BEST LAND-USE STRATEGIES TOWARDS SUSTAINABLE BIODIVERSITY AND LAND DEGRADATION MANAGEMENT IN SEMI-ARID WESTERN RANGELANDS IN SOUTHERN AFRICA, WITH SPECIAL REFERENCE TO ANTS AS BIO-INDICATORS

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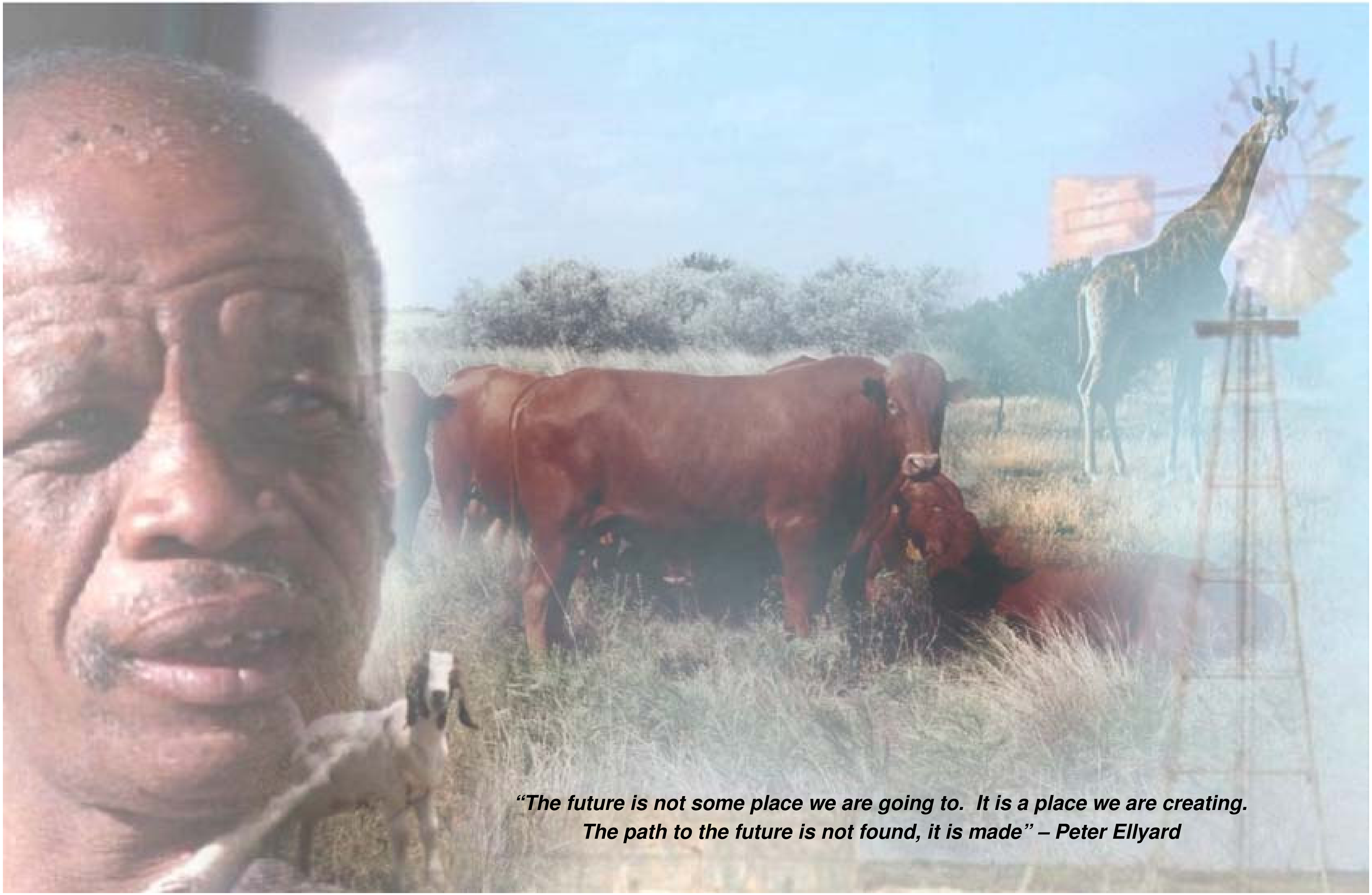

“The future is not some place we are going to. It is a place we are creating.
The path to the future is not found, it is made” – Peter Ellyard

Dedicated to my husband, Jaco, our children, and to my parents, for their love and support throughout the study

"You are worthy, O Lord,
To receive glory and honor and power;
For You created all things,
And by Your will they exist and were created." – Revelation 4:11

ABSTRACT

Best land-use strategies towards sustainable biodiversity and land degradation management in semi-arid western rangelands in Southern Africa, with special reference to ants as bio-indicators

In South Africa, the unsustainable use of natural resources by domestic livestock has led to resource depletion and serious land degradation. Rangeland degradation, especially bush encroachment and soil erosion, is particularly acute in the North-West Province, where all districts show signs of desertification and a loss of biodiversity resulting in a deterioration of human and animal health. This has a major impact on livestock productivity and the economic viability of livestock farming with serious consequences for the livelihoods of pastoral communities. It is important to recognise ecological change before irreversible changes occur. The aim of this study, which falls within the Global Environmental Facility Desert Margins Programme (GEF-DMP), was to investigate to what extent vegetation in combination with ant communities can be used as indicators of ecosystem change due to anthropogenic human induced land-use patterns and how can this information be used in land degradation management and biodiversity conservation in the semi-arid western rangelands of Southern Africa. Sites, representing a degradation gradient (relative poor and relative good rangeland condition extremes) within each of three Tribal-, three Commercial- and three Reserve areas, were surveyed. The impacts of these land uses on the herbaceous species composition, woody-, soil- and ant components were evaluated. Both the woody and herbaceous species components reflected the existence of a rangeland condition/degradation gradient across the larger study area. The herbaceous species composition reflected similar degradation tendencies within the Commercial and Reserve land uses, with sites being associated with low rangeland as well as high rangeland condition scores. The tendencies differed between these two land uses based on the woody degradation gradient. The entire Tribal herbaceous- and woody species components showed a transitional shift towards another state, which differed significantly from the Commercial and Reserve land uses. Both the Tribal herbaceous and woody components were associated with low to intermediate rangeland condition ranges, with no significant rangeland condition gradient existing within the Tribal land use.

Understanding and quantification of the soil-vegetation dynamics hold important implications for rangeland degradation management. This study provided criteria for selecting the most appropriate measures when incorporating the soil parameters as additive data in the multivariate analyses with the vegetation, ant and nominal environmental data. Different land use practices resulted in different soil patterns, with significant gradients pertaining to the soil stratum and openness/woodiness groups. There was a significant though neglectable difference pertaining to the rangeland condition/degradation gradient based on the soil component.

Ants have been extensively used as bio-indicators, also with regard to the monitoring of the environmental effects of rangeland pastoralism. Ant species compositional patterns and functional groups displayed congruent clustering and diversity patterns as those of the vegetation and soil components. In contrast to the vegetation components, ant assemblages did not reflect a degradation gradient, but rather reflected environmental changes (modifications) to the habitat structure and -heterogeneity as a result of different land use disturbances.

Both vegetation and ant diversity measures were mainly associated with the Tribal land use. These diversity indices were indicators of habitat complexity, heterogeneity and moderate disturbance, rather than indicators of a rangeland condition/degradation gradient. The diversity patterns are best described by a dichotomy between the humped-shaped productivity/diversity and the habitat complexity/heterogeneity models. Vegetation and ant diversity measures for this study should be considered as environmental indicators of habitat disturbance rather than as biodiversity indicators.

It is suggested that vegetation, soil and ant patterns are best described by the state-and-transition model, which encompasses both equilibrium and non-equilibrium systems. The resilient nature of these rangelands, typical of non-equilibrium systems, was reflected by the low to intermediate differences between land uses with regard to the herbaceous, woody, soil and ant components. However, density-dependent coupling of herbivores to key resources resulted in transitional shifts and modification of the vegetation composition and structure within and between land uses, displaying the equilibrium dynamics pertaining to these rangelands. Small disturbances in these rangelands may result in detrimental "snowball" interactive biotic-biotic/abiotic cascades. Spatial heterogeneous patterns within and between land uses as displayed by the vegetation, soil and ant parameters, necessitate that monitoring and management at patch, paddock and landscape scale should be conducted, cautioning against the extrapolation and over simplification of management strategies across all land uses. Because these arid rangelands are linked socio-ecological systems, it is not possible to address biophysical issues associated with land degradation without including the human dimensions. A "Key assessment matrix" is provided for monitoring and management purposes pertaining to land degradation and diversity aspects within and between the different land uses, and can be used by the land user, extension officer and scientist.

Key words: Land use; rangeland condition; degradation; biodiversity; species composition; indicators; key species; ants; semi-arid rangeland; "Key assessment matrix"

UITTREKSEL

Die beste landsgebruik strategieë vir volhoubare biodiversiteit en landdegradasiebestuur in 'n semi-ariede weiveld van Suider Afrika, met spesiale verwysing na miere as bio-indikator

Die onvolhoudbare benutting van natuurlike hulpbronne deur vee het ernstige uitputting en landdegradasie in Suid-Afrika tot gevolg gehad. Velddegradasie, veral bosindringing en gronderosie, is veral ernstig in die Noordwes Provinsie, waar tekens van verwoestyning en 'n verlies in biodiversiteit in alle distrikte 'n verswakking in menslike- en dieregesondheid tot gevolg het. Dit het 'n geweldige impak op vee produktiwiteit en die ekonomiese lewensvatbaarheid van veeboerdery tot gevolg, wat ernstige implikasies vir die lewenswyses van veeboere inhou. Dit is belangrik om ekologiese veranderinge te herken alvorens onomkeerbare veranderinge plaasvind.

Die doel van hierdie studie, wat deel vorm van die "Global Environmental Facility Desert Margins Programme (GEF-DMP)", was om vas te stel tot watter mate plantegroei in kombinasie met miergemeenskappe as indikator van ekosisteemverandering as gevolg van antropogeniese mens-geïnduseerde landsgebruik patrone gebruik kan word. Dit het verder ten doel om vas te stel hoe hierdie inligting gebruik kan word in die bestuur van gedegradeerde weiveld en biodiversiteitbewaring in die semi-ariede westelike veldgebiede van Suider Afrika. Opnames in persele verteenwoordigend van 'n degradasiegradiënt (relatief swak en relatief goeie veldtoestand uiterstes) binne drie Kommunale, drie Kommersiële en drie Reservaat areas is gedoen. Die impak van hierdie landsgebruiktipes op die grasspesiesamestelling, houtagtige-, grond- en mierkomponente is geëvalueer. Beide die houtagtige en grasspesiegemeenskappe het 'n veldtoestand/degradasiegradiënt oor die totale studie area weerspieël. Die grasspesiesamestelling het soortgelyke tendense binne beide die Kommersiële en Reservaat landsgebruike weerspieël, met persele wat geassosieër is met lae sowel as hoë veldtoestandwaardes. Die tendense gebaseer op die houtagtige degradasiegradiënt, het verskil tussen hierdie twee landsgebruike. Die totale grasspesie en houtagtige komponente in die Kommunale gebiede het 'n totale verskuiwing na 'n ander toestand getoon, wat beduidend van die Kommersiële en Reservaat landsgebruike verskil. Beide die grasspesies en houtagtige komponente in die Kommunale gebiede was geassosieër met lae tot intermediêre veldtoestande, met geen beduidende veldtoestandgradiënt wat bestaan in die Kommunale landsgebruik nie.

Kennis en kwantifisering van die grond-plant dinamika hou belangrike implikasies vir die bestuur van weiveld. Hierdie studie het kriteria daargestel vir die selektering van die mees aangewese maatstawwe vir die implementering van die grond parameters as toeliggende data in die veelvoudige analises tesame met die plantegroei, mier en nominale omgewingsdata. Landsgebruike het verskillende grondpatrone tot gevolg gehad, met beduidende gradiënte met betrekking tot die grondstratum en oop/beboste groepe tot gevolg. Daar was 'n beduidende maar weglaatbaar klein verskil met betrekking tot die veldtoestand/degradasiegradiënt gebaseer op die grondkomponent.

Miere word omvangryk as bio-indikator gebruik, ook ten opsigte van die monitering van die omgewingsimpakte van veeboere. Mierspesiegemeenskappe en funksionele groepe het meer ooreenstemmende groeperings- en diversiteitspatrone as die plantegroei- en grondkomponente getoon. In teenstelling met die plantegroeikomponente, het mier gemeenskappe nie ‘n degradasiegradiënt, maar eerder omgewingsveranderinge (modifikasies) aan die habitat struktuur en heterogeniteit as gevolg van verskillende landsgebruik versteurings getoon.

Beide plantegroei- en mierdiversiteitsmaatstawwe was hoofsaaklik geassosieer met die Kommunale landsgebruik. Hierdie diversiteitsmaatstawwe was indikatore van habitat kompleksiteit, heterogeniteit en matige versteuring, eerder as indikatore van ‘n veldtoestand/degradasiegradiënt. Die diversiteitspatrone word die beste beskryf deur ‘n tweeledige verwantskap tussen die “humped-shaped” en die habitat kompleksiteit/heterogeniteit modelle. Hierdie studie het getoon dat plantegroei en mierdiversiteitmaatstawwe eerder as omgewingsindikatore van habitatversteuring as indikatore van biodiversiteit beskou moet word.

Daar word voorgestel dat plantegroei-, grond- en mierpatrone die beste beskryf word deur die “Toestand-en-Oorgangsmodel”, wat beide die ekwilibrium en nie-ekwilibrium sisteme insluit. Die veerkragtige herstelvermoë van hierdie veld, kenmerkend van nie-ekwilibrium sisteme, is weerspieël deur die lae tot intermediêre verskille tussen die landsgebruike met betrekking tot die grasspesies-, houtagtige-, grond- en mierkomponente. Digtheidsafhanklike verbinding van herbivore tot kern hulpbronne het egter gelei tot oorgangsverskuiwings en modifikasie van die plantegroeisamestelling en struktuur binne en tussen landsgebruike, wat die ekwilibrium dinamiek van hierdie weiveld vertoon. Klein versteurings in hierdie veld mag ongewenste sneeubal interaktiewe biotiese-biotiese/abiotiese veranderinge tot gevolg hê. Ruimtelike heterogene patrone binne en tussen landsgebruike, soos vertoon deur die plantegroei-, grond- en mierparameters, maak die monitering en bestuur by “kol-”, “kamp-” sowel as landskapsvlak noodsaaklik. Daar moet dus gewaak word teen die ekstrapolering en oorvereenvoudiging van bestuursstrategieë dwarsoor alle landsgebruike. Aangesien hierdie ariede veld gekoppelde sosio-ekologiese sisteme is, is dit nie moontlik om die biofisiese aspekte geassosieer met landdegradasie aan te spreek sonder die insluiting van die menslike dimensies nie. ‘n “Sleutel evalueringsmatriks” word vir moniterings- en bestuursdoeleindes voorsien ten opsigte van landdegradasie en diversiteitsaspekte binne en tussen verskillende landsgebruike. Hierdie sleutel kan gebruik word deur die landsgebruiker, voorligter en wetenskaplike.

Sleutelwoorde: Landsgebruik; veldtoestand; degradasie; biodiversiteit; spesiesamestelling; indikatore; sleutelspesies; miere; semi-ariede weiveld; “Sleutel evauleringsmatriks”

GLOSSARY OF ABBREVIATIONS

Anon.	Anonymous
ANOSIM	Analysis of Similarities
ARC	Agricultural Research Council
CBD	Convention on Biological Diversity
CCD	Convention to Combat Desertification
CCA	Canonical Correspondence Analysis
CGC	Current Grazing Capacity
DCA	Detrended Correspondence Analysis
DFS	Directorate Field Services
DMP	Desert Margins Programme
DPSIR	Driving Forces-Pressures-State-Impact-Responses
EV	Eigenvalue
GEF	Global Environment Facility
GIS	Geographic Information Systems
IEK	Indigenous Environmental Knowledge
in prep.	in preparation
IndVal	Indicator Value
IS	Index Score
ISPD	Integrated System for Plant Dynamics

ABBREVIATIONS (continue)

LFA	Landscape Function Analysis
LSU	Large Stock Unit
MDS	Multi-dimensional scaling
NAP	National Action Programme
NDA	National Department of Agriculture
NEMA	National Environmental Management Act
NLSIF	National Livestock Strategy and Implementation Framework
NW DACE	North West Department of Agriculture, Conservation, Environment
PCA	Principal Components Analysis
pers. comm.	personal communication
RDA	Redundancy Analysis
SIMPER	Similarity percentages
SOER	State of the Environment Report
STSS	Scientific Technical Support Services
TL	Total length
UNCCD	United Nations Convention to Combat Desertification
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environment Programme

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CHAPTER 1
Introduction

1.1 GENERAL

There is an increasing need to assess changes in the environment, with human actions causing ecosystem and biodiversity declines worldwide (Graves & Reavey 1996; Gutzwiller 2002). Land degradation is believed to be one of the most severe and widespread environmental problems in South Africa (Hoffman *et al.* 1999) as well as globally (Dregne *et al.* 1991a; UNCED 1992; Reynolds and Stafford Smith 2002). A further concern for managers of arid and semi-arid rangelands is the loss of diversity and secondary productivity, often being attributed to the overutilisation of rangelands by a narrow suite of domesticated herbivores (Milton *et al.* 1994). Land degradation can thus be considered as the result of the disruption of the normal functioning of ecological and hydrological processes (Hoffman *et al*. 1999). It is therefore crucial, from both a biophysical and socio-economical perspective, to gain a better understanding and to describe the multivariate processes and factors that govern biodiversity and land degradation patterns within the arid and semi-arid rangelands. Knowledge regarding these factors and processes is essential in order to ensure effective rangeland monitoring, which is considered as a critical component in rangeland management, regardless of the scale; with risk assessments, adaptive management analyses or management by hypothesis requiring an understanding of the linkages between environmental and management options (Brown & Havstad 2004).

1.2 BIODIVERSITY, LAND DEGRADATION AND DESERTIFICATION

In order to attain the above-set goals, it is essential to understand what is meant by the terms biodiversity and land degradation. Biodiversity refers to all species of animals, plants and micro-organisms existing, circulating and interacting within ecosystems (Vandermeer & Perfecto 1995; Paoletti 1999), and can thus be assessed at genetic, species or ecosystem level (Noss 1990). Biodiversity does not only produce valuable plants and animals, but also performs important ecological services (Altieri 1999). Stated differently, biodiversity encompasses all the species, food chains and biological patterns in an environmental system, ranging from as small as micro-organisms to as large as a landscape or geographic region (Heywood & Watson 1995). Biodiversity is thus crucial to the earth's "life-support system", and as we lose species, the integrity of processes such as supporting food webs, etc. are altered (Baskin 1994). Important though, is that the maintenance of biodiversity does not mean a local maximisation of the number of species, but rather the sustenance of diversity typical to the location and the landscape (Hoffmann & Greef 2003).

Causes for biodiversity impoverishment, which may be considered to have a more detrimental impact in arid regions than in other, include population growth, inequity and inadequate economic policies and institutional systems (Ayyad 2003). In addition, biodiversity is threatened by habitat degradation and fragmentation, overexploitation of biological resources, introduction of alien species, changes in climate and biogeochemical cycles, pollution and unsustainable agricultural practices (Ayyad 2003; Polasky *et al.* 2004). Myers (1988) stated that habitat destruction is widely considered as the most pervasive anthropogenic cause of the loss of biodiversity.

Within agricultural systems, biodiversity provides ecosystem services not only pertaining to food-, fuel-, timber production and other incomes, but it also forms an integral part of nutrient recycling, control of local micro-climate, regulation of local hydrological processes, regulation of the abundance of undesirable organisms. (Altieri 1999). If the biological processes are impaired, the economic and environmental costs can be significant (Altieri 1999). Biodiversity in arid regions is often rated as poor and less valuable than biodiversity in other biogeographic regions (Ayyad 2003). Arid regions are often characterised by relatively fewer species than the better-watered biomes, making it all the more important that the biodiversity in such arid environments should be given a higher priority, with each species being lost resulting in a higher percentage of loss for the region's biodiversity than in more species-rich regions (McNeely 2003). Therefore, other objective ways of assessing where biodiversity occurs need to be established (Harper & Hawksworth 1996). Ayyad (2003) suggests that assessment and quantification of biodiversity in arid regions need to move towards "calculate diversity" instead of merely counting species.

According to Darkoh (2003), there is a global acceleration (including in Southern Africa) in the loss of biodiversity due to agricultural activities that aims to feed the increasing population and contribute to the growth of the national economies. Unsustainable agricultural practices have resultantly intensified soil and vegetation degradation and led to a rapid decline of species types and numbers (Darkoh 2003). Grazing practices within Southern Africa threatens biodiversity by displacing wildlife and disrupting plant-species composition (Darkoh 2003). However, biodiversity and agriculture can be complementary activities, and if managed correctly, agriculture can enhance biodiversity in the drylands of Africa (Darkoh 2003). This requires the assessment of the agricultural potential of the semi-arid drylands of Africa and the development of programmes or policies to enhance biodiversity conservation and utilisation (Darkoh 2003). Drylands can be defined as regions where the annual potential evaporation and plant transpiration exceed annual precipitation (Hassan & Dregne 1997), with the ratio of mean annual rainfall to potential evapotranspiration being between 0.05 and 0.65 (Hoffman *et al.* 1999). The term arid, semi-arid and dry sub-humid climatic zones, according to the United Nations Convention to Combat Desertification (UNCCD 1994), are "areas, other than polar and sub-polar regions.

Land degradation impacts on biodiversity is also associated with desertification in drylands. Land degradation can be defined as a decrease in either or both the biological productivity or usefulness of a particular area due to human interference (Levia 1999). It is also described as the process by which habitat quality for a given species is diminished (Ayyad 2003). The UNCCD (1994) defines land degradation as the "reduction or loss, in arid, semi-arid and dry sub-humid areas, of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns such as soil erosion; deterioration of the physical, chemical and biological or economic properties of soil; and long-term loss of natural vegetation" (Hoffman *et al.* 1999). Land degradation includes spatial, temporal, cultural, economic and interpretative heterogeneity (Warren 2002; Archer 2004). Human-induced degradation in semi-arid areas is regularly mentioned as one of the primary causes of desertification, with land degradation in arid and semi-arid areas resulting from factors that include climate variations and human activities (Evans & Geerken 2004).

Rangelands are important in that they not only support livestock grazing, but other uses including biodiversity conservation, game farming, tourism, crop farming, thatch harvesting etc., or a combination of several of these activities, depending on environmental, social and economic circumstances (Friedel *et al.* 2004). Rangeland degradation has been observed in arid and semi-arid rangelands of every continent where these arid rangelands occur (Archer 1995). However, according to Ayyad (2003), the assessment and monitoring of habitat degradation and its impact on biodiversity in arid regions are rare. The Southern African region as a whole is faced with serious environmental problems and land degradation in particular, being caused among other factors, by human activity (Pelser & Kherehloa 2000). Rangeland degradation affects the biological and economic productivity of an area (Evans & Geerken 2004), and can be categorised into soil degradation and vegetation degradation (Hoffman *et al.* 1999).

Soil degradation includes degradation by water, wind (both erosive forms) and non-erosive forms such as salinisation, acidification, waterlogging, pollution, soil mining, loss of fertility, fallow and permanent cropping, compaction and crusting (Hoffman *et al.* 1999; Wezel & Rath 2002; Hoffman 2003; Evans and Geerken 2004). Soil degradation also affects plant growth, biodiversity and agricultural production in South Africa (Hoffman *et al.* 1999). Vegetation degradation may be caused by a loss of cover due to grazing and trampling patterns of livestock; change in species composition as result of the selective grazing patterns of domestic animals; bush encroachment; alien plant invasions; deforestation; clearing of rangeland; mining pollution, depletion of seed banks, etc. (Hoffman *et al.* 1999; Hoffman 2003; Evans and Geerken 2004). Overwhelming evidence has led to the conclusions that unsustainable commercial agriculture had a direct negative impact on biodiversity at ecosystem, species and genetic level (Ayyad 2003). Heavy grazing is considered to be a major cause for vegetation degradation (Ringrose *et al.* 1990), with intensive grazing impairing the productivity of semi-arid rangelands (Roux & Vorster 1983). Climate change and increasing atmospheric carbon dioxide concentration have also been suggested as causes for bush encroachment, but according to Archer *et al.* (1995), stronger evidence implicates unsustainable grazing as the cause.

Desertification is defined as land degradation in arid, semi-arid and dry sub-humid areas resulting from factors such as human activities and climatic variations (UNEP 1994, 1999), with more than 90% of South Africa being classified as "affected drylands" (Hoffman *et al.* 1999). Desertification is thus a term associated with land degradation in drylands, and is presumed to result in a reduction in the biological as well as the economic potential of land to support humans, livestock and wild herbivores (Reynolds *et al.* 2003). An understanding of the impacts of desertification on the structure and function of rangeland ecosystems is considered essential for developing effective management strategies (Heitschmidt *et al.* 2005).

1.3 GLOBAL ENVIRONMENTAL FACILITY DESERT MARGINS PROGRAM AND LANDCARE

Ms Thoko Didiza, the previous MP and Minister for Agriculture and Land Affairs, South Africa, stated that the "Strategic Agricultural Sector Plan" is of critical importance since it is a product of both the government and the industry (The Strategic Plan for South African Agriculture 2001). The core focus in support of the vision for agriculture is as follows: "To generate equitable access and participation in a globally competitive, profitable and sustainable agricultural sector contributing to a better life for all" (The Strategic Plan for South African Agriculture 2001). In this core focus, the following challenges are addressed by agriculture:

1. Constrained competitiveness and low profitability
2. Skewed participation
3. Low investor confidence in agriculture
4. Poor and unsustainable management of natural resources. In this respect, it is mentioned that land degradation remains a large problem in good as well as marginal lands, and that the major challenge in this respect is to ensure that, with increasing pressure on agriculture to increase output per unit of land, this will not take place to the detriment of our natural resource base.

