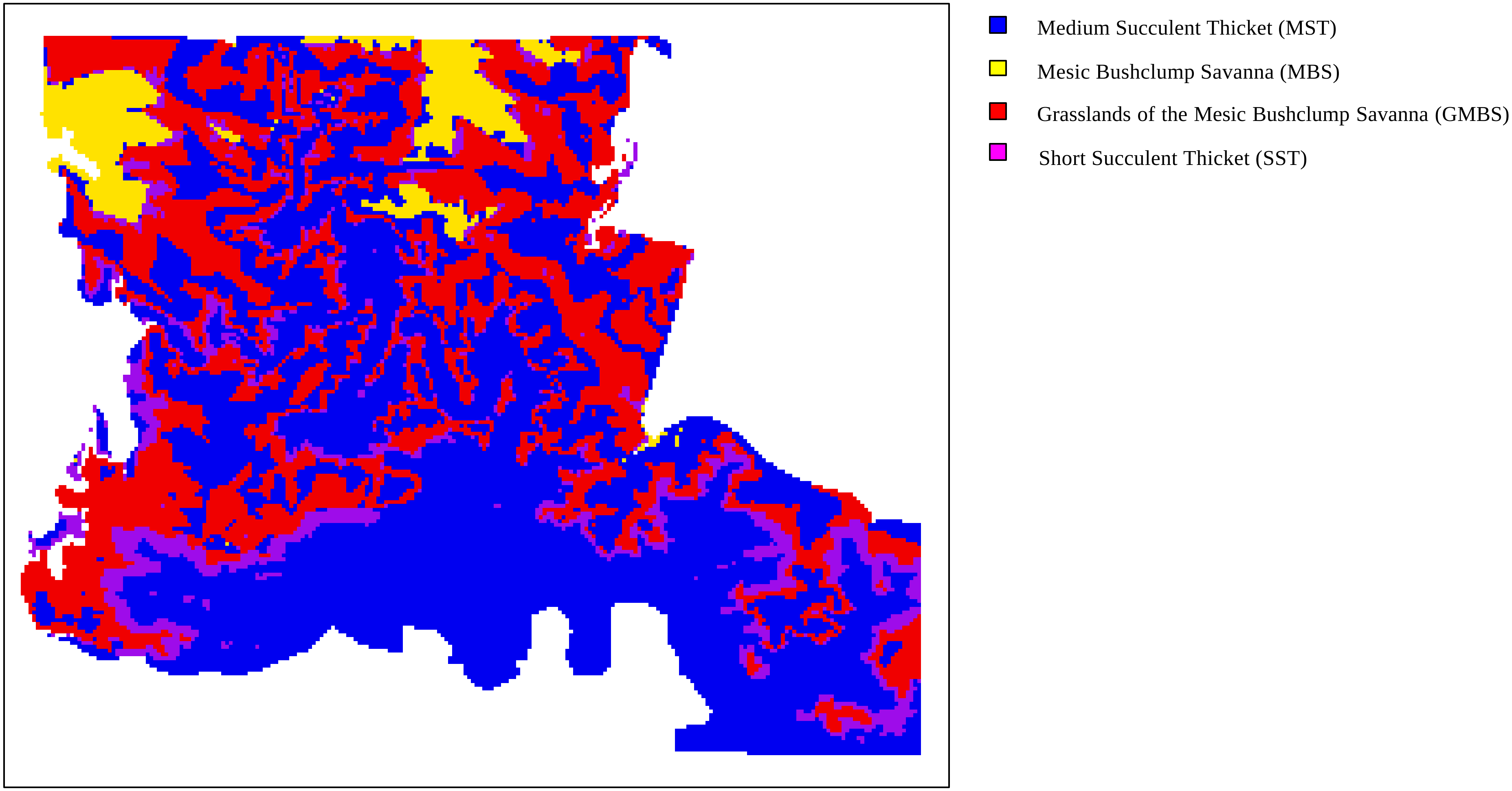


Figure 6.2.2 Predicted distribution of the vegetation communities under commercial management for the mid-Fish River Valley.

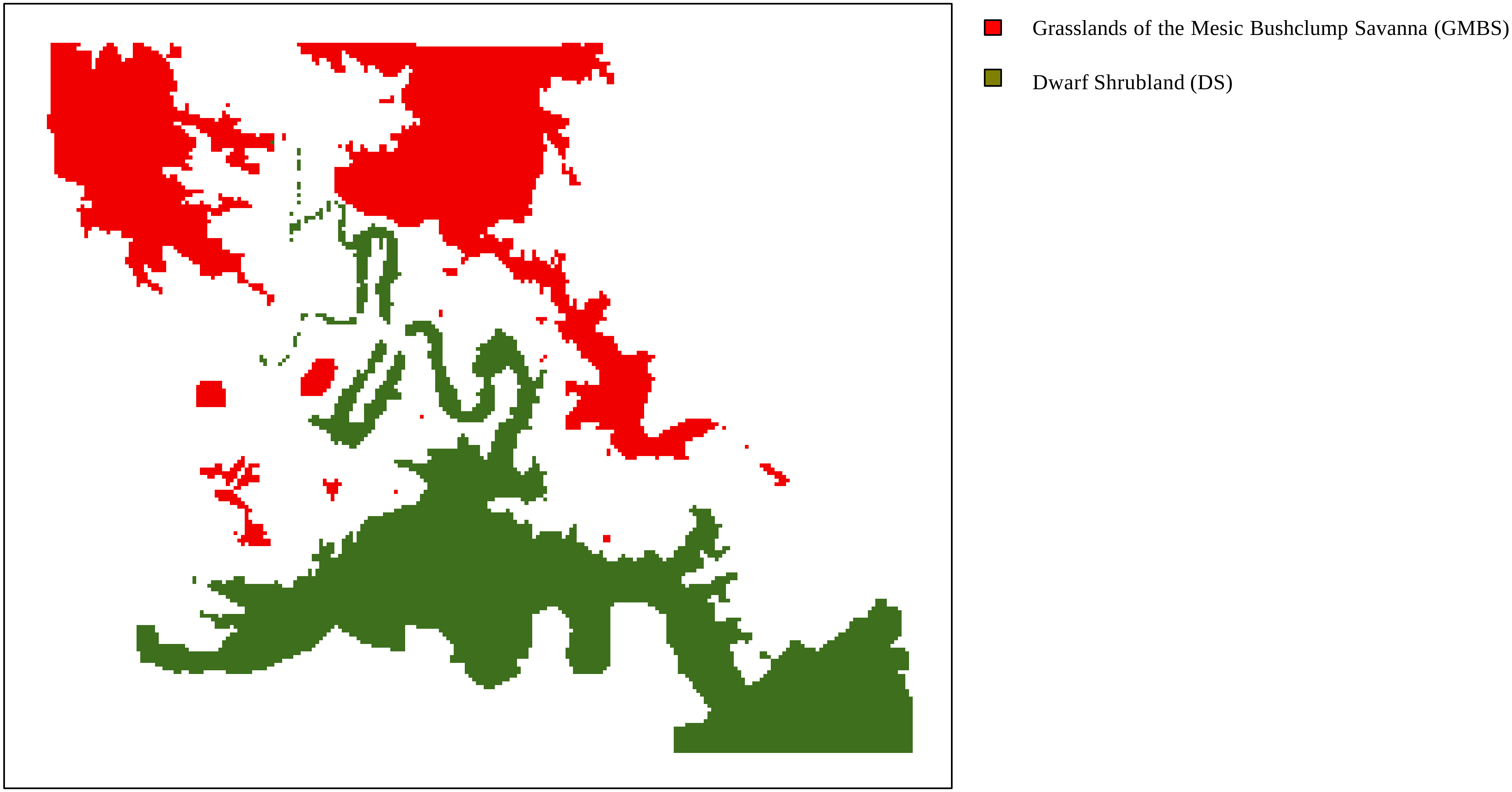


Figure 6.2.3 Predicted distribution of the vegetation communities under the communal rangeland system within the mid-Fish River Valley.

6.3 Predicted vegetation communities along the Kei River Valley according to land-use

6.3.1 Study area

The predictive vegetation model formulated for the mid-Fish River Valley is based on the strong topo-moisture gradient present in the area. Therefore, in order to extrapolate this model into another area, this area must display a similar topo-moisture gradient. The area of interest forms part of the Kei River Valley and extends from 31° 50’ S, 27° 30’ E to 32° 15 S, 28° 00’ E. The area has a similar range in topographic features to the mid-Fish River Valley, although the altitude and rainfall in this area is slightly higher than that of the mid-Fish River Valley. The altitude ranges from 141m asl to over 1000m asl on the ridges and the rainfall ranges from 410mm to 1000mm.

Acocks (1953) described the vegetation in this area as having both Northern and Southern variations of Valley Bushveld. He described the Northern variation as being far less thorny and more open than the Southern variation, with more grass, fewer succulents and more species of a tropical nature. Low and Rebelo (1995) categorise this vegetation type as Valley Thicket, which they describe as a very dense thicket of woody shrubs and trees which occur in the river valleys of the Eastern Cape extending to Kwazulu-Natal.

6.3.2 Method

To extrapolate the model of potential vegetation from the mid-Fish River Valley to the Kei River Valley, two sets of information were used. Firstly, a Z surface was prepared by overlaying surface response models for the area. Each surface image was weighted according to the importance of that environmental variable, as determined from the CCA run on the mid-Fish River Valley vegetation data. Secondly, the Z scores calculated for the original model were used as a means to determine the location of the communities on a prepared Z surface for the Kei River Valley. Using the RECLASS module in IDRISI, the plant communities present were defined within the image for the three land-use classes, namely nature conservation, commercial farming and communal rangeland management, thus producing maps of potential vegetation under three management options.

A digital form of Acocks’ vegetation map, which represents a classical vegetation survey, was used as a method to evaluate the predictive vegetation maps.

6.3.3 Results

Acocks' Vegetation Map:

The digital form of the Acocks' map (Figure 6.3.1) reveals three vegetation types, namely Valley Bushveld, False Thornveld and Dohne Sourveld, the distribution of which is clearly defined on the vegetation map. The Valley Bushveld, which is restricted to the steep river valley forms a dense thorny scrub. The False thornveld described by Acocks as invading the grasslands, ranges from grasslands thickly covered by *A. karroo* to patches where the vegetation forms a clumpy shrub bushveld. The Dohne sourveld as described by Acocks lies at altitudes between 600 –1350m asl and receives between 650 – 1000mm of rain per annum. Relics of forests and scrub forests can be found within this vegetation type resulting in a grassland with scattered tree species in certain areas.

Predictive Vegetation Map:

The predictive vegetation maps for the Kei River Valley under nature conservation (Figure 6.3.3) and commercial rangeland management (Figure 6.3.4) show a distinct separation of communities according to an elevation and rainfall gradient. This gradient is presented in Figure 6.3.2. The MST, SBS and SST communities are all restricted to the steep river valley, where the elevation ranges from 200 – 500m asl and the rainfall is between 300 – 400 mm. The MBS community and the GMBS community are found in the higher elevation and rainfall areas. The prediction under commercial management (Figure 6.3.5) shows a decrease in the spatial extent of the MBS community as the grasslands extend its distribution. Under communal management, the DS community is predicted to occur in the lower elevation and rainfall areas, previously vegetated by the thicket communities, indicating that under heavy utilisation pressure these communities are likely to undergo large changes in species composition and structure. The distribution of the GMBS community shows very little change in distribution with a change in management from commercial farming to communal rangeland management, thus denoting that the areas that receive a higher rainfall are more resistant to increased utilisation pressure.

Upon comparing the three predictive vegetation maps with that of Acocks' map, a problem is immediately evident, that being that the plant communities in the predicted vegetation maps differ from those described by Acocks. Extrapolating the model into other areas presents certain problems, as the vegetation communities predicted for the Kei River Valley are based on the analysis of the mid-Fish River Valley data, and this creates problems as the model does not account for differences between the vegetation of the two areas. This problem is manifested in different ways; firstly the direct comparison of the communities that differ in species composition, and secondly the response of the different communities to different management practices. The first problem of comparing communities that differ from those of the predicted vegetation model can be overcome to a certain extent by comparing the species and structural similarities between the communities. Once these have been matched, the communities can then be projected onto the model to evaluate the predicted distribution. If one examines the vegetation types closely, certain similarities between the communities described by Acocks and those of the predicted vegetation maps become evident. The communities MST, SST and SBS described for the mid-Fish River Valley fall into Acocks' veld type, Valley Bushveld, and can therefore be compared to the Valley Bushveld described for the Kei River Valley. The community MBS is comparable to a degree to the False Thornveld described in Acocks' map, as many of the species that occur in this community have been described to occur in the False Thornveld. However, a more noticeable point of comparison is the structural similarity, as Acocks described the False Thornveld as being a dense, clumpy shrub bushveld. The GMBS community and the Dohne sourveld are both grasslands that contain some tree and shrub species scattered throughout. Although the overall species composition differs, there are some species that are common to both vegetation types, and therefore one is able to extrapolate the distribution of the GMBS in the prediction to represent the distribution of the Dohne sourveld in Acocks' map.

The problem of superficially matching the communities, however, lies in the different communitie's responses to utilisation, for example, comparing MBS with False Thornveld. Within the mid-Fish River Valley, when the vegetation is subjected to increased utilisation, the bush is opened up, resulting in a more open grassland community. The scenario presented by the predictive vegetation model for the Kei River Valley shows an expansion of the grasslands with a change in management from nature conservation (Figure 6.3.3) to commercial farming (Figure 6.3.4). This is consistent with the management objectives for commercial farming, that is to increase the area of grazing available. Acocks, however, defined False Thornveld as invading the grasslands and therefore one would expect the extent of this community to increase with increasing grazing pressure. Under these circumstances it becomes necessary to investigate the management policies of the commercial farmers in the area, in order to validate the model's prediction. In other words, to confirm that the invasion of the thorn trees is being controlled under commercial management.

The predicted vegetation map under communal farming (Figure 6.3.5) shows the invasion of a karroid dwarf shrubland into the lower elevation and rainfall areas, suggesting that when placed under heavy utilisation pressure these areas would undergo a transformation into a more arid state, resulting in the formation of a karroid shrubland. Acocks himself predicted that this area under heavy utilisation would indeed consist of karroid vegetation, hence in this instance the model presents a testable prediction of change in the vegetation in response to land-use.

6.3.4 Discussion

The usefulness of extrapolating the predictive vegetation model to other areas of similar topo-moisture classifications depends on the user's objectives. That is, whether the intention of the extrapolation is to explore reasons into the distribution of certain vegetation types, or to look at the consequences of change in management policies of an area. The objectives need to be clearly defined before interpretation of the model takes place because the vegetation communities described for the model are very location specific and this can create problems when investigating the effect of changes of land-use, especially if the community cannot be positively identified. In cases where the topo-moisture gradient differs slightly from that of the base data used to create the model, the problem of differing plant communities becomes a realistic factor. If such a case does present itself, one needs to take this into consideration before determining the effectiveness of predicting the responses of the differing communities to land-use options. The results presented here display the amount of uncertainty that can occur when the plant communities in the prediction do not match those communities described for the area. The uncertainty in this case is that the community described in the prediction as MBS is a naturally occurring vegetation type in the mid-Fish River Valley, but has been extrapolated to represent an invasive vegetation type in the Kei River Valley. Owing to this discrepancy in identification, this vegetation type would need a certain amount of ground truth surveying to appraise its worth within the study area before the prediction can be interpreted and assessed. Therefore the model’s capacity to be extrapolated depends on the ability to match the communities in the prediction to those described for the area. The broader the classification of the communities in the baseline data set and closer the overlap of the topo-moisture gradient between the two areas, the easier the extrapolation of the model.

The predicted vegetation model does however highlight a striking feature of the Valley Bushveld in the Kei River Valley, that is the narrowness of its extent. Unlike the Valley Bushveld along the Fish River Valley, which has a greater expanse either side of the river, the bushveld along the Kei River Valley forms a very narrow belt. This narrow belt is a result of the rapid increase in elevation as one moves further from the river, in other words, the river valley rises over a very short distance to the ridge where the terrain is not as undulating as that of the mid-Fish River Valley. However, the altitude and rainfall on the ridge is higher in the Kei River Valley than that of the mid-Fish River Valley (over 1000m asl & 1000mm for the Kei River Valley but only 650m asl & 615mm for the Fish River Valley). These differences in elevation and rainfall result in the limited extent of the Valley Bushveld and the occurrence of the grasslands on the ridges of the Kei River Valley. Consequently this area takes on a very different appearance to that of the mid-Fish River Valley, and this difference in appearance is also reflected in Acocks’ map. The model therefore confirms that the limited extent of the Valley Bushveld is a result of the topographic features within the landscape and not a consequence of land-use.