With reference to point 4 stated above, sustainability is described as a multifaceted concept, and is expressed as "to ensure that the past and current management and use of natural resources does not diminish their capacity to meet economic, environmental, social and aesthetic needs and opportunities of the present and future generations" (Dalal *et al.* 2003).

In South Africa, the lost of cover and the change in species composition (both together implicating rangeland condition), are considered as the most important types of rangeland degradation (Hoffman *et al.* 1999). Rangeland condition can be stated as the "state of health" of a particular rangeland (Tainton 1988). Rangeland degradation is acute in the North West Province, where all districts show signs of desertification and a loss of biodiversity resulting in a deterioration of human and animal health (Hoffman *et al.* 1999). This has a major impact on livestock productivity and the economic viability of livestock farming with serious consequences for the livelihoods of pastoral communities. The Global Environmental Facility Desert Margins Program (GEF-DMP) has identified sites in the North West Province, South Africa, as one of the key areas harbouring globally significant ecosystems to serve as "field laboratory" for monitoring biodiversity and land degradation (Koala 2003).

The overall objective of the larger GEF-DMP programme is to arrest land degradation in Africa's desert margins through demonstration and capacity building activities (Koala 2003). Key sites harbouring globally significant ecosystems and threatened biodiversity have been selected in each of the nine countries in Africa participating in the DMP Program, to serve as field laboratories for demonstration activities related to monitoring and assessment of biodiversity status, testing of most appropriate natural resource management options, developing sustainable alternative livelihoods and policy guidelines and replicating successful models (Koala 2003). The DMP Program will attempt to make a significant contribution in reducing land degradation in the marginal areas and help conserve biodiversity. Guidelines, recommendations and supportive national policies that address biodiversity concerns are envisaged to be in place in the implementing countries (Koala 2003).

The DMP builds on the existing National Action Programmes (NAPs) of the CCD and involve both development and action-research efforts to unravel the complex causal factors of biodiversity loss through land degradation, and formulate and pilot appropriate solutions (Koala 2003). Three major areas within the DMP were identified: environmental protection, poverty alleviation and increased agricultural production. The wider objective of the DMP is to conserve and restore biodiversity in the desert margins through sustainable utilisation, with the biodiversity and sustainable use component of DMP focusing on: the identification of sustainable livestock practices, preserving and minimising land degradation and biodiversity loss; establishing restoration methods reducing biodiversity loss; enhance sustainable crop production that is environmentally, socially and economically acceptable; and address strategies for enhancing ecosystem resilience through optimisation of biodiversity (Koala 2003). Appropriate policies and technical interventions can be applied only if the fundamental dynamics of the target system are clearly understood, and pastoral ecosystem dynamics need to be understood as guidelines for development policies, otherwise inventions might prove to be “development experiments” that might result in unfortunate implications for both the ecosystems and people (Ellis & Swift 1988). Hence, in order to manage rangelands, it is essential to understand how they function and what the potential impacts of the different management strategies are (Leggett *et al.* 2003b).

Not only does the focus of the DMP fall within the vision of “The Strategic Plan for South African Agriculture”, but it also falls within the scope of Agenda 21 and the National Environmental Management Act (NEMA-Act No. 107 of 1998). This accentuates South Africa’s commitment to regularly monitoring and reporting on the state of the environment and addressing the driving forces, pressures, impacts and responses on the environment. In South Africa, the sites within the North West Province were selected on the grounds of current projects in those areas already being supported by the National Department of Agriculture (NDA) (LandCare projects) and by other organisations/institutions. The “Guide for the National LandCare Programme” state that “The vision of the National Department of Agriculture is to raise the long term productivity and ecological sustainability of our land resources and thereby ensure a future for our land resources within the agricultural sector” (North West Department of Agriculture, Conservation and Environment – NW DACE- 2000). Within the North West Province, the primary objective is to improve the rangeland condition for increased animal production through various reclamation techniques and management systems (DACE- 2000). Secondary objectives include improved rangeland management through implementation of different veld management systems; improved production and composition of rangeland through improved bush control practices, and; improved rangeland production and composition through limiting stocking density (DACE- 2000).

Target areas within the North West Province were also selected to ensure collaboration and cross border activities with neighbouring DMP countries, i.e. Botswana and Namibia.

1.4 RANGELAND MONITORING

The management of rangelands is not easy, since rangeland owners/managers seldom have complete information about the impact of actions that may be taken (Batabyal & Godfrey 2002). For example, plant communities can be described according to numerous parameters, e.g. canopy cover, stem diameter, species community patterns and associations, forage value, toxic elements being present etc. (Zacharias 2004). One may ask then what is the relevant information required for monitoring, with the approaches to monitoring inevitably varying according to the inclination of the operator, scale, management objectives, funding available, level of expertise to audit data etc. (Zacharias 2004). Waldhardt & Otte (2003) suggested that parameters that are directly related to both biodiversity and land uses may prove to be useful measures in indicating biodiversity in landscapes.

Range monitoring has been defined as the "regular surveillance to establish whether any properties of the range are changing" (Mentis 1984), a crucial process in detecting ecological change before irreversible changes occur, because management inputs and costs increase for every step in the degradation process (Milton *et al.* 1994). Rangeland monitoring thus attempts to establish whether temporal changes are taking place in response to conditions being imposed on the ecosystems (Aucamp *et al.* 1992). Rangeland assessment also provides an indication of the state of a range community, relative to some desired state (condition) at any state of time (Foran *et al.* 1978). Changed land use condition, especially as a result of increased agricultural production, has resulted in a significant reduction in species diversity (Hoffman & Greef 2003). In addition, biotic links can be density dependent or independent, making an understanding of equilibrium, non-equilibrium and "state-and-transitions" systems crucial in order to understand how paradigms such as these affect arid and semi-arid rangelands (Westoby *et al.* 1989; Benke & Scoones 1993; Legget *et al.* 2003a, b). This is necessary to establish whether or not agricultural activities have contributed to land degradation, as has been described in a large volume of literature (Legget *et al.* 2003b).

Plants are not only important components of biodiversity, but also reflect the physical environment, and are primarily influenced by several pressures acting on the rangelands, with measurements based on plants having considerable potential to be efficient indicators of the responses of rangeland biodiversity to land use (Landsberg & Crowley 2004). Rangeland condition is thus considered as an important determinant of ecosystem processes (Hoffman *et al.* 1999). Vegetation is the primary target of many pressures which directly impacts on the composition of plant communities and structure, with plants acting as indicators of changes in the composition of vegetation communities or the relative abundance of plant species (Landsberg & Crowley 2004). These authors suggest that plants can act as early warning indicators of potentially catastrophic changes. However, plant-related indicators alone will never be sufficient for monitoring all threats to biodiversity (Landsberg & Crowley 2004).

With large numbers of species occurring in one area, a small number of key-species typical to the landscape for which good ecological information is available, can be selected as indicators of species diversity (Hoffman & Greef 2003). Hence, such species serve as indicators of the current status of an area (Hoffman & Greef 2003). Andersen (1990) emphasises the importance of recognising ecological change before irreversible changes occur and suggests that indicator taxa, interrelated with parts of the ecosystem, should act as indicators (or bio-indicators) in a standard evaluation system. Limited financial resources and taxonomic expertise will benefit if one surrogate organism group, representative of the richness of other taxa, can act as indicators of the biodiversity monitoring programmes for landscapes (e.g. agricultural landscapes) (Sauberer *et al*. 2004). The use of invertebrates as bio-indicators has increased significantly in recent times, especially in using them to assess ecological change and stress especially caused by human induced disturbance (e.g. land-use type) (Andersen *et al*. 2002). Invertebrates are often more sensitive indicators of ecosystem health than plants (Greenslade & Greenslade 1984; Disney 1986; Rosenberg *et al.* 1986; Majer 1989). Invertebrates are good indicators of ecological change, since they are diverse, functionally important, are sensitive to environmental change, are easily sampled and can integrate a variety of ecological processes (McGeoch 1998). Ants have been extensively used as bio-indicators at species and community level with regard to the monitoring of the environmental effects of rangeland pastoralism for the semi-arid and arid rangelands of Australia (Wilson 1990).

1.5 AIM AND JUSTIFICATION

There are three fundamental characteristics of State of the Environment (SOE) reports (SOER 2002):

1. Interpretation, assessment and integration of high quality data to generate meaningful information;
2. Development of spatial and temporal information; and
3. Identification of the linkage between biophysical and socio-economical consideration within a sustainable development contect.

The research question for this study, which falls within the Global Environmental Facility Desert Margins Program (GEF-DMP), LandCare, SOER (2002) and "Strategic Plan for South African Agriculture" (2001), could therefore be formulated as follows: to what extent can vegetation in combination with ant communities be used as indicators of ecosystem modification due to anthropogenic human induced land-use patterns and how can this information be used in land degradation management and the conservation of biodiversity in the semi-arid western rangelands of Southern Africa?

The research question of this study thus primarily falls within the context of the first two SOE characteristics stated above. In response, the North West Department of Agriculture, Conservation and Environment, has undertaken to indicate trends in environmental conditions in the North West Province; identify knowledge gaps of the North West Province's environment; provide information for the next State of the Environment Report; serve as baseline for future management decisions for environmental protection and sustainability, etc. (SOER 2002) Hence, the focus this study fall within all of these responses.

In support of the importance of this study, based on the consideration that the Molopo rangelands have been described as a "black hole" in terms of information available with regard to the biophysical-, social- and economical environments (SOER 2002), the NEMA-Act No. 107 of 1998 provides basic environmental principles in Section 2, with some of the sections reading as follows:

4 (a) Sustainable development requires the consideration of all relevant factors, including the following:

(i) That the disturbance and lost of biological diversity are avoided, or, where they cannot be altogether avoided, are minimised and remedied;

(ii) that pollution and degradation of the environment are avoided, or, where they cannot be altogether avoided, are minimised and remedied;

(iii) that the development, use and exploitation of renewable resources and the ecosystems of which they are part do not exceed the level beyond which their integrity is jeopardised;

(b) Environmental management must be integrated, acknowledging that all elements of the environment are linked and interrelated, and it must take into account the effect of decisions on all aspects of the environment and all people in the environment by pursuing the selection of the best practicable environmental option.

Some strategic functions, accountability and responsibilities of the North West Department of Agriculture, Conservation and Environment, include: supporting, leading, monitoring and auditing the environmental performance of local authorities; investigating, evaluating, assessing and promoting appropriate environmental management technologies; researching, investigating and evaluating the natural environmental resource of the Province, etc. (SOER 2002). It is thus envisaged that this first-ever baseline study with regard to land use impact on the rangeland condition and biodiversity of the Molopo semi-arid rangelands of the North West Province, can significantly contribute to some of the above-mentioned principles, strategic functions and responsibilities.

According to Hoffman *et al.* (1999), studies of land degradation in South Africa should focus on both commercial and communal areas, with the dynamic interaction between commercial and communal areas becoming increasingly important. Settlement patterns within the North West Province are likely to have localised degradation of soil, vegetation and water resources (SOER 2002). Hence, sites representing a degradation gradient (relative poor and relative good rangeland condition extremes) within each of three Tribal-, three Commercial- and three Reserve areas ("control") were surveyed. Drivers of rangelands change dramatically across spatial scale, changing over time, making it unlikely that one set of attributes will function equally well at landscape, paddock, property, regional or national scale (Brown & Havstad 2003). Hence, the impacts of these land uses on the herbaceous species composition, woody-, soil- and ant components were evaluated. This was also done to be in line with the LandCare objectives, strategies and principles discussed above. In support of this, the SOER (2002) states that agricultural activities are an important component of the Province's economy, but is faced with the environmental challenges of rangeland and soil degradation. The SOER (2002) also emphasises that there is a greater need to conserve biological diversity, especially through a greater reliance on protected areas.

1.6 OBJECTIVES AND KEY FOCUS AREAS

Objectives of this study were: (i) to establish the factors and processes that maintain biodiversity and those that cause land degradation in the semi-arid rangelands of the Molopo, North West Province; (ii) to determine the impacts of various land-use practices on the biodiversity; and (iii) to make recommendations regarding sustainable natural resource management practices.

In order to attain these objectives, the impact of different land use practices with regard to the following parameters, was investigated:

1. Herbaceous species composition and rangeland condition;
2. Woody species composition, structure and density;
3. Ant species composition and functional group structures and patterns;
4. Soil chemical and physical patterns.

Brown & Havstad (2003) suggest that analyses of major changes in rangeland ecosystem function showed that an incomplete understanding of biophysical, socio-economical and policy drivers, and the incorporation of that information into decision-making, dramatically improve sustainability. According to Darkoh (2003), there is a serious lack of natural resource inventories and other baseline data that are fundamental for monitoring biodiversity trends within the drylands of Africa, suggesting that there is an urgent need for regular ecological monitoring to establish these trends. Monitoring of benchmark sites on a regular basis, with reliable data acquisition and storage, is essential to quantify trends can changes taking place in the North West Province and hence Molopo region, with parameters such as rangeland condition and soil quality being of vital importance (SOER 2002).

This study attempted to establish whether the observed patterns as reflected by the parameters, were mainly the result of different land use impacts and/or due to inherent environmental differences between land use types. Congruent patterns between the listed parameters with regard to compositional, diversity and land degradation patterns as result of different land use impact were investigated. Environmental variables that are responsible for the greatest proportion of the species-environment relationship pertaining to the different parameters were investigated. The appropriateness of ants as bio-indicators of the impact of land use (assess ecological change and stress especially caused by human induced disturbance) on biodiversity and land degradation in the three land-use types, were investigated.

Land use data, in particular agricultural data in the former Bophuthatswana, is scant and needs to be updated (SOER 2002). Land use data, especially agricultural data, is required to integrate agricultural and other development data at the district level for the entire Province, but especially for the Molopo rangelands, being described as a "black hole" in terms of any biophysical and socio-economic data, in order to facilitate a comprehensive and effective integrated environmental management programme (SOER 2002). Non-agricultural land uses, such as conservation and tourism, should be encouraged (SOER 2002), hence further motivating why a Reserve (conservation) land use was included in the study.

There is reasonable consensus amongst rangeland researchers that understanding the impact of domestic herbivores on vegetation, and *vice versa* (i.e. the performance of herbivores grazing on rangeland) is central to the discipline of rangeland management in the RSA. The application of "optimum" stocking rates and "the best" grazing system are two contentious issues central to discussions around herbivore impact. For adapting the animal factor to the vegetation component, the management of livestock distribution patterns requires a knowledge of pasture (and browse) characteristics as well as animal behavioural patterns, suggesting that a further challenge for range managers is to achieve rangeland management objectives in view of complex and dynamic livestock behavioural patterns. The key role of land uses' behaviour (management pertaining to different land use types) in sustainable agricultural development needs to be acknowledged, implicating that the state of the natural resources is largely a function of their management or decisions (Dűvel & Afful 1997).

Ecological and economic aspects can be interrelated by means of indicator systems through the measurement of consumer-orientated values of landscapes and biodiversity issues (Osinski *et al.* 2003). This relationship depends on knowledge of the ecological processes that operate within these semi-arid rangelands, while also acknowledging that there is a fundamental difference between a "management monitoring system" envisioned for management by the land owners/users, and a monitoring system for research purposes. Thus, partnerships between land users/owners and scientists from different disciplines, in which the different land users/owner client groups identify their own priorities and are given assistance, are essential for resources management and monitoring purposes.

This study is the first comprehensive ecological study that has been conducted within the Molopo rangelands (thus including the communal areas of the former Bophuthatswana). No long-term biophysical data, or how it is interrelated with the socio-economic pillar, exist for the Molopo study area. This study acknowledges the importance of how sustainable livestock/game production is perceived by different land users, and how it is interrelated with rangeland "health", productivity and the socio-economic environment, but it should be emphasised that no data or research findings exist for the Molopo study area with regard to these aspects. Thus, as departure point, this study focused primarily on the parameters given above.

It is envisaged that this study provided baseline information for the Molopo semi-arid rangelands that have been poorly described with regard to land use, biodiversity and degradation patterns (SOER 2002). This study thus serves as a reference point for future research with regard to other biophysical aspects, such as livestock production norms and management systems, soil quality and faunal/floral taxonomic diversity, that can be interrelated with the socio-economical and policy environments. Different ecological transitional states pertaining to the different parameters have been identified (summarised in Chapter 9, Section 9.1), and can serve as departure point in identifying thresholds between different ecological states. It also serves as departure point to outline a monitoring programme for the Molopo semi-arid rangelands with appropriate **biophysical** indicators of desertification and dryland degradation which could feed into the National Action Programme (Hoffman *et al.* 1999). It is also envisaged that this study can contribute the "Ambient Environmental Monitoring Programme" of the North West Province (SOER 2002), with the mandate lying within the North West Department of Agriculture, Conservation and Environment.

Because these arid rangelands are linked socio-ecological systems, it is not possible to address biophysical issues associated with land degradation without including the human dimensions. A "Key assessment matrix" is provided for monitoring and management purposes pertaining to land degradation and diversity aspects within and between the different land uses, and can be used by the land user, extension officer and scientist. This is done, since monitoring applied within one land use type, is not always suited for all land uses and client groups Friedel *et al.* (2004). However, is should be emphasised that the purpose of this study was mainly to provide biophysical indicators of degradation and biodiversity loss due to different land use practices, but is envisaged to be incorporated into adaptive management packages, thus recognising the social and economic pillars of sustainable resource and development (SOER 2002). A proposed "Collaborative Terrestrial Ecosystems Research and Development Programme" for the North West Province, focusing on the Molopo as pilot study area, is presented in Chapter 9 (Concluding Remarks).

CHAPTER 2

Study area

2.1. GENERAL BACKGROUND

The study area falls within the Kalahari Plains Thorn Bushveld (Low & Rebelo 1996) (Acocks veldtype 16 – Kalahari Thornveld and Shrub Bushveld; Acocks 1988) of the North West Province (Fig. 2.1), South Africa. This vegetation type covers approximately 50 857 km^2 and falls within the Savanna Biome (Low & Rebelo 1996). The Kalahari Plains Thorn Bushveld is found mostly in the North West Province, and also in the north-eastern part of the Northern Cape (Low & Rebelo 1996). Approximately 71.5% of the North West Province falls within the Savanna Biome (State of the Environment Report – SOER – 2002), with the portion of the North West Province's Kalahari Plains Thorn Bushveld (38 203 km^2) (hereafter referred to as the Molopo study area) composing 32.93% of the Province's 116 320 km^2 vegetation types (SOER 2002). The Molopo study area is located in the Bophirima Agricultural Region (Western Region) of the Province (Fig. 2.2), with livestock and game farming being the major economic activities (Low & Rebelo 1996). It is found on deep, loose sand, and is characterised by undulating to flat sandy plains, at 1 000m altitude (Low & Rebelo 1996).

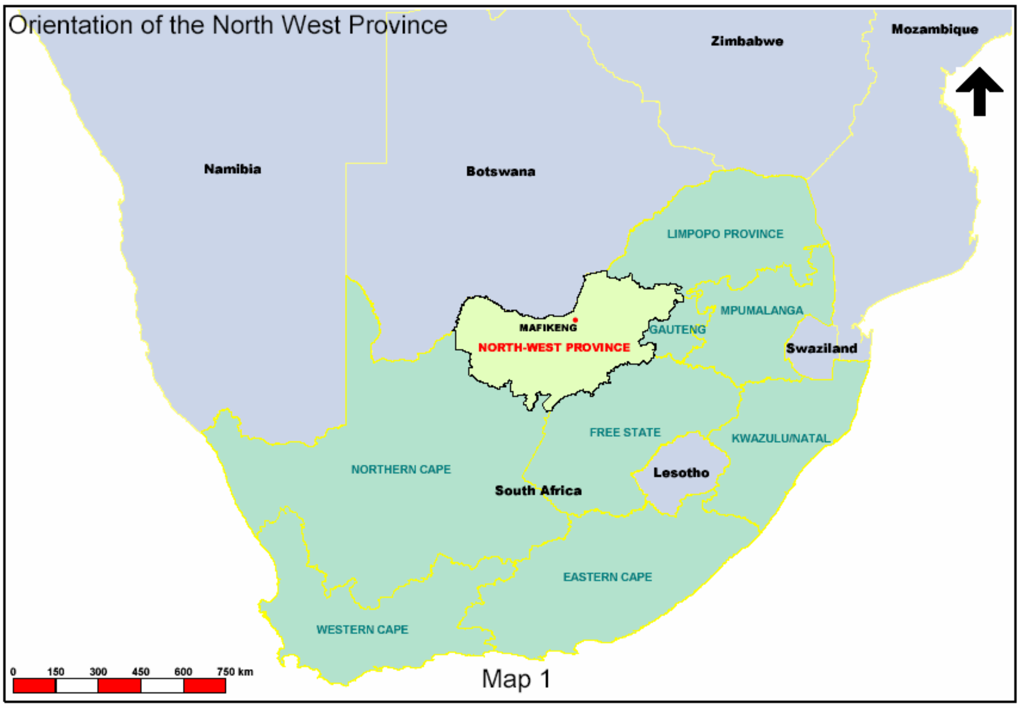


Fig. 2.1. Orientation of the North West Province within Southern Africa (SOER 2002).

2.2. EXPERIMENTAL DESIGN

2.2.1 Site selection

The Molopo study area falls within the larger Global Environmental Facility Desert Margins Programme (DMP-GEF) (Koala 2003). The sites were selected on grounds of current LandCare projects in those areas already being supported by the National Department of Agriculture (NDA). Namibia, Botswana, Zimbabwe and South Africa, notably the North West Province and the Northern Cape, participate in the DMP. In the North West Province, the DMP primarily focuses on sites within the Molopo and Kagisano municipal districts (agricultural areas), including the adjacent Molopo Nature Reserve (Fig. 2.2). The study area (Fig. 2.3) is representative of different land-use practices, primarily game farming and beef cattle enterprises, lies adjacent to the Northern Cape and shares common boundaries with Botswana, ensuring collaboration with regard to the sub-regional DMP-GEF project.

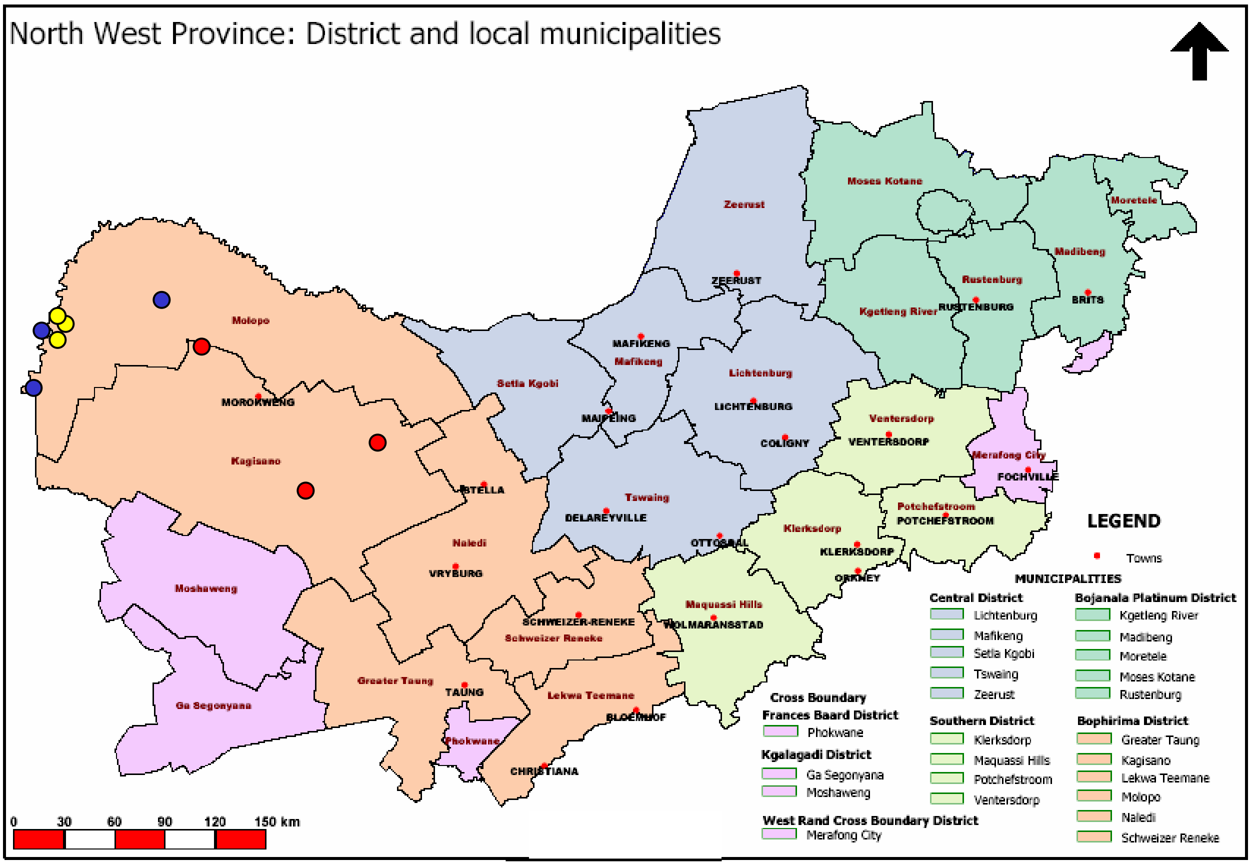


Fig. 2.2. Orientation of the study area within the Bophirima region of the North West Province - red dots represent the Tribal villages, blue dots the Commercial farms and yellow dots the Reserve survey areas for this study (SOER 2002).

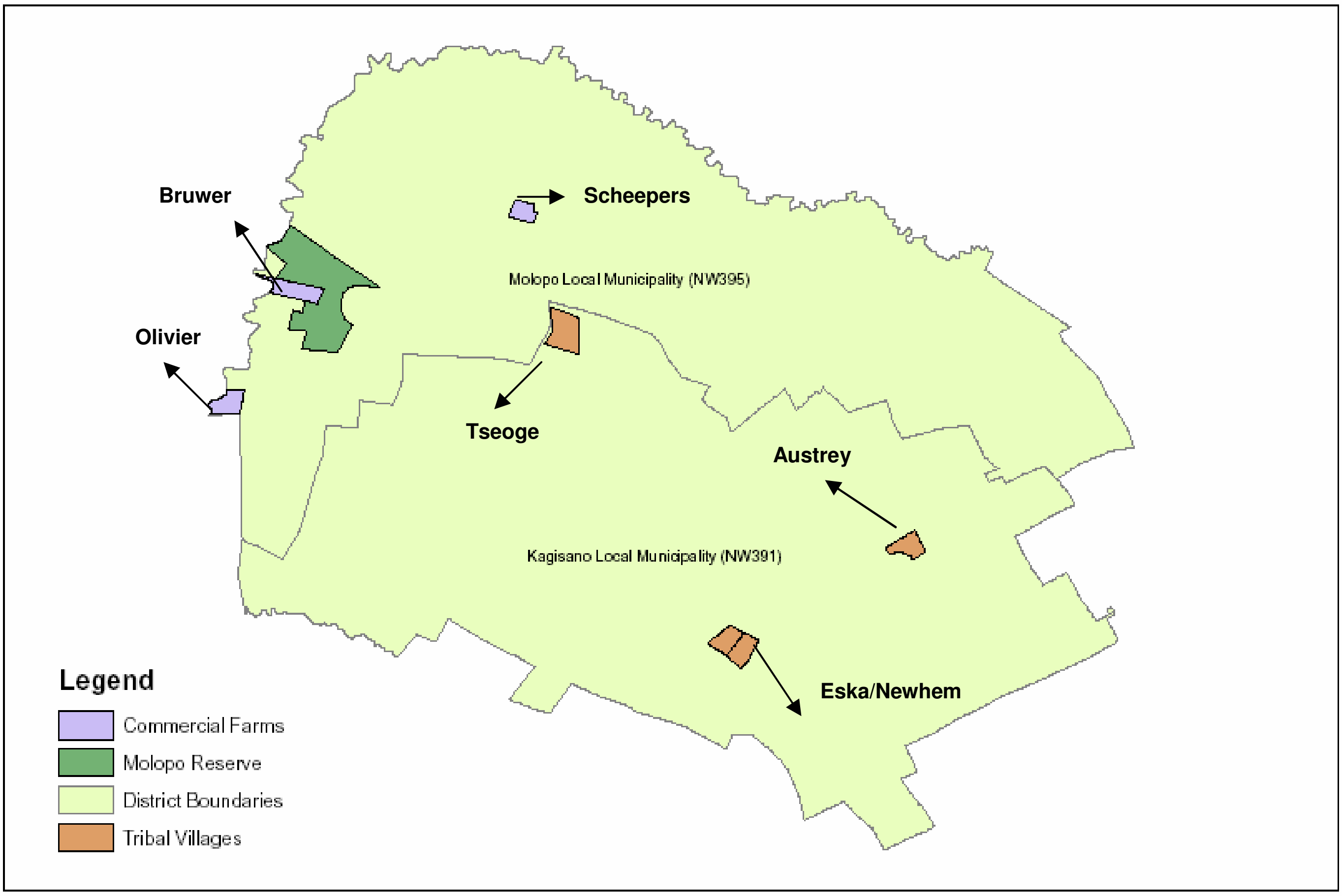
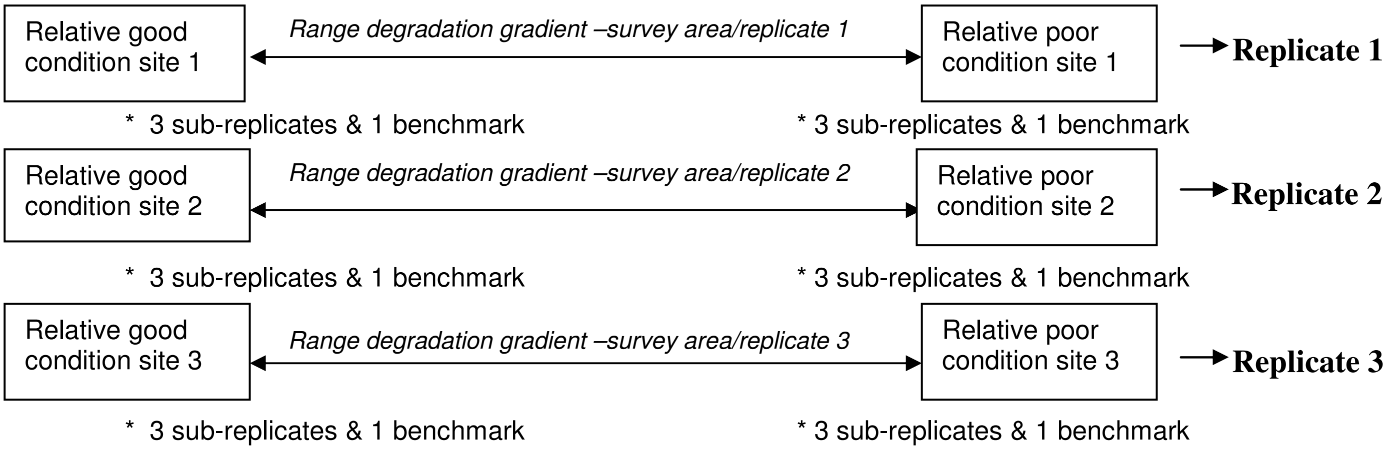


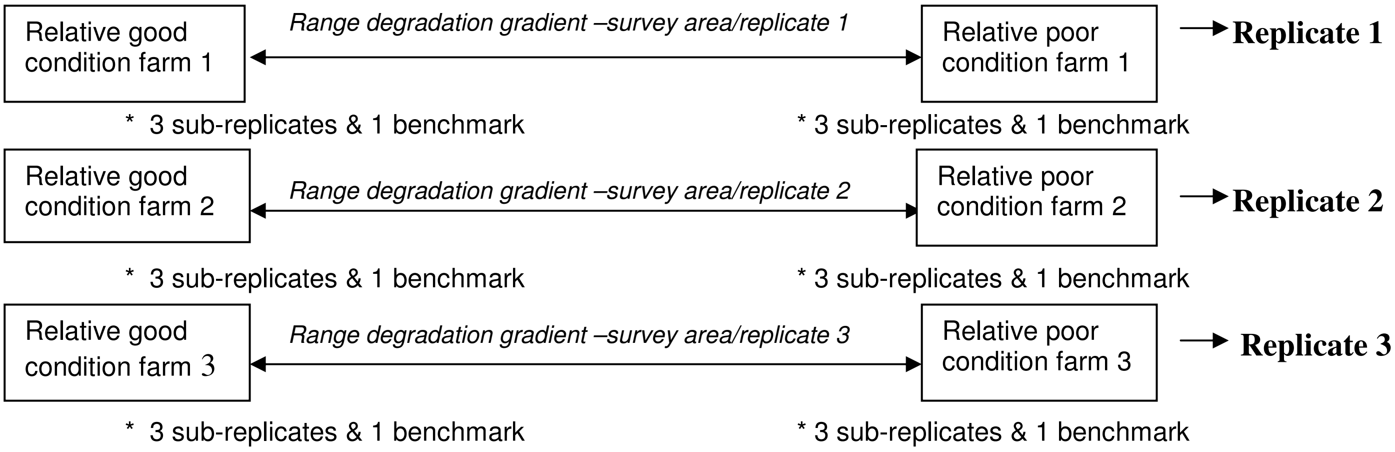
Fig. 2.3. The study area within the Molopo semi-arid rangelands – representing the Tribal villages, Commercial farms and Reserve survey areas that were included in the surveys.

2.2.2 Replicates, sub-replicates and benchmarks

1. Nature Reserve land-use (“control”)



2. Commercial land-use



3. Tribal land-use

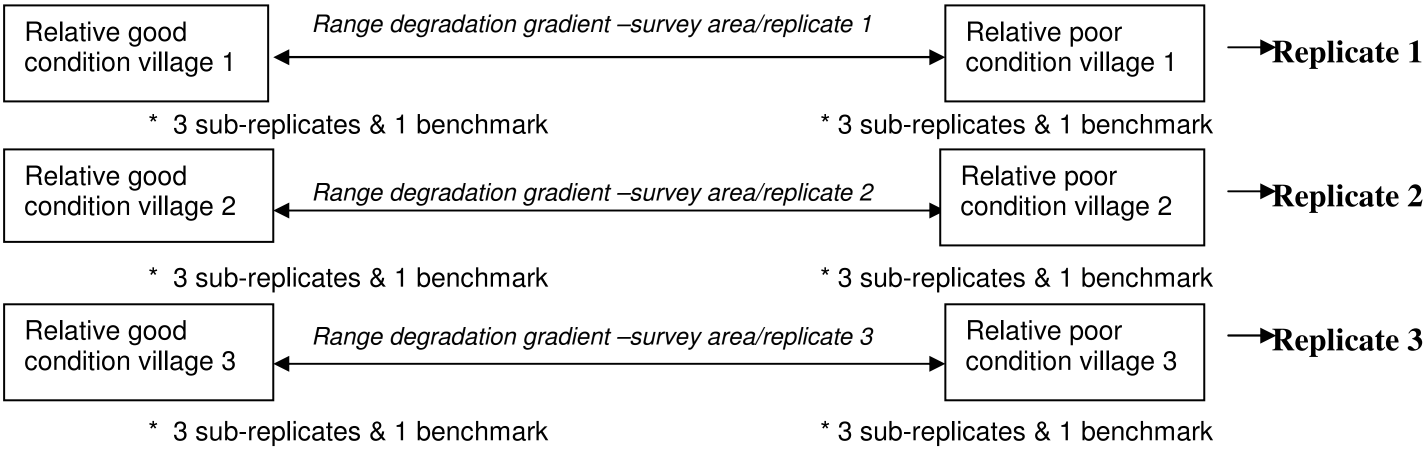
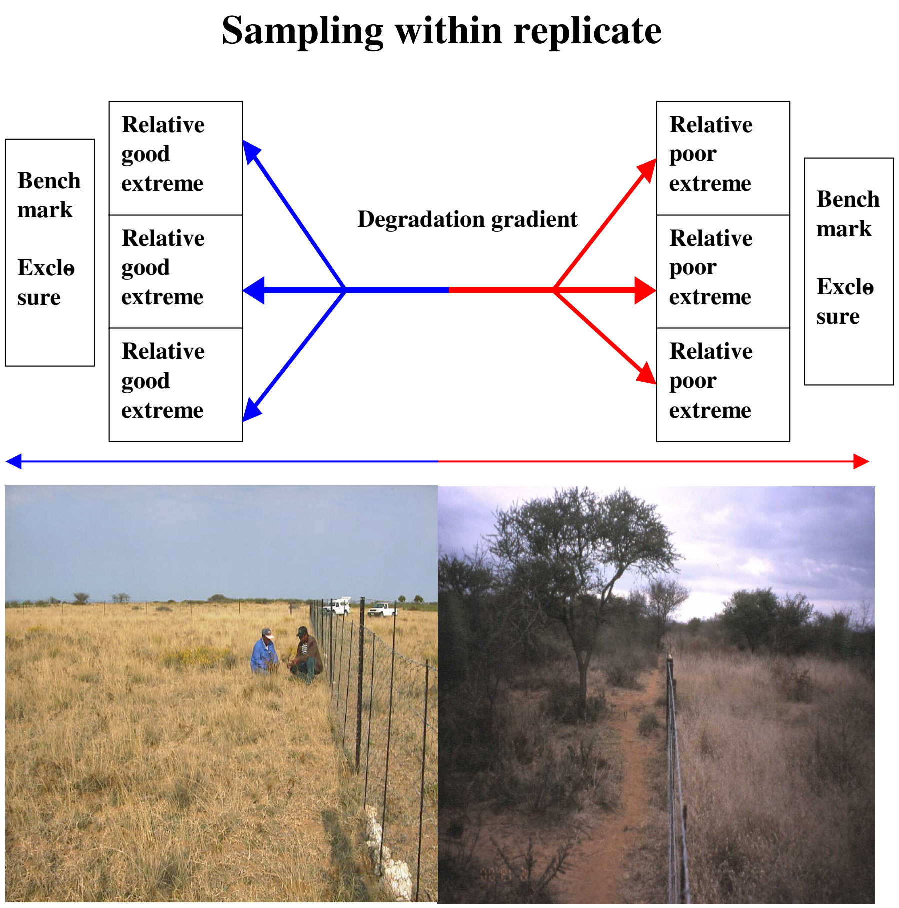


Fig. 2.4. Site selection within the Commercial, Tribal and Reserve land uses.

Survey areas within each of three land-use types (hence, three treatments) – Commercial ("conservation beef ranching"; Molopo local municipality), Tribal (Kagisano local municipality) and Conservation areas (Molopo local municipality), were selected for this study (Fig. 2.4). The term "Tribal" instead of "Communal" land use was used. This was done for practical reasons as to ensure that discussions, illustrations and tables pertaining to the Commercial land use, are not confused with the Communal/Tribal land use. Within each land-use type, another three survey areas (replicates, *i.e.* farms, villages or conservation areas) were identified (Fig. 2.3 and Fig. 2.4). Within each of these survey areas, surveys were performed in "sub-replicates": four at the relative good (termed "Good" for the rest of the study)- and four at the relative poor (termed "Poor") extremes, representative of the land tenure practices (management and grazing) of that specific survey area (replicate within the land-use) (Fig. 2.4). One of the four sub-replicates at each condition type extreme was a benchmark (Fig. 2.5). *Sub-replicates and benchmarks were subjectively selected based on specialist knowledge of the study area in order to represent the "extremes" of a degradation gradient or rangeland "health" within each survey area.* Benchmark sites are important for distinguishing between seasonal fluctuations and management effects, and for providing a mechanism for standardised cross-regional reporting (Landsberg & Crowley 2004).

Additional criteria, other than those mentioned above, were used to select the sub-replicates within each survey area. These criteria are as follows: the ecological and grazing status of the herbaceous species composition (also making reference to bare patches as indicator of "poor" rangeland "health"); woody species composition and –density; the sub-replicate's representation on the survey area's land-tenure practices; comparability within- and between survey areas within a land-use. Thus, when referring to a land use's productivity, reference to the general state of "health" of the rangeland within a land use, and not to the how a specific land user perceives rangeland productivity, is made (refer to Chapter 3, Section 3.1 Introduction for further definitions on rangeland "health" and productivity).

The benchmarks were subjected to zero grazing/browsing, and grazed only once a year for one to two day periods during August to remove the herbaceous material, without trampling the benchmark. Hence, grazing of the benchmark was subjectively evaluated. The benchmarks were relatively homogenous plots of 120 m x 30 m (for the Commercial and Reserve land uses, and 110 m x 20 m for the Tribal land uses, which was erected in 1999 as part of LandCare projects), representative of either the relative good or – poor extreme for the specific survey area (replicate) (Fig. 2.5). All surveys performed outside the benchmarks, were also repeated within the benchmarks (Chapter 3, Fig. 3.1), with the exception of the ant surveys, which were not performed within the benchmarks (refer to Chapter 3 – Material and methods, Section 3.3 – for the explanation).



Surveys within and outside benchmark performed: “Good” rangeland condition extreme

Surveys within and outside benchmark performed: “Poor” rangeland condition extreme

Fig. 2.5. Experimental lay-out of surveys performed within each replicate (survey area), with the red lines representing relative “Poor” rangeland condition sites, and the blue lines relative “Good” rangeland condition sites.

The purpose of a benchmark is to represent a stable and productive site, which reflects the pristine and climatic climax condition of an area (Tainton 1981). However, it is recognised that benchmarks in arid areas may vary according to the annual rainfall distribution pattern, and may not be so static (Vorster 1982). Benchmarks serve as reference point for calculating and describing the range condition and the potential grazing capacity (PGC) as opposed to the current grazing capacity (CGC) measured in animal units per ha. One animal unit is equivalent to a Large Stock Unit (LSU) of one 450 kg animal that gains 500g/day on grazing with energy digestibility of 55% (Meissner *et al.* 1983). Benchmark selection is thus primarily based on agronomic and ecological features (Hoffman *et al.* 1999). Hence, in this study, surveys were performed within eight “sub-replicates” within each survey area (farm, Tribal village, Reserve area), representing the extremes of a degradation gradient for that specific survey area. “Sub-replicates” were also selected in such a respect that they are not near watering points or dwellings, hence key resources, as to ensure that results reflect the natural land-tenure system of the specific survey area, and not gradients related directly to these key resources, such as piosphere gradients (after Legget *et al.* 2003a) or direct human-induced (e.g. “kraal” and human settlements) effects. *See discussion that makes* *reference to these key resources in Chapters 4 – 10.* Some of the sub-replicates, representative of the relative “Poor” extremes, were associated with the proximity (indirectly) of these key resources.

Hence, a total of 72 sub-replicates (also described as samples or survey sites for this study), including the 18 benchmark exclosures (2 per survey area), representing a degradation gradient (relative poor and relative good extremes) within each of three tribal-, three commercial (commercial beef ranching) - and three conservation areas were surveyed (Fig. 2.4).

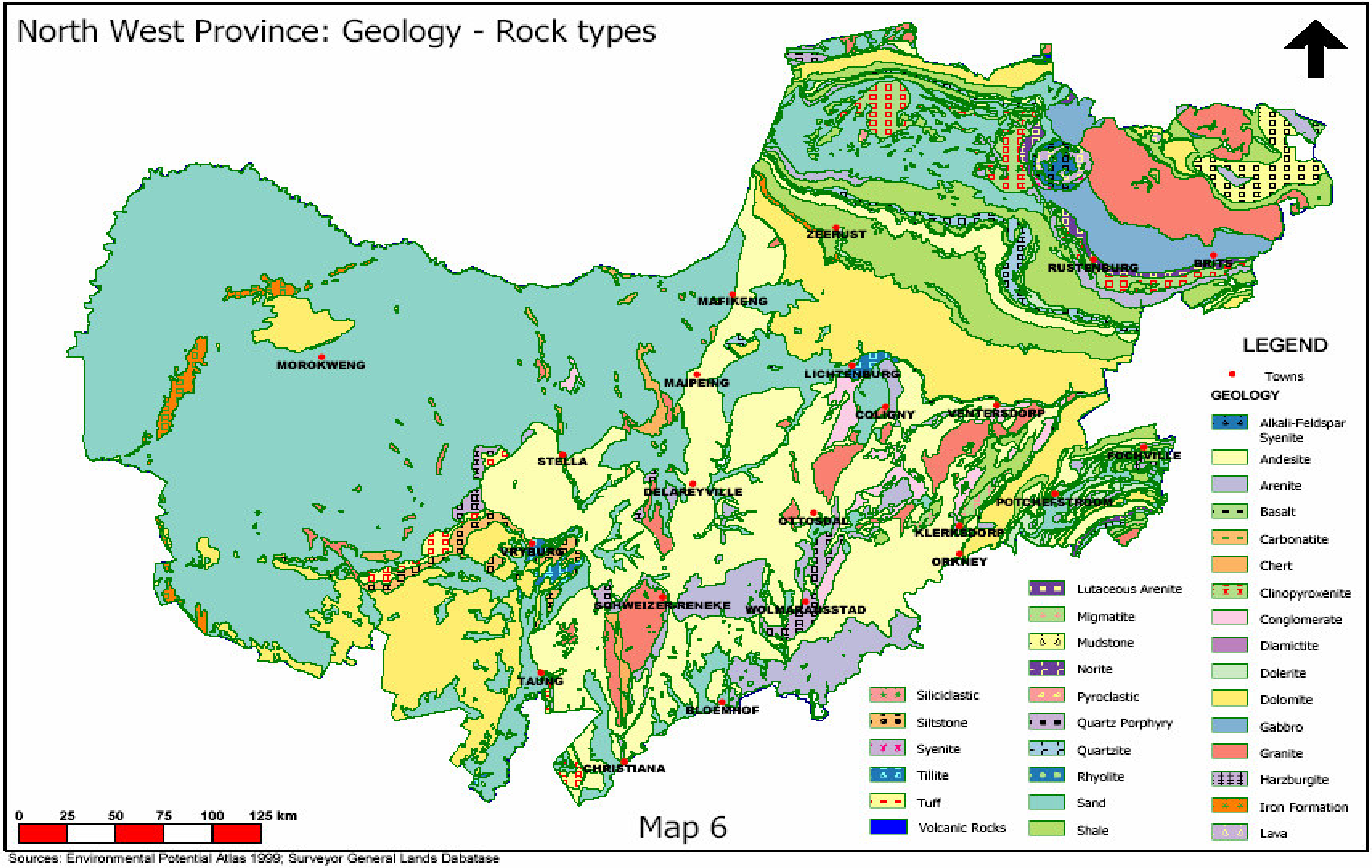
The Commercial beef ranching areas are located near Vorstershoop (farms Lafras/Lands End – Bruwer’s property; 22°49’7’’E, 25°49’29’’S), Taylor’s pan area (near McCarty’s Rest: farm Dunsinane – Olivier’s property; 22°40’26’’E, 26°5’31’’S) and Terra Firma (farm Ottowa – Scheeper’s property; 23°22’12’’E, 25°39’21’’S). The three Tribal farming areas (beef, goats and donkeys) are located at Austrey 1 (called Austrey hereafter) (24°13’40’’E, 26°25’5’’S), Eska/Newhem (23°52’30’’E, 26°38’36’’S) and Tseoge (23°27’56’’E, 25°55’13’’S). The historical and current grazing- and management systems (land-tenures), vary within and between these land-uses, implicating that different survey areas/replicates and their sub-replicates are not necessarily located on the same point of the degradation gradient for the larger study area. Three conservation areas were selected within the Molopo Nature Reserve (22°54’33’’E, 25°56’6’’S), a Category II protected area (primary focus being an ecosystem protection and recreation area) (Strategic Environmental Focus 2003) of approximately 24 000 ha. These survey sites fall within the “pristine” southern part of the Reserve, where no human intervention has taken place since the proclamation of the Reserve in 1987. Prior to proclamation, this area historically was agricultural land consisting of several commercial farms, where tenures varied from beef ranching to maize cropping. For the purpose of this study, sites were selected to avoid previously cultivated areas, or areas that were managed by human-induced fires.

2.2.3 Soil characteristics

The Bophirima Agricultural Region is subject to wind erosion due to the low clay content (Department of Agricultural Technical Services 1978). The climate severely limits the soil potential, and in the area adjacent to the Tseoge survey site, the soils are predominantly shallow, rocky and with outcroppings (Department of Agricultural Technical Services 1978). As a result of the low rainfall experienced in the Western Region, soils are deemed to be only slightly leached, and with the high evapotranspiration rate, there is a predominance of upward moisture movement in the soils (SOER 2002).

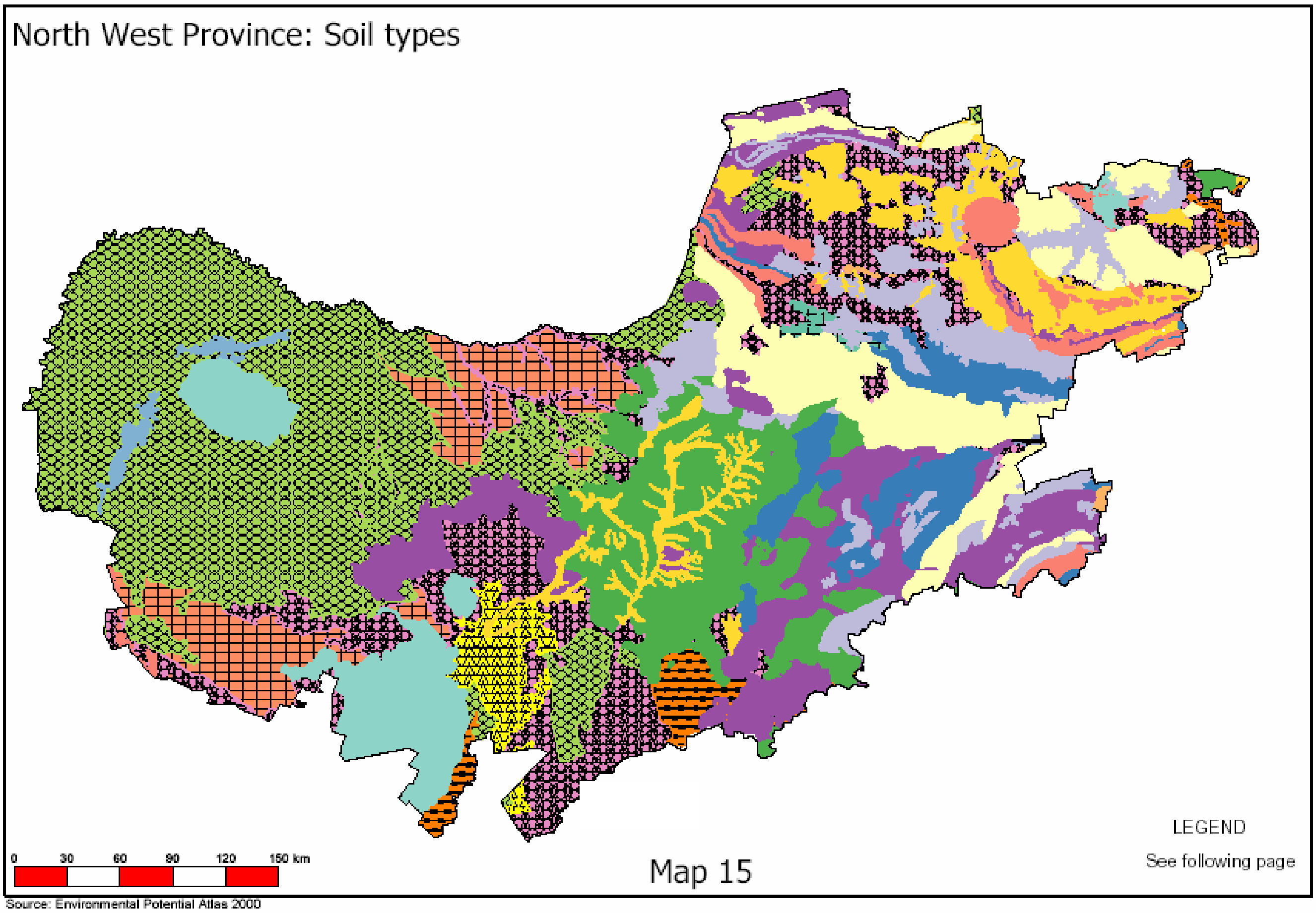
Soil information was obtained from: (i) 1:250 000 Landtype maps (2522 Bray, 2622 Morokweng, 2624 Vryburg) (Department of Agricultural Technical Services 1978), (ii) topographical maps (1:50 000) as baseline information. Soils were classified according to the Taxonomical System for South Africa (Soil classification working group 1991).