6.3.5 <u>Conclusions</u>

The application of the predictive vegetation model is useful for predicting changes to vegetation communities in other areas of similar topographical-moisture gradients but it does have limitations. The accuracy by which it is able to predict changes in vegetation in response to land-use depends on the degree of similarity between the area under investigation and the area for which the model data was collected. If large differences occur, the reliability of the prediction decreases considerably, and under these circumstances further vegetation surveys of the area are required. However, the model can be used successfully to predict the occurrence of the valley thicket communities associated with the steep river valleys in the Eastern Cape.

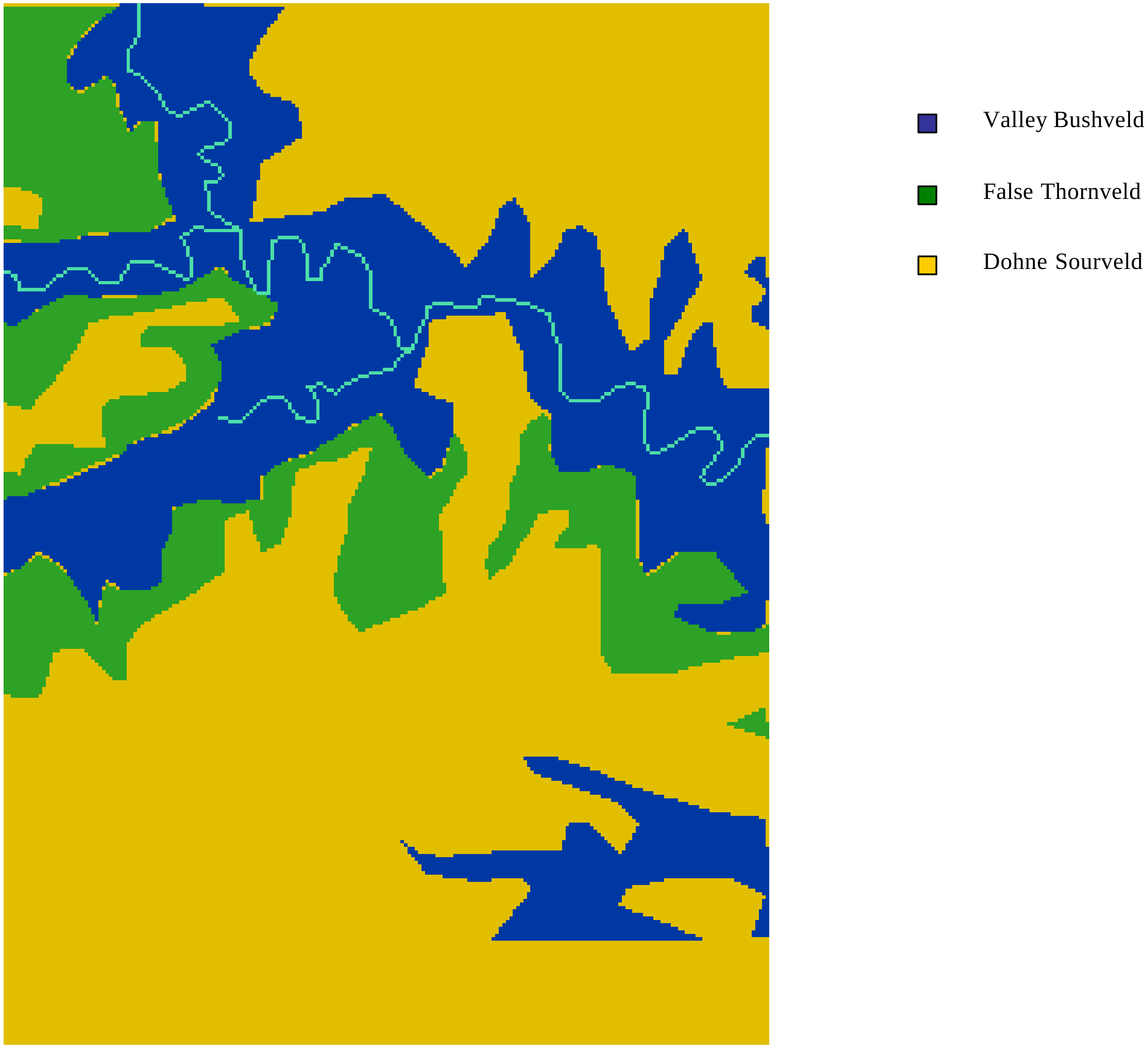


Figure 6.3.1 A digital form of Acocks'(1953) vegetation map for the Kei River Valley

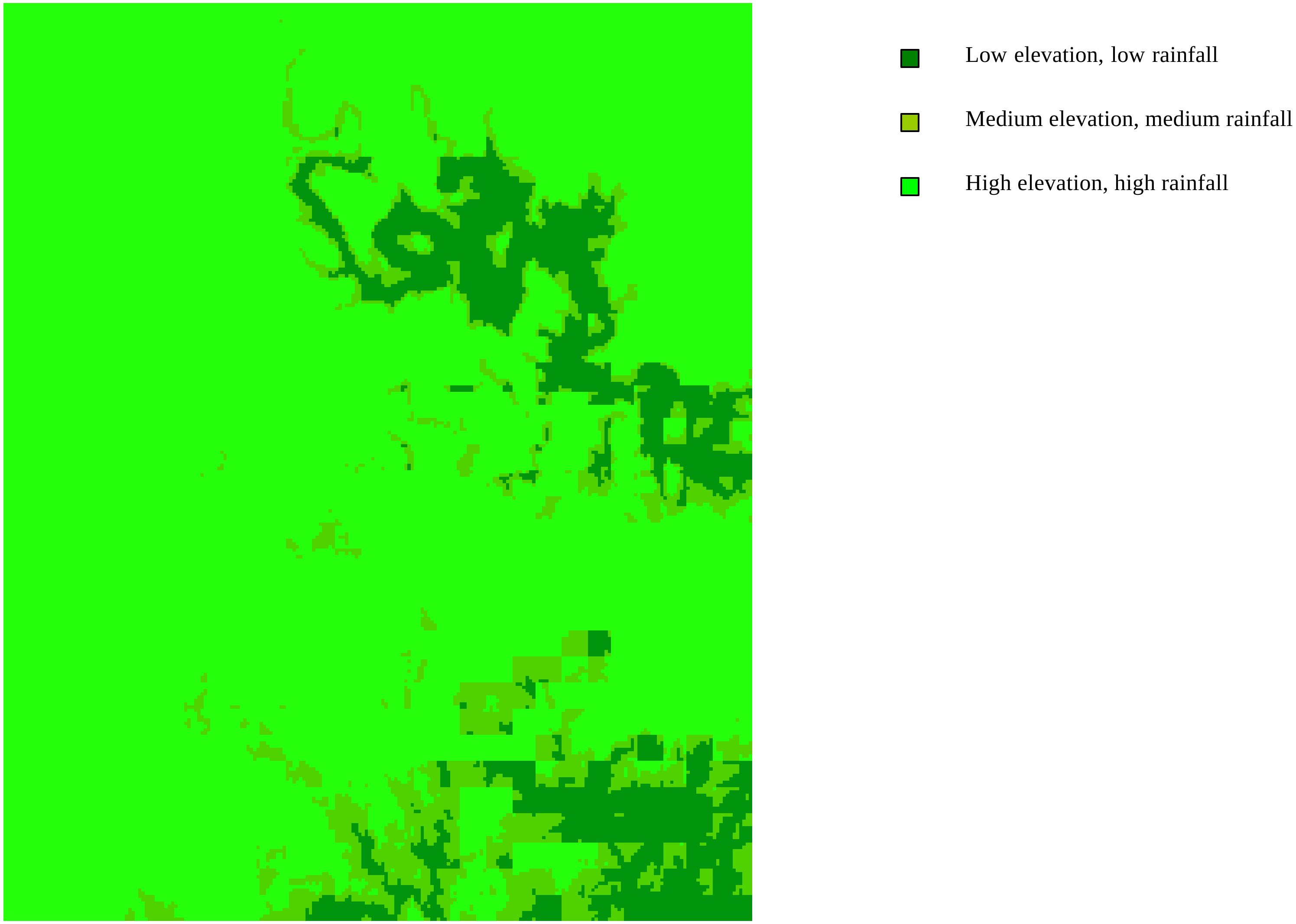


Figure 6.3.2 The distribution of the three principal topographical moisture classes within the Kei River Valley

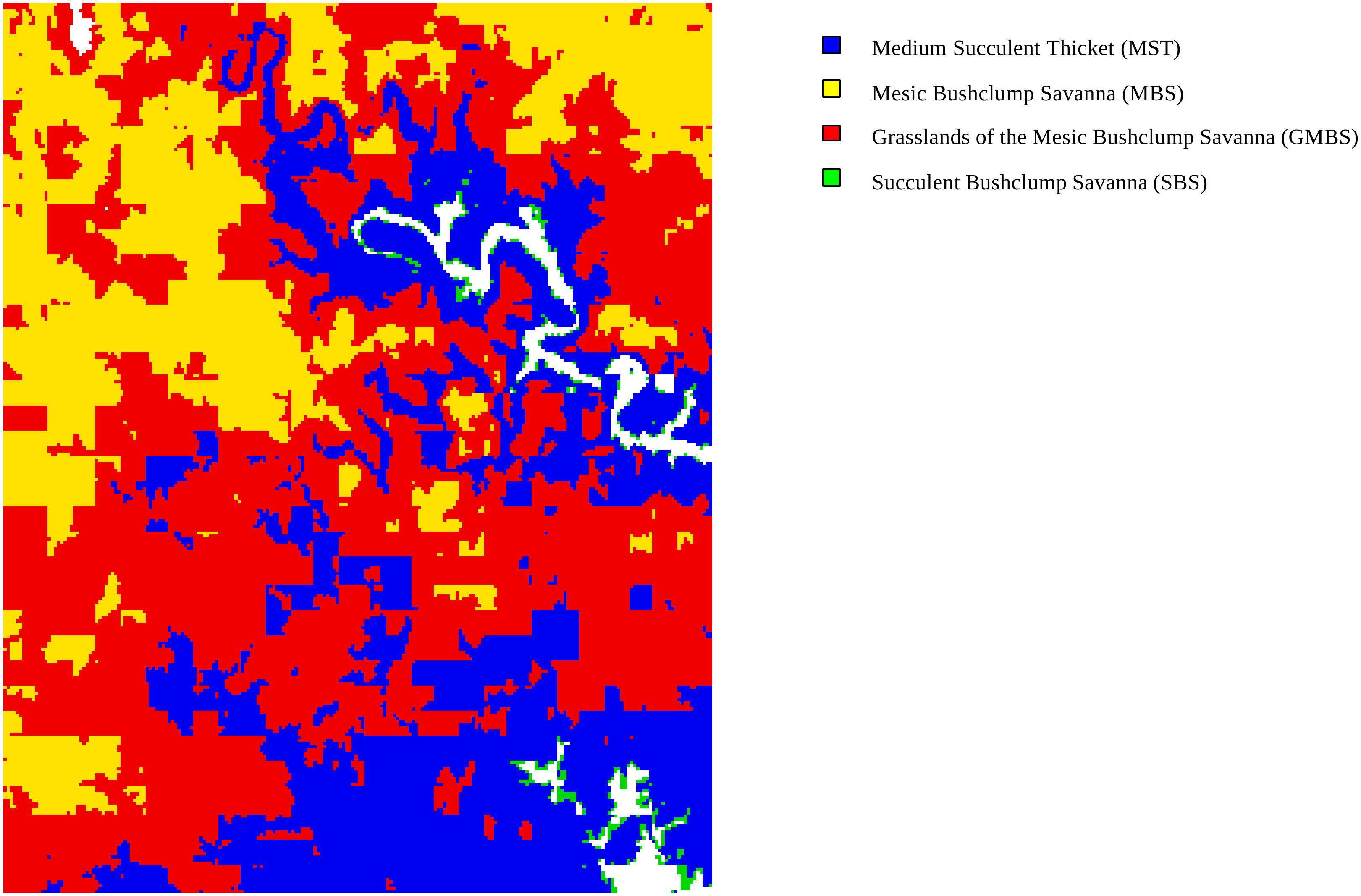


Figure 6.3.3 Predicted distribution of the vegetation communities under nature conservation for the Kei River Valley

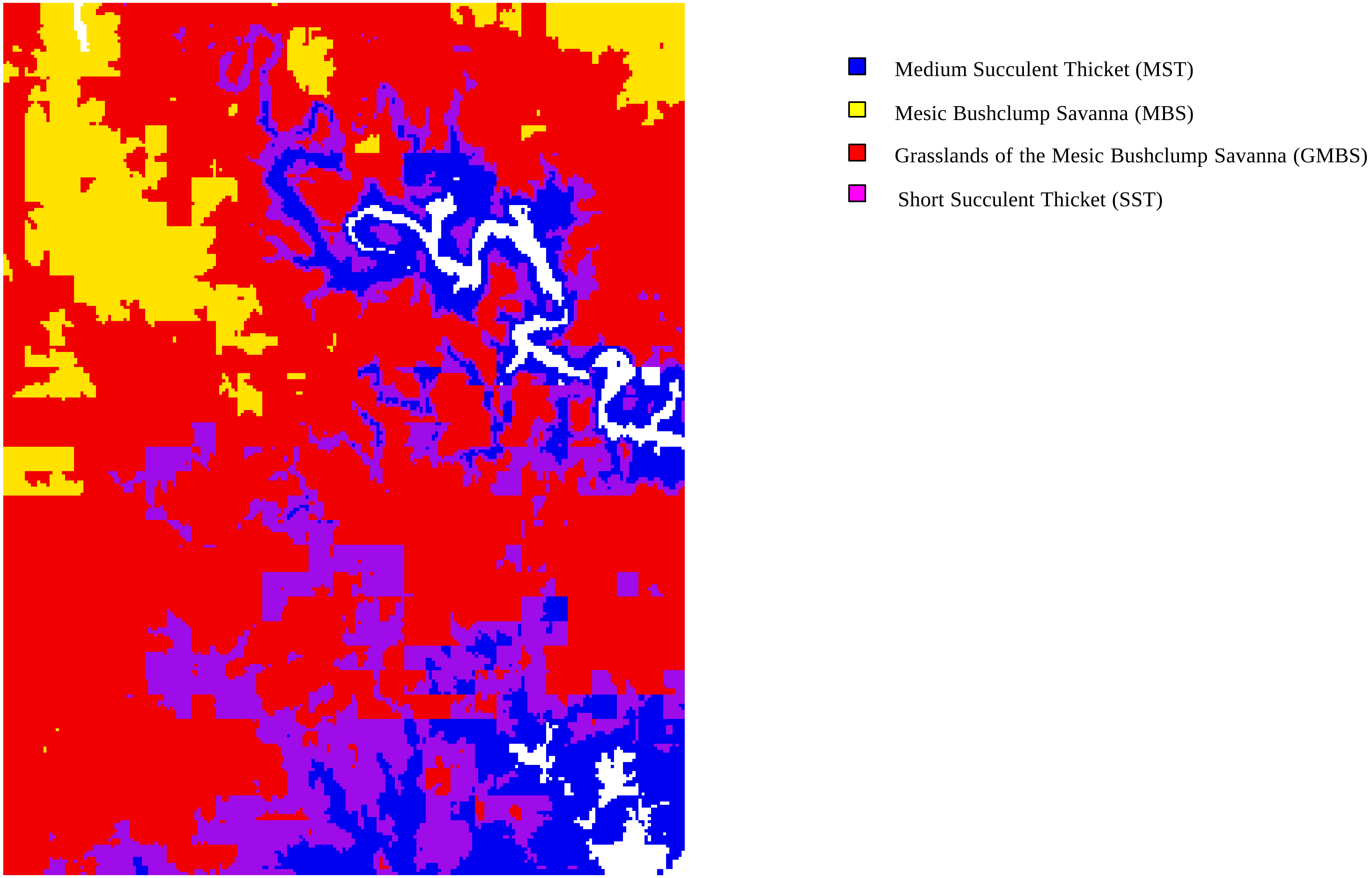


Figure 6.3.4 Predicted distribution of the vegetation communities under commercial management for the Kei River Valley

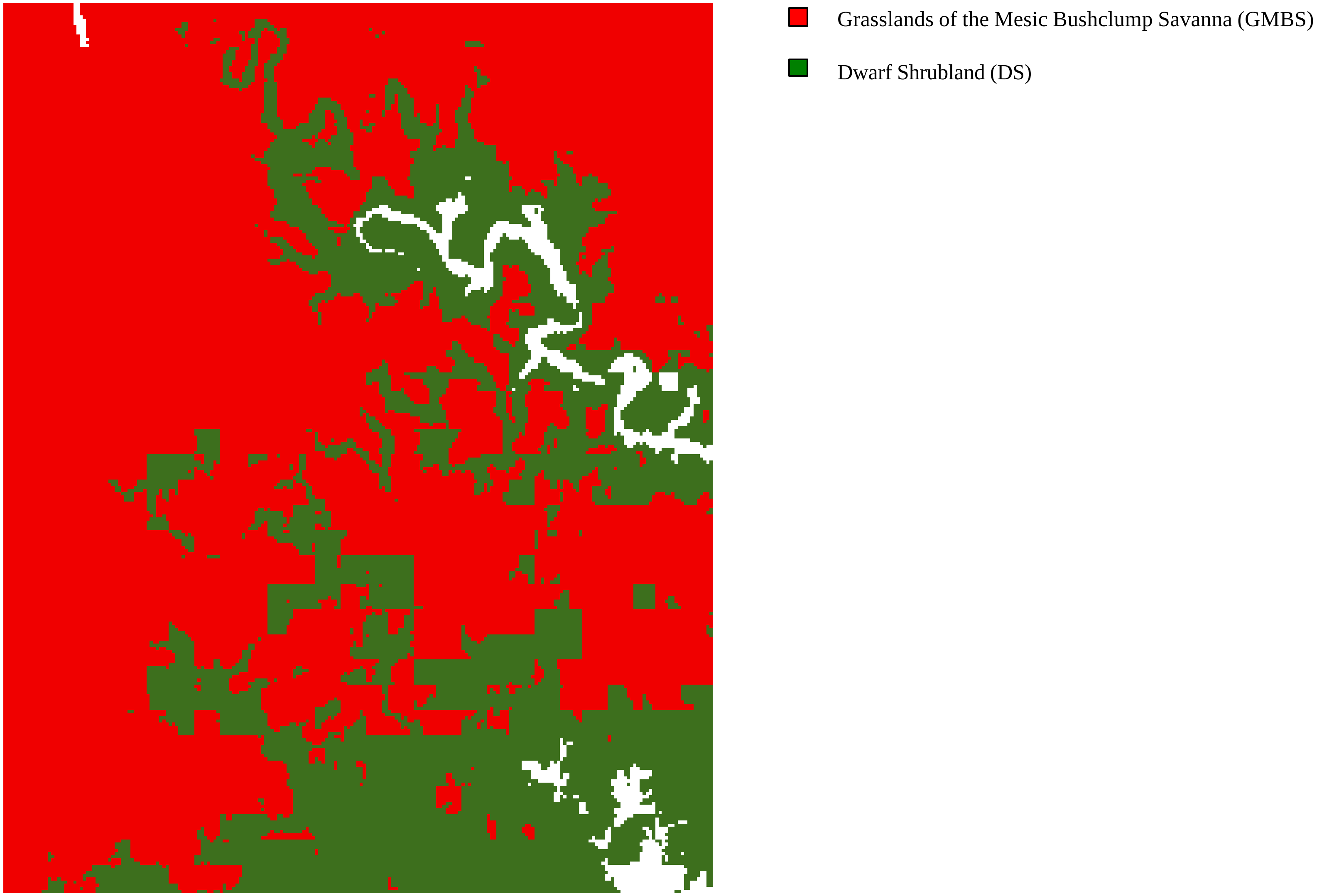


Figure 6.3.5 Predicted distribution of the vegetation communities under the communal rangeland system for the Kei River Valley.

CHAPTER 7

CONCLUSIONS

The controversy surrounding communal rangeland management stems from the lack of knowledge on communal grazing systems (Meyer et al. 1998). Studies on communal rangelands have revealed an array of results of the effects communal grazing is having and therefore there remains a great deal of uncertainty about the overall status of these rangelands and their sustainability. Questions remain as to whether all communal areas are severely degraded or if certain areas remain productive under this management scheme. Palmer and Avis (1995) suggested that utilisation pressure has had an impact on the species composition and production of the vegetation in the mid-Fish River valley.

Three major plant communities predominate in the mid-Fish River valley, namely Short Succulent Thicket, Medium Succulent Thicket and Mesic Bushclump Savanna. Within these communities a number of variations are present the nature of these variations being dependent on local climatic conditions and the type of management strategy implemented. The results from this study revealed that the communities within the land-use classes are restricted to certain positions along the topo-moisture gradient. In broad terms the higher elevation sites which receive a higher annual rainfall are characterised by more mesic plant communities such as Mesic Bushclump Savanna. While the plant communities found at lower elevation and rainfall sites, such as Medium Succulent Thicket are characterised by having a high percentage of succulents and plants adapted to xeric conditions.

The results from this study revealed a definite grazing gradient within the vegetation of the mid-Fish River valley, where changes in vegetation pattern occur according to the type of land-use. If the grazing intensity of the land-use treatments is compared, the nature conservation areas can be described as being under the least intensive pressure, while the communal rangelands are under the heaviest utilisation pressure. The grazing gradient is a transformation from a mesic environment towards a more arid environment with an increase in grazing and browsing pressure. This gradient is reflected in a change from valley thicket to a karroid dwarf shrubland with increased utilisation pressure. Along with a change in vegetation from valley thicket to karroid dwarf shrubland is another less visually dramatic effect of increased grazing and browsing pressure. This effect is a shift in community position along the environmental gradient, towards a higher elevation and rainfall class with increased utilisation pressure. This ecosystem transformation that occurs along the grazing gradient is also evident in changes to the invertebrate, bird and small mammal assemblages.

The results from this study revealed some differences in productivity levels for the three land-use treatments, as well as a relationship between areas that have undergone a change in species composition and structure and areas that are showing greater deviations in the productivity levels over time. These results suggest that when changes in species composition and structure occur as a result of heavy grazing and browsing pressure, the productivity of these rangelands begin to fluctuate. Although the communal rangelands are difficult to assess in terms of conventional methods (Shackelton et al. 1998), they do comply to some degree with the conventional interpretation of degradation. That is, there has been a loss of biodiversity, increased soil erosion, an inability to reverse the changes that have taken place, loss of palatable species, loss of biomass, reduction in soil nutrients and a change in plant productivity.

The predictive vegetation model provided a means of comparing the expected vegetation under communal management to the vegetation condition at present. The model thus provided a method by which to evaluate land-use practices and their effects on the vegetation determined against a source of reference. Although the communal rangelands complied to some degree with the conventional interpretation of degradation, the predictive vegetation model revealed that this degraded state is not uniformly reflected throughout the communal areas. The model highlighted that there were some areas within the communal rangelands where the vegetation was in a better than expected state, thus indicating that, although the communal rangeland system does result in degradation of the rangelands, there are patches where the rangelands are still in good condition. The explanation for this patchiness may be due to different localised management styles of grazers, and these areas therefore need to be investigated further. If these management styles are responsible for the good condition of the rangelands, these skills could possibly be transferred to degraded areas in an attempt to decrease the degradation process within the communally managed areas. The primary hypothesis regarding the degradation of communally managed areas therefore cannot be accepted in its entirety because even though the communal rangelands exhibit a more degraded state relative to the other two land-use classes, there are some patches that are still in good condition and this requires further investigation. The results do however reflect that livestock densities do have an effect on rangeland resources and productivity and that the rangelands are at risk of being overgrazed. This overgrazing causes a change in species composition and structure resulting ultimately in the process of desertification along the grazing gradient.

The approach used to develop a predictive vegetation model proved to be an effective method of relating the patterns in community composition to the environmental variables. The model did, however, have limitations in its predictive capacity. The degree of confidence of predicting certain communities was very low owing to the large degree of overlap in the predicted distributions between the communities. To increase the degree of confidence of the model's predictions, more environmental variables need to be incorporated into the model, which would refine the range of distribution of the communities, thereby increasing the degree of confidence of the prediction. Soil characteristics has been shown to be important in determining pattern in the thicket biome (Hoffman and Cowling 1990). However soil is a categorical variable and is therefore not suitable for spatial modelling as only continuous variables can be used, therefore other environmental variables need to be explored for their use in determining pattern within the vegetation of this area.

For this model the underlying assumption is that within each land-use class the utilisation intensity is constant. This assumption however results in an over simplification of the predicted distributions of the communities, as areas that deviate from the predetermined stocking rate will not be highlighted within the prediction. However these areas that deviate from expectation will be identified when a comparison is made with a contemporary vegetation map. Thus, although the model had limitations in its predictive capabilities it achieved the original objective, which was to identify areas that deviate from expectation. The model also provided a tool to explore the outcome of various forms of land management for the region.

The second primary hypothesis can therefore be accepted as the potential vegetation of an area was predicted by correlating the vegetation units and major environmental variables using a direct gradient analysis

The application of the predictive model is useful to a degree for predicting changes to vegetation communities in other areas of similar topographical-moisture gradients but it does have limitations, as the model does not account for variation in vegetation composition. The accuracy by which it is able to predict changes in vegetation response to land-use depends on the degree of similarity between the area under investigation and the area for which the model data was collected. The model can however be used successfully to predict the occurrence of the valley thicket communities associated with the steep river valleys in the Eastern Cape.

The challenge of rangeland management facing today's scientists, policy makers and users is to develop management strategies that will realise all the stakeholders' needs and such a challenge can only be met if a participatory approach is adopted. This is particularly vital under the communal grazing system, where the local communities should be involved in the decision making process if they are expected to implement the policies. Management plans are more likely to be implemented if the local communities have had some input into its creation. Conventionally, the role of local knowledge in the formulation of management plans has rarely been recognised even though traditional ecological knowledge has highlighted strategies for sustainable development in the rangelands. The model identified areas within the communally managed areas that are in a better than expected condition. The localised management of these areas needs further investigation in order to verify if these differences are in fact a response to different management or are merely responding differently to the management of the area. These areas will provide further evidence of the effect communal management is having on the natural rangelands within the study area.

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APPENDIX 1

Environmental data for the mid-Fish River Valley study area

Sample	GPS position	Aspect	Elevation	MAR	Slope	Land-use	Community
1	33º 05’ 52”S 26º 47’ 09”E	120	264	502	8	nature conservation	MST
2	33º 06’ 01”S 26º 47’ 28”E	85	319	410	4	nature conservation	MST
3	33º 05’ 58”S 26º 47’ 24”E	103	299	502	6	nature conservation	MST
4	33º 05’ 57”S 26º 47’ 32”E	108	307	502	6	nature conservation	MST
5	32º 56’ 12”S 26º 49’ 55”E	321	522	434	5	nature conservation	MBS
6	33º 05’ 30”S 26º 44’ 26”E	345	304	461	7	nature conservation	MST
7	33º 05’ 01”S 26º 44’ 56”E	131	210	461	3	nature conservation	SBS
8	33º 05’ 03”S 26º 45’ 18”E	64	222	496	7	nature conservation	MST
9	33º 05’ 26”S 26º 44’ 48”E	56	246	461	6	nature conservation	MST
10	33º 04’ 25”S 26º 46’ 59”E	248	218	388	3	nature conservation	SBS
11	33º 05’ 31”S 26º 47’ 02”E	3	211	383	6	nature conservation	SBS
12	33º 05’ 38”S 26º 44’ 05”E	355	312	461	6	commercial	MST
13	33º 05’ 35”S 26º 44 17”E	7	324	461	3	commercial	MST
14	33º 06 11”S 26º 43’ 46”E	48	409	489	6	commercial	MST
15	33º 08’ 49”S 26º 38’ 48”E	120	321	408	2	commercial	MST
16	33º 08’ 58”S 26º 38’ 56”E	340	321	408	1	commercial	MST
17	33º 09’ 55”S 26º 40’ 29”E	302	266	419	2	commercial	MST
18	33º 10’ 26”S 26º 43’ 01”E	316	219	366	5	commercial	MST
19	33º 13’ 05”S 26º 43’ 00”E	166	193	584	5	commercial	MST
20	33º 13’ 45”S 26º 42’ 07”E	108	241	553	5	commercial	MST
21	33º 13’ 41”S 26º 42’ 11”E	28	251	553	9	commercial	MST
22	33º 13’ 40”S 26º 42’ 14”E	51	236	553	9	commercial	MST
23	33º 13’ 32”S 26º 42’ 16”E	10	226	553	10	commercial	MST
24	33º 14’ 08”S 26º 41’ 59”E	0	472	617	0	commercial	MST
25	33º 13’ 54”S 26º 38’ 54”E	40	540	564	1	commercial	GMBS
26	33º 13’ 55”S 26º 38’ 51”E	40	540	564	1	commercial	GMBS
27	33º 13’ 58”S 26º 39’ 10”E	67	540	567	4	commercial	MST
28	33º 14’ 02”S 26º 39’ 07”E	253	536	661	3	commercial	GMBS
29	33º 14’ 01”S 26º 39’ 35”E	73	540	661	5	commercial	MST
30	33º 14’ 08”S 26º 40’ 07”E	40	505	645	6	commercial	MST
31	33º 14’ 03”S 26º 40’ 27”E	41	480	645	11	commercial	MST
32	33º 14’ 00”S 26º 40’ 26”E	53	441	551	11	commercial	MST
33	33º 13’ 52”S 26º 40’ 53”E	23	293	488	11	commercial	MST
34	33º 13’ 52”S 26º 41’ 00”E	256	389	551	6	commercial	MST
35	33º 13’ 59”S 26º 41’ 15”E	271	370	566	5	commercial	MST
36	33º 14’ 00”S 26º 41 21”E	263	370	566	6	commercial	MST
37	33º 14’ 03”S 26º 41’ 40”E	317	321	617	10	commercial	MST
38	33º 12’ 28”S 26º 37’ 57”E	80	388	564	5	commercial	MST
39	33º 13’ 27”S 26º 37’ 57”E	66	523	588	7	commercial	MST
40	33º 13’ 09”S 26º 37’ 34”E	68	532	588	5	commercial	MST
41	33º 12’ 09”S 26º 37’ 07”E	72	408	564	6	commercial	MST
42	33º 12’ 08”S 26º 37’ 37”E	77	408	564	6	commercial	MST
43	33º 12’ 43”S 26º 37’ 49”E	109	480	564	5	commercial	MST
44	33º 12’ 35”S 26º 37’ 48”E	71	435	564	12	commercial	MST
45	33º 11’ 07”S 26º 37’ 14”E	274	266	510	9	commercial	MST