The geology of the larger study area (Fig. 2.6) is characterised by deep sandy to loamy, freely drained sands of aeolian origin (Fig. 2.7) (predominantly Ah landtype, interspersed with Ae and Ai landtypes), underlain by calcrete (Low & Rebelo 1996).



Sources: Environmental Potential Atlas 1999; Surveyor General Lands Dabatase

Fig. 2.6. Geology of the study area within the larger North West Province (SOER 2002).



Source: Environmental Potential Atlas 2000

LEGEND

🟦 Glenrosa and/or Mispah forms (other soils may occur), lime generally present in the entire landscape

🟨 Glenrosa and/or Mispah forms (other soils may occur), lime rare or absent in the entire landscape

🟪 Glenrosa and/or Mispah forms (other soils may occur), lime rare or absent in upland soils but generally present in low-lying soils

🟥 Miscellaneous land classes, rocky areas with miscellaneous soils

🟦 Miscellaneous land classes, very rocky with little or no soils

🟨 One or more of: vertic, melanic, red structured diagnostic horizons, undifferentiated

🟧 Plinthic catena: dystrophic and/or mesotrophic; red soils not widespread, upland duplex and margalitic soils rare

🟦 Plinthic catena: dystrophic and/or mesotrophic; red soils widespread, upland duplex and margalitic soils rare

🟩 Plinthic catena: eutrophic; red soils not widespread, upland duplex and margalitic soils rare

🟪 Plinthic catena: eutrophic; red soils widespread, upland duplex and margalitic soils rare

▨ Prismacutanic and/or pedocutanic diagnostic horizons dominant. In addition, one or more of: vertic, melanic, red structured diagnostic horizons

▨ Red-yellow apedal, freely drained soils, red, high base status, < 300 mm deep

▨ Red-yellow apedal, freely drained soils; red and yellow, dystrophic and/or mesotrophic

▨ Red-yellow apedal, freely drained soils; red and yellow, high base status, usually < 15% clay

▨ Red-yellow apedal, freely drained soils; red, dystrophic and/or mesotrophic

▨ Red-yellow apedal, freely drained soils; red, high base status, > 300 mm deep (no dunes)

▨ Red-yellow apedal, freely drained soils; yellow, high base status, usually < 15% clay

Fig. 2.7. Soil types of the study area within the larger North West Province (SOER 2002).

The Reserve land-use, as well as two of the Commercial land-use farms: Lafras/Lands End (Vorstershoop) and Dunsinane (Taylor's Pan; McCartys' Rest) fall within the Ah2 landtype. Red Aeolian sand of Recent age with a few outcrops of Tertiary Kalahari beds (surface limestone and silcrete) with jaspilite and banded ironstone of the Asbestos Hills Formation of the Griquatown Group dominate this land type. The Ah2 land type has a dominant terrain type of four (4) (95.7%) according to the terrain form sketch (Fig. 2.8), and is dominated by Hutton (Roodepoort) (47.9%) and Clovelly (Sunbury) (32.5%) soil types underlain by red-yellow apedal soil < 7% clay (Department of Agricultural Technical Services 1978).

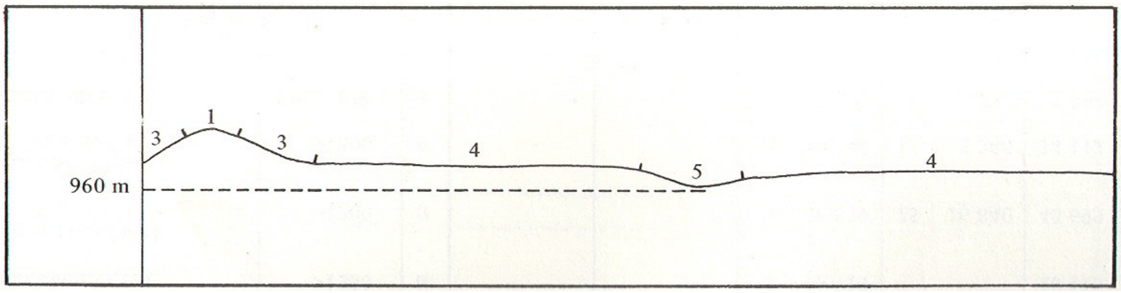


Fig. 2.8. Terrain form sketch for the terrain types (1 - 5) within the Ah2 landtype – Molopo Reserve, Vorstershoop and Taylor's pan/McCarty's Rest areas (Department of Agricultural Technical Services 1978).

Eska/Newhem and Tseoge (Tribal land-use) fall within the Ah3 landtype, with a dominant terrain type of four (4) (95%) according to the terrain form sketch for the area (Fig. 2.9) (Department of Agricultural Technical Services 1978). The geology is characterised by Aeolian sand of Recent age with a few outcrops of Tertiary Kalahari beds (surface limestone, silcrete and sandstone) in the riverbeds. Clovelly (Sunbury) (39.9%), Clovelly (Annandale) (17.1%) and Hutton (Mangano) (17.1%) are the dominant soils, with clay < 19% (Department of Agricultural Technical Services 1978).

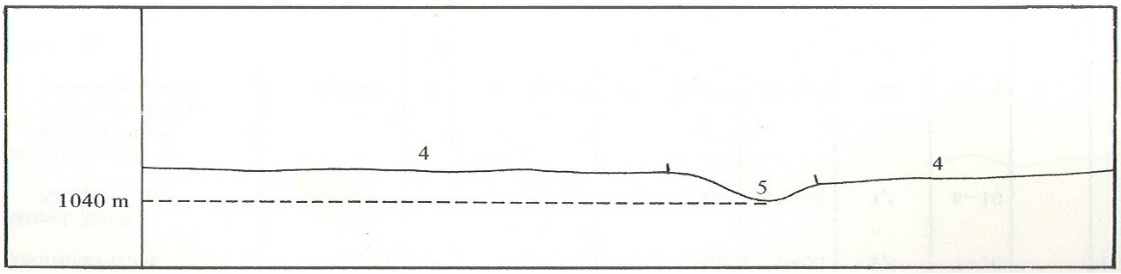


Fig. 2.9. Terrain form sketch with for the terrain types (1 - 5) within the Ah3 landtype Eskha/Newhem and Tseoge areas (Department of Agricultural Technical Services 1978).

Tseoge lies adjacent to Morokweng, which falls within the Fc1 landtype (Fig. 2.10). The geology is described as surface limestone of the Kalahari beds and dolomite with interbedded chert and quartzite in the basal portion (Schmidtsdrif and Ghaap plateau Formations). It has a dominant terrain type of four (4) (85%) according to the terrain form sketch (Department of Agricultural Technical Services 1978). Mispah (Kalkbank) (53%), Mispah (Muden, Mispah) (18.4%) and Clovelly (Sandspruit, Sunbury) (18.2%) are the dominant soils. The clay contents of these soils are < 9% (Department of Agricultural Technical Services 1978).

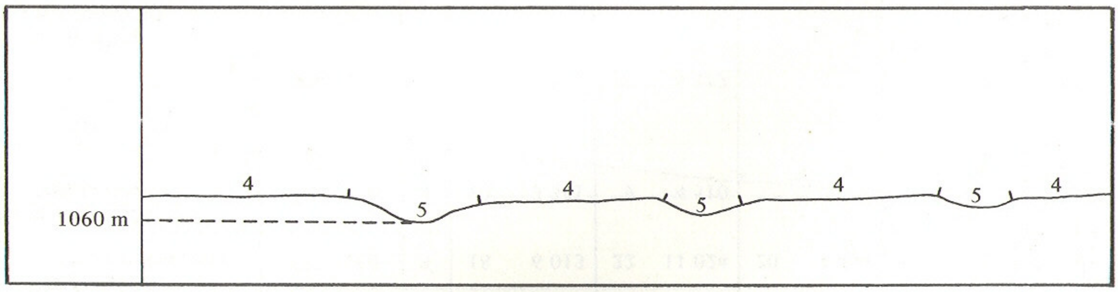


Fig. 2.10. Terrain form sketch for the terrain types (1 - 5) within the Fc1 landtype - Morokweng area, adjacent to Tseoge (Department of Agricultural Technical Services 1978).

Austrey falls within the Ah6 landtype, with geology being described as red to flesh-coloured wind-blown sand and surface limestone of Tertiary to Recent age. The land type has a dominant terrain type of four (4) (41%) (Fig. 2.11) according to the terrain form sketch for the area, and is dominated by Clovelly (Sunbury and Annandale) (45.3%) and Hutton (Roodepoort) soils with clay 3 – 10% for these soil series (Department of Agricultural Technical Services 1978).

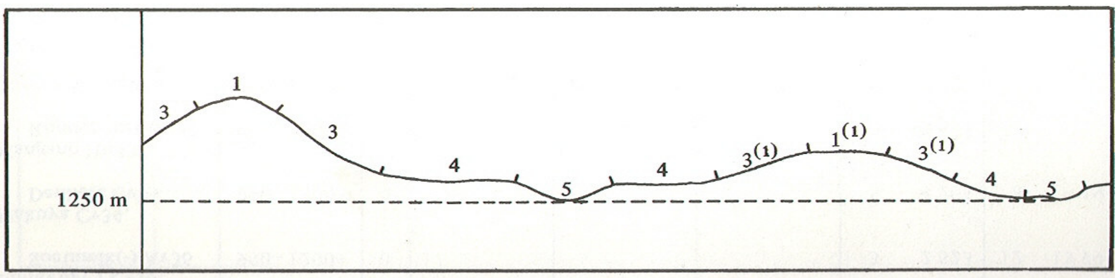


Fig. 2.11. Terrain form sketch for the terrain types (1 - 5) within the Ah6 landtype - Austrey area (Department of Agricultural Technical Services 1978).

Ottowa farm falls with the Ah7 landtype, with geology characterised by red Aeolian sand of Recent age with a few outcrops of the Tertiary Kalahari bed (surface limestone and silcrete) with jaspilite and banded ironstone of the Asbestos Hills Formation of the Griquatown Group. The land type has a dominant terrain type of four (4) (95.7%) according to the terrain form sketch for the area (Fig. 2.12), and is dominated by Hutton (Roodepoort) (47.8%) and Clovelly (Sunbury) (32.5%) soils, with clay < 9% (Department of Agricultural Technical Services 1978).

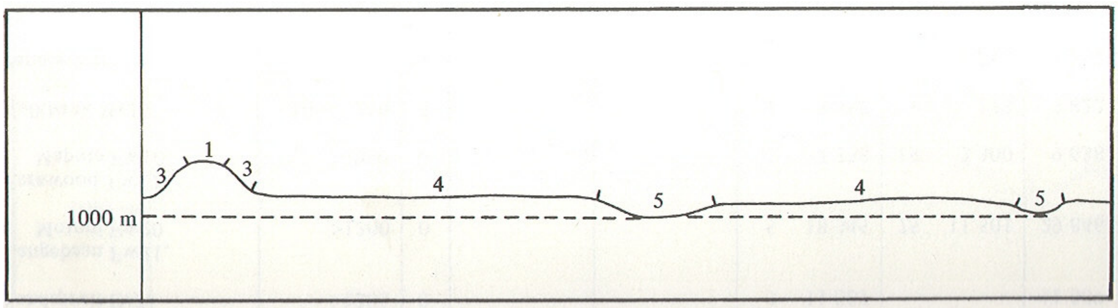
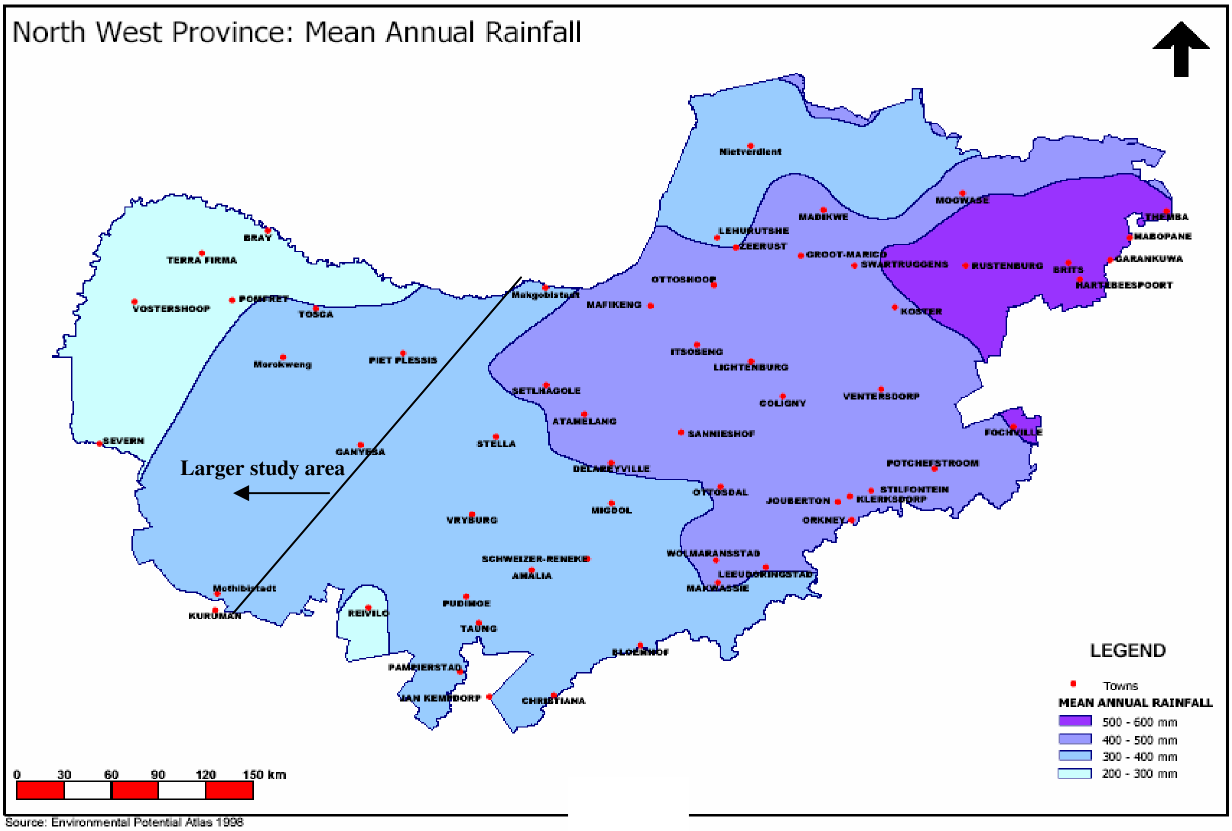


Fig. 2.12. Terrain form sketch for the terrain types (1 - 5) within the Ah7 landtype - Terra Firma area (Department of Agricultural Technical Services 1978).

2.2.4 Climate

The rainfall pattern is highly variable both spatially and temporally, with the average rainfall in this area being 300 mm, which falls in summer and early autumn (Low & Rebelo 1996). The average rainfall on the Western border of the Province (Vorstershoop and McCarty's Rest study areas) is as low as 244 mm per annum, and towards the east of the study area (Austrey, Eska/Newhem) between 400-500 mm per annum (Department of Agriculture, Technical Support Services 2000; SOER 2002) (Fig. 2.13). Hence, the average rainfall for the Reserve and Commercial land-uses ranges between 200-300 mm/annum, and between 400-500 mm/annum for the Tribal land-use (Department of Agriculture, Technical Support Services 2000; SOER 2002). The coefficient of variation (CV, %) of annual precipitation is an index of climatic risk, indicating a likelihood of fluctuations in reservoir storage, with the CV (%) varying from 30 – 40 for the study area (Schulze *et al.* 1997). The median monthly rainfall (mm) for each month for the study area is summarised in Table 2.1 (Schulze *et al.* 1997). The median designates a statistically expected value, with several years having had less rain than the median value, whereas many years have been wetter than the median (Schulze *et al.* 1997). The median rainfall regimes are thus representative of expected conditions, whereas the mean values are frequently inflated by heavy and extreme events (Schulze *et al.* 1997). The study area receives rain in late summer during February (Schulze *et al.* 1997), but the evaporation exceeds precipitation, contributing to the arid and semi-arid conditions (SOER 2002).



Source: Environmental Potential Atlas 1998

Fig. 2.13. The mean annual rainfall for the study area within the larger North West Province (SOER 2002).

Table 2.1. Median monthly rainfall for the study area (Schulze *et al.* 1997).

Month	Mean mm	Month	Mean mm	Month	Mean mm
January	20-60 (20-80)	February	40-60 (40-80)	March	20-60 (40-60)
April	10-40 (20-40)	May	< 5 (< 5 – 10)	June	< 5 (< 5)
July	< 5 (< 5)	August	< 5 (< 5)	September	< 5 (< 5)
October	5-20 (10-40)	November	20-40	December	20-40 (20-60)

( ) – brackets for the Tribal land use, while the Commercial and Reserve land uses are not indicated within brackets

Sporadic hail from convective storms average 1-3 per year for the study area (Schulze *et al.* 1997 cite Le Roux & Olivier 1996), and lightning ground flash density averages 2-3 flashes/km^2/yr for the study area (Schulze *et al.* 1997).

The study area is characterised by great seasonal and daily variations in temperature. Temperatures have a direct effect on all forms of life on earth, thus affecting a wide range of processes and activities ranging from human comfort and energy supply to domestic responses, rates of evapotranspiration etc. (Schulze *et al.* 1997). The absolute maximum temperatures range up to 42°C (Low & Rebelo 1996), with the absolute minimums ranging between -8.3°C and -9.7°C (SOER 2002). Mean daily maximum temperatures for each month are summarised in Table 2.2, and mean daily minimum temperatures for each month in Table 2.3.

Table 2.2. The means of daily maximum monthly temperatures (˚C) (Schulze *et al.* 1997).

Month	˚C	Month	˚C	Month	˚C
January	> 34 (32-34)	February	> 32 (30-32)	March	> 30 (28-30)
April	26-28 (24-26)	May	24-26 (22-24)	June	20-22 (18-20)
July	20-22 (18-20)	August	22-24 (20-22)	September	26-28 (24-26)
October	> 30 (28-30)	November	> 32 (30-32)	December	> 32 for all survey areas

( ) – brackets for the Austrey and Eska/Newhem Tribal areas, while the rest of the survey areas are not indicated within brackets, unless indicated differently

Table 2.3. The means of daily minimum monthly temperatures (˚C) (Schulze *et al.* 1997).

Month	˚C	Month	˚C	Month	˚C
January	18-20 (16-18)	February	18-20 (16-18)	March	*16-18 (14-18)
April	10-12 (8-10)	May	*6-8 (4-6)	June	*2-4 (0-2)
July	0-2 for all areas	August	4-6 (2-4)	September	8-10 (6-8)
October	12-14 all areas	November	16-18 (14-16)	December	18-20 (16-18)

( ) – brackets for the Austrey and Eska/Newhem Tribal areas, while the rest of the survey areas are not indicated within brackets, unless indicated differently

* Mean minimum temperatures for the Commercial and Reserve land uses; the Tribal land use indicated in brackets

The first date of heavy frost occurs from May 16-31 for the Tribal areas, and from May16 – June for the Reserve and Commercial land uses (Schulze *et al.* 1997). The average last date of heavy frost occurs during August for the study area (Schulze *et al.* 1997), with the average duration of heavy frost for the area ranging between frost free for the Reserve and Commercial areas to the 91 – 120 ranges for the Eska/Newhem and Austrey Tribal areas (Schulze *et al.* 1997). The average duration of the frost period is defined as the number of days between the average first date of heavy frost and the average last date of heavy frost (Schulze *et al.* 1997). The actual days of heavy frost for the Reserve, Commercial and Tseoge areas vary between 1 – 30 days, and from 31-60 days for the Eska/Newhem and Austrey areas (Schulze *et al.* 1997). Figures obtained from Tsabong weather station in Botswana, adjacent to the study area, indicate that the annual average percentage of sunshine days received is 88% (SOER 2002).

Relative humidity is low, being below 30% in July for the study area, while ranging from 40 – 42 % during January (Schulze *et al.* 1997). The potential evaporation (mm) for an A-pan equivalent, is > 360mm for the Reserve and Commercial land uses during January, and between 320-360 mm for the Tribal areas (Schulze *et al.* 1997). These potential evaporation rates (mm) are during July > 130 mm for the Reserve and Commercial land uses, and ranges from 120-130 mm for the Tribal areas (Schulze *et al.* 1997).

The predominant wind direction is from a northerly direction, with this trend being more pronounced between August and November (SOER 2002).

2.2.5 Vegetation

The vegetation of the Kalahari Plains Thorn Bushveld is characterised by a well-developed tree stratum, a moderately developed shrub layer with a grass cover depending on the amount of rainfall during the growing season (Low & Rebelo 1996). However, results from this study showed that in degraded areas in all three land-uses, the shrub layer dominated the landscape. Camel thorn (*Acacia erioloba*) and Shepherd's tree (*Boscia albitrunca*) are described by Low and Rebelo (1996) as the dominant trees, along with scattered individuals of Silver clusterleaf (*Terminalia sericea*) and Belly thorn (*Acacia luederitzii*). Black thorn (*Acacia mellifera* subsp. *detinens*), Weeping Candle thorn (*Acacia hebeclada*), Karee-thorn (*Lycium hirsutum*), Velvet Raisin (*Grewia flava*) and Grey Camel thorn (*Acacia haematoxylon*) dominate the shrub layer (Low & Rebelo 1996). The vegetation of Austrey is characterised by dense shrub bushveld of which the Camphor tree (*Tarchonanthus camphoratus*) is a principle shrub. This can be ascribed to the vegetation characteristics of the adjacent Kalahari Plateau Bushveld vegetation type (Low & Rebelo 1996) that is confined to the plateau at 1 250 m altitude, in the Vryburg-Kuruman-Griekwastad area of the North West Province and Northern Cape. In this study, Common Spike-thorn (*Gymnosporia buxifolia*) was found to be a dominant shrub within the Tribal-, but not in the Commercial- and Reserve land-uses (Chapter 4).

According to Low and Rebelo (1996) Lehmann's Lovegrass (*Eragrostis lehmanniana*), Sour Bushman grass (*Schmidtia kalahariensis*) and Silky Bushman grass (*Stipagrostis uniplumis*) are characteristic of the study area. Results from this study for the 2004 survey year indicated that, depending on the seasonal rainfall distribution pattern, Sand Quick (*Schmidtia pappohoroides*) was characteristic of the Commercial and Reserve land-uses and Long-awned grass (*Aristida stipitata*), *Eragrostis lehmanniana* and *Schmidtia pappohoroides* of the Tribal land-use (Chapter 4).

Livestock enterprises and the low and variability of the rainfall distribution pattern are considered important determinants of the vegetation structure in the study area (Low & Rebelo 1996; SOER 2002).

2.2.6 General degradation trends

A combined degradation index (CDI), including soil (SDI) - and vegetation degradation (VDI) indices, indicates that the North West Province has the third highest mean CDI, with degradation occurring in all of the Province's magisterial districts, of which bush encroachment and soil erosion (wind blown) are considered to be the most important rangeland- and soil degradation contributors within the study area (Hoffman *et al.* 1999).

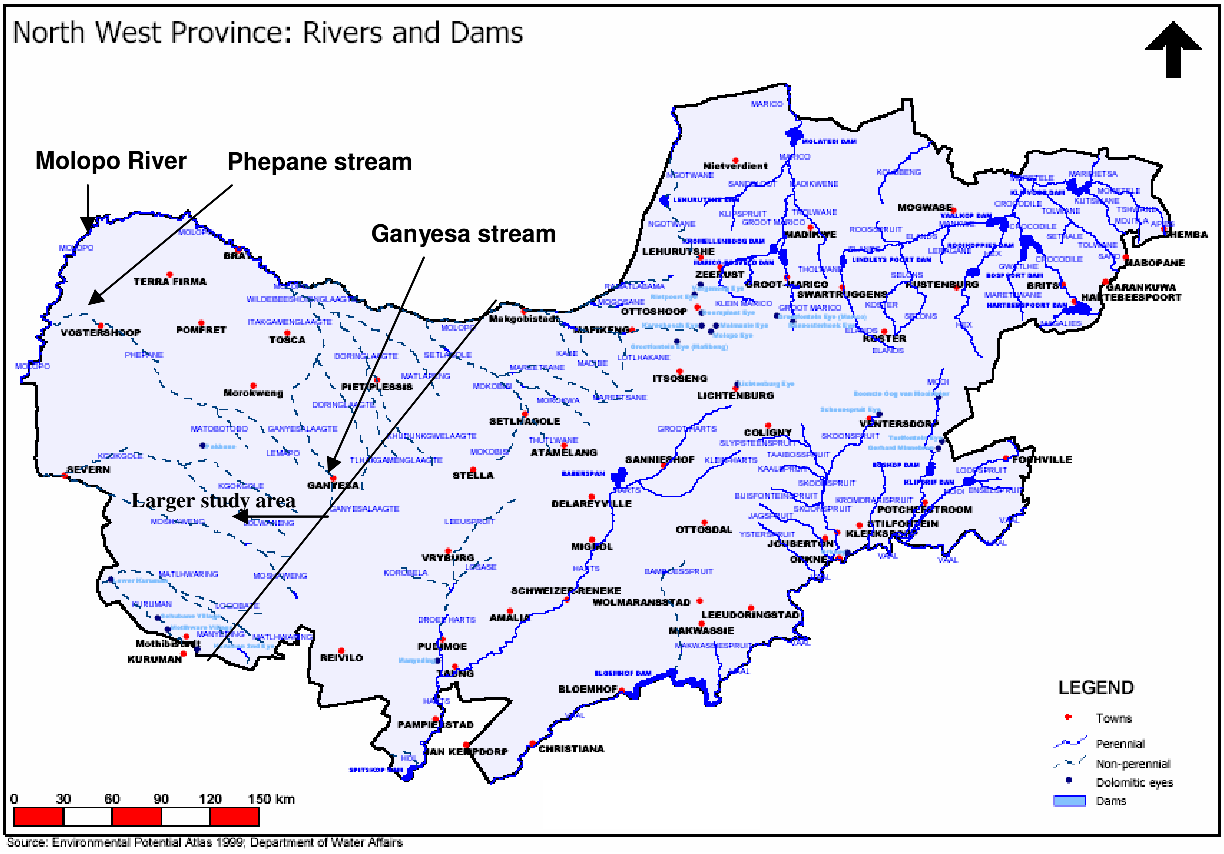
According to Low and Rebelo (1996), 55% of the Kalahari Plains Thorn Bushveld has been transformed, with only 0.47% being conserved. Within the North West Province, 0.63% of this vegetation type is conserved (SOER 2002).