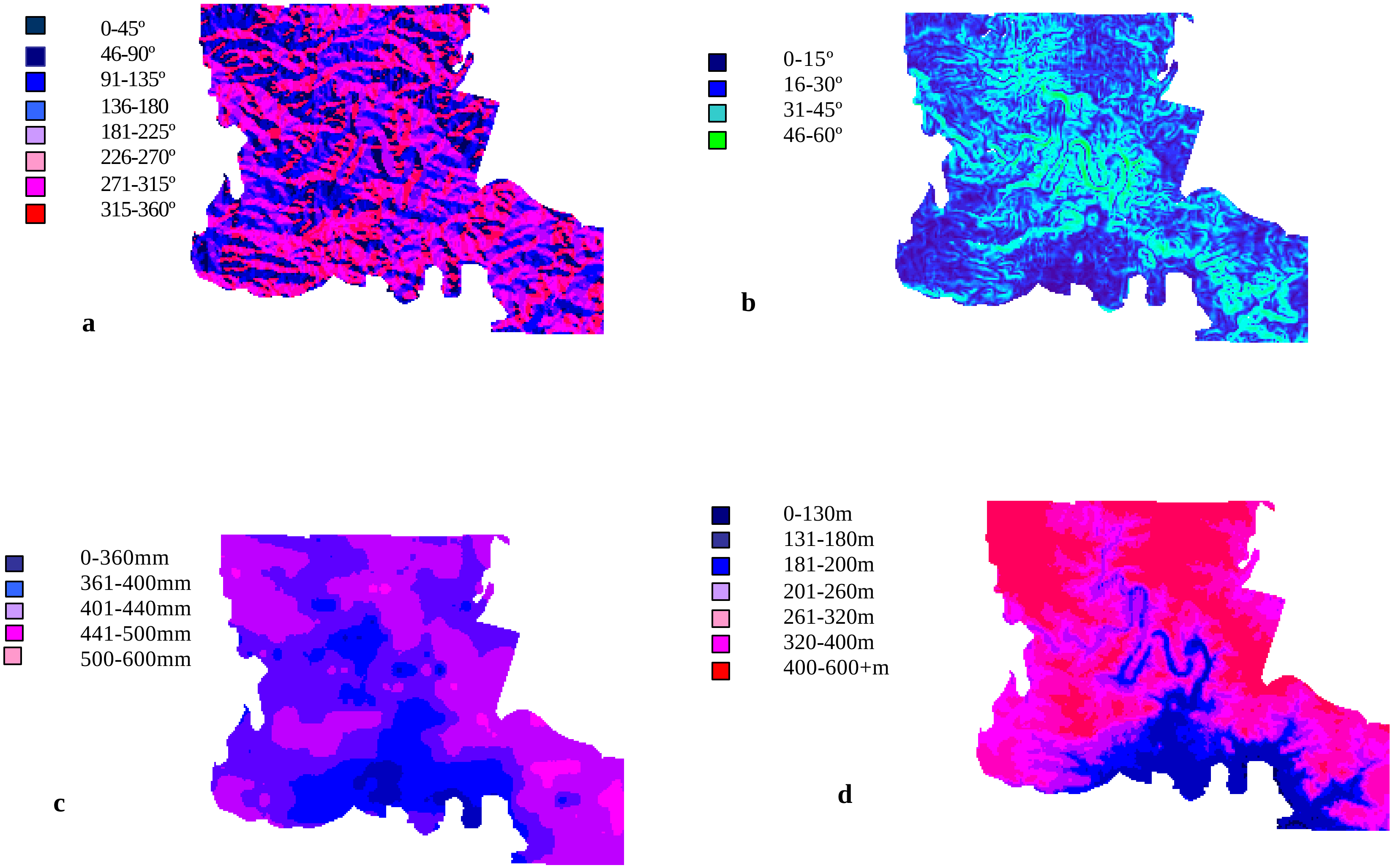
46	33º 10’ 08”S	26º 36’ 07”E	171	361	450	2	commercial	MST
47	33º 10’ 06”S	26º 37’ 08”E	285	279	510	9	commercial	MST
48	33º 09’ 55”S	26º 37’ 33”E	190	344	456	3	commercial	GMBS
49	33º 09’ 17”S	26º 37’ 31”E	116	335	456	2	commercial	GMBS
50	33º 08’ 05”S	26º 37’ 35”E	360	277	417	1	commercial	GMBS
51	33º 09’ 17”S	26º 37’ 24”E	148	326	456	4	commercial	GMBS
52	33º 09’ 17”S	26º 37’ 03”E	157	311	456	2	commercial	GMBS
53	33º 08’ 06”S	26º 37’ 26”E	90	278	417	2	commercial	GMBS
54	33º 08’ 07”E	26º 37’ 25”E	38	280	417	2	commercial	GMBS
55	33º 08’ 06”S	26º 37’ 30”E	117	330	456	3	commercial	GMBS
56	33º 08’ 09”S	26º 36’ 38”E	235	277	417	2	commercial	MST
57	33º 07’ 06”S	26º 38’ 06”E	154	304	417	2	commercial	GMBS
58	33º 08’ 53”S	26º 37’ 56”E	140	339	417	4	commercial	GMBS
59	33º 05’ 05”S	26º 57’ 30”E	268	480	512	7	communal	GMBS
60	33º 05’ 11”S	26º 57’ 50”E	268	480	512	7	communal	GMBS
61	33º 11’ 29”S	26º 37’ 24”E	31	248	510	5	commercial	MST
62	33º 12’ 18”S	26º 40’ 27”E	32	200	488	5	commercial	MST
63	33º 12’ 20”S	26º 41’ 28”E	62	197	488	2	commercial	MST
64	33º 14’ 20”S	26º 40’ 41”E	13	181	488	3	commercial	MST
65	33º 10’ 53”S	26º 45’ 41”E	103	184	488	5	commercial	MST
66	33º 15’ 30”S	26º 41’ 05”E	86	182	421	8	commercial	MST
67	33º 12” 30”S	26º 41’ 05”E	53	207	421	8	commercial	MST
68	33º 10’ 38”S	26º 41’ 29”E	41	192	421	3	commercial	MST
69	33º 14’ 35”S	26º 44’ 26”E	57	166	432	3	commercial	MST
70	33º 12’ 41”S	26º 44’ 31”E	36	166	432	3	commercial	MST
71	33º 13’ 17”S	26º 45’ 06”E	106	166	436	3	commercial	MST
72	33º 12’ 24”S	26º 45’ 09”E	217	167	436	3	commercial	MST
73	33º 11’ 43”S	26º 45’ 28”E	164	135	383	1	commercial	MST
74	33º 10’ 40”S	26º 45’ 12”E	140	135	383	1	commercial	MST
75	33º 11’ 59”S	26º 46’ 12”E	89	159	436	3	commercial	GMBS
76	33º 10’ 46”S	26º 43’ 31”E	28	143	366	5	commercial	MST
77	33º 10’ 39”S	26º 43’ 42”E	95	163	366	7	commercial	MST
78	33º 11’ 36”S	26º 45’ 17”E	156	135	383	2	commercial	MST
79	33º 08’ 37”S	26º 38’ 38”E	59	314	408	3	commercial	GMBS
80	33º 09’ 45”S	26º 39’ 41”E	35	317	408	4	commercial	MST
81	33º 07’ 49”S	26º 38’ 51”E	133	327	409	2	nature conservation	SBS
82	33º 07’ 30”S	26º 39’ 48”E	140	331	409	2	nature conservation	SBS
83	33º 07’ 06”S	26º 41’ 14”E	64	340	437	2	nature conservation	GMBS
84	33º 04’ 33”S	26º 47’ 10”E	345	192	383	9	nature conservation	MST
85	33º 05’ 35”S	26º 47’ 58”E	345	192	383	9	nature conservation	SBS
86	33º 04’ 16”S	26º 46’ 51”E	170	232	388	8	nature conservation	SBS
87	33º 05’ 13”S	26º 47’ 02”E	201	280	383	8	nature conservation	MST
88	32º 57’ 32”S	26º 50’ 32”E	360	466	433	4	communal	GMBS
89	32º 58’ 01”S	26º 50’ 15”E	0	498	433	0	communal	GMBS
90	32º 55’ 12”S	26º 52’ 09”E	133	551	438	2	communal	GMBS
91	32º 51’12”S	26º 50’ 09”E	133	551	438	2	communal	GMBS
92	32º 53’ 59”S	26º 49’ 33”E	19	573	469	2	communal	GMBS
93	32º 53’ 33”S	26º 49’ 12”E	196	566	469	1	communal	GMBS
94	32º 53’ 40”S	26º 49’ 16”E	251	562	469	4	communal	GMBS
95	32º 51’ 43”S	26º 48’ 49”E	249	566	461	5	communal	GMBS

96	32º 52’ 45”S	26º 46’ 57”E	180	528	446	4	communal	GMBS
97	32º 51’ 02”S	26º 48’ 05”E	159	599	461	4	communal	GMBS
98	32º 49’ 51”S	26º 47’ 34”E	262	148	381	5	communal	GMBS
99	32º 48’ 58”S	26º 48’ 36”E	282	96	360	4	communal	GMBS
100	32º 49’ 44”S	26º 49’ 54”E	282	96	360	4	communal	GMBS
101	33º 05’ 48”S	26º 56’ 12”E	260	469	513	9	communal	GMBS
102	33º 06’ 31”S	26º 57’ 21”E	152	385	524	4	communal	GMBS
103	33º 09’ 25”S	26º 50’ 55”E	103	95	379	4	communal	DS
104	33º 09’ 22”S	26º 51’ 03”E	166	87	381	6	communal	DS
105	33º 08’ 21”S	26º 51’ 26”E	218	131	387	3	communal	DS
106	33º 09’ 33”S	26º 52’ 20”E	253	161	371	4	communal	DS
107	33º 07’ 06”S	26º 53’ 01”E	305	218	384	6	communal	GMBS
108	33º 03’ 08”S	26º 53’ 09”E	82	216	461	8	communal	GMBS
109	33º 07’ 07”S	26º 55’ 40”E	279	194	384	4	communal	DS
110	33º 07’ 53”S	26º 57’ 06”E	237	196	384	10	communal	DS
111	33º 04’ 56”S	26º 54’ 06”E	147	339	421	4	communal	DS
112	33º 06’ 06”S	26º 56’ 19”E	353	354	406	7	communal	GMBS
113	33º 04’ 54”S	26º 53’ 04”E	9	414	524	4	communal	GMBS
114	33º 05’ 09”S	26º 56’ 07”E	132	384	524	3	communal	GMBS
115	33º 03’ 06”S	26º 57’ 06”E	238	372	489	5	communal	GMBS
116	33º 05’ 25”S	26º 58’ 06”E	296	471	489	8	communal	GMBS
117	33º 04’ 09”S	26º 57’ 08”E	3	402	489	4	communal	GMBS
118	33º 04 44”S	26º 58’ 58”E	200	454	508	3	communal	GMBS
119	33º 04’ 59”S	26º 59’ 09”E	252	447	540	5	communal	GMBS
120	33º 04’ 07”S	26º 56’ 05”E	303	417	540	8	communal	GMBS
121	33º 08’ 56”S	26º 52’ 40”E	189	195	385	3	communal	DS
122	33º 09’ 08”S	26º 52’ 46”E	357	188	371	4	communal	DS
123	33º 09’ 22”S	26º 54’ 56”E	13	156	371	4	communal	DS
124	33º 06’ 32”S	26º 54’ 39”E	2	212	376	18	communal	DS
125	33º 09’ 37”S	26º 57’ 07”E	267	227	434	15	communal	DS
126	33º 10’ 24”S	26º 58’ 41”E	162	77	460	6	communal	DS
127	33º 13’ 05”S	26º 59’ 08”E	351	96	412	2	communal	DS
128	33º 13’ 47”S	27º 00’ 25”E	113	52	410	4	communal	DS
129	33º 14’ 08”S	27º 02’ 01”E	0	67	478	0	communal	DS
130	33º 14’ 10”S	27º 01’ 08”E	200	126	478	2	communal	DS
131	33º 48’ 06”S	26º 41’ 07”E	200	126	478	2	communal	GMBS
132	33º 51’ 09”S	26º 47’ 24”E	175	496	490	6	communal	GMBS
133	32º 53’ 54”S	26º 45’ 46”E	52	452	463	5	communal	DS
134	33º 09’ 36”S	26º 28’ 06”E	52	452	463	5	commercial	GMBS
135	33º 10’ 25”S	26º 27’ 06”E	52	452	463	5	commercial	GMBS
136	33º 08’ 08”S	26º 29’ 09”E	2	334	473	2	commercial	MBS
137	33º 09’ 06”S	26º 30’ 28”E	84	328	473	3	commercial	MST
138	33º 08’ 44”S	26º 31’ 49”E	80	316	443	2	commercial	GMBS
139	33º 10’ 07”S	26º 30’ 07”E	113	325	470	2	commercial	GMBS
140	33º 08’ 07”S	26º 32’ 09”E	103	378	439	2	commercial	GMBS
141	33º 08’ 06”S	26º 32’ 38”E	143	350	481	3	commercial	GMBS
142	33º 05’ 06”S	26º 34’ 53”E	183	362	481	4	commercial	GMBS
143	33º 09’ 54”S	26º 32’ 57”E	132	358	461	4	commercial	GMBS
144	33º 08’ 54”S	26º 33’ 51”E	88	361	435	4	commercial	GMBS
145	33º 04’ 23”S	26º 33’ 34”E	23	318	456	2	commercial	MST

146	33º 08’ 11”S	26º 34’ 02”E	2	325	430	3	commercial	GMBS
147	33º 09’ 40”S	26º 35’ 08”E	71	309	440	5	commercial	GMBS
148	33º 07’ 44”S	26º 35’ 07”E	162	299	440	6	commercial	GMBS
149	33º 09’ 05”S	26º 36’ 34”E	18	305	448	3	commercial	GMBS
150	33º 08’ 09”S	26º 36’ 31”E	64	332	448	4	commercial	GMBS
151	33º 03’ 40”S	26º 30’ 13”E	270	598	503	10	commercial	MBS
152	33º 03’ 38”S	26º 30’ 00”E	0	600	503	0	commercial	MBS
153	33º 04’ 38”S	26º 31’ 07”E	246	588	487	6	commercial	MBS
154	33º 03’ 10”S	26º 32’ 07”E	301	580	487	5	commercial	MBS
155	33º 02’ 07”S	26º 33’ 09”E	303	461	404	6	commercial	MBS
156	33º 03’ 07”S	26º 32’ 07”E	272	440	404	7	commercial	MBS
157	33º 04’ 08”S	26º 38’ 06”E	327	506	390	8	commercial	MBS
158	33º 03’ 17”S	26º 33’ 07”E	77	541	450	3	commercial	MBS
159	33º 03’ 09”S	26º 35’ 08”E	258	318	436	5	commercial	MBS
160	33º 03’ 09”S	26º 34’ 09”E	282	354	436	6	commercial	GMBS
161	33º 13’ 06”S	26º 37’ 09”E	270	522	651	6	nature conservation	SBS
162	33º 14’ 58”S	26º 39’ 07”E	264	535	564	3	nature conservation	SBS
163	33º 13’ 39”S	26º 38’ 03”E	264	535	564	3	nature conservation	SBS
164	33º 14’ 24”S	26º 37’ 26”E	15	587	673	6	nature conservation	SBS
165	33º 12’ 53”S	26º 39’ 06”E	243	569	588	4	commercial	GMBS
166	33º 18’ 26”S	26º 36’ 30”E	19	556	673	5	commercial	MBS
167	33º 14’ 27”S	26º 37’ 24”E	37	597	673	4	commercial	MBS
168	33º 14’ 07”S	26º 36’ 07”E	37	597	673	4	commercial	MBS
169	33º 115’ 07”S	26º 36’ 26”E	37	597	673	4	commercial	MBS
170	32º 58’ 59”S	26º 41’ 53”E	213	489	455	4	nature conservation	SBS
171	32º 59’ 26”S	26º 41’ 27”E	213	489	455	4	nature conservation	SBS
172	32º 59’ 58”S	26º 42’ 26”E	296	476	455	5	nature conservation	MBS
173	32º 59’ 51”S	26º 40’ 59”E	225	488	474	7	nature conservation	SBS
174	32º 57’ 47”S	26º 40’01”E	197	462	474	5	nature conservation	SBS
175	32º 58’ 50”S	26º 39’ 52”E	289	480	500	4	nature conservation	SBS
176	32º 59’ 57”S	26º 39’ 57”E	316	466	500	5	nature conservation	MBS
177	33º 04’ 07”S	26º 37’ 35”E	284	302	392	7	commercial	MST
178	33º 03’ 59”S	26º 37’ 30”E	302	332	386	4	commercial	MST
179	33º 06’ 36”S	26º 38’ 21”E	214	318	408	4	nature conservation	MST
180	33º 08’ 03”S	26º 40’ 25”E	257	320	402	6	nature conservation	MST
181	33º 08’ 07”S	26º 40’ 25”E	267	317	402	6	nature conservation	MST
182	33º 08’ 10”S	26º 40’ 21”E	262	332	402	4	nature conservation	MST
183	33º 07’ 37”S	26º 40’ 52”E	224	336	433	4	nature conservation	MST
184	33º 07’ 44”S	26º 40’ 48”E	224	336	433	4	nature conservation	MBS
185	33º 07’ 32”S	26º 40’ 45”E	192	328	433	3	nature conservation	GMBS
186	33º 07;’ 49”S	26º 40’ 29”E	84	332	433	4	nature conservation	GMBS
187	33º 07’ 58”S	26º 40’ 39”E	255	313	402	6	nature conservation	GMBS
188	33º 07 50”S	26º 41’ 28”E	212	361	437	4	nature conservation	GMBS
189	33º 07’ 57”S	26º 41’ 59”E	99	389	437	5	nature conservation	GMBS
190	33º 07’ 44”S	26º 42’ 02”E	149	371	437	3	nature conservation	GMBS
191	33º 07’ 34”S	26º 41’ 54”E	149	371	437	3	nature conservation	MST
192	33º 07’ 45”S	26º 42’ 02”E	123	375	432	2	nature conservation	MST
193	33º 07’ 28”S	26º 41’ 41”E	115	356	437	6	nature conservation	GMBS
194	33º 07’ 32”S	26º 42’ 02”E	218	374	432	2	nature conservation	GMBS
195	33º 07’ 23”S	26º 42’ 02”E	204	374	432	2	nature conservation	GMBS