Degradation, which encompasses soil and rangeland degradation, is described within the Tribal land-use as moderately high, and low in the Reserve and Commercial land-uses (SOER 2002).

2.2.7 Surface drainage

Water is considered to be one of the North West Province's most limiting and critical natural resources (SOER 2002). The highly variable spatial and temporal annual rainfall, as well as the variable and low actual runoff because of the sandy soils, affect the surface water in the study area. Runoff, calculated as a percentage of the precipitation is less than 1%, which is below the average of 9% for Southern Africa (SOER 2002).

The study area has no perennial rivers. The Molopo River is a non-perennial river, which forms the northern border of the North West Province, as well as the study area, with Botswana (Fig. 2.14). It has several tributaries, of which the Ganyesa stream and Phepane stream, all of which are non-perennial, fall within the study area. The Phepane stream runs through the Molopo Nature Reserve and through one of the Commercial land-use farming areas studied (Lafras/Lands End; Vorstershoop), which lies adjacent to the Reserve.



Source: Environmental Potential Atlas 1999; Department of Water Affairs

Fig. 2.14. The non-perennial Ganyesa and Phepane streams and Molopo River within the study area (SOER 2002).

2.2.8 Socio-economic aspects

According to the DPSIR (Driving Forces-Pressures-State-Impact-Responses) framework for the North West Province (SOER 2002), human influences and their activities, as well as natural processes act as direct and indirect pressures on the processes that underpin landscape health, and hence soil, pasture and animal productivity.

The Province's economy is derived from a variety of sectors, of which mining and agriculture are the main contributors. Of the total surface area of the NW Province, approximately 85% (10 million ha) is classified as agricultural land, with 34% of the agricultural land classified as potentially arable and 66% as grazing lands (SOER 2002). However, 30% of the North West Province consists of affected drylands (SOER 2002). An affected dryland is defined by the United Nations Convention to Combat Desertification (UNCCD) as "arid, semi-arid and/or dry sub-humid areas affected or threatened by desertification" (Hoffman *et al.* 1999). Hence, these areas are characterised by low annual rainfalls and high evapotranspiration rates. Of the total farmland, 33% lies in the former homelands, with 67% used for commercial agricultural enterprises. In the former homelands, 29% of the land is arable and 71% grazing land with 35% of commercial land being arable and 65% grazing land (SOER 2002).

Only 34.9% of people in the North West Province are urban dwellers with most of the population (65.1%) living in the rural areas, compared to the National trends of 46.3% and 53.7% for rural and urban figures, respectively (SOER 2002). There are approximately 7600 commercial farming units in the North West Province, while the small-scale farmers in the former homelands amount to approximately 147 000, with most of the farming units having livestock production enterprises as their dominant branch of agriculture (SOER 2002). With the constraints imposed by climate and soil, it is expected that the livestock sector will become the most important agricultural sector in terms of added value. The estimated livestock numbers in the North West Province (thousands: National Livestock Strategy and Implementation Framework – NLSIF – 2003), with the contributions made by the Tribal areas as percentages in brackets are: cattle – 1816 (30.2), sheep - 734 (28.5), pigs – 172 (6), goats – 771 (80) (NLSIF – 2003). The North West Province has the largest number of poultry (thousands) (16 585) of all the provinces (NLSIF 2003). The estimated contributions from the Tribal areas to the total cattle, sheep and goat numbers in South Africa are 40.8%, 12.1% and 69.5% respectively (NLSIF 2003).

In the Western Agricultural Region (Bophirima region), agricultural land covers 4 168 197 ha (44% of province), of which 0.2% is irrigated, 84% is grazing areas, 3% is under cultivated pastures and 12.8% is considered drylands (SOER 2002). Extensive livestock and wildlife farming is prevalent in the Bophirima Region, with statistics (percentage of total for the NWP for each commodity) presented as follows: beef cattle – 496 985 (34%), dairy cattle – 59 852 (23%), sheep – 279 053 (31%), goats – 344 629 (60%), game – 10 549 (2%), pigs – 12 494 (11%), chickens – 79 690 (1%), horses – 10 655 (70%), mules and donkeys – 14 712 (54%) (SOER 2002). Within this region, 43.8% is State Trust and tribal land, 47.9% private property and 8.3% rented or leased land (SOER 2002).

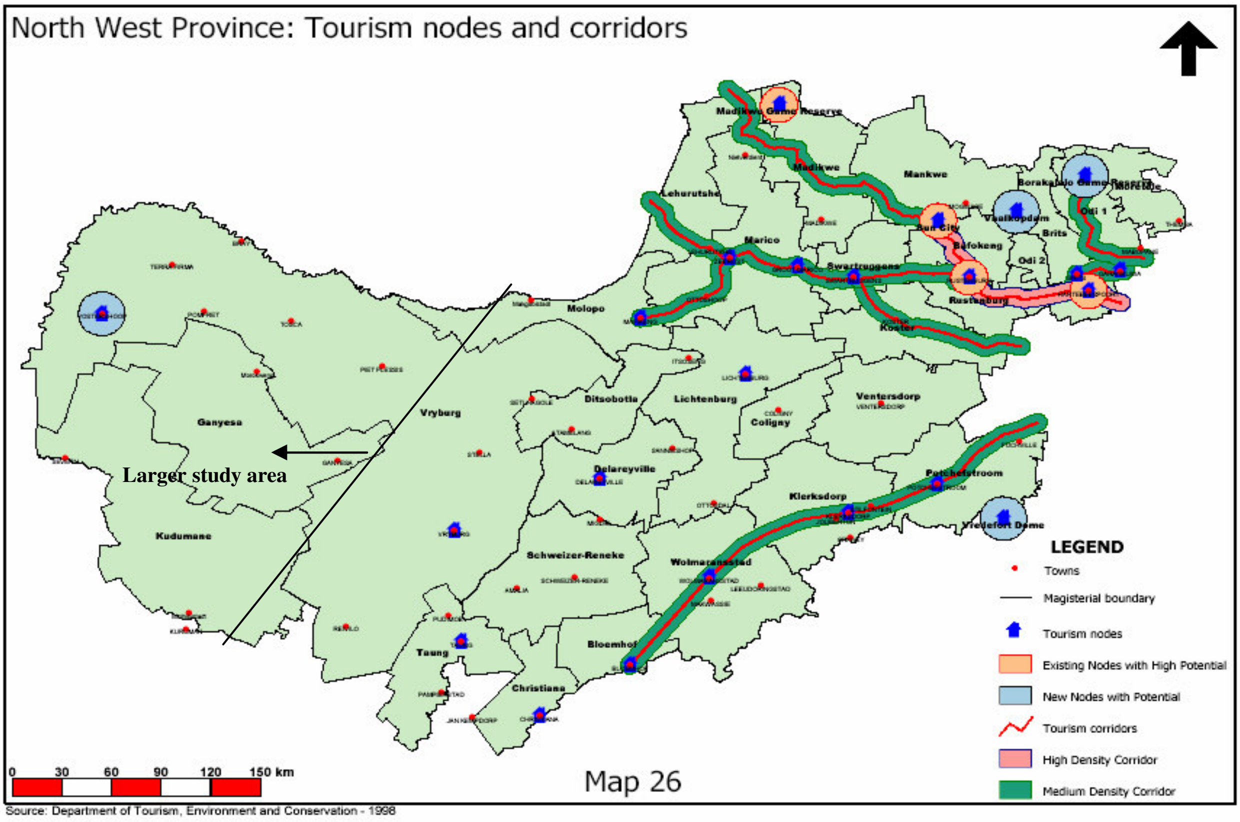
According to Kumleben *et al.* (1998), in 1998 South Africa had 12 820.73 km^2 formal protected areas, of which 2 156.36 km^2 are protected by the North West Parks and Tourism Board, whilst 16 064.37 km^2 are informally protected and managed by private persons and institutions. Protected areas in the North West Province are represented by National Parks, Proclaimed Provincial Reserves, Protected Natural

Environments, Municipal Nature Reserves, Natural Heritages Sites, Ramsar sites, Private Nature Reserves and Conservancies, with the latter two areas not being formally protected (SOER 2002). In the Bophirima Region, the primary objectives of the Molopo Nature Reserve is to conserve biological diversity associated with the Molopo Thornveld; to provide a focus for management orientated research in the Molopo Thornveld, aimed at effective and viable options and theories for land use in the area; to educate and involve local communities and the public about the sustainable utilisation and conservation of the Molopo Thornveld; to provide outdoor recreational possibilities; to market and utilise natural resources; and to provide economic opportunities to local entrepreneurs (Newbery 2001). Conservancies are envisaged to provide a platform to create environmental awareness and contribute to environmental education and research (SOER 2002). There is one registered conservancy in the Molopo area, namely the Molopo Raptor Conservancy (SOER 2002).

South Africa has a long history in trade in biological resources, with the trade in biological resources ranging from live game and game products to indigenous medicinal plants (SOER 2002). There are figures available for some of the commercial trade of biological resources, but it is difficult to quantify it on provincial scale (SOER 2002). Limited information does exist in the North West Province through permitting, however, very little is known about the extent of indigenous plant use and horticulture trade (SOER 2002). The extent and overexploitation of Devil's Claw (*Harpagophytum procumbens procumbens*) and the undermining of indigenous knowledge and rights within the Bophirima Region, need to be quantified in order to prevent the loss of intellectual property rights and unsustainable utilisation of these resources (Moolman 2000).

Settlement development as well as intensification of grazing use showed only a moderate increase over the past 10 years (SOER 2002) in the study area. Vorstershoop, representing one of the nearby Commercial land-use survey areas, is described as a potentially new existing tourism node (SOER 2002). However, it is not linked to any tourism corridor, which poses a severe limitation (Fig. 2.15).

Land use data, in particular agricultural data in the former Bophuthatswana, is scant and needs to be updated (SOER 2002). Land use data, especially agricultural data, is required to integrate agricultural and other development data at the district level for the entire Province, but especially for the Molopo rangelands, being described as a "black hole" in terms of any biophysical and socio-economic data, in order to facilitate a comprehensive and effective integrated environmental management programme (SOER 2002). Non-agricultural land uses, such as conservation and tourism, should be encouraged (SOER 2002), hence further motivating why a Reserve (conservation) land use was included in the study.



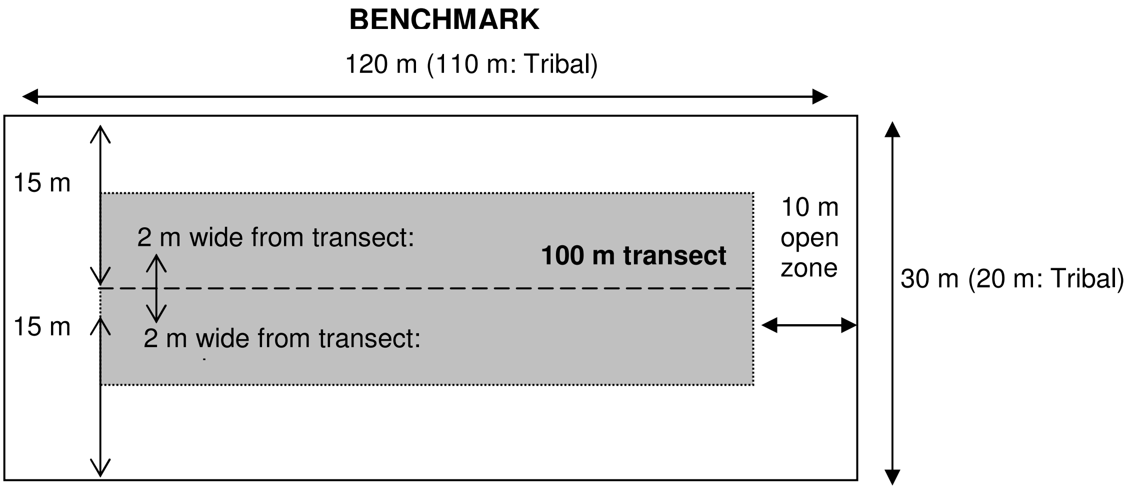
Source: Department of Tourism, Environment and Conservation - 1998

Fig. 2.15. The potential Vorstershoop Tourism node (SOER 2002).

CHAPTER 3

Material and methods

Herbaceous species composition surveys; woody composition, density and cover surveys; ant surveys and soil surveys were performed within each sub-replicate, and repeated within each benchmark (barring the ant surveys, refer to Section 3.3), and are presented below (Fig. 3.1):



- Grass production: 30 quadrats sampled within each sub-replicate, = 30 m^2.

----► Herbaceous species composition: No predetermined transect length – performed within each sub-replicate until 98% of the variance is explained.

└----┘ Woody survey: Survey along fixed transect, 2 m wide on every side of transect line. Hence an area of 400 m^2 is sampled within each sub-replicate.

- Soil surveys: Two from beneath the primary woody component and two from beneath the open herbaceous component within each sub-replicate.

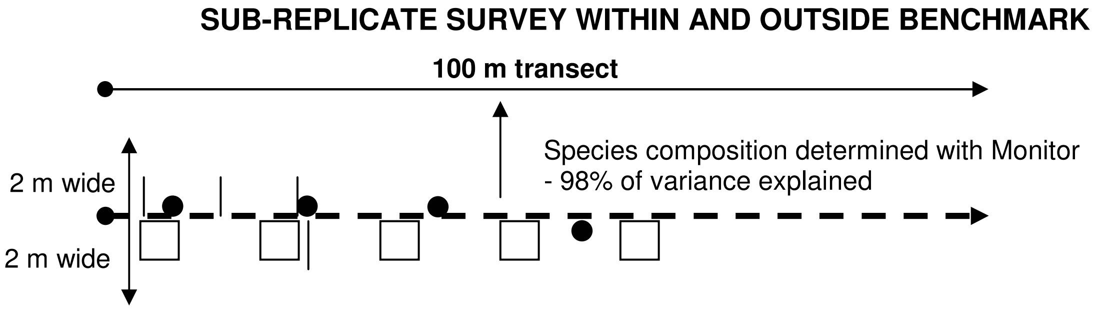


Fig. 3.1. Surveys performed within each sub-replicate within and outside the benchmark.

3.1. HERBACEOUS SPECIES COMPOSITION SURVEYS

3.1.1 Surveys

Herbaceous species composition surveys within all the sub-replicates (Chapter 2, Fig. 2.3) were conducted during the rainy (growing) season of the year (April-May 2004), and determined using the descending point, nearest-plant method (Roux 1963). The rainfall pattern of this particular survey season reflected the long-term average rainfall mean for the study area. The rainfall pattern thus did not deviate significantly from that of the long-term rainfall distributional pattern. Frequency of occurrence was established with the wheel point apparatus (Tidmarsh & Havenga 1955) and by using the Psion Monitor. The Monitor statistically determined the number of points that should be surveyed at each sub-replicate (plot) in order to give a significant reflection of the species composition. Hence, the plots did not have a specific size or number of survey points, since surveys were completed once 98% of the variation had been sampled.

Nearest plant point surveys within a radius of 45 cm of that point were performed (Fig. 3.2). When an annual herbaceous species or a bare patch was pointed out, the nearest perennial species within a radius of 45 cm from the point was also recorded. When the nearest plant was further than 45 cm from the marked wheel point, it was recorded as a bare patch. Bare ground was thus recorded as a “vegetation species”, and equates to the lack of herbaceous cover within that point (radius of 45 cm for this study) (Legget *et al*. 2003a). Point observations were spaced by 1 m intervals and records were made over the length of the plot, moving in straight parallel lines and with approximately 1 m distance among them (Fig. 3.2).

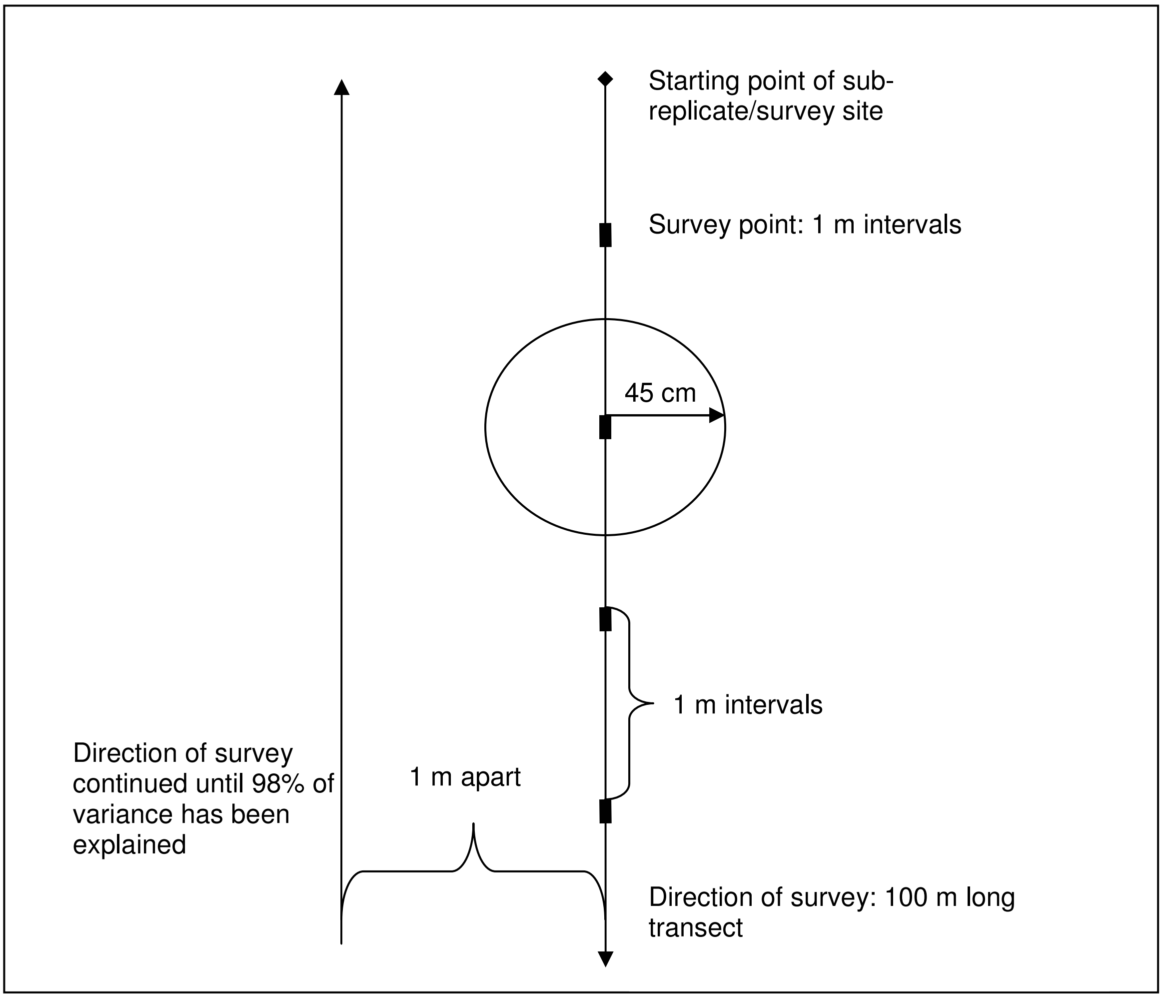


Fig. 3.2. Illustration of the herbaceous descending plant-point surveys done with the Psion Monitor until 98% of the variance has been explained within each sub-replicate.

3.1.2 Herbaceous species composition, classification and rangeland condition assessment

Classification of grasses was based on the quantitative climax method of Dyksterhuis (1949) and adapted according to the ecological information for the arid to semi-arid regions of South Africa (Anon undated; Foran *et al.* 1978; Tainton *et al.* 1980; Vorster 1982; Fourie & Du Toit 1983; Fourie & Fouché 1985; Fourie & Visagie 1985; Gibbs Russell *et al.* 1990; Van Oudtshoorn 2002). Accordingly, the species were classified according to the grazing-index, ecological-index, and life-form (e.g. perennial/annual), and rangeland condition scores were calculated to convey multivariate information about the current state of the vegetation at a site. Classification according to the grazing-index grouped species into: (i) highly desirable species (HD), (ii) desirable species (DE), (iii) less desirable species (LD), (iv) undesirable species (UD) and into forbs (FORBS) and bare patches (BP). The grouping of the species was also based on specialists' knowledge for the particular survey area. Each class was given a relative index value: highly desirable species = 10; desirable species = 7; less desirable species = 4 and undesirable species and forbs = 1 (Fourie & Fouché 1985). The range condition index was calculated by summing the percentage composition of grass species in each class, after which the sum for each class was multiplied by its relative index value.

Classification according to the ecological-index (Vorster 1982; Van Oudtshoorn 2002) grouped species into: (i) Decreasers: palatable, climax grasses that are abundant in good rangelands, but that decrease with heavy grazing or underutilisation, (ii) Increaser I: grasses that are abundant in underutilised rangelands, (iii) Increaser II: grasses that include mostly pioneer and subclimax species and that are likely to increase with moderately heavy grazing (this ecological group is common in lower rainfall areas (Van Oudtshoorn 2002)), (iv) Increaser III: most often unpalatable, dense climax grasses (Van Oudtshoorn 2002) that are likely to increase with severe/extreme overgrazing. These grasses are considered as strong competitors that increase because the palatable grasses have been selected and become weakened through overgrazing (Van Oudtshoorn 2002). The grouping of the species was also based on specialists' knowledge for the particular survey area (Anon undated). Specialists' knowledge was informative, since the ecological status of grasses may vary from one region to another (Van Oudtshoorn 2002). Each class was given a relative index value: Decreaser = 10; Increaser I = 7; Increaser II = 4 and Increaser III = 1 (Vorster 1982) and forbs = 1. The range condition index was calculated by summing the percentage composition of grass species in each class, after which the sum for each class was multiplied by its relative index value (Vorster 1982).

Based on the life-form (perenniality), an annual tufted grass grows for one season; a weak perennial tufted grass for two to five seasons; a perennial tufted grass grows for longer than five seasons; and a creeping grass creeps with stolons and/or rhizomes (Van Oudtshoorn 2002).

3.2. WOODY COMPOSITION, DENSITY AND RELATIVE COVER SURVEYS

Bush density and woody species composition (given as relative abundances of total density within a sub-replicate) were expressed in terms of tree equivalents/bush equivalents per hectare (either TE/ha or BE/ha; for the purpose of this study, TE = BE), area cover (m^2/ha) and bush numbers per species/ha.

Bush density was initially determined by categorising woody individuals into one of six height classes (>0-0.5m; >0.5-1.0m; >1.0-2.0m; >2.0-3.0m; >3.0-4.0m; >4.0m) and standardising to tree equivalents per hectare (1TE = 1 tree of 1.5m height) (Teague *et al.* 1981). However, bush density and relative abundance were then determined by using the exact height of each woody individual and standardising it to tree equivalents per hectare. Transects of 100 m were sampled within each sub-replicate (including benchmarks) (refer back to Fig. 3.1). Within each sub-replicate, a 2 m wide strip, one on each side of the transect, was sampled (refer back to Fig. 3.1). Hence and area of 400 m^2 was sampled within every sub-replicate. Bush density and relative abundance were then calculated per hectare for the TE/ha, area cover (m_2/ha) and bush numbers per species/ha matrices.

3.3. ANT SURVEYS

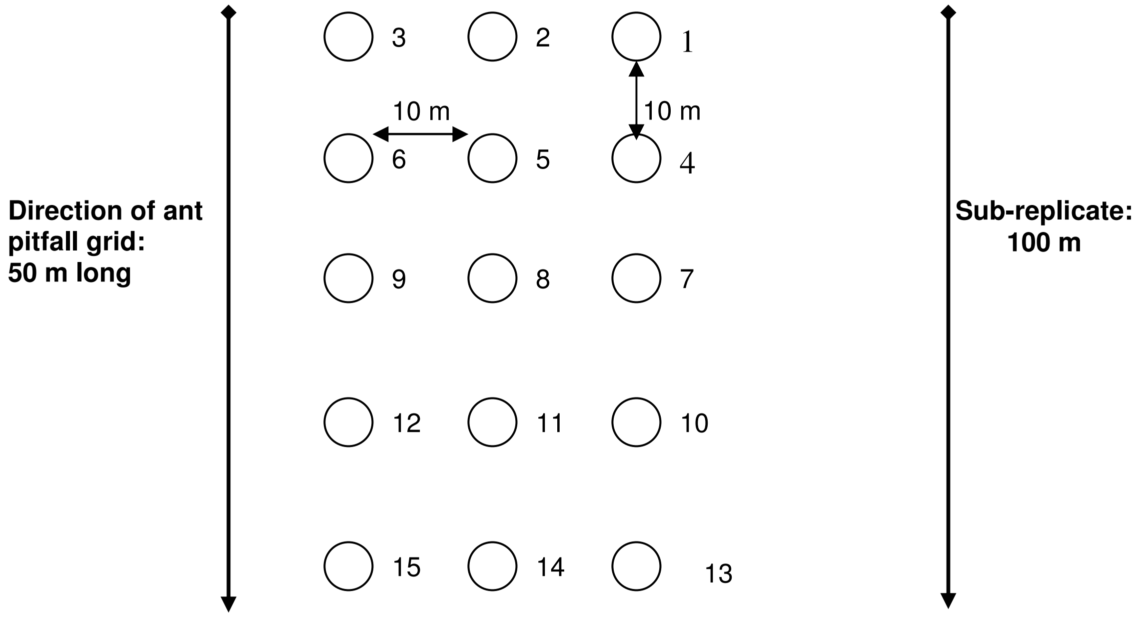


Fig. 3.3. Illustration of an ant pitfall grid lay-out within each sub-replicate/survey site.