196	33º 07’ 21”S 26º 41’ 58”E	212	380	437	5	nature conservation	GMBS
197	33º 07’ 15”S 26º 41’ 58”E	230	391	437	7	nature conservation	MST
198	33º 07’ 18”S 26º 42’ 05”E	128	380	432	5	nature conservation	MST
199	33º 07’ 10”S 26º 44’ 12”E	30	388	452	5	nature conservation	MST
200	33º 07’ 08”S 26º 44’ 17”E	20	388	452	5	nature conservation	MST
201	33º 07’ 05”S 26º 44’ 16”E	20	388	452	5	nature conservation	MST
202	33º 07’ 07”S 26º 44’ 14”E	357	404	452	5	nature conservation	MBS
203	33º 07’ 11”S 26º 44’ 27”E	347	383	452	11	nature conservation	MST
204	33º 07’ 13”S 26º 44’ 35”E	48	361	452	11	nature conservation	MBS
205	33º 07’ 18”S 26º 44’ 35”E	43	372	452	10	nature conservation	GMBS
206	33º 06’ 49”S 26º 44’ 39”E	105	320	467	3	nature conservation	MST
207	33º 06’ 48”S 26º 44’ 29”E	242	365	467	13	nature conservation	MST
208	33º 06’ 47”S 26º 44’ 29”E	112	374	467	16	nature conservation	SBS
209	33º 06’ 30”S 26º 44’ 29”E	90	317	467	8	nature conservation	MST
210	33º 06’ 28”S 26º 44’ 26”E	272	305	467	2	nature conservation	MST
211	33º 08’ 08”S 26º 43’ 06”E	169	322	433	3	nature conservation	GMBS
212	33º 07’ 47”S 26º 40’ 48”E	91	336	433	4	nature conservation	GMBS
213	33º 07’ 33”S 26º 40’ 52”E	182	326	433	3	nature conservation	MST
214	33º 07’ 49”S 26º 40’ 58”E	41	319	399	1	nature conservation	MST
215	33º 07’ 02”S 26º 38’ 06”E	17	420	404	3	nature conservation	MBS
216	33º 08’ 16”S 26º 42’ 08”E	319	435	431	9	nature conservation	MBS
217	33º 08’ 11”S 26º 43’ 06”E	49	379	432	3	nature conservation	MBS
218	33º 06’ 31”S 26º 46’ 12”E	301	421	404	3	nature conservation	MBS
219	33º 07’ 49”S 26º 42’ 02”E	67	416	404	5	nature conservation	MST
220	33º 08’ 11”S 26º 42’ 43”E	360	299	404	5	nature conservation	MBS
221	33º 08’ 10”S 26º 42’ 10”E	53	410	396	8	nature conservation	MST
222	33º 06’ 49”S 26º 38’ 43”E	254	328	409	3	nature conservation	MBS
223	33º 08’ 08”S 26º 44’ 16”E	165	370	396	13	nature conservation	MST
224	33º 07’ 34”S 26º 39’ 54”E	250	441	450	3	nature conservation	GMBS
225	33º 08’ 08”S 26º 44’ 25”E	349	412	450	5	nature conservation	MBS
226	33º 07’ 57”S 26º 43’ 27”E	94	435	450	3	nature conservation	MBS
227	33º 07’ 32”S 26º 43’ 23”E	354	429	432	7	nature conservation	MBS
228	33º 07’ 24”S 26º 43’ 10”E	273	401	432	6	nature conservation	MBS
229	33º 07’ 29”S 26º 42’ 56”E	245	414	404	4	nature conservation	MBS
230	33º 08’ 03”S 26º 41’ 50”E	352	282	410	10	nature conservation	MBS
231	33º 08’ 11”S 26º 42’ 35”E	357	290	404	8	nature conservation	MST
232	33º 06’ 32”S 26º 39’ 10”E	205	427	450	4	nature conservation	MBS
233	33º 06’ 02”S 26º 38’ 47”E	51	319	409	3	nature conservation	MST
234	33º 07’ 47”S 26º 43’ 48”E	277	321	409	2	nature conservation	MST
235	33º 07’ 54”S 26º 39’12”E	122	375	467	16	nature conservation	MST
236	33º 07’ 47”S 26º 39’ 27”E	142	319	467	4	nature conservation	MBS
237	33º 06’ 41”S 26º 44’ 29”E	80	424	404	3	nature conservation	MBS
238	33º 06’ 42”S 26º 44’ 40”E	198	382	420	6	nature conservation	MBS
239	33º 08’ 02”S 26º 42’ 47”E	299	411	404	5	nature conservation	SBS
240	33º 06’ 00”S 26º 44’ 00”E	41	307	467	5	nature conservation	MST
241	33º 08’ 23”S 26º 42’ 16”E	147	318	467	6	nature conservation	MST
242	33º 06’ 03”S 26º 44’ 58”E	314	324	496	4	nature conservation	MST
243	33º 06’ 10”S 26º 44’ 52”E	327	293	410	3	nature conservation	MBS
244	33º 05’ 50”S 26º 45’ 23”E	333	447	431	5	nature conservation	MST
245	33º 06’ 50”S 26º 39’ 41”E	274	412	450	2	nature conservation	MBS

246	33º 08’ 23”S	26º 43’ 35”E	131	305	410	3	nature conservation	MST
247	33º 07’ 41”S	26º 43’ 56”E	14	373	419	11	nature conservation	MST
248	33º 06’ 45”S	26º 39’ 43”E	255	391	419	9	nature conservation	MST
249	33º 07’ 44”S	26º 45’ 16”E	86	407	418	6	nature conservation	MST
250	33º 07’ 29”S	26º 45’ 21”E	212	313	412	13	nature conservation	MST
251	33º 07’ 11”S	26º 46’ 14”E	288	448	431	5	nature conservation	MBS
252	33º 07’ 28”S	26º 47’ 08”E	141	306	404	5	nature conservation	GMBS
253	33º 08’ 02”S	26º 43’ 08”E	117	346	404	4	nature conservation	MST
254	33º 06’ 54”S	26º 38’ 45”E	314	301	409	3	nature conservation	GMBS
255	33º 06’ 36”S	26º38’ 21”E	203	287	410	1	nature conservation	GMBS
256	33º 07’ 26”S	26º 39’ 04”E	292	362	378	13	nature conservation	MST
257	33º 06’ 55”S	26º 39’ 23”E	140	424	485	6	nature conservation	MST
258	33º 07’ 11”S	26º 48’ 10”E	4	424	485	6	nature conservation	MBS
259	33º 05’ 09”S	26º 40’ 47”E	271	338	446	5	nature conservation	MST
260	33º 07’ 18”S	26º 42’ 56”E	253	448	432	4	commercial	SST
261	33º 07’ 18”S	26º 41’ 52”E	18	448	432	4	commercial	GMBS
262	33º 07’ 35”S	26º 40’ 40”E	25	328	433	3	commercial	SST
263	33º 08’ 00”S	26º 49’ 10”E	6	118	378	2	nature conservation	SBS
264	33º 08’ 23”S	26º 39’ 20”E	249	379	459	5	nature conservation	MST
265	33º 02’ 30”S	26º 56’ 24”E	227	432	489	8	communal	DS
266	33º 05’ 50”S	26º 58’ 08”E	251	415	487	11	communal	DS
267	33º 06’ 01”S	26º 58’ 04”E	195	383	489	6	communal	DS
268	33º 06’ 07”S	26º 57’ 589”E	191	348	496	3	communal	DS
269	33º 03’ 42”S	26º 59’ 51”E	293	412	508	5	communal	GMBS
270	33º 04’ 11”S	26º 59’ 29”E	85	416	508	4	communal	GMBS
271	33º 04’ 15”S	26º 59’ 19”E	5	385	421	2	communal	GMBS
272	33º 07’ 05”S	26º 55’ 35”E	342	318	461	2	communal	GMBS
273	33º 07’ 34”S	26º 53’ 38”E	261	288	461	13	commercial	SST
274	33º 07’ 50”S	26º 53’ 12”E	342	199	385	1	commercial	SST
275	33º 08’ 09”S	26º 52’ 39”E	85	182	371	1	commercial	SST
276	33º 09’ 18”S	26º 52’ 30”E	268	115	379	7	commercial	SST
277	33º 09’ 12”S	26º 50’ 52”E	305	132	409	3	commercial	SST
278	33º 11’ 33”S	26º 46’ 22”E	23	278	406	3	commercial	SST
279	33º 08’ 25”S	26º 39’ 13”E	2	278	406	3	commercial	SST
280	33º 08’ 23”S	26º 39’ 14”E	77	278	406	3	commercial	SST
281	33º 08’ 21”S	26º 39’ 13”E	15	278	406	3	commercial	SST
282	33º 08’ 19”S	26º 39’ 12”E	19	278	406	3	commercial	SST
283	33º 08’ 27”S	26º 39’ 23”E	73	273	406	2	commercial	SST
284	33º 08’ 25”S	26º 39’ 23”E	41	273	406	2	commercial	SST
285	33º 07’ 26”S	33º 39’ 04”E	38	273	406	2	commercial	SST
								SST



Appendix 2 **The surface response images for the mid-Fish River Valley.**

(a) Surface image showing the aspect of the study area in degrees. **(b)** The slope surface image displayed in degree of slope. **(c)** Surface image representing the mean annual rainfall (MAR). **(d)** The digital elevation map for the study area shown in meters above sea level.

APPENDIX 3

Species list for the mid-Fish River Valley study area
Source of nomenclature: Arnold, T.H. and de Wet, B.C. (eds). 1993. Plants of southern Africa: names and distrubutions. *Memoirs of the Botanical survey of South Africa.* No 62

SPECIES	**FAMILY**
Abutilon sonneratianum (Cav.) Sweet	MALVACEAE
Abutilon species	MALVACEAE
Acacia karroo Hayne	FABACEAE
Acalypha ecklonii Baill.	EUPHORBIACEAE
Acalypha glabrata Thunb. var. *glabrata*	EUPHORBIACEAE
Achyropsis leptostachya (E.Mey. ex Meisn.) Baker & C.B.Clarke	AMARANTHCEAE
Acokanthera oppositifolia (Lam.) Codd	APOCYNACEAE
Adromischus species	CRASSULACEAE
Adromischus sphenophyllus C.A.Sm.	CRASSULACEAE
Aizoon glinoides L.f.	AIZOACEAE
Allophylus decipiens (Sond.) Radlk.	SAPINDACEAE
Aloe ciliaris Haw. var. *ciliaris*	ASPHODELACEAE
Aloe ferox Mill.	ASPHODELACEAE
Aloe pluridens Haw.	ASPHODELACEAE
Aloe speciosa Baker	ASPHODELACEAE
Aloe striata Haw. ssp. *striata*	ASPHODELACEAE
Aloe tenuior Haw.	ASPHODELACEAE
Amellus strigosus	ASTERACEAE
Anthospermum aethiopicum L.	RUBIACEAE
Antizoma angustifolia (Burch.) Miers ex Harv.	MENISPERMACAEA
Arctotis acaulis L.	ASTERACEAE
Arctotis arctotoides (L.f.) O.Hoffm.	ASTERACEAE
Aristida congesta	POACEAE
Aristida congesta Roem. & Schult. ssp. *congesta*	POACEAE
Aristida diffusa	POACEAE
Ascolepis species	ASCLEPIADACEA
Aspalathus sericea P.J.Bergius	FABACEAE
Asparagus aethiopicus L.	ASPARAGACEAE
Asparagus africanus Lam.	ASPARAGACEAE
Asparagus aspergillus Jessop	ASPARAGACEAE
Asparagus crassicladus Jessop	ASPARAGACEAE
Asparagus densiflorus (Kunth) Jessop	ASPARAGACEAE
Asparagus mucronatus Jessop	ASPARAGACEAE
Asparagus plumosus Baker	ASPARAGACEAE
Asparagus racemosus Willd.	ASPARAGACEAE
Asparagus setaceus (Kunth) Jessop	ASPARAGACEAE
Asparagus species	ASPARAGACEAE
Asparagus striatus (L.f.) Thunb.	ASPARAGACEAE
Asparagus suaveolens Burch.	ASPARAGACEAE
Asparagus subulatus Thunb.	ASPARAGACEAE
Azima tetracantha Lam.	SALVADORACEAE
Barleria obtusa Nees	ACANTHACEAE
Barleria pungens L.f.	ACANTHACEAE
Becium burchellianum (Benth.) N.E.Br.	LAMIACAEA
Bergeranthus multiceps (Salm-Dyck) Schwantes	MESEMBRYANTHEMACEAE
Berkheya cardopatifolia (DC.) Roessler	ASTERACEAE

Berkheya heterophylla	ASTERACEAE
Blepharis capensis	ACANTHACEAE
Boscia oleoides (Burch. ex DC.) Toelken	CAPPARACEAE
Boophane disticha (L.f.) Herb.	AMARYLLIDACEAE
Brachylaena ilicifolia (Lam.) E.Phillips & Schweick.	ASTERACEAE
Buddleja saligna Willd.	LOGANIACEAE
Bulbine frutescens (L.) Willd.	ASPHODELACEAE
Bulbine latifolia (L.f.) Roem. & Schult.	ASPHODELACEAE
Bulbine narcissifolia Salm-Dyck	ASPHODELACEAE
Bulbine species	ASPHODELACEAE
Cadaba aphylla (Thunb.) Wild	CAPPARACEAE
Capparis sepiaria L. var. c*itrifolia* (Lam.) Toelken	CAPPARACEAE
Capparis sepiaria L. var. subglabra (Oliv.) Dewolf	CAPPARACEAE
Carissa bispinosa (L.) Desf. ex Brenan ssp. *bispinosa*	APACYNACEAE
Carpobrotus deliciosus (L.Bolus) L.Bolus	MESEMBRYANTHEMACEAE
Cassine aethiopica Thunb.	CELASTRACEAE
Cassine crocea (Thunb.) Kuntze	CELASTRACEAE
Ceterach cordatum (Thunb.) Desv.	ASPLENIACEAE
Cheilanthes hirta	ADIANTACEAE
Chenopodium album L.	CHENOPODIACEAE
Chenopodium ambrosioides L.	CHENOPODIACEAE
Chenopodium multifidum L.	CHENOPODIACEAE
Chloris virgata Sw.	POACEAE
Chlorophytum comosum (Thunb.) Jacq.	ASPHODELACEAE
Chrysocoma ciliata L.	ASTERACEAE
Cineraria lobata L'H,r.	ASTERACEAE
Clerodendrum pilosum H.Pearson	VERBANACEAE
Cliffortia repens Schltr.	ROSACEAE
Cliffortia species	ROSACEAE
Clutia alaternoides	EUPHORBIACEAE
Clutia laxa Eckl. ex Sond.	EUPHORBIACEAE
Coddia rudis (E.Mey. ex Harv.) Verdc.	RUBIACEAE
Combretum caffrum (Eckl. & Zeyh.) Kuntze	COMBRETACEAE
Commelina africana L. var. *africana*	COMMELINACEAE
Commelina benghalensis L.	COMMELINACEAE
Commiphora kraeuseliana Heine	BURSERACEAE
Conyza bonariensis (l.) Cronq.	ASTERACEAE
Cotula nigellifolia (DC.) Bremer & Humphries var. *nigellifolia*	ASTERACEAE
Cotyledon barbeyi Schweinf. ex Baker	CRASSULACEAE
Cotyledon orbiculata	CRASSULACEAE
Cotyledon species	CRASSULACEAE
Cotyledon velutina Hook.f.	CRASSULACEAE
Crassula capensis	CRASSULACEAE
Crassula capitella Thunb. ssp. thyrsiflora (Thunb.) Toelken	CRASSULACEAE
Crassula ciliata L.	CRASSULACEAE
Crassula corallina Thunb. ssp. *corallina*	CRASSULACEAE
Crassula cultrata L.	CRASSULACEAE
Crassula ericoides Haw. ssp. *ericoides*	CRASSULACEAE
Crassula expansa Dryand. ssp. *expansa*	CRASSULACEAE
Crassula flava L.	CRASSULACEAE
Crassula lactea Sol.	CRASSULACEAE
Crassula mesembryanthoides (Haw.) D.Dietr. ssp. *mesembryanthoides*	CRASSULACEAE
Crassula muscosa L. var. *muscosa*	CRASSULACEAE