Ants were sampled in 54 sub-replicates (grids). The 18 benchmark plots were excluded from the sampling, since the 12 benchmarks in the Commercial and Reserve land-use were relatively newly erected, as opposed to the 6 benchmarks of the Tribal areas that were erected since 1999. Invertebrates are known to be sensitive to habitat complexity (structure and heterogeneity) (refer to Chapter 8), hence, surveys for the purpose of the invertebrate bio-indication were done only in the sub-replicates that were subjected to the continuous “normal” land tenure practices within each land use, as to correctly quantify whether land use or initial environmental differences resulted in the observed ant assemblage structures. Thus, the ant pitfall grids sampled in the 54 sub-replicates were integrated with the biotic and abiotic data surveyed within those 54 sub-replicates (see Chapter 8). Thus, for the purpose of the invertebrate discussions, the benchmarks in all three land-uses were thus excluded from the analyses. Within each sub-replicate, ants were sampled using 15 pitfall traps located in a 5 x 3 grid with 10 m spacing between each trap (Fig. 3.3). Traps operated for 48 hrs and were sampled during February 2004, as to get an indication of the ant/site affinities within and between the different land uses. Ants were sampled using pitfall traps, which were 50 mm diameter plastic specimen jars, partly filled with ethylene glycol as a killing agent and preservative. Pitfall traps provide a relatively good unbiased estimate of relative abundances and distribution of ground foraging ant species (Andersen 1990, 1991b, 1997a; Andersen & Sparling 1997; Retana & Cerdá 2000), but may possibly undersample arboreal-nesting ants.

Ants collected were sorted to species level, and either named to species or assigned species code numbers applying only to this study. Voucher specimens are held at the Department of Agriculture, Conservation and Environment (Scientific Technical Support Services, Potchefstroom). Functional group classification follows Andersen (2003), Andersen and Majer (2004), and Andersen (2005, pers. comm.)

3.4. SOIL SURVEYS

The following was noted at each survey site (sub-replicate) (Fig. 3.4):

The underlying parent rock formation of different survey areas within and across each land-use was compared by studying geological maps in order to select survey areas with similar geology.

Soil samples from beneath the dominant woody component, within each survey site (sub-replicate) (Fig. 3.1), as well as from the "open" herbaceous area were collected, analysed and related to the vegetation, ants and other environmental properties.

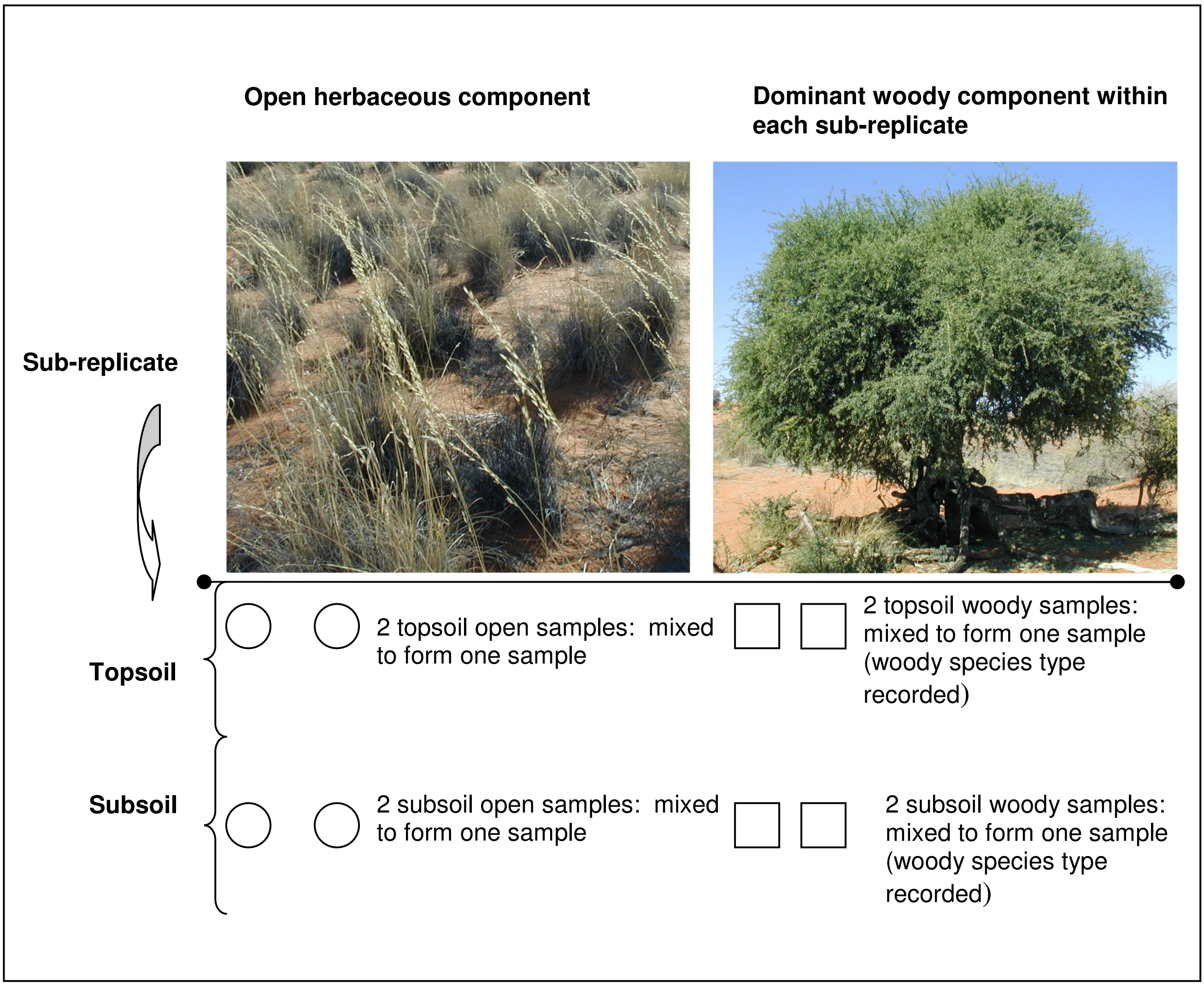


Fig. 3.4. Illustration of topsoil and subsoil samples collected within the open herbaceous areas as well as under the dominant woody component within each sub-replicate.

At each sub-replicate, eight samples (for four categories) were collected and analysed: 2 topsoil- (up to 25cm; "open" herbaceous stratum), 2 subsoil- (from approximately 50 – 75cm; "open" herbaceous stratum), 2 topsoil- (woody stratum) and 2 subsoil (woody stratum) samples (Fig. 4). Plant litter was discarded in all the samples. Statistical analysis with ANOSIM (Clarke & Warwick 2001) showed that there were no significant differences in the general (total) topsoil (up to 25cm) chemical and physical composition versus that of the top 5 cm, or for the separate chemical and physical elements/particles between these two sample strata. Hence, for the purpose of this study, topsoil (up to 25 cm) and subsoil samples, as defined above, were used in the analyses. The two samples within a category were mixed together in order to eventually draw one sample representative of the whole site, and kept apart from the other mixture (Fig. 3.4). Chemical and physical soil properties were analysed.

Soil analyses were done by standard methods (The Non-Affiliated Soil Analyses Work Committee 1990). Soil pH was determined in a 1:2:5 soil to 1M KCL suspension. Calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) were determined by atomic absorption after extraction in 1M ammonium acetate, using a soil to solution ratio of 1:10. Plant available phosphorus was extracted with the Bray 1 solution (0.025 mol L^{-1} HCl + 0.03 mol L^{-1} NH_4F) using a soil to solution ratio of 1:7.5. Cation exchange capacity (CEC) was determined by saturating the soil with sodium and displaced sodium concentration (by ammonium acetate) was then determined by atomic absorption spectrophotometry. The percentage Carbon (C) was done by wet oxidation-redox titration. Nitrate (NO_3) was determined by 1M KCl extraction and automatic flow-system. Zinc (Zn) was extracted by 0.1M HCl on a 1:4 soil to solution ratio. Zn was then determined by atomic absorption spectrophotometry. Particle size and composition of the soil (clay, silt and sand contents) were determined by the hydrometer method (The Non-Affiliated Soil Analyses Work Committee, 1990). Percentage carbon (C) in the soil was determined by standard methods (The Non-Affiliated Soil Analyses Work Committee 1990).

3.5. HERBACEOUS PRODUCTION SURVEYS

The aboveground phytomass (production) of the grass layer was determined in the rainy (growing) season of the year (April-May 2004). The herbaceous production was surveyed to convey and calculate the following information for the purpose of this study: (i) the dry material yield per hectare (DM yield – kg/ha); (ii) ha/LSU. For the purpose of this study, based on the objectives of this study, it was sufficient to express the herbaceous production as DM yield/ha (kg/ha), by incorporating it as passive/supplementary data into the multivariate analyses (see Chapter 10, Recommendations, for further discussions regarding the herbaceous production surveys).

The herbaceous production, and hence DM yield (kg/ha), was calculated as follows. All herbaceous material in thirty 1m^2 quadrats within each sub-replicate (Fig. 3.1) was estimated on a species basis, by using the dry-weight rank method (T' mannetjie & Haydock 1963). The grass material cut for rank estimation was dried to a constant mass, weighed and production per hectare for each replicate was calculated on a dry mass basis.

Current grazing capacity (CGC) calculations were made according to the formula proposed by Moore and Odendaal (1987):

$y = a \div (b \times c)/d$

where: y = current grazing capacity (ha/LSU)

a = 365 days (number of days in a year)

b = total utilisable dry matter production (kg/ha)

c = 0.40 (utilisation factor)

d = 12 kg/DM/LSU (daily fodder requirement of one LSU)

The utilisation factor of 40% is based on assumptions that 40% of the total utilisable production remains on the rangeland as tufts and stubble, while a further 20% of herbage is lost due to decay caused by environmental factors, resulting in only 40% of grass production being utilised (Moore & Odendaal 1987).

3.6. ADDITIONAL DATA

The following additional data, where available, were gathered from the co-workers (farmers or landowners) as well:

- Management information from each farm/village/reserve within each land-use type;
- Type of animal used for grazing/browsing;
- Grazing capacity applied according to farmer/land-owner/land-user;
- Rainfall data – monthly rainfall figures (mm) were required for each paddock where monitoring sites (at the benchmark exclosures) occurred.

Additional data were firstly evaluated on grounds of availability, significance and reliability before being used for the interpretation of the data and the tendencies observed.

3.7. DATA ANALYSIS

Different procedures from the CANOCO 4 (Ter Braak & Šmilauer, 1998) and Primer v. 5 for Windows (Clarke & Warwick 2001) packages were used in order to address the key questions stated for this study. It can not be emphasised enough that, although these different analyses techniques might result in the **incorrect** perception of over-analysing, the different procedures were all essential and complementary to each other. It was only after the in-dept analyses, using the different procedures that it was possible to establish the different multivariate spatial patterns, heterogeneity complexity and diversity- and rangeland gradients pertaining to the different parameters, which exist within and between land uses due to different land use impacts (refer to Conclusions within each chapter and final Concluding Remarks in Chapter 9).

This holds important consequences for rangeland monitoring and management purposes, and the correct identification of biophysical indicators of rangeland degradation, biodiversity and ecosystem "health", which in return impact on the socio-economical indicators. The following procedures were followed for each of the different data compositional matrices:

- Multidimensional scaling (MDS) to establish whether there were outlier sites within each of the separate data matrices that need to be removed from the rest of the analyses;
- Analysis of similarities (ANOSIM): one-way and two-way crossed to establish whether there were significant differences between the different land uses based and/or relative condition groups within and across land uses;
- Univariate diversity measures to present diversity information for the different species compositional matrices;
- Ranked species abundance (dominance) curves and k-dominance curves;
- Indirect ordination of species compositional data for the different matrices, by means of Detrended correspondence analysis (DCA) for unimodal data that displayed an artificial arch effect, and Principal component analysis for linear data;
- Ordination of species compositional data for the different matrices, by employing Canonical correspondence analysis (CCA) for unimodal data, and Redundancy analysis (RDA) for linear data;
- Monte Carlo permutation test (within the direct CCA and RDA ordinations) to establish the significance of the species-environment relations for the first and all the canonical axes;
- Forward selection of environmental variables in the Monte Carlo test, to determine which variables, in order of importance and significance, primarily accounted for the species-environment variance;
- BVSTEP stepwise test to investigate the species that primarily accounted for the species-environment relation, in complement and in addition to the analyses of points 6 and 8;
- Partial canonical correspondence analysis, incorporating covariables as well as environmental variables, to establish whether the environmental variables are the primary or secondary determinants of the species-environment relation;
- SIMPER analysis, an explanatory procedure, to explain which variables primarily accounted for similarities within and between land uses, as well as within and between rangeland condition groups ("Good" and "Poor" rangeland condition groups). Species typical of each land use, and discriminating between land uses, were also indicated;
- IndVal, an indicator value programme to establish which ant species are indicators of the different land uses, as well as the significance of the indicator values.

The Molopo semi-arid rangelands have been described as a "black hole" in terms of information available with regard to the biophysical-, social- and economical environments (SOER 2002). This study thus serves as a baseline reference point for future research with regard to other biophysical aspects that can be interrelated with the socio-economical aspects. Different ecological transitional states pertaining to the different parameters have been identified (Section 9.1), and can serve as departure point in identifying thresholds between different ecological states. This was possible only after incorporating the different analyses procedures complementary to each other. The procedures, and how they interrelate with each other, will be described in the sections below. It is essential that the following section, when reading the "Results and discussion" pertaining to each parameter (presented in separate chapters), should be consulted as reference for why procedures were used complementary to each other, to avoid the perception of over-analysing.

3.7.1 Herbaceous Species Composition

The term Multidimensional scaling (MDS) follows Kruskal's non-metric, iterative procedure (Kruskal 1964). A MDS constructs a configuration of the samples (sub-replicates) in a number of dimensions, which attempts to satisfy all the conditions imposed by the rank dissimilarity matrix (Clarke & Warwick 2001). The measure of goodness-of-fit is calculated by the **stress** value (Clarke & Warwick 2001). Values near zero indicate low stress values, whereas a large scatter of samples (sub-replicates) results in large stress, and can be due to compressing the sample relationships into a small number of dimensions (Clarke & Warwick 2001). Stress < 0.05 indicates no prospect of misinterpretation, stress < 0.1 corresponds to a good ordination with no prospect of misleading interpretation, and stress < 0.2 gives a potentially useful two-dimensional picture. Stress > 0.3 indicates that the points are too close to being arbitrarily placed in the two-dimensional ordination space (Clarke & Warwick 2001). The MDS plot was based on Bray-Curtis dissimilarity measures. The MDS plot was used to detect any outliers that need to be removed from further analyses. Results from the MDS plot were cross-checked with ANOSIM tests (Clarke & Warwick 2001) and compositional patterns indicated by the DCA/PCA ordinations in the CANOCO package (Ter Braak & Šmilauer 1998).

Analysis of similarity (ANOSIM), a non-parametric permutation procedure applied to rank similarity matrices underlying sample ordinations (Clarke & Warwick, 2001), was used to establish significant differences in the herbaceous species composition (as well as by incorporating categorisation according to the life-form, ecological- and grazing indices) within and between land-uses, based on different environmental and biotic criteria. A Bray-Curtis dissimilarity matrix was computed between samples (sub-replicates for this study) and entered into the ANOSIM procedure. In ANOSIM, the R-statistic provides an absolute measure of how separated groups are, and a value close to one indicates significant differences between the assemblages for the specific criterion used (Clarke & Warwick, 2001). R = 1 only if the replicates (sub-replicates for this study) within a group (land use for this study) are more similar to each other than any replicates (sub-replicates for this study) from different groups (Clarke & Warwick 2001). R is approximately zero if dissimilarities between and within sites will be similar on average (Clarke & Warwick, 2001). A value close to zero (R < 0.25) indicates that the assemblages are barely separable, whereas R > 0.45 indicates that groups are overlapping but clearly different and R > 0.75 that groups are well separated (Clarke & Warwick 2001). R-values below zero indicate that similarities across different sub-replicates for this study, are higher than within groups (Clarke & Warwick 2001). The R-value can be significantly different from zero, yet be inconsequentially small, given that there are many replicates at each site (Clarke & Warwick 2001). The significance level is calculated by referring the observed value of R to its permutation distribution (Clarke & Warwick 2001).

One-way analysis (Clarke & Green 1988) as well as two-way crossed ANOSIM analysis for the different data sets were performed. In the one-way analysis, the test assumes that groupings were decided *a priori* and a statistical test of the null hypothesis that there are no assemblage differences between groups of samples (sub-replicates). The two-way crossed layout of the null hypothesis tests that there are no differences between treatments (i.e. land uses and the "Good" and "Poor" rangeland condition groups), allowing for location differences on the assumption that all treatments are replicated at each location (Clarke & Warwick 2001). Analyses were performed based on different criteria such as land-use and rangeland condition type (relative "Good" vs. relative "Poor") for the species composition data set, ecological-, grazing and life-form classification indices.

Ordination helps to identify those environmental variables that significantly influence species composition and those species, which are varying along those gradients. Ordination techniques could assist in understanding a local environmental classification (Verlinden & Dayot 2005). Indirect ordination using Detrended correspondence analysis (DCA) (unimodal response) was used to extract ordination axes that describe the main special compositional gradient, and to establish which environmental variables are related to the species gradients (Ter Braak & Šmilauer 1998). Detrending was required since an artificial arch effect was observed. Detrending is a method that aims to remove the spurious curvilinear trend by dividing the first CA axis into a number of segments, and then within each segment sample scores on axis two are subtracted from the mean. Land use type (Commercial, Reserve, Tribal) and rangeland condition type ("Good" and "Poor) were incorporated as nominal environmental variables into the analyses. Principal components analysis (PCA, linear response) was used to describe the main gradients of the grazing- and ecological indices and life-form data sets. Direct ordination using Canonical components analysis (CCA) was then performed to extract only the gradients in the species compositional data (direct Redundancy analysis - RDA for ecological and grazing indices and life-form data) that are related to the environmental data measured and incorporated in the analysis. The RDA is best used on data with low species turnover (< 1.5 SD), whereas a CCA can deal with diverse data sets. Results from the direct ordination were compared with the indirect ordination which included the environmental variables to establish, by comparing changes in the eigenvalues and plot interpretations, whether major variability in the indirect ordination was accounted for (based on the measured environmental variables). Indirect ordination provides a summary of the community patterns, whereas canonical ordination focuses on the species-environment relationship.

Therefore, if the patterns of the indirect and direct ordinations are similar, one can assume that the environmental variables used in the canonical ordination adequately explain the community pattern (Morris 2004). If the plots differ and the eigenvalues and percentage variance accounted for of the canonical axes are much less than the indirect ordination, one or more of the influential environmental variables have not been accounted for (Morris 2004). Downweighting of rare species was selected as option in the direct, unimodal ordination. In unimodal methods, rare species may distort the analysis, and their influence can be downweighted when performing the analysis (Ter Braak & Smilauer 1998). Passive (supplementary) data, such as species richness and diversity, rangeland condition scores (VCS…), DM yield (calculated form the herbaceous production surveys), woody density (TE/ha, bush area coverage/ha and bush numbers/ha) were added to the ordinations. Passive data do not influence the definition of the ordination axes, with its data being regressed on the existing ordination axis (Ter Braak & Šmilauer 1998).

Monte Carlo Permutations (n = 499) to test the significance of the relation between the species and environment data were performed, using CCA and RDA ordinations (Manly 1997).

Canonical ordination plots and statistics can be interpreted as follows (Morris 2004):

- The proximity of species point indicates their similarity in distribution along environmental gradients;
- Nominal variables are represented by a centroid position in ordination space of members of that class, with sites close to a particular class centroid most likely belonging to that class;
- Quantitative environmental variables are represented by arrows indicating the direction of maximum change of variables in ordination space. Environmental variables having the greatest influence on an axis, are indicated by the longest arrow relative to the axis, with the angle between arrows indicating the degree of correlation between variables;
- The association order of species along a particular environmental gradient can be obtained by dropping a perpendicular bisector from the species to the arrow line. Species associated with the head of the arrow, have a higher average value for that variable than species being associated with the opposite end of the projected arrow;
- Commonly the variance of only a few species is represented along each axis, with several species displaying no relationship to the axis. Thus, more attention can be focused on influential species, by setting Inclusion rules. The responses of herbaceous species with at least 10% of their variance being accounted for by the first two canonical axes (after Lawes *et al.* 2005), were identified as key species in explaining the species-environment relation (after Hurt & Hardy 1989; Lawes *et al.* 2005). These species can be indexed on a scale from 0-10 as explanatory measure with regard to the environmental variables best associated with each specific axis (opposed to the scale of 1-10 employed by Hurt & Hardy 1989; Lawes *et al.* 2005). This was done by indexing the eigenvector scores of the key species associated best with either the first or second axes. A value of 0 means that the specific species/variable was poorly associated with the environmental/passive variable best representing that particular axis, while a score of 10 indicates that the particular species/variables best represent the environmental/passive variable along that axis.

For the purpose of this study, the x-axis is called the first canonical axis, and the y-axis the second canonical axis (Fig. 3.5). The numbering of the quadrants of the ordination plots for the rest of the discussions, is presented in Fig. 3.5.

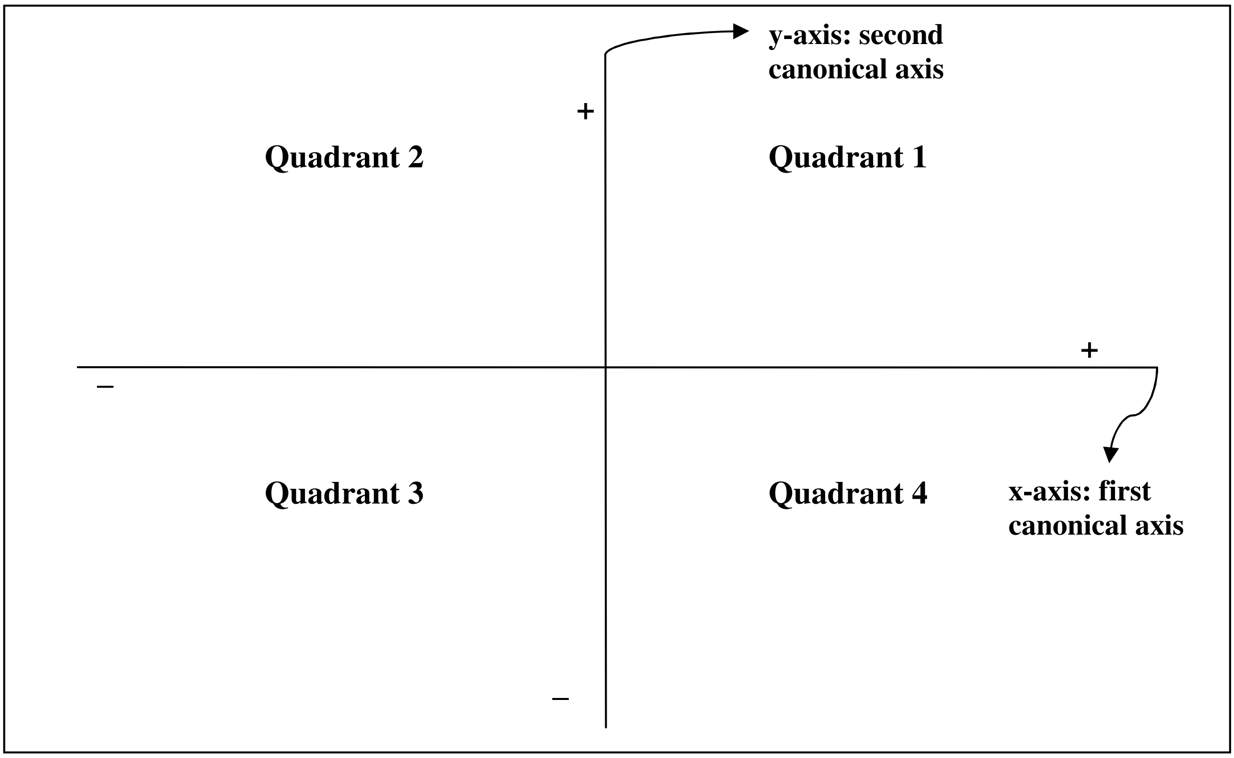


Fig. 3.5. The numbering of the ordination plot's quadrants and axes.

One may argue that the differences in herbaceous species composition are not caused by the land use type, but by differences in the (initial?) environmental characteristics of the land uses. Hence, the question is whether there are still differences in herbaceous composition among land use types after accounting for the effect of the woody and soil variables. This was investigated in Chapter 7 by specifying the key woody and soil characteristics as covariables (Ter Braak & Šmilauer 1998). A partial CCA test is performed, using F-ratio statistics to ensure a good level-accuracy for the test (i.e. to ensure that P-value is accurate) (Ter Braak & Šmilauer 1998). With covariables, CANOCO gives an ordination of the residual variation in the species data that remains after fitting the effects of the covariables, with the ordination axes being made uncorrelated to the covariables. The environmental variables are regressed on the covariables, with the residuals of the multiple regressions taking the place of the original environmental values. The constrained ordination of the axes will thus represent the patterns that can be uniquely attributed to the environmental variables and not to the covariables (Ter Braak & Šmilauer 1998).

Univariate diversity measures were employed to present diversity information for the full species assemblage data set (Clarke & Gorley 2001). The purpose of diversity indices, which exploit sample information on species richness (total number of species) and equitability (evenness or distribution of individuals among different species), is to reduce multivariate complexity of assemblage data into a single index. It can then be submitted to univariate analyses, treating the diversity indices as if they were environmental data (Clarke & Warwick, 2001). Species richness is often described simply as the total numbers of species (S) present, hence the bigger the sample, the more species there are likely to be. Or it can be expressed as some adjusted form that allows for differing numbers of individuals (Clarke & Warwick 2001) and is measured as the number of species present for a given number of individuals (N) (richness expressed as Margalef's index; $d = (S-1)/\log N$). Evenness (also called equitability, e.g. Pielou's evenness) describes how evenly individuals are distributed among different species. If a species is distributed inconsistently among samples (sub-replicates for this study), showing high abundances in some samples and low abundances in other, it has a high dominance but a low evenness, and vice versa. Diversity indices emphasise the species richness or evenness to varying degrees, with the Shannon (or Shannon-Wiener) diversity index ($H' = -\sum_i p_i \log(p_i)$, where p_i is the proportion of the total count arising from the ith species) being most commonly used (Clarke & Warwick 2001). It is advised that H' should only be compared across equivalent experimental designs, which was the case for this study.