Crassula nemorosa (Eckl. & Zeyh.) Endl. ex Walp.	CRASSULACEAE
Crassula obovata Haw. var. *obovata*	CRASSULACEAE
Crassula ovata (Mill.) Druce	CRASSULACEAE
Crassula perforata Thunb.	CRASSULACEAE
Crassula rogersii Sch”nland	CRASSULACEAE
Crassula rubricaulis Eckl. & Zeyh.	CRASSULACEAE
Crassula scabra L.	CRASSULACEAE
Crassula spathulata Thunb.	CRASSULACEAE
Crassula species	CRASSULACEAE
Crassula subulata	CRASSULACEAE
Crassula tetragona	CRASSULACEAE
Cussonia spicata Thunb.	ARALIACEAE
Cyanotis speciosa (L.f.) Hassk.	COMMELINACEAE
Cymbopogon marginatus (Steud.) Stapf ex Burtt Davy	POACEAE
Cymbopogon plurinodis (Stapf) Stapf ex Burtt Davy	POACEAE
Cynodon dactylon (L.) Pers.	POACEAE
Cynodon incompletus Nees	POACEAE
Cynodon species	POACEAE
Cyperus species	CYPERACEAE
Cyperus tenax Boeck.	CYPERACEAE
Cyphostemma quinatum (Dryand.) Desc. ex Wild & R.B.Drumm.	VITACEAE
Delosperma calycinum L.Bolus	MESEMBRYANTHEMACEAE
Delosperma echinatum (Aiton) Schwantes	MESEMBRYANTHEMACEAE
Delosperma species	MESEMBRYANTHEMACEAE
Dietes iridioides (L.) Sweet ex Klatt	IRIDACEAE
Digitaria eriantha Steud.	POACEAE
Diospyros dichrophylla (Gand.) De Winter	EBENACEAE
Diospyros lycioides	EBENACEAE
Diospyros pallens (Thunb.) F.White	EBENACEAE
Diospyros scabrida	EBENACEAE
Diospyros simii (Kuntze) De Winter	EBENACEAE
Diospyros whyteana (Hiern) F.White	EBENACEAE
Dolichos falciformis E.Mey.	FABACEAE
Dolichos hastaeformis E.Mey.	FABACEAE
Dovyalis rhamnoides (Burch. ex DC.) Harv.	FLACOURTIACEAE
Dovyalis rotundifolia (Thunb.) Thunb. & Harv.	FLACOURTIACEAE
Ehretia rigida (Thunb.) Druce	BORAGINACEAE
Elytropappus rhinocerotis (L.f.) Less.	ASTERACEAE
Eragrostis chloromelas Steud.	POACEAE
Eragrostis ciliaris (L.) R.Br.	POACEAE
Eragrostis curvula (Schrad.) Nees	POACEAE
Eragrostis lehmanniana	POACEAE
Eragrostis obtusa Munro ex Ficalho & Hiern	POACEAE
Erianthemum dregei (Eckl. & Zeyh.) Tiegh.	LORANTHACEAE
Euclea undulata	*EBENACEAE*
Euphorbia bothae Lotsy & Goddijn	EUPHORBIACEAE
Euphorbia burmannii E.Mey. ex Boiss.	EUPHORBIACEAE
Euphorbia cumulata R.A.Dyer	EUPHORBIACEAE
Euphorbia inermis Mill. var. inermis	EUPHORBIACEAE
Euphorbia loricata Lam.	EUPHORBIACEAE
Euphorbia mauritanica	EUPHORBIACEAE
Euphorbia species	EUPHORBIACEAE
Euphorbia tetragona Haw.	EUPHORBIACEAE
Euphorbia triangularis Desf.	EUPHORBIACEAE

Euryops tenuilobus (DC.) B.Nord.	ASTERACEAE
Euryops trifidus (L.f.) DC.	ASTERACEAE
Eustachys paspaloides (Vahl) Lanza & Mattei	POACEAE
Exomis microphylla (Thunb.) Aellen var. *axyrioides* (Fenzl) Aellen	CHENOPODIACEAE
Falckia repens L.f.	CONVOLVULACEAE
Felicia filifolia	ASTERACEAE
Felicia muricata	ASTERACEAE
Felicia species	ASTERACEAE
Ficus species	MORACEAE
Fingerhuthia species	POACEAE
Flueggea verrucosa (Thunb.) G.L.Webster	EUPHORBIACEAE
Galenia pubescens (Eckl. & Zeyh.) Druce var. *cerosa* Adamson	AIZOCEAE
Garuleum bipinnatum (Thunb.) Less.	ASTERACEAE
Gazania linearis (Thunb.) Druce var. *linearis*	ASTERACEAE
Glossochilus parviflorus Hutch.	ACANTHACEAE
Gnidia cuneata Meisn.	THYMELAEACEAE
Gnidia racemosa Thunb.	THYMELAEACEAE
Grewia occidentalis L.	TILIACEAE
Grewia robusta Burch.	TILIACEAE
Helichrysum anomalum Less.	ASTERACEAE
Helichrysum cymosum (L.) D.Don ssp. calvum Hilliard	ASTERACEAE
Helichrysum dregeanum Sond. & Harv.	ASTERACEAE
Helichrysum nudifolium (L.) Less.	ASTERACEAE
Helichrysum rosum (P.J.Bergius) Less. var. *arcuatum* Hilliard	ASTERACEAE
Helichrysum species	ASTERACEAE
Hermannia althaeifolia L.	STERCULIACEAE
Hermannia burkei Burtt Davy	STERCULIACEAE
Hermannia concinnifolia I.Verd.	STERCULIACEAE
Hermannia cuneifolia Jacq. var. *cuneifolia*	STERCULIACEAE
Hermannia flammea Jacq.	STERCULIACEAE
Hermannia velutina DC.	STERCULIACEAE
Heteromorpha arborescens (Thunb.) Cham. & Schltdl.	APIACEAE
Hibiscus aridus R.A.Dyer	MALVACEAE
Hibiscus pedunculatus L.f.	MALVACEAE
Hibiscus pusillus Thunb.	MALVACEAE
Hippobromus pauciflorus (L.f.) Radlk.	SAPINDACEAE
Hyparrhenia hirta (L.) Stapf	POACEAE
Hypoestes aristata	*ACANTHACEAE*
Hypoestes aristata (Vahl) Sol. ex Roem. & Schult. var. *aristata*	ACANTHACEAE
Hypoestes forskaolii (Vahl) R.Br.	ACANTHACEAE
Hypoxis species	HYPOXIDACEAE
Hypoxis stellipilis Ker Gawl.	HYPOXIDACEAE
Indigofera denudata L.f.	FABACEAE
Indigofera disticha Eckl. & Zeyh.	FABACEAE
Indigofera heterophylla Thunb.	FABACEAE
Indigofera sessilifolia DC.	FABACEAE
Indigofera setiflora Baker	FABACEAE
Indigofera species	FABACEAE
Ipomoea ficifolia Lindl.	CONVOLVULACEAE
Jasminum angulare Vahl	OLEACEAE
Jasminum multipartitum Hochst.	OLEACEAE
Jatropha capensis (L.f.) Sond.	EUPHORBIACEAE
Justicia cuneata	ACANTHACEAE
Justicia protracta (Nees) T.Anderson ssp. *protracta*	ACANTHACEAE

Kalanchoe rotundifolia (Haw.) Haw.	CRASSULACEAE
Kedrostis africana (L.) Cogn.	CUCURBITACEAE
Lampranthus productus (Haw.) N.E.Br. var. *lepidus* (Haw.) Schwantes	MESEMBRYANTHEMACEAE
Lampranthus spectabilis (Haw.) N.E.Br.	MESEMBRYANTHEMACEAE
Lantana camara L.	VERBANACEAE
Lantana rugosa Thunb.	VERBANACEAE
Lepidium africanum	BRASSICACEAE
Leucas capensis (Benth.) Engl.	LAMIACEAE
Limeum aethiopicum Burm. ssp. *aethiopicum* var. *aethiopicum*	AIZOCEAE
Lippia javanica (Burm.f.) Spreng.	VERBANACEAE
Lotononis pungens Eckl. & Zeyh.	FABACEAE
Lycium ferocissimum Miers	SOLANACEAE
Lycium oxycarpum Dunal	SOLANACEAE
Lycium schizocalyx C.H.Wright	SOLANACEAE
Lycium species	SOLANACEAE
Manulea annua (Hiern) Hilliard	SCROPHULARIACEAE
Matricaria nigellifolia DC. var. *nigellifolia*	ASTERACEAE
Mariscus capensis (Steud.) Schrad.	CYPERACEAE
Mariscus congestus (Vahl) C.B.Clarke	CYPERACEAE
Mariscus uitenhagensis Steud.	CYPERACEAE
Maytenus capitata (E.Mey. ex Sond.) Marais	CELASTRACEAE
Maytenus heterophylla (Eckl. & Zeyh.) N.Robson	CELASTRACEAE
Maytenus linearis (L.f.) Marais	CELASTRACEAE
Maytenus nemorosa (Eckl. & Zeyh.) Marais	CELASTRACEAE
Maytenus peduncularis (Sond.) Loes.	CELASTRACEAE
Maytenus polyacantha (Sond.) Marais	CELASTRACEAE
Maytenus undata (Thunb.) Blakelock	CELASTRACEAE
Merxmuellera disticha (Nees) Conert	POACEAE
Mesembryanthemum aitonis Jacq.	MESEMBRYANTHMACEAE
Mesembryanthemum species	MESEMBRYANTHMACEAE
Mestoklema albanicum N.E.Br. ex Glen	MESEMBRYANTHEMACEAE
Moraea polystachya (Thunb.) Ker Gawl.	IRIDACEAE
Nemesia floribunda Lehm.	SCROPHULARIACEAE
Oedera genistifolia (L.) Anderb. & K.Bremer	ASTERACEAE
Olea europaea L. ssp. *africana* (Mill.) P.S.Green	OLEACEAE
Oligocarpus calendulaceus (L.f.) Less.	ASTERACEAE
Opuntia aurantiaca Lindl.	CACTACEAE
Opuntia ficus-indica (L.) Mill.	CACTACEAE
Opuntia species	CACTACEAE
Oropetium capense Stapf	POACEAE
Othonna triplinervia DC.	ASTERACEAE
Oxalis bowiei Lindl.	OXALIDACEAE
Oxalis depressa Eckl. & Zeyh.	OXALIDACEAE
Oxalis smithiana Eckl. & Zeyh.	OXALIDACEAE
Oxalis species	OXALIDACEAE
Ozoroa mucronata (Bernh. ex C.Krauss) R.& A.Fern.	ANACARDIACEAE
Pachypodium bispinosum (L.f.) A.DC.	APOCYNACEAE
Pachypodium succulentum (L.f.) Sweet	APOCYNACEAE
Panicum coloratum L. var. *coloratum*	POACEAE
Panicum deustum Thunb.	POACEAE
Panicum maximum Jacq.	POACEAE
Pappea capensis Eckl. & Zeyh.	SAPINDACEAE
Pelargonium alchemilloides (L.) L'H,r.	GERANIACEAE

Pelargonium ovale (Burm.f.) L'H,r. ssp. *veronicifolium* (Eckl. & Zeyh.) Hugo	GERANIACEAE
Pelargonium reniforme Curtis ssp. *velutinum* (Eckl. & Zeyh.) Dreyer	GERANIACEAE
Pelargonium species	GERANIACEAE
Pelargonium trifidum Jacq.	GERANIACEAE
Pelargonium zonale (L.) L'H,r.	GERANIACEAE
Pentzia globosa Less.	ASTERACEAE
Pentzia incana (Thunb.) Kuntze	ASTERACEAE
Pentzia spinescens Less.	ASTERACEAE
Peristrophe cernua Nees	ACANTHACEAE
Pharnaceum dichotomum L.f.	AIZOCEAE
Phylica parviflora P.J.Bergius	RHAMNACEAE
Phymaspermum parvifolium (DC.) Benth. & Hook. Ex Jackson	ASTERACEAE
Plexipus cuneifolium (L.f.) E.Mey.	VERBENACEAE
Plumbago auriculata Lam.	PLUMBAGINACEAE
Polygala leptophylla Burch.	POLYGALACEAE
Polygala microlopha DC. var. *microlopha*	POLYGALACEAE
Polygala myrtifolia L.	POLYGALACEAE
Polygala uncinata E.Mey. ex Meisn.	POLYGALACEAE
Portulacaria afra Jacq.	PORTULACACEAE
Priva cordifolia (L.f.) Druce var. *abyssinica (* Jaub. & Spach) Moldenke	VERBENACEAE
Priva species	VERBANACEAE
Ptaeroxylon obliquum (Thunb.) Radlk.	PTAEROXYLACEAE
Pteronia incana (Burm.) DC.	ASTERACEAE
Pteronia oblanceolata Phill. FP	ASTERACEAE
Pteronia tricephala DC.	ASTERACEAE
Putterlickia pyracantha (L.) Szyszyl.	CELASTRACEAE
Pycreus species	CYPERACEAE
Restio species	RESTIONACEAE
Rhigozum obovatum Burch.	BIGNONIACEAE
Rhoicissus tridentata (L.f.) Wild & R.B.Drumm. ssp. *cuneifolia* (Eckl. & Zeyh.) Urton	VITACEAE
Rhus crenata Thunb.	ANACARDIACEAE
Rhus gueinzii Sond.	ANACARDIACEAE
Rhus laevigata L. var. villosa (L.f.) R.Fern.	ANACARDIACEAE
Rhus pentheri Zahlbr.	ANACARDIACEAE
Rhus pterota C.Presl	ANACARDIACEAE
Rhus refracta Eckl. & Zeyh.	ANACARDIACEAE
Rhus species	ANACARDIACEAE
Rhus undulata Jacq.	ANACARDIACEAE
Rhynchosia calvescens Meikle	FABACEAE
Rhynchosia capensis (Burm.) Schinz	FABACEAE
Rhynchosia caribaea (Jacq.) DC.	FABACEAE
Rhynchosia ciliata (Thunb.) Schinz	FABACEAE
Rhynchosia species	FABACEAE
Rhynchosia totta	FABACEAE
Ruellia cordata Thunb.	ACANTHACEAE
Ruellia species	ACANTHACEAE
Ruschia species	MESEMBRYANTHEMACEAE
Ruschia uncinata (L.) Schwantes	MESEMBRYANTHEMACEAE
Salpinctium stenosiphon (C.B.Clarke) T.J.Edwards	ACANTHACEAE
Salvia repens Burch. ex Benth. var. repens	LAMIACEAE
Salvia scabra L.f.	LAMIACEAE

Salvia species	LAMIACEAE
Salvia triangularis Thunb.	LAMIACEAE
Sansevieria hyacinthoides (L.) Druce	DRACANEACEAE
Sarcostemma viminale (L.) R.Br.	ASCLEPIADACEAE
Schismus inermis (Stapf) C.E.Hubb.	POACEAE
Schkuhria pinnata (Lam.) Cabrera	ASTERACEAE
Schotia afra (L.) Thunb. var. afra	FABACEAE
Schotia latifolia Jacq.	FABACEAE
Scirpus species	CYPERACEAE
Scolopia mundii (Eckl. & Zeyh.) Warb.	FLACOURTIACEAE
Scolopia zeyheri (Nees) Harv.	FLACOURTIACEAE
Scutia myrtina (Burm.f.) Kurz	RHAMNACEAE
Secamone alpini Schult.	ASCLEPIADACEAE
Secamone filiformis (L.f.) J.H.Ross	ASCLEPIADACEAE
Selago corymbosa L.	SELAGINACEAE
Senecio angulatus L.f.	ASTERACEAE
Senecio burchellii DC.	ASTERACEAE
Senecio deltoideus Less.	ASTERACEAE
Senecio filifolius Harv.	ASTERACEAE
Senecio lineatus (L.f.) DC.	ASTERACEAE
Senecio pterophorus DC.	ASTERACEAE
Senecio radicans (L.f.) Sch.Bip.	ASTERACEAE
Senecio species	ASTERACEAE
Setaria incrassata (Hochst.) Hack.	POACEAE
Setaria species	POACEAE
Setaria sphacelata (Schumach.) Moss var. *sericea* (Stapf) Clayton	POACEAE
Sida cordifolia L.	MALVACEAE
Sida ternata L.f.	MALVACEAE
Sideroxylon inerme L. ssp. *inerme*	SAPOTACEAE
Solanum aculeastrum Dunal	SOLANACEAE
Solanum burbankii Bitter	SOLANACEAE
Solanum coccineum Jacq.	SOLANACEAE
Solanum hermannii Dunal	SOLANACEAE
Solanum species	SOLANACEAE
Spiloxene trifurcillata (Nel) Fourc.	HYPOXIDACEAE
Sporobolus fimbriatus (Trin.) Nees	POACEAE
Sporobolus nitens Stent	POACEAE
Stachys aethiopica L.	LAMIACEAE
Strelitzia reginae Aiton	STRELITZIACEAE
Sutera aspalathoides (Benth.) Hilliard	SCROPHULARIACEAE
Sutera aurantiaca (Burch.) Hilliard	SCROPHULARIACEAE
Sutera campanulata (Benth.) Kuntze	SCROPHULARIACEAE
Sutera canescens (Benth.) Hilliard var. *canescens*	SCROPHULARIACEAE
Sutera halimifolia (Benth.) Kuntze	SCROPHULARIACEAE
Sutera pinnatifida (Benth.) Kuntze	SCROPHULARIACEAE
Sutera polelensis	SCROPHULARIACEAE
Sutera uncinata (Desr.) Hilliard	SCROPHULARIACEAE
Talinum caffrum (Thunb.) Eckl. & Zeyh.	PORTULACACEAE
Tecoma capensis (Thunb.) Lindl.	BIGNONIACEAE
Tephrosia capensis	FABACEAE
Tephrosia grandiflora (Aiton) Pers.	FABACEAE
Tephrosia shiluwanensis Schinz	FABACEAE
Tetragonia echinata Aiton	AIZOCEAE
Teucrium africanum Thunb.	LAMIACEAE