Ranked species abundance curves (dominance curves) were used to extract information on patterns of relative species abundances without reducing the information to a single summary index, e.g. the diversity index (Clarke & Warwick 2001). The ranked abundances (expressed as percentage of the total abundance of all species) were plotted against the relevant species ranks. K-dominance plots were presented, by plotting cumulative ranked abundances against species rank. The most elevated fit thus represented the lowest diversity.

SIMPER analysis (similarity percentages) was performed to compare two groups at a time (e.g. two land uses, "Good" and "Poor" rangeland condition groups), identifying the influential species for each comparison (Clarke & Warwick 2001). The SIMPER procedure is not a statistical framework, but an explanatory procedure that indicates which species are principally responsible for the similarities or for the dissimilarities between groups (e.g. land uses, rangeland condition type), as has been confirmed by the ANOSIM tests (Clarke & Warwick 2001). Species were listed in decreasing order of their importance in discriminating between two sets of groups. Only species contributing 90% and higher to the similarities within groups and dissimilarities between groups, were selected (Clarke & Gorley 2001). Therefore, species will be listed in decreasing order of their importance, in contributing to the average similarity/dissimilarity, until the point is reached where 90% of the similarity/dissimilarity is accounted for (Clarke & Gorley 2001). The SIMPER procedures apply to Bray-Curtis dissimilarities only, and are used for pair-wise comparisons of well-defined groups of samples, but do not cater for a more continuous pattern of among-sample relationships (Clarke & Gorley 2001). Species that are found at consistent abundances in most samples (sub-replicates for this study) within a group, are called typical species. These species are often good discriminators between groups, but this does not necessarily follow because they could be typical of both groups (Clarke & Warwick 2001). Species that consistently contribute to not only dissimilarities between two groups, but also do so consistently in inter-comparisons of all samples in the two groups, are called discriminating species (Clarke & Gorley 2001). The more abundant a species is within a group, the higher its contribution will be to the intra-group similarities ($S_i =$

average contribution by *i*th species to overall similarity within groups, or dissimilarity between groups), typifying that group if it is found at a consistent abundance throughout. As result, the standard deviation of its contribution SD(S_i) is low, and the ratio S_i/SD(S_i) is high (Sim/SD > 1.0) were considered as "better" typical species for this study). The same principle applies for the discriminating species (*Diss*/SD > 1.0) were considered as "better" discriminating species for this study. Species that are found to be consistently typical of each group are considered as generalist species. The SIMPER analyses were complementary to the ANOSIM tests and to the MDS plot, PCA, DCA, RDA and CCA ordinations, and should be viewed in conjunction with these ordination plots and analyses.

BVSTEP tests, for large scale problems (Clarke and Warkwick 2001), were used in addition and complementary to the Monte Carlo tests. The BVSTEP procedure is a stepwise routine that allows the user to search for influential subsets of species whose among-sample relationships capture nearly the same multivariate pattern as the full species set. The fixed similarity matrix, based on Bray-Curtis dissimilarity measures (for biotic data, but normalised Euclidean measures for abiotic data) for the herbaceous species compositional matrix, gave the among-sample relationships for the full set of species and the second active data matrix. These element-by-element correlations of two similarity matrices are known as Mantel coefficients (Clarke & Gorley 2001). The two matrices can be biotic-biotic (BIO-BIO), abiotic-abiotic (ENV-ENV), biotic-abiotic (BIO-ENV) etc (Clarke and Warkwick 2001). BVSTEP is thus a stepwise search through the vast space of possible combinations (Clarke & Gorley 2001). For example, an ENV-BIO (abiotic-biotic) model selects subsets of species that best characterise a defined environmental gradient (Clarke & Gorley 2001; Clarke and Warkwick 2001). In another case, a BIO-BIO model searches subsets of species whose similarity matrix best matches that of another (fixed) set of species (Clarke & Gorley 2001; Clarke and Warwick 2001). Hence, the similarity matrix data set (Bray-Curtis dissimilarity) acts as "predictor" of the second active data set. Hence, only species/variables having Rho > 0.95 (at the 5% significance level) and Delta rho < 0.001 explained, are selected from the active data set, as "predicted" by the fixed similarity matrix. If the among-sample relationships are the same, then the rank correlation coefficient (ρ) = 1.0. If there is no relation between the two matrices, the rank correlation coefficient will be approximately zero (Clarke & Gorley 2001).

For descriptive purposes, the most common measure of central tendency employed during this study, was the arithmetic mean, or arithmetic average (Steel & Torrie 1980).

3.7.2 Woody component

The same analyses procedures described in Section 7.1, barring the PCA and RDA ordinations, were followed for the woody component, which was expressed as TE/ha, area coverage/ha (m^2/ha) and number of individuals/hectare. Species abundance for the TE/ha matrix was expressed as relative abundances (% of occurrence of species from the total for sub-replicate). The woody component was also expressed as the woody structural component, hence the average height and canopy diameter of each woody species within each land use and within each rangeland condition group within each land

use. Since all the measurements as indicated for the BECVOL model (Biomass Estimates from Canopy Volume) (Smit 1996) were not taken, and in addition problems were experienced with capturing data in the model, it was not employed for this study. However, it must be emphasised that BECVOL may provide to be very useful in future studies to estimate the production of trees and tree volume.
The key soil and herbaceous components were employed as covariables in the partial CCA ordination (refer to Section 7.1).

3.7.3 Ants

Records from pitfall traps were combined to determine plot/grid species richness (*i.e.* number of species and Margalef's species richness), species abundances and species occurrences (absence/presence data) at each sub-replicate (see Chapter 2, Fig. 2.1). In terms of abundance, the following qualifications for the purpose of this study: the absolute abundance of each species within each sub-replicate (hence grid of 15 pitfalls) were calculated as the sum of abundance scores at an individual trap within a sub-replicate. Total abundances of species were calculated as the sums across all replicates within and across land uses. Total abundances within each sub-replicate were calculated as the sum of the absolute abundances for each species collected in that sub-replicate. Species abundances (absolute abundance) were also expressed as relative abundances, hence, the percentage of abundance of a species within a sub-replicate of the total abundance within that sub-replicate. Pitfall data were used as estimates of the abundances of species at each sub-replicate, as well as the distribution of species and genera across sub-replicates within- and between land-uses.

Multivariate analyses were done using PRIMER v. 5.0 (Clarke & Warwick 2001) and CANOCO v. 4 for Windows (Ter Braak & Smilauer 1998). Bray-Curtis dissimilarity measures were employed to establish patterns within- and between land-uses, based on presence/absence, species absolute abundance and relative abundance data. Data for analyses (barring the dominance plots and the SIMPER analyses, which were employed for explanatory purposes) were square-root transformed prior to analyses to reduce the weight of common species.

The same analyses procedures, described in Section 7.1, barring the PCA and RDA ordinations, were employed for the ant data.

In addition, characteristic ant species (indicator species) were identified for each land use type using the Indicator Value Method (Dufrêne & Legendre 1997). This method assesses the degree to which each species fulfils the criteria of specificity, hence, uniqueness to a particular site (expressed as a percentage) and frequency within that habitat type (fidelity). A high percentage IndVal obtained indicates a high specificity and fidelity for that species, and a high representativeness for that particular habitat. McGeoch and Chown (1998) stated that species with high IndVal are reliable indicator species because of their locality specificity and high probability of being sampled in that locality. The species abundance matrix was used to identify indicator species. For the purpose of this study, comparisons between the land-uses were made, using random reallocation procedures to test the significance of the IndVal measures for each species (Dufrêne & Legendre 1997).

In the absence of ant species-level information, species were assigned to functional groups to assist in interpreting distributional patterns. The functional groups are based on higher taxon responses to environmental stress and disturbance (Andersen 1995a), with classification following Andersen (2003), Andersen and Majer (2004) and Andersen (2005, pers. comm.).

3.7.4 Soil

Abiotic data are usually on mixed measurement scales, with mg/kg, mS/m (conductivity) vs. % concentrations of some soil chemical data and sediment fracture size for physical data. Hence, a dissimilarity measure such as Bray-Curtis, which assumes common measurement scales, is not appropriate (Clarke & Gorley 2001). Each variable is firstly normalised by subtracting the mean and divided by the standard deviation to create a common, dimensionless scale. The measure of dissimilarity between samples (sub-replicates) is then described by Euclidean (standard) distance (Clarke & Gorley 2001).

The same analyses procedures, described in Section 7.1, were applied. The one-way and two-way crossed ANOSIM tests were used to establish significant differences in the soil physical and chemical data within and between land-uses, based on different environmental and biotic criteria (land-use, “range condition type”, openness/woodiness, and topsoil/subsoil).

Ordination for the total data set (hence, 288 samples based on the following subsets: 1 topsoil open, 1 subsoil open, 1 topsoil woody, 1 subsoil woody for each replicate, Fig. 3.1) was done by using an indirect DCA ordination, since an artificial arch effect was evident, as well as a direct CCA ordination. Separate ordinations based on the topsoil open, subsoil open, topsoil woody and subsoil woody subsets were performed. These ordinations were performed by employing Principal Component Analysis, which employs Euclidean distance as its dissimilarity measure. A PCA operates most effectively when data are near multivariate normality (Clarke & Gorley 2001). Hence, data were firstly analysed by employing a Draftsman plot, in which the pair-wise scatter plots of the environmental variables should roughly display linear relationships and symmetric instead of heavily skewed distribution of points (Clarke & Gorley 2001). Such a plot can suggest the possible transformation of variables (log or square-root) (Clarke & Gorley 2001) before entering it into the ordination analyses.

3.8. ENVIRONMENTAL, PASSIVE AND SPECIES DATA EMPLOYED IN THE ANALYSES, DISCUSSIONS, TABLES, APPENDICES AND FIGURES

The following environmental, passive and species variables, as well as their abbreviations, were employed in the analyses, results, discussions, Tables, Appendices and Figures. Thus, Table 3.1 serves as explanatory measure for the rest of the discussions. Thus, further discussions, Figures, Tables and Appendices should refer back to Table 3.1 of this chapter for clarity purposes.

Table 3.1. Passive, Environmental and selected species' variables employed in the study, and their abbreviations

Passive/Supplementary variables	**Nominal Environmental variables**
BE/HA (bush equivalents per hectare - BE/ha – total) – discussed as TE/ha (Tree equivalents/ha) in text	Commercial
Bushcov (Bush cover – total m^2/ha)	Tribal
Bush.num per ha; Bush./ha (Bush numbers/ha)	Reserve
VCSAGRAZ (rangeland condition score: annual grazing)	Good (relative good rangeland condition sites)
VCSPGRAZ (rangeland condition score: perennial grazing)	Poor (relative poor rangeland condition sites)
DM/HA (**Herbaceous** dry material yield/ha – kg/ha)	Com*Good (Commercial-Good)
VCSAECOL (rangeland condition score: annual ecological)	Com*Poor (Commercial-Poor)
VCSPECOL (rangeland condition score: perennial ecological)	Res*Good (Reserve-Good)
ANNrich(annual herbaceous Margalef's species richness)	Res*Poor (Reserve-Poor)
ANNeve (annual herbaceous species Pielou's evenness)	Tri*Good (Tribal-Good)
ANNdiv (annual herbaceous Shannon diversity)	Tri*Poor (Tribal-Poor)
PERrich (perennial herbaceous Margalef's species richness)	B (Bruwer – Commercial farmer)
PEReve (perennial herbaceous species Pielou's evenness)	SC (Scheepers – Commercial farmer)
PERdiv (perennial herbaceous Shannon diversity)	O (Olivier – Commercial farmer)
Bush eve (bush Pielou's evenness – for TE/ha matrix)	A (Austrey – Tribal village)
Bushrich (bush Margalef's species richness for TE/ha matrix)	S (Southey area – Tribal village: Eska/Newnham survey areas)
Bsh div/Bushdiv (Woody Shannon diversity for TE/ha matrix)	T (Tseoge – Tribal village)
Bsh num.div (Woody Shannon diversity for bush numbers)	M1 (Molopo Reserve survey area 1)
Antdiv (Ant Shannon diversity)	M2 (Molopo Reserve survey area 2)

Table 3.1. (continue …)

Antrich (Ant Margelef's species richness)	M3 (Molopo Reserve survey area 2)
AntSpec (actual number of ant species)	
Antabun (Ant abundance)	
Anteven (Ant Pielou's evenness)	
Species/environmental data: full name	**Species/environmental data: Abbreviations**
Increaser I	Incr I
Increaser II	Incr II
Increaser III	Incr III
Highly desirable	HD
Desirable	DE
Less desirable	LD
Undesirable	UD
Bare patches	BP
Organic material	Org.mat
Hot Climate Specialist	HCS
Tropical Climate Specialist	TCS
Cryptic Species	CS
Generalised Myrmicinae	GMC
Specialist Predator	SPR
Subordinate Camponotini	Subcam
Opportunist	OPP
Sp XII	CODED/CODE
Anteven (Ant Pielou's evenness)	

Chapter 4

Herbaceous species composition

4.1. INTRODUCTION

Three main types of rangeland management systems can be found in South Africa, namely commercial- and communal livestock rangelands and game ranching (Smet & Ward 2005). These management systems, referred to as land uses within this study, differ in management structure (multiple vs. single farmers), animal diversity, management of grazing resource (grazing system and pressure, vegetation diversity/uniformity) and products (quantity, quality, diversity, market) (Smet & Ward 2005). Moleele and Chanda (2003) state that land use can be defined as the human use of land for purposes such as settlement, wildlife and pastoral farming, recreational activities and settlements.

This chapter seeks to investigate differences between these land uses, with special reference to degradation and diversity patterns within and between land uses in order to establish best sustainable natural resource management practices.

The approach towards understanding land degradation should include the measuring of the capability and sustainability of the biophysical system to produce goods and services relevant to the socio-economic system (Reynolds & Stafford Smith 2002). Hence, degradation implies that the productive capacity of the land has been depleted to such an extent, that its resilience and hence regenerative capacity has been seriously impacted (Leopold 1949; Dahlberg 2000). UNEP (1997) defines land degradation as "a reduction of the resource potential [of] the land". Land degradation can be short-term (reversible) and long-term (irreversible), and is related to the resilience of an area (Levia 1999). Resilience is defined as the ability of a system "to absorb change and still persist" (Levia 1999). Jordaan *et al.* (1997) further state that degradation gradients within rangelands represent a suite of sample sites in deteriorating ecological condition along a grazing gradient.

The lack of agreement on the meaning of rangeland degradation has given rise to often contradictory definitions (Behnke & Scoones 1992). The purpose of this study is not to enter into this debate, but rather to compare patterns in Commercial, Tribal (Communal) and Reserve land uses, as a basis for understanding degradation and where possible, isolating indicators of degradation.

Much attention has been given to techniques for the quantification of the "state of health", hence the condition of vegetation types within South Africa. This is essential to the development of management programmes focusing on optimal use, without detrementing these resources (Tainton 1988). Vegetation changes can be either the result of long-term degradation, or changes due to rainfall variability (Smet & Ward 2005). These authors mentioned that several indicators of long-term degradation due to herbivore impact exist. Therefore, qualification of rangeland degradation indicators is important. Important indicators of rangeland degradation can be the classification of herbaceous species according to the ecological rangeland condition concept (Dyksterhuis 1949), bush density as an indicator of bush encroachment (Tolsma *et al.* 1987b), bare soil (Whitford *et al.* 1998; De Soyza *et al*. 2000) and the composition of species according to their life-form (annual, perennial, weak perennial) (Van Oudthoorn 2002; Whitford *et al*. 1998).

Botanical composition is according to Timarsh and Havenga (1955) the best means of studying ecological changes in the development of rangeland. In support of this, Smet and Ward (2005) hypothesised that vegetation indicators, such as species composition, species abundance and shrub density can act as indicators of grazing impact. Bosch and Gauch (1991) stated that monitoring and assessing vegetation condition or conservation status within a particular area, as well as the ecological interpretation thereof, is essential for rangeland planning and management. Several methods for indexing and improving rangeland condition techniques in southern Africa are being used (Foran *et a*l. 1978 and revised by Tainton *et al*. 1980; Vorster 1982; Barnes *et al.* 1984; Heard *et al*. 1986; Willis & Trollope 1987; Hurt & Hardy 1989; Martens *et al*. 1990; Hurt & Bosch 1991). Although these techniques differ in their approach, all methods aim to establish and monitor rangeland condition trends and grazing capacity (Heard *et al.* 1986).

The impacts of land use management systems on herbaceous species composition, abundance, diversity and richness were addressed in this chapter. The purpose of this study and chapter was not to enter into a debate regarding the evaluation of different rangeland condition techniques, but rather to calculate and present rangeland condition scores to convey multivariate information about the current state of the vegetation for three land uses within the Molopo study area.

This chapter would like to address the following key questions. Do the three different land uses result in different herbaceous composition and diversity patterns? Does herbaceous composition reflect a rangeland condition degradation gradient (expressed as relative “Good” vs. “Poor” extremes) as a result of environmental disturbance caused by different land uses? Finally, which of the rangeland monitoring techniques and interpretation methods employed in this study, are recommended for the semi-arid rangelands of the Molopo?

4.2. OVERVIEW OF RESULTS AND DISCUSSION

In order to address the above-mentioned key questions, the Results and the discussion will be presented under the same headings due to the complexity of the data, and as motivated in the brackets next to each heading. ***For further clarification as to what the purpose of each analysis technique is, refer to Chapter 3, Material and Methods.*** In this study, species composition was interpreted according to the “Annual” and “Perennial” interpretations according to the life-form, grazing- and ecological indices and their respective rangeland condition scores calculated from the indices.

“Annual” interpretation refers to the actual species composition without taking into consideration the nearest perennial herbaceous species when an annual species was pointed out, hence reflecting the seasonal rainfall pattern. All annual species are thus included in this interpretation. In the “Perennial” interpretation the nearest perennial species was noted when an annual species was pointed out, or a bare patch was recorded if no perennial species occurred within a radius of 45 cm from the point. This was done because perennials show a more stable state over growing seasons, as opposed to annuals, which are driven by rainfall variability (Whiford *et al.* 1998). Studies by Leggett *et al.* (2003a) indicated that the number of grass species showed a marked decline during the dry season in Hoanib river catchment, Namibia, with the largest decrease in annual grass species. These authors observed no seasonal difference in the perennial grass abundances, but did find that perennial grass abundance differed between focus areas. The “perennial” interpretation thus employed the nearest perennial species in each circumstance that an annual species was pointed out in order to reflect on the longer-term ecological range composition in order to minimise seasonal rainfall effects in the data analyses. Results from the “annual” and “perennial” interpretations were compared to reflect whether there were differences between these two methods for the particular survey year. This chapter will reflect on whether seasonal rainfall resulted in the species composition of the “annual” interpretation to differ significantly from the perennial (longer-term) herbaceous sward associated with each land use. ***Average abundances for species composition, as well as for the different indices and life-forms within and between land uses are presented within the Tables and Appendices, as indicated by each relevant section. However, it should be emphasised that these GENERAL descriptive statistics, although informative, may result in major incorrect assumptions that do not reflect on spatial heterogeneity, complexity and gradients within and between land uses pertaining to rangeland degradation and biodiversity indices, neither does it reflect on the models operating within these rangelands. Neither does it reflect on key species that are consistently associated with particular land uses, rangeland conditions or other criteria. Hence, this may result in incorrect over-extrapolation of management and monitoring techniques between land uses and across different parameters, which might prove to be “development experiments” that might result in unfortunate implications for both the ecosystems and people (Ellis & Swift 1988).***

Hence, it can not be emphasised enough that, although these different analyses techniques might result in the **incorrect** perception of over-analysing, the different procedures were all essential and complementary to each other. It was only after the in-dept analyses, using the different procedures that it was possible to establish the different multivariate spatial patterns, heterogeneity complexity and diversity- and rangeland gradients pertaining to the herbaceous compositional data (species composition, ecological and grazing index values, rangeland condition scores, life-form data), which exist within and between land uses due to different land use impacts (refer to Conclusions within each chapter and final Concluding Remarks in Chapter 9).

The Results and Discussion will be presented in Section 4.3 as follows:

4.3. RESULTS AND DISCUSSION

4.3.1 Herbaceous species composition (a general overview)

4.3.1.1 Analysis of similarities (ANOSIM) and Multidimensional scaling (MDS iterative procedures, based on relative abundances of species, to establish whether removal of sites from further analyses is necessary)

4.3.1.2 Species richness and diversity (based on relative abundance data: ANOSIM to establish patterns within and between land uses for the different diversity measures, and relate it to relative rangeland condition groups)

4.3.1.3 Community patterns

- **Indirect DCA ordination** (based on relative abundance data)
- **Direct CCA ordination and Monte Carlo test** - establish species-environment relation (employing the land use, relative “Good” and relative “Poor” groups as environmental variables)

4.3.1.4 SIMPER analysis for general species composition matrix between land uses (Explanatory procedure as complement to Section 4.3.1.1 and Section 4.3.1.3 for adaptive management purposes)

4.3.1.5 Cumulative k-dominance plot (establish whether species accumulative asymptotes in respective land uses have been reached)

4.3.1.6 ANOSIM and SIMPER for relative condition groups *within* each land use

4.3.1.7 Discussion (discuss results pertaining to this section)

4.3.2 Grazing classification- and index (applicability of analyses according to palatability classes to establish whether land use type results in different grazing index results; incorporate grazing index as measure to calculate range condition scores; Section 4.3.2 follow the same procedure as Section 4.3.2)

4.3.3 Ecological classification- and index (applicability of analyses according to ecological classes to establish whether land use type results in different ecological index results; incorporate grazing index as measure to calculate range condition scores; Section 4.3.3 follow the same procedure as Section 4.3.1)

4.3.4 Life-form (applicability of analyses according to life-form classes to establish whether land use type results in different life-form patterns; Section 4.3.4 follow the same procedure as Section 4.3.1)

4.3.5 Rangeland condition scores derived from the “annual” and “perennial” grazing- and ecological indices (distinguish within and between land use patterns based on range condition scores)

4.3.6 Integration of herbaceous species composition with other environmental and biotic variables (recommendations pertaining to these multivariate analyses)

4.3. RESULTS AND DISCUSSION

4.3.1 Herbaceous species composition

A total of 31 grass species were identified, of which 15 were perennials (of which one was a creeping grass), 7 weak perennials and 10 annuals (Appendix 4.1). In addition, forbs and bare patches were also included in the surveys and analyses. Of the 31 grass species, 7 species were classified as highly desirable, 5 as desirable, 7 as less desirable species and 12 as undesirable (Appendix 4.1). According to the ecological classification of species, 9 species were classified as Decreasers, one as an Increaser I, 14 as Increasers II and 7 as Increasers III (Appendix 4.1). *The abbreviations for the herbaceous species are summarised in Appendix 4.1, and should be consulted for the interpretation of the Tables, Figures and Appendices.*

4.3.1.1 ANOSIM and MDS for total species compositional matrix

The procedures and strategies for interpretation, pertaining to ANOSIM statistics and MDS ordinations, are fully described in Chapter 3 (Material and Methods).

Pair-wise tests from a two-way crossed ANOSIM to test for differences between land-use groups (averaged across all relative condition groups) for the “annual” interpretation showed intermediate significant differences between the Commercial and Tribal land uses ($r = 0.471$, $P < 0.001$) and the Tribal-Reserve land uses ($r = 0.596$, $P<0.001$). The differences between the Commercial and Reserve land uses were not statistically significant ($r = 0.066$, $P > 0.05$). A two-way crossed ANOSIM test for differences between the relative “Good” and “Poor” condition groups averaged across all land uses, was relatively low but significant ($r = 0.36$, $P < 0.001$). Hence, based on species composition, the Commercial and Reserve land uses displayed similar compositional structures, which were distinct from the Tribal herbaceous compositional structure. A rangeland condition gradient for the larger study area was also evident, and it should be established whether this gradient was reflected in each land use.

In the “perennial” interpretation, analyses incorporating the nearest perennial species (or a bare patch in the absence of a perennial species) when an annual species was pointed out in the descending point method, were carried out in order to minimise the variation caused by the seasonal rainfall distribution for the particular survey year. A two-way crossed ANOSIM to test for differences between land use groups, averaged across all relative condition groups, was of intermediate significance between the Commercial-Tribal land uses ($r = 0.414$, $P < 0.001$) and the Reserve-Tribal land uses ($r = 0.544$, $P < 0.001$). There was only a very small difference between the Commercial and Reserve land uses ($r = 0.084$, $P < 0.05$). Relative “Good” and “Poor” groups, averaged across all land use groups, differed intermediately ($r = 0.403$, $P < 0.001$). Differences between the land uses were statistically lower with the “perennial” interpretation method. What came out as very important though is that the differences between the relative “Good” and “Poor” extremes were statistically more pronounced. This indicates that the length of the range condition gradient was longer and hence the degradation gradient more pronounced when analysed according to the "perennial' interpretation method opposed to the "annual" interpretation method. This can possibly be ascribed to the fact that the annual life-form reflects seasonal rainfall variations and thus "masking" degradation effects, whereas the perennial life-form (thus the "perennial" interpretation) reflects the longer-term actual rangeland degradation and loss of resilience. These results will be further verified in the remainder of the chapter by incorporating different analyses and finally comparing the range condition indices scores derived from the ecological and grazing indices for both interpretation methods with each other.

A MDS ordination of the 72 sites based on the species composition was constructed to satisfy conditions imposed by the rank dissimilarity matrix (Fig 4.1). Site O2 was identified as a possible "outlier" due to the high presence (97.8%) of *Schmidtia kalahariensis*, and was removed from the data set. However, the "stress" value, which is a measure of goodness-of-fit of the regression, only improved from 0.19 to 0.18 (the lower the stress value the better the fit) (Fig 4.2).

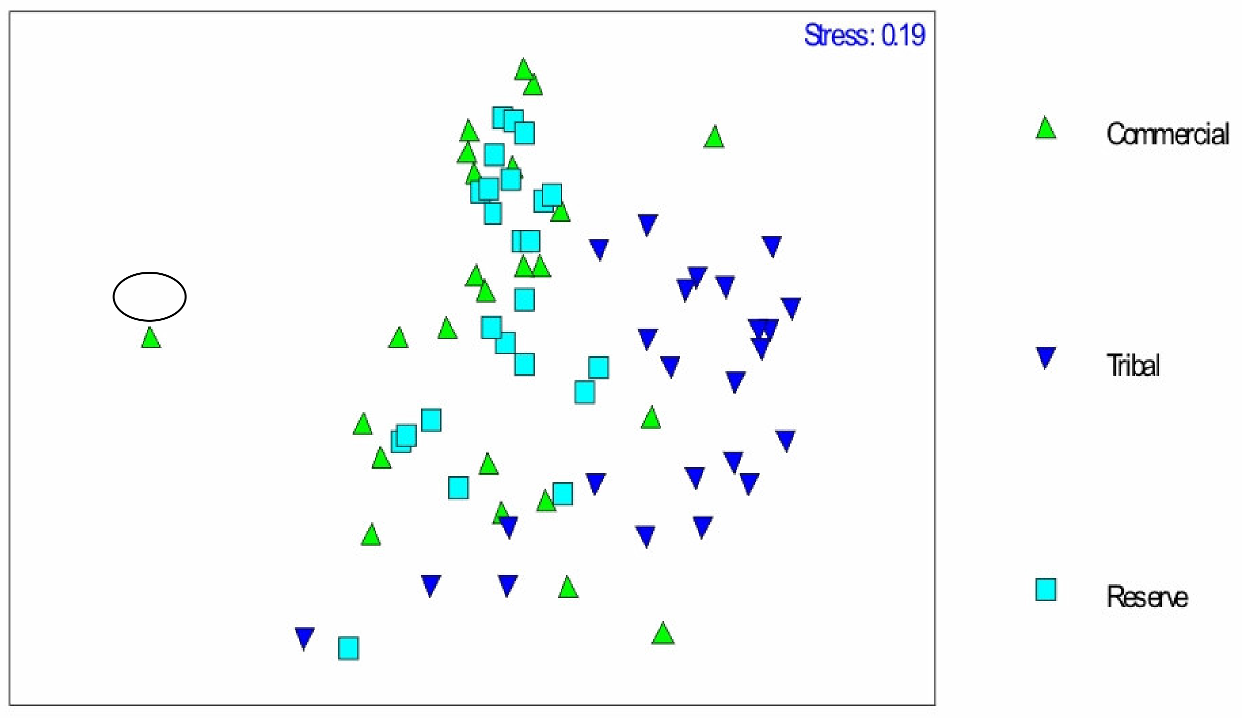


Fig. 4.1. The MDS plot including "outlier" site O2.

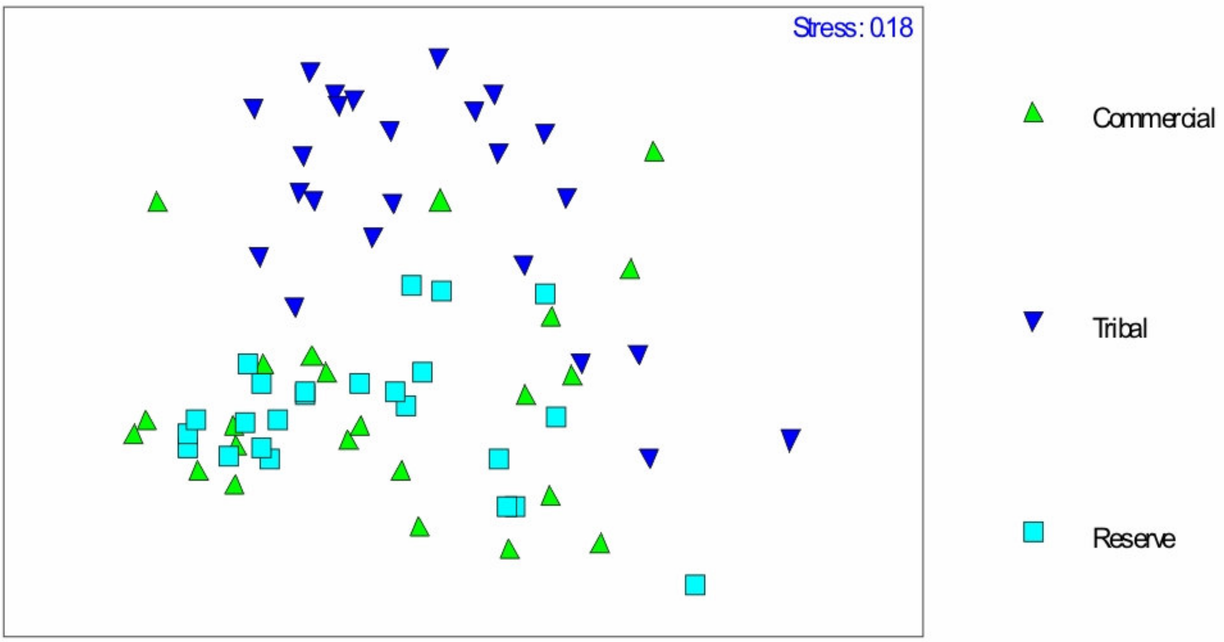


Fig. 4.2. The MDS plot excluding the "outlier" site O2.

One- and two-way crossed ANOSIMS were performed to establish whether differences improved with the removal of site O2. However, the improvement for the two-way crossed ANOSIM was neglectably small (r = 0.483, P < 0.001 for the Commercial-Tribal groups; r = 0.596, P < 0.001 for the Tribal-Reserve groups; r = 0.067, P > 0.05 for the Commercial-Reserve land uses; r = 0.373, P < 0.001 for the relative Condition groups) when compared to the analyses including site O2. Hence, the site was not removed from the analyses, as it did not result in a significant improvement in subsequent ordinations. This was done since it would allow the gradient to cater for a wider diversity of conditions (Zimmerman *et al.* 2001). For the species compositional data, *Schmidtia kalahariensis* was also surveyed in other areas during the production-, herbaceous composition and seedbank surveys, hence suggesting that this species does occur in survey sites, and that site O2 does not show a unique species not occurring elsewhere. Hence, based on these two arguments, the site was not removed from the "annual" interpretation analyses, as was also confirmed by the multivariate DCA and CCA analyses (Section 3.1.3). A MDS ordination for the "perennial" interpretation did not indicate any outliers, since the annual species such as the relative high occurrence of *Schmidtia kalahariensis*, which resulted in the O2 site not to be identified as a possible outlier, as discussed above. Hence, both interpretation methods included the site in the remainder of the analyses.

4.3.1.2 Species richness, species diversity and Pielou's evenness

A variety of different statistics can be used as measures of community structure attributes, with diversity indices reducing the complexity of the multivariate data into a single index or a small number of indices evaluated for each sample, which can then be further employed in multivariate analyses (Clarke & Warwick 2001). Within this chapter, diversity indices measured were - herbaceous species richness, Pielou's evenness and species diversity. Vegetation diversity was determined using Shannon's diversity index (see Chapter 3, Material and Methods). The purpose of the diversity indices were not only to reduce the herbaceous structural complexity, but also to establish whether the diversity indices were correlated or inversely related to range condition and productivity of a system. Herbaceous species richness often has a hump-shape with a peak in species richness at a low to intermediate level of biomass (Grime 1997). Low levels of biomass result in low species richness due to unfavourable abiotic conditions, whereas high levels of biomass result in a decline of species richness due to competitive exclusion (Gough *et al.* 1994).

A two-way crossed ANOSIM for the "annual" interpretation indicated that the Commercial-Tribal and Tribal-Reserve land uses showed intermediate differences for species richness (for both: $r = 0.419$, $P < 0.001$), whereas the Commercial-Reserve land uses did not differ significantly ($r = -0.033$, $P > 0.1$). The test for differences between the relative condition groups, averaged across all land use groups, was not significant ($r = -0.021$, $P > 0.1$). Thus, based on this level of analysis, the Commercial and Reserve land uses were similar based on species richness, which differed significantly from that of the Tribal land use. These results indicated that species richness is a good measure to distinguish between the different land uses, but not a good measure of relative rangeland condition (Fig. 4.3).

For the "perennial" interpretation, pair-wise tests performed with a two-way crossed ANOSIM, showed, for species richness, small differences between the Commercial-Tribal groups ($r = 0.277$, $P < 0.001$), intermediate differences (higher than in the annual interpretation) between the Tribal-Reserve land uses ($r = 0.529$, $P < 0.001$) and no significant differences between the Commercial-Reserve land uses ($r = 0.031$, $P > 0.1$). There was no significant difference between the relative condition groups when averaged across all land use groups ($r = -0.016$, $P > 0.1$). Results from the "perennial" interpretation are consistent with that of the "annual" interpretation, which showed that the Reserve's species compositional structure showed a more distinct difference from especially the Tribal land use, as that indicated in the "annual" interpretation. With the "perennial" interpretation, the Commercial-Tribal land uses still differed significantly, but less so than indicated with the "annual" interpretation. Hence, the annual life-form resulted in more "shared" characteristics between the Commercial-Tribal land forms, though still differing significantly, than between these two land uses and the Reserve land use. Although the statistical differences between the two methods were not very pronounced, it remained significant. This suggests that these patterns should be addressed in more detail to establish differences within and between land uses, based on the two interpretation methods.

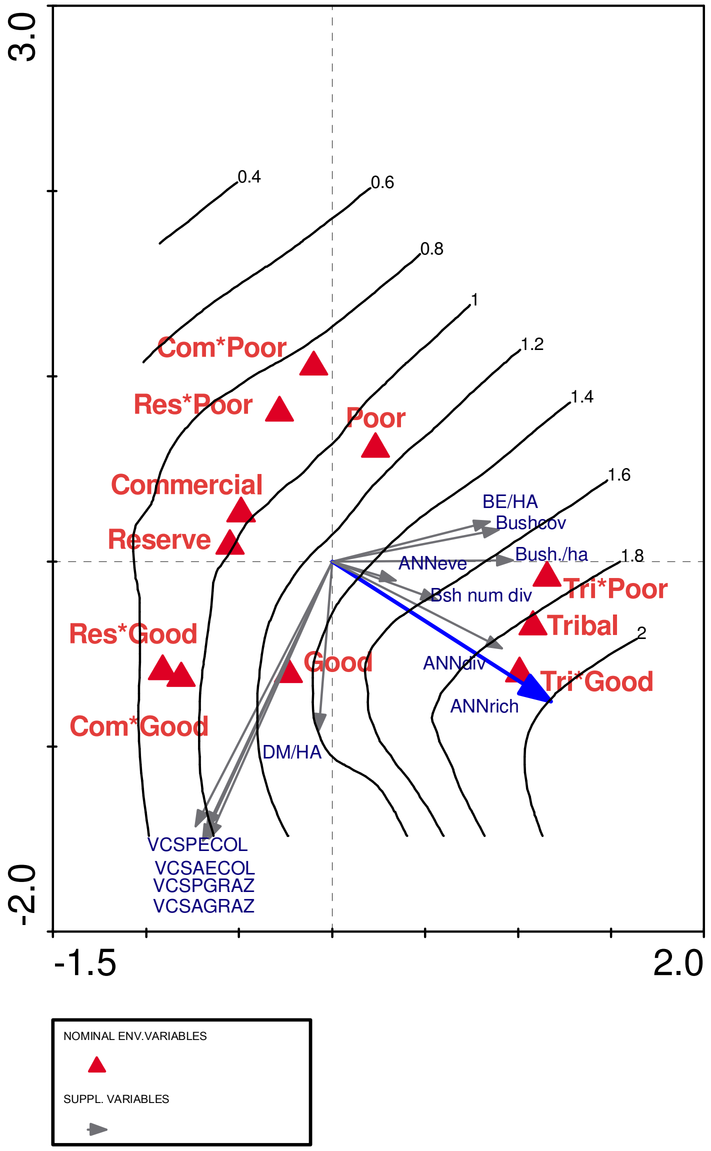


Fig. 4.3. A CCA ordination LOESS plot displaying higher Margalef's species richness (indicated by blue arrow) for the "annual" interpretation within the Tribal land use.

The "annual" interpretation pair-wise ANOSIM tests for Pielou's evenness (equitability), a diversity measure of how evenly individuals are distributed among the different species, indicated that there were no significant differences between the Commercial-Tribal (r = 0.06, P > 0.05) or the Commercial-Reserve groups (r = 0.056, P > 0.05), whereas there was only a small difference between the Tribal-Reserve land uses (r = 0.149, P < 0.001). The test for differences between the relative condition groups were significant but low (r = 0.092, P < 0.001), suggesting that evenness does indicate rangeland condition, but not that strong. The results further suggest that the Commercial land use showed a "mixture" of evenness' characteristics between the Reserve and Tribal land uses, with the Reserve land use showing more unique patterns based on the consistent distribution of species (equitability; see Chapter 3, Material and Methods) than the other two land uses did. Pielou's evenness for the "perennial" interpretation showed significant higher differences than the "annual" interpretation between the Tribal-Reserve land uses (r = 0.31, P < 0.001), the Commercial-Tribal (r = 0.173, P < 0.001) and the small differences between Commercial-Reserve groups ($r = 0.072$, $P < 0.05$). The difference between the relative “Good” and “Poor” groups was insignificant, when averaged across all land uses ($r = 0.136$, $P < 0.001$). Based on evenness, the “perennial” interpretation improved the statistics and hence highlighted differences between the land uses, but the rangeland condition gradient was not significant. Hence, evenness within especially the “perennial” interpretation was an indicator of differences between land uses, but not of rangeland condition.

The “annual” interpretation pairwise ANOSIM tests for the Shannon’s diversity index indicated small differences between the Commercial-Tribal ($r = 0.194$, $P < 0.001$) and Tribal-Reserve ($r = 0.241$, $P < .001$) land uses, and no significant differences between the Commercial-Reserve land uses ($r = 0.018$, $P > 0.1$). The test for differences between the relative condition groups was insignificant ($r = 0.007$, $P > 0.1$). Based on the diversity results, the Tribal land differed from the Commercial and Reserve land uses, with the last two land uses showing more congruent diversity patterns among each other. The statistics suggest that the Commercial land use was more closely associated, though not significant, with the Tribal land use than the Reserve was. The Shannon diversity index did not prove to be a good indicator of rangeland condition. Pair-wise tests for differences between land uses, based on the “perennial” interpretation diversity, were low between the Commercial-Tribal groups ($r = 0.173$, $P < 0.001$), intermediate-low for the Tribal-Reserve land uses ($r = 0.31$, $P < 0.001$) and low for the Commercial-Reserve groups ($r = 0.072$, $P < 0.05$). There was no significant difference between the relative condition groups, averaged across all land uses ($r = 0.036$, $P > 0.1$). Results from the “perennial” interpretation improved statistics and hence showed more significant differences between all the land uses, compared to the results of the “annual” interpretation.

One-way ANOSIMS to test for differences between the relative “Poor” and “Good” condition groups *within* each land use were performed for each of the diversity indices to establish whether significant patterns existed at this more in-depth level. However, based on a rangeland condition gradient within each land use, none of the tests yielded significant differences ($P > 0.1$), suggesting that species richness within a land use was not correlated with rangeland condition. It is suggested that this more in-depth level of monitoring for species richness as function of rangeland condition, is not necessary. One-way ANOSIM tests to establish differences between the relative “Poor” and “Good” condition groups within each land use for the “perennial” interpretation also showed no significant differences ($P > 0.1$), and are consistent with the result of the “annual” interpretation. These results suggest that species richness, diversity and evenness were not good indicators of relative rangeland condition within or across all land use, irrespective of the interpretation method.

The role of herbivory in shaping ecosystems has been well documented (Ehrlich & Raven 1964; McNaughton 1983). It has been stated that heavy grazing pressure in an arid and semi-arid environment affects rangeland plant communities and individual plants’ abundance (Dodd 1994). It has also been documented by several authors that herbivore grazing can alter landscape heterogeneity (McNaughton 1985; Belsky 1992) as well as vegetation composition and production (Dahlberg 2000; Shackleton 2000).

Changes in grazing regimes often result in biodiversity changes (Chapin *et al.* 1997; Vitousek *et al.* 1997; Mooney *et al.* 1996). These arguments were consistent with this study's results, and are discussed below.

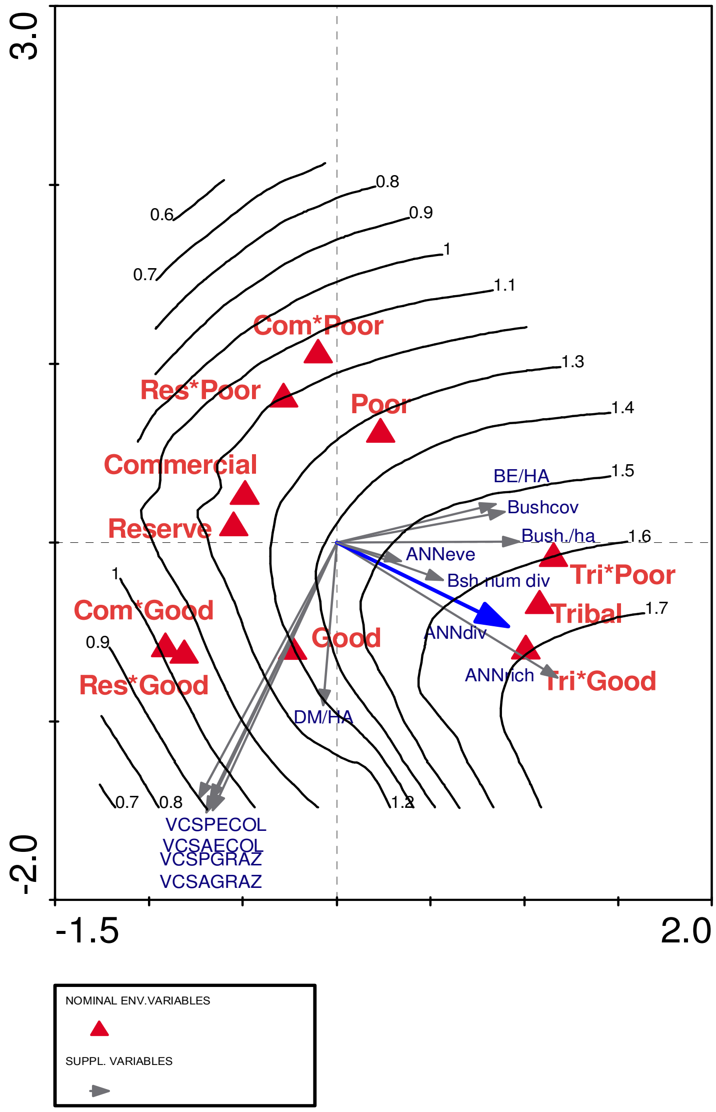


Fig. 4.4. A CCA ordination LOESS plot, with Shannon's diversity ("annual" interpretation) as predictor (indicated with blue arrow), being highest within the Tribal land use.

The CCA ordinations for both interpretations indicated that Shannon species diversity and Margalef's species richness were most strongly associated especially with the Tribal land use (Fig. 4.4). Herbaceous diversity and species richness for both interpretation methods were not correlated with the rangeland condition (Fig. 4.3 and Fig. 4.4). This tendency is also congruent with species richness and diversity patterns found for the woody component, discussed in Chapter 5 and those of ant compositional and functional structures (Chapter 8, Section 2.5). Species richness and Pielou's evenness, indicating the consistent distribution of species within this land use, were most strongly associated with the Tribal land use (Fig 4.3). Margalef's species richness was correlated with the species diversity, and highest within the Tribal land use (Fig. 4.5). The diversity indices for all three land uses for both the “annual” and “perennial” interpretation methods are presented in Fig. 4.5.

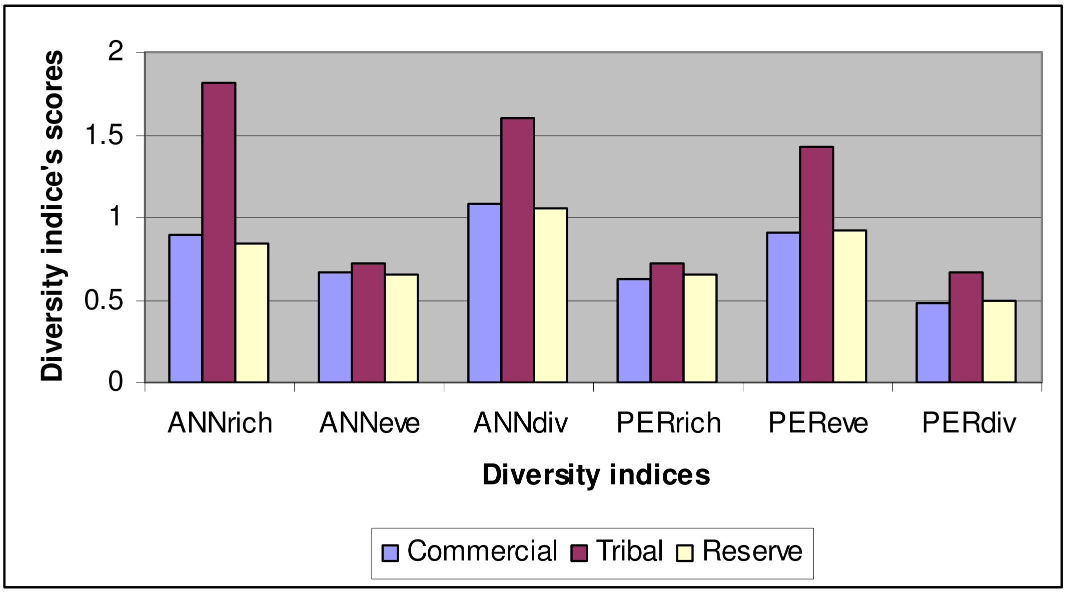


Fig. 4.5. Average diversity indices for each land use for both the “annual” and “perennial” interpretation methods, indicating that the average diversity indices for the “annual” interpretation method were higher than for the “perennial” interpretation method – both being highest in the Tribal land use.

Plants have been shown to be a poor surrogate for invertebrate biodiversity patterns (Crisp *et al.* 1998; Jonsson & Jonsell 1999; Eyere & Luff 2002). Results for the ants (Chapter 8, Section 2.5) indicated that habitat modification influences species richness, with the effect varying with the degree of disturbance and with the taxon being considered (Lawton *et al.* 1998). Lobry de Bruyn (1999) indicated that ant species richness was almost always lower in farmlands than in natural vegetated areas, as a result of habitat modification. It was also found that ant species richness was negatively affected by pastoralism, with species richness being least in grazed areas (Woinarski *et al.* 2002). This was consistent with this study’s findings, as discussed in Chapter 8. Herbaceous species richness and diversity patterns for this study were congruent with those of the ants discussed in Chapter 8, and hence were consistent with the findings by Lobry de Bruyn (1999) and Woinarksi *et al.* (2002). This study suggests that herbaceous richness and diversity, as the result of the historical land use impacts (long-term changes) by the different land uses, reflect diversity patterns, which are consistent with the ant diversity patterns for the study area. However, this study does not suggest that the herbaceous diversity patterns will be as sensitive responders to short-term changes in habitat (non-equilibrium events) as invertebrates are to land transformation (Rosenberg *et al.* 1986; Roth *et al.* 1994; Folgarait 1998). Herbaceous diversity patterns for this study rather reflected changes in habitat structure and composition (McNaughton 1985; Belsky 1992) as a result of longer-term disturbances (modification) by the different land-use practices, and did not reflect rangeland condition as such. This study suggests that the herbaceous diversity patterns did not reflect a rangeland condition gradient (degradation gradient) or biodiversity *per se*, but rather different environmental changes (McGeoch 1998) induced by the different land uses. This theory will be discussed more thoroughly in the remainder of this section, reflecting on the non-equilibrium and equilibrium theory, as well as the Clementesian and state-and-transitional models.

Differences between the Tribal and other land uses, based on species richness were significant, with species richness being highest in the Tribal land use. This is in contrast to Dahlberg (2000) who found that species richness was slightly higher in commercial ranches than in the communal rangelands. Ward *et al.* (1998) also found no differences in perennial species richness or Shannon diversity between communal and commercial rangelands, with no significant differences between the communal and commercial farms.

4.3.1.3 Community patterns – indirect DCA, direct CCA ordination and Monte Carlot test

Ordination techniques are commonly used to reduce community composition variation in an ordination diagram (Ter Braak & Šmilauer 1998). The diagram is interpreted with the help of calculating correlation coefficients between environmental variables and ordination, or by multiple regressions of the ordination axes on environmental variables. The patterns of variation in the herbaceous composition in relation to the different land uses and relative condition groups (“Good” vs. “Poor”) were examined by detrended correspondence analysis (DCA) using CANOCO 4 (Ter Braak & Šmilauer 1998). Detrending was required as an artificial “arch effect” was evident in the joint plot. The main gradients in composition (DCA axes) were related (indirect ordination) to measured environmental and vegetation variables by multiple regression to identify the main determinants of the herbaceous species composition. The species composition (relative abundances) for the total study area is summarised in Appendix 4.2.

A. “Annual” interpretation”

The first four axes of the DCA for the “annual’ interpretation accounted for 42.6% of the species variance (Table 4.1), with a joint plot of the first two axes adequately representing the main pattern of compositional variation among the samples (Fig. 4.6). The Commercial and Reserve land uses’s samples were clustered together (positively associated) on the right hand side of the first axis (associated with the first axis - x-axis), whereas the Tribal land use’s samples formed a separate cluster on the left hand side of the first axis. It showed a strong association with the first axis (r = -0.7258), but also among the three land uses the strongest association with the second (y-) axis (Table 4.1, Fig. 4.6). All three land uses were thus associated with the same quadrant, which can firstly be ascribed to the intermediate and not higher differences between the land uses (see results from ANOSIM, Section 4.3.1.1), and secondly to the fact that the direct