Teucrium trifidum Retz.	LAMIACEAE
Themeda triandra Forssk.	POACEAE
Thesium flexuosum A.DC.	SANTALACEAE
Thunbergia capensis Retz.	ACANTHACEAE
Thunbergia dregeana Nees	ACANTHACEAE
Tragus berteronianus Schult.	POACEAE
Tragus racemosus (L.) All.	POACEAE
Tragus species	POACEAE
Tritonia laxifolia Benth. ex Baker	IRIDACEAE
Tritonia species	IRIDACEAE
Urginea altissima (L.f.) Baker	HYACINTHACEAE
Viscum rotundifolium L.f.	VISCACEAE
Walafrida geniculata (L.f.) Rolfe	SELAGINACEAE
Watsonia species	IRIDACEAE
Zanthoxylum capense (Thunb.) Harv.	RUTACEAE
Ziziphus mucronata	RHAMNACEAE
Zygophyllum foetidum Schrad. & J.C.Wendl.	ZYGOPHYLLIACEAE

APPENDIX 4

DOMINANT PLANT SPECIES DEFINING THE PLANT COMMUNITIES WITHIN THE NATURE CONSERVATION AREAS

		SUCCULENT BUSHCLUMP SAVANNA																			MEDIUM SUCCULENT THICKET																																																		MESIC BUSHCLUMP SAVANNA																										GRASSLANDS OF THE MESIC BUSHCLUMP SAVANNA																	
		239	161	162	163	164	81	62	170	173	263	7	10	11	66	171	208	85	174	175	183	1	2	6	8	9	84	87	256	179	180	181	182	200	201	206	214	219	221	223	231	233	234	240	242	244	246	248	250	253	259	192	197	203	207	209	191	213	235	241	247	249	3	4	188	199	210	257	264	5	172	176	218	229	215	225	226	227	228	232	258	202	204	236	237	238	245	251	216	217	220	222	230	243	184	83	186	252	168	212	224	254	166	167	195	205	189	190	211	255	165	163	194
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	AIZO GLI				+		1	+	+		1	+		1			+	+		+																	+														1																														1			+												+				1						+							
	HELI ORE		1	1	+								+			+		+	+																																																				1																																														
	COMM AFR			+	+		+	1	+	+		+	+			+	+					+	+																				+										+						1																													+											+							+		+							
	SANS HYA	+	1	+			1		+		1		+		+	+	+	+		+																														+									+																							+					1			+																					
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	KALA ROT		+		+		+		+		1			1		+	+		+			+	+															1													+																							+	1										+																													
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	CRAS PER	+	+		+	1			+	+	+	+	+				+					+	+		+	+		+	+	+	1		+	+	+		1		+		1	+		+	+		+	+	1	+	1	+				+		+												1												+																																							
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	RHOI TRI			+	+				1	+	1	+		+			+	+				+	+	+	+	1	+	+	1		+			+			+	+	+	+	+	+	1		+	+	+	+	+	+	1		+		2	+		2	1			1					+									+										+			+	+			+	1					+															
	PANI MAX								1	+	1			1	+	+		+		+		+	2		1	1			1		1	4			+	4	1	3		3	1		3		+	1	4	1	2	3	1	1	+			1	3	2	1	+	4	+	1	+	2	2	+	1							+	1	+	+	+		1	2	3			+	+								1	+		1	+	+		1	+	1	+	3	4		4	3	4	2	1	1
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	EHRE RIG								+	+		+		+		1		+	+		+	+				+		+							2			1		1			+			1		+	+		1		+	+			1	1	1	+	+	+	+		+	+		1	1	4	1				+	1				1			2	+	+		1		1			+	+	+							+												
	GREW ROB		1	1					1		1	1	4	1	2	3	4		1	1		+	1		1	1		1	1		4	1			3		+	2			1	+	2		2	+	2		3	+	1		+	1	4	2		1						1	+				1		1		+	1	1	1	+		+	2		2	1	+	1	1	+		4	3	+	1	1	1	2	4	3	1		1	+		+		2	2				+			+
	CAPP SEP			1											1									+		1	1			1	+		1	1	+		+	+		+			1			1			+									2		1	+	+			+			+										+	+																																		+		
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	AZIM TET	1		1						2					+			+					1			2			1	1	1	+	+	+	+			2		3		+	+	+	+			+	+	+	1						2		+	2			+					1															2												+																		1	
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	MAYT CAP		2	1	1			1				+		1	+				+							1			1		+	1								1		+	3								1	1	2	+	2	+	3		2						1			1	1		+			1			1	1	+			2		1					+		+					2	+																
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	CYMB MAR																																				1										2																												+	1			+				2				3	2		1	1	+	4																		
	GAZA LIN																																																						+										+										+	1				1	1						+			+				+															+				
	RHUS INC																																																																														1	2	2		2	1	1	+	+		4																															
	RHUS REP															+			+																																				1	1		+						+	+		1		+							+	+						+		3	+	+		1			+	+	+	+			+										3				2				2
	RHUS UND							1																																																													1				+	+	+	1	1		+		+						+	+	+	+			1	1	1		2		1													4		
	BUDD SAL																																																												1			+	+							1				1							+		1	1	1	1	1																										1				1
	COOD RUD																																				1								+																						1							1		+	+	+	1	+		+					+			1	1	1	1																					
	CLUT ALA																1																																																				+								+		+	+	+		+	+	+	+							+					+						+												
	ERAG CUR																																												+																								1	4						1	1	2	+	+		+								+																									
	HIBI PUS				+		+						+				+				+																					+						+																		+										+	1	1		+		1	1	1		1	1	1	1	+		+	+	+		+	+																			
	OLEA EUR																																				1																														3						+						1	1						+	+	+															+										+	1	
	SUTE PIN																+																			+			+			+																	+														+	+		+	1		1					1		+	+						1	+					+		+			+		+							1
	THEM TRI						1												+																		1					+					+															+									1			+	+		1	2			1	1		+	+		2			3	+	1		+	2	2													2				
	ERAG LEH																																												+															+	+													1		1			1	1					+	+	+															+											
	GNID CUN																																									+											+																											+			+				1	+	1	+	+									+											
	PELA REN																	+								+																												1																				+		+		1		1	1	1	1				1																							+					+
	VISC ROT																																								+															+											+										+	+						+	+	+			+		+			+												+	+							
GMBS	ARIS CON		+					+					+													+																1					1																										1	+			+			+	1		3		1			1			1	1	1	3	1	4	+	1		+			1	+	4		+							
	WALA GEN								+											1		+							+																													3																	2	1								+	+	+	+	+	+										+		+	+	1	+			+	+		1	+				
	ASPA STR				+							+			+				+												1					1		1			+					+							+			+																		+			+		+		+	1			+		+	1		1	1	+	+	+	+		+		1						+	+	+							
	ERAG OBT		+					1																																										+																					+		+	1	1		+			1	+	1	2					1							+		+	+	+	+	1			+	+	1	1	+	+	1	+			3
	LEUC CAP								+							+			1						+			1				+											1																							1			1			+	1					1			+		+	+											1				+	1					+						+
	BETA SPH																					+																												1				+		1						+			+												1	+	1		1		1		4		+	3	3		+	1	+	+	1	1	1		+	+	+	1			2		1	+	+		1				
	CHRY CIL				+																								+							+																1						+																				1	1		2	+		+		+	+	+				1	1	1	1	1			+	+			1	4			3	1	+	3					
	HERM ALT																1																													+			+								+																			1	1	+	+	1		1	+	1		+	+	+	+	+		+	1		+								+		+	+			+	+	+	1	+				
	DIGI ERI																		1							+																									1											+			+											1	1	2	1	1		2	+	1	3	4	+	4	3				1	+	+	1	1	4	+			2			1	3	3			+	+	1	+			
	HELI ROS										1																				+							+					1																																		3	4	3		1	2		2	1	1	1	2	1			1			+	+	+				1	1	1	+	+	+	+	+			1				
	LYCI FER												+																														+														+																					1			+					+	+			+											+	+	+		1		+	+	+	+	+		+	1		+	
	SPOR NIT		+					+			1																				+																								+																															+											+						+	+	+	+	+		1				+		+			
	CYNO DAC																																			+																					+		+																			1																								1		1	1	+	1	+	1	+	2	4		+	3	2	2	
	FELI MUR		1																										+																									+									+		+									+						+				+									1		+	1			1			+	4		+					+		+	
	PENT INC		+				4									1	+															1										+			+																																																		+					1						3	1	4	4		4			1			+	3		4			+
	TRAG BER											1																														+																																																											+			+			+					+			+	1			+				
	OXAL BOW																																																																																																														+	+	+				1					+		2	1	+
	SPOR FIM																		1																	+					+											1		+			+	1							+												2			+				1									1					+	1			2	+			+		+		+		1				3
	SCHI INE																																																																																																																								1							3	
	PUTT PYR								+													1															1						2						1									+				1					1		+					4	1														1						1		2		1		+		+	+	+	+										
	ACAC KAR																																																																											1										+				2									1		+	+	+	1		2		1		+		+	1	4	1	2

DOMINANT PLANT SPECIES DEFINING THE PLANT COMMUNITIES WITHIN THE COMMERCIAL RANGELANDS

SHORT SUCCULENT THICKET

2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
7 7 7 7 6 7 7 8 8 8 7 8 6 8 8 8
4 5 6 7 2 3 8 0 2 5 9 1 0 3 4 5

MEDIUM SUCCULENT THICKET

2 6 6 1 1 1 3 2 4 4 5 6 6 7 7 8 3 7 1 1 2 2 3 3 4 6 6 5 6 6 7 7 7 7 7 1 2 3 4 4 7 7 4 2 3 3 3 3 4 1 3 3 4 4 1 2
9 7 9 4 6 7 0 0 5 7 6 1 2 0 2 0 7 7 6 9 2 4 4 6 2 3 4 5 6 8 1 5 7 8 8 8 3 8 3 5 3 4 5 7 1 2 3 8 1 3 5 7 0 4 2 1

GRASSLANDS OF THE MESIC BUSHCLUMP SAVANNA

2 2 6 4 4 4 4 6 4 6 5 7 3 3 3 3 4 4 4 4 6 6 2 4 5 5 5 6 6 5 4 7
6 8 1 1 2 3 3 0 8 0 4 9 4 5 8 9 4 6 7 8 0 5 5 8 1 2 3 6 7 8 0 6

MESIC BUSHCLUMP SAVANNA

1 1 1 1 1 1 1 1 1 1 1 1 1 1
3 6 6 5 5 6 5 5 5 5 5 5 6 6
6 7 9 1 2 8 9 3 4 6 7 5 6 8

SST	EUPH BOT
	PLUE VER
	TRAG RAC
	CAPP SEP
	OZOR MUC
	SANS HYA
	BOSC OLE
	JASM MUL
	KALA ROT
	SARC VIM
	EHRE RIG
	KEDR AFR
	PANI DEU
MST	PANI MAX
	PTAE OBL
	JATR CAP
	RHOI TRI
	SCHO AFR
	ASPA AFR
	EUPH TET
	PORT AFR
	MAYT CAP
	GREW ROB
	RHIG OBO
	EUCL UND
	ASPA CRA
	CRAS PER
	DELO CAL
	AIZO GLI
	AZIM TET
	PUTT PYR
	CRAS OVA
	CRAS TET
	EUPH TRI
	GLOS PAR
	ASPA SUB
	BARL OBT
	CRAS EXP
	CRAS MUC
	CRAS OBO
	SETA INC
	GREW OCC
	TETR ECH
	STRE REG
	TRAG BER
	INDI DIS
	CARI BIS
	CHEN ALB
	WALA GEN
	CYNO DAC
	OPUN FIC
GMBS	PAPP CAP
	BRAC ILI
	BLEP CAP
	LANT RUG
	MAYT POL
	ASPA STR
	LEUC CAP
	PERI CER
	LAMP PRO
MBS	ASPA SUA
	ASPA RAC
	ERAG OBT
	FELI MUR
	LYCI SPP
	PENT INC
	RHUS REF
	SOLA COC
	SPOR FIM
	ARIS CON
	THEM TRI
	SPOR NIT
	DIGI ERI
	ACAC KAR
	HERM BUR
	HIBI PUS
	HELI DRE
	ABUT SON
	DIOS DIC
	FELI FIL
	PLUM AUR
	CHRY CIL
	CYMB PLU
	PANI COL
	CUSS SPI
	EUST PAS
	SCUT MYR
	ALOE FER
	COMM AFR
	CRAS NES
	CYPH QUI
	PELA REN
	RHUS CRE
	SUTE ASP
	EUPH MAU
	PACH SUC
	RHUS PTE
	PTER INC
	CRAS ERI
	PACH BIS

DOMINANT SPECIES DEFINING THE PLANT COMMUNITIES WITH THE COMMUNAL RANGELANDS

		GRASSLANDS OF THE MESIC BUSHCLUMP SAVANNA																																		DWARF SHRUBLAND																					
		107	108	272	101	59	112	116	117	119	120	60	90	92	93	94	95	96	99	100	115	118	132	89	91	97	98	88	102	113	114	131	269	270	271	109	111	126	105	106	121	122	123	124	104	110	125	130	127	128	129	133	103	265	266	267	268
CMBS																																																								
	EUPH TRI	3	4	1																																																				
	COMM AFR	+	+			+				+																																														
	PANI DEU		1		+				+																																																
	CUSS SPI			1			+	1	+	+		+																																													
	ALOE TEN						1			1	1	+									+		+																																				
	CETE COR	+			1			+	+	+	+		+																+																														
	DIOS DIC				1			+	1		4																	1	+																														
	GLOS PAR				4																																																				
	KALA ROT					+	+				+	+																	+																														
	PUTT PYR							1				2											1					2																														
	HELI ORE										1																			4	1		1																									
	PANI COL	2	1		+																																																				
	MAYT NEM													+		2				+																																						
	BARL OBT	+										1					+										+																														
	ACHY LEP		+														+	+																																						
	EUST PAS																						+	1		+						1																									
	OLEA EUR										+						+	+																																						
	SALV REP									+	1															+																																
	BRAC ILI		+		+	4		1	1				4		+									2				1	3		+																+											
	PAPP CAP	1								+		+					+																	1																								
	ASPA RAC							+	+	+	+	+	+	+			+		1			+	+				+	+										+											+									
	CYMB PLU															1	+		1	2				1	+	1	1	2																														
	GREW OCC	+	1					1	1			1				+	+		2	1		+				1	1																														
	RHUS REF								1	1		1						2		+			1			1		3								+																						
	RHUS UND			1	2									+						3			1				+																																	
	SOUT MYR							1	1	1	1	1	1		3	3	4	3	1	1			3				2																															
	SPOR FIM					+	+	1	4	3	1	4	1	4	4	4	4	4	4	3	4	4	4	1	2	1	1	1	+			1													1								3					
	THEM TRI								1					2		+	+	+	+					4		1	1																															
	ACAC KAR				1		1	1		1	1		3	3	3	1	+	1	1	3	2	1	2	1		1		+	1	1	4	4	1	1	1		+																					
	EUCL UND	2	1			1				1		2		+		+										2	1	1	+		+																											
	HIBI PUS					+		+		+	+		+	+	+				+	+			+	+	+	+		+			+	+																										
	EHRE RIG	1						+	+					+	+		+	1	2	2		+	+	2	1			1				+															+								1
	LANT RUG	+	+			+		+	+	+	+	+			+		+	+	1	+	2	+	1													+																				
	HERM BUR													+	+	+	+	+		+	+	+	+	+	+	+				+																+									
	ALOE FER					1	+	3	2	3	2	2	1		1			+	+	2		+				+								1	1																					1		
	JASM ANG				1		+		+	+																																													
	MAYT POL	1	1		3			1	1	1		1	1	+				1	2	+		1		+			+	1																				+					3							
	JASM MUL				1		+		+	+	+		+					+										+																													
	MAYT CAP		1				2		1	+							1						+			2	1	+	2																								1										1
	ABUT SON	1			1						+	+			+		+											+							+					+																	
	PANI MAX	1	1		1	1		1	1			1	+		1					1		+		+		3		+		+				1	1	4								+								1			1	
	ERAG OBT					+	+	+	+	1	+		+	+					+		+	1	+		+	1		+	1			+			1										+	+		+	+		+	+	+				
	DIGI ERI					+	1	+	+	1			+	1	1	3	+	+	3	1		1		3			1	+				2	1		1										1	1			+				2	1		1	1
	FELI FIL					1	1	2															+	+		3	3													+	+				+		+			1	1	+								
	ARIS CON					+	+				+		1	+						+	2	1			1	+		+	+	+	1	2	1		1							+			1	+	+		+		+	+		1	1	1	1
	SUTE HAL				+										+			+	+				+										+					3	+																					
	ASPA SUA	1	+		+		1	+	+	+	+		+	+	1	1	+	1	+	1			1		+	+	+	+									+		+	+	+			+	+	+			+		1		1	1	1	1		
	PTER INC				+	4	4	2	+	+	4		1																		1		1				1										+		+		2	4	4				1	1	
	RHUS CRE															2																																		1							
DS	SCHO AFR	1										1																							1									+												+				1
	FELI MUR					+				+				+										+											+				+	+	1			3	+						+	+				
	WALA GEN																									+																			2												1
	CYNO DAC																													4		+			1		1		+	1																1	1	1	
	CHRY CIL						1																																							+			1	1	1	1		1	1	1	1
	DELO CAL					+				+																																							1		1	+							1
	CARI BIS										+					+							+																				2				1	1										
	ADM TET	4																																		3		4	+	+	2		+		1		1	1										
	GREW ROB									1					+									+																+		2	1	+	1	+	1	+	1		1		1	+		1				1
	PTAE OBL	2	1					+				+					+																					1			3	2	1	1		1	3	1										1	1
	SPOR NIT			+																																					+	1		+	+	+		+	+				+	+		2		1		
	KEDR AFR		+																																									+						+		+	+				+			
	LEUC CAP					+						+				+										+													+						+		+	+	1	1				1	1			
	MORA POL											+										+																					+				+			+		+	+				1			
	LAMP SPE																																													1					1	1	+							
	ASPA SUB					+																															+			+	+	+			+	+			+	+				+			
	EUPH MAU																																							1		1		+			1			1	1		1		+				1
	LAMP PRO									+																																	1					+				+	1			1				
	PENT INC																														+					+	1	2		3	+	+	4	+	1		+	2	1	2	1	1	+	1	1		
	RHIG OBO																														+					1	1	1			+	1		+			4		2	1		2				
	EUPH SPP																																											1															
	FLUE VER					+	+																													1			1			1	+		1				+		1						1
	ASPA CRA	+	+																																	+		+	1	+		+	+			+							+				
	CYPH QUI		+																																							1			+											+			
	JATR CAP																																							+	3		1	1		+	1		1	+				1				1
	TRAG BER		+																																	2			3	3			+			2		1									
	AIZO GLI																											+										1				+							+	1	+		+		1	1	1
	ALOE STR																																																	+	1	+						1	
	ASPA STR																											1												+							+			+	+	+	2	+	1			
	ERAG CUR																																		1																					1	1		
	INDI SES																				+									+																									1	1		
	LASI CAP																																		1																						1	1	
	PORT AFR																																1																											1
	OPUN FIC						+			+		+						+																						+													1	1	
	RHOI TRI	+								+																																															1
	ASPA SPP																																		1																						1		1
	HERM ALT																																																									1	1	
	SETA SPH																																		1																					1		1	1
	ASPA AFR					+						+																																				+								1
	CODD RUD																																									1														1	1	1	
	EXOM MIC																																				1																				1		
	ALOE CIL																																																							1				1
	CRAS PER																																																											1
	LYCI SCH																																																							1	1		
	CAPP SEP																																			1				+				+	+												
	PLUM AUR																																			+		+					1															
	SOLA COC																																					+							+					+							
	SARC VIM																																																						+				1
	EUPH TET																																												1								3				
	SANS HYA																																						+	+							+				+				
	GALE PUB																																					1												1								

APPENDIX 5

Publications

Evans, N.V., Avis, A.M. and Palmer, A.R. 1997. Changes to the vegetation of the mid-Fish River valley, Eastern Cape, South Africa, in response to land-use, as revealed by a direct gradient analysis. . *African Journal of Range and Forage Science* **14**(2): 68-74.

Birch, N.V., Avis, A.M. and Palmer, A.R. 1999. The Effect of land-use on the vegetation communities along a topo-moisture gradient in the mid-Fish River valley, South Africa. *African Journal of Range and Forage Science* **16**(1&2): 1-8.

Birch, N.V., Avis, A.M. and Palmer, A.R. 1999. Changes to the vegetation communities of natural rangelands in response to land-use in the mid-Fish River valley, South Africa. *People and Rangelands Building the Future* (Eds D. Eldridge & D. Freudenberger) pp.319-320 vol 1. Proceeding of the VI International Rangeland Congress, Townsville, Queensland, Australia

APPENDIX 6

Rainfall statistics from the rainfall recording stations within the study site

STATION I.D.	LAT	LONG	ALT. (M)	RECORD SPAN	COMPLETE DATA YEARS	LOCATION/CONTRACT
0057580 W	3310	2650	91	1967 2000	24	COMMITTEES (POL)

MEAN	361.8
MEDN	340.6
STD	118.7
C.V.	32.8
SKEW	.2

STATION I.D.	LAT	LONG	ALT. (M)	RECORD SPAN	COMPLETE DATA YEARS	LOCATION/CONTRACT
0057159 W	3310	2636	305	1917 1938	11	UPLANDS

MEAN	304.0
MEDN	323.9
STD	92.1
C.V.	30.3
SKEW	.2

STATION I.D.	LAT	LONG	ALT. (M)	RECORD SPAN	COMPLETE DATA YEARS	LOCATION/CONTRACT
0057099 W	3309	2632	317	1898 1913	7	HEATHERTON TOWERS

MEAN	349.2
MEDN	334.7
STD	69.4
C.V.	19.9
SKEW	. 6

STATION I.D.	LAT	LONG	ALT. (M)	RECORD SPAN	COMPLETE DATA YEARS	LOCATION/CONTRACT
0057188 W	3308	2637	274	1967 2000	25	FORT BROWN (POL)

MEAN	394.8
MEDN	360.5
STD	126.2
C.V.	32.0
SKEW	.4

STATION I.D.	LAT	LONG	ALT. (M)	RECORD SPAN	COMPLETE DATA YEARS	LOCATION/CONTRACT
0057366 A	3306	2643	366	1980 1991	9	BUCKLANDS

MEAN	442.0
MEDN	373.7
STD	166.8
C.V.	37.7
SKEW	.9

STATION I.D.	LAT	LONG	ALT. (M)	RECORD SPAN	COMPLETE DATA YEARS	LOCATION/CONTRACT
0057187 W	3306	2637	282	1909 1918	4	BRANDESTON

MEAN	409.2
MEDN	418.0
STD	105.7
C.V.	25.8
SKEW	2

STATION I.D.	LAT	LONG	ALT. (M)	RECORD SPAN	COMPLETE DATA YEARS	LOCATION/CONTRACT
0057755 W	3305	2657	521	1938 1952	10	BREAKFAST VLEI

MEAN	466.3
MEDN	502.1
STD	171.5
C.V.	36.8
SKEW	3

STATION I.D.	LAT	LONG	ALT. (M)	RECORD SPAN	COMPLETE DATA YEARS	LOCATION/CONTRACT
0058334 W	3304	2712	162	1932 1973	20	LINE DRIFT

MEAN	403.2
MEDN	400.9
STD	114.6
C.V.	28.4
SKEW	.2

STATION I.D.	LAT	LONG	ALT. (M)	RECORD SPAN	COMPLETE DATA YEARS	LOCATION/CONTRACT
0057454 W	3304	2646	228	1938 1950	11	GREENLANDS

MEAN	422.2
MEDN	421.8
STD	113.3
C.V.	26.8
SKEW	.0

STATION I.D.	LAT	LONG	ALT. (M)	RECORD SPAN	COMPLETE DATA YEARS	LOCATION/CONTRACT
0058122 W	3302	2706	210	1929 1942	7	DANK DEN GOEWERNEUR

MEAN	365.4
MEDN	351.4
STD	80.9
C.V.	22.1
SKEW	1.2

STATION I.D.	LAT	LONG	ALT. (M)	RECORD SPAN	COMPLETE DATA YEARS	LOCATION/CONTRACT
0057631 W	3301	2653	451	1934 1963	25	BRAKFONTEIN

MEAN	460.4
MEDN	451.3
STD	134.5

C.V. 29.2
SKEW 1.0

STATION I.D.	LAT	LONG	ALT. (M)	RECORD SPAN	COMPLETE DATA YEARS	LOCATION/CONTRACT
0078296 W	3257	2640	511	1938 1989	44	MERINO

MEAN 479.4
MEDN 474.6
STD   123.3
C.V. 25.7
SKEW.4

STATION I.D.	LAT	LONG	ALT. (M)	RECORD SPAN	COMPLETE DATA YEARS	LOCATION/CONTRACT
0077895 W	3256	2631	533	1930 1955	10	SEVENFONTEIN

MEAN 332.1
MEDN 309.6
STD   99.1
C.V. 29.8
SKEW .8

STATION I.D.	LAT	LONG	ALT. (M)	RECORD SPAN	COMPLETE DATA YEARS	LOCATION/CONTRACT
0079384 W	3254	2713	500	1948 1977	21	NTSIKIZINI

MEAN 495.5
MEDN 490.3
STD   154.0
C.V. 31.1
SKEW.2

STATION I.D.	LAT	LONG	ALT. (M)	RECORD SPAN	COMPLETE DATA YEARS	LOCATION/CONTRACT
0079234 W	3254	2710	555	1938 1953	14	XUKWANE

MEAN 532.2
MEDN 539.6
STD   134.9
C.V. 25.3
SKEW.6

STATION I.D.	LAT	LONG	ALT. (M)	RECORD SPAN	COMPLETE DATA YEARS	LOCATION/CONTRACT
0079200 W	3252	2705	518	1922 1951	17	FORT WHITE

MEAN 570.8
MEDN 568.0
STD   125.8
C.V. 22.0
SKEW.0

STATION I.D.	LAT	LONG	ALT. (M)	RECORD SPAN	COMPLETE DATA YEARS	LOCATION/CONTRACT
0078530 W	3251	2646	550	1916 1953	28	GARFIELD

MEAN 434.3
MEDN 432.4
STD   123.8
C.V. 28.5
SKEW.4

STATION I.D.	LAT	LONG	ALT. (M)	RECORD SPAN	COMPLETE DATA YEARS	LOCATION/CONTRACT
0078890 W	3250	2700	457	1914 1923	8	HOBBS DRIFT

MEAN 549.9
MEDN 524.4
STD   169.8
C.V. 30.9
SKEW.0

STATION I.D.	LAT	LONG	ALT. (M)	RECORD SPAN	COMPLETE DATA YEARS	LOCATION/CONTRACT
0078860 W	3250	2659	469	1911 1957	25	MIDDELDRIFT (SAR)

MEAN 472.8
MEDN 467.9
STD   139.9
C.V. 29.6
SKEW.2

APPENDIX 7

The default options used in the classification and ordination of the vegetation data of the mid-Fish River Valley

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Default options set for TWINSPAN

Pseudospecies cut levels are: 0 2 5 10 20.
Minimum group size for a division is 5.
Maximum number of indicators per division is 7.
Maximum number of species in final table is 100.
Maximum level of divisions is 6.
No diagrams of divisions will be printed.
No machine readable output will be produced.
Pseudospecies will be weighted equally.
All cut levels will have equal indicator potential.
All species will be considered potential indicators.

Default options set CCA CANOCO

Sample scores are weighted mean species scores
No further product variable used
No transformation of species data
Samples not weighted
Species not weighted
No down weighting of rare species

APPENDIX 8

Ordination statistics
Results from the CCA run on all three land-use classes within the study site

---

Nature Conservation

```
Eigenvalue axis 1 = 0.32358
Eigenvalue axis 2 = 0.30909
Eigenvalue axis 3 = 0.17121
Eigenvalue axis 4 = 0.10981

Percentage variance accounted for by first s axes of species-environment
biplot
   s          perc
   1          35.4
   2          69.2
   3          88.0
   4         100.0

Sum of all canonical eigenvalues: trace =     0.91369

Weighted correlation matrix (weight = sample total)
 SPEC AX1     1.0000
 SPEC AX2      .0060     1.0000
 SPEC AX3     -.0156     -.0141     1.0000
 SPEC AX4     -.0009     -.0362     -.0420     1.0000
 ENVI AX1      .8426      .0000      .0000      .0000     1.0000
 ENVI AX2      .0000      .8365      .0000      .0000      .0000     1.0000
 ENVI AX3      .0000      .0000      .6736      .0000      .0000      .0000     1.0000
 ENVI AX4      .0000      .0000      .0000      .6031      .0000      .0000      .0000     1.0000
   ASPECT      .3556     -.0253      .2960     -.4779      .4220     -.0303      .4395     -.7924
   ELEVAT     -.0246      .7978      .1869      .0674     -.0292      .9538      .2774      .1117
  RAINFAL      .6713      .4474     -.1270      .1260      .7967      .5349     -.1885      .2090
    SLOPE      .1847     -.2109      .4288      .4193      .2192     -.2522      .6365      .6951

           SPEC AX1   SPEC AX2   SPEC AX3   SPEC AX4   ENVI AX1   ENVI AX2   ENVI AX3   ENVI AX4
```

Commercial Rangelands

```
Eigenvalue axis 1 = 0.29272
Eigenvalue axis 2 = 0.17729
Eigenvalue axis 3 = 0.12736
Eigenvalue axis 4 = 0.08378

Percentage variance accounted for by first s axes of species-environment
biplot
   S          PERC
   1          43.0
   2          69.0
   3          87.7
   4         100.0

 Sum of all canonical eigenvalues: trace =     0.68116
```

```
Weighted correlation matrix (weight = sample total)
 SPEC AX1     1.0000
 SPEC AX2     -.1005     1.0000
 SPEC AX3     -.0592      .0619     1.0000
 SPEC AX4      .0014      .0282     -.0435     1.0000
 ENVI AX1      .7936      .0000      .0000      .0000     1.0000
 ENVI AX2      .0000      .7361      .0000      .0000      .0000     1.0000
 ENVI AX3      .0000      .0000      .6253      .0000      .0000      .0000     1.0000
 ENVI AX4      .0000      .0000      .0000      .5914      .0000      .0000      .0000     1.0000
   ASPECT      .0804     -.0873      .2262     -.5436      .1013     -.1186      .3617     -.9192
   ELEVAT      .7530      .2294      .0267     -.0152      .9489      .3117      .0427     -.0257
  RAINFAL      .3375      .6576     -.0624     -.0622      .4252      .8934     -.0999     -.1052
    SLOPE     -.0385      .3677      .5366      .0633     -.0486      .4995      .8583      .1071

            SPEC AX1   SPEC AX2   SPEC AX3   SPEC AX4   ENVI AX1   ENVI AX2   ENVI AX3   ENVI AX4
```

Communal Rangelands

```
Eigenvalue axis 1 = 0.44307
Egenvalue axis 2 = 0.28709
Eigenvalue axis 3 = 0.24448
Eigenvalue axis 4 = 0.16259


Percentage variance accounted for by first s axes of species-environment
biplot
   S          PERC
   1          39.0
   2          64.2
   3          85.7
   4         100.0

Sum of all canonical eigenvalues: trace =    1.13724

Weighted correlation matrix (weight = sample total)

 SPEC AX1     1.0000
 SPEC AX2      .0001     1.0000
 SPEC AX3      .0274     -.0350     1.0000
 SPEC AX4      .1044      .0967     -.0813     1.0000
 ENVI AX1      .8183      .0000      .0000      .0000     1.0000
 ENVI AX2      .0000      .7711      .0000      .0000      .0000     1.0000
 ENVI AX3      .0000      .0000      .7736      .0000      .0000      .0000     1.0000
 ENVI AX4      .0000      .0000      .0000      .7292      .0000      .0000      .0000     1.0000
   ASPECT     -.1018     -.1164      .6307     -.3974     -.1244     -.1509      .8153     -.5451
   ELEVAT     -.7542      .0209      .0686      .2747     -.9217      .0272      .0887      .3767
  RAINFAL     -.4646      .6198      .1000      .0886     -.5678      .8038      .1293      .1215
    SLOPE      .2699      .0540      .5888      .4040      .3298      .0700      .7611      .5541

            SPEC AX1   SPEC AX2   SPEC AX3   SPEC AX4   ENVI AX1   ENVI AX2   ENVI AX3   ENVI AX4
```

APPENDIX 9

Summary table showing the range of values and the mean and median values for the environmental variables for the three land use classes in the study area

	Mean values				Median values				Range of values			
Land use	**Aspect**	**Elevation**	**MAR**	**Slope**	**Aspect**	**Elevation**	**MAR**	**Slope**	**Aspect**	**Elevation**	**MAR**	**Slope**
Nature conservation	186.8	361.2	440.3	5.4	201	362	433	5	3-360	118-587	378-673	1-16
Commercial rangelands	127.0	340.4	476.9	4.4	86	321	456	4	0-360	115-600	366-673	0-13
Communal rangelands	189.7	328.5	448.9	4.9	198	377.5	461	4	0-360	52-600	360-540	0-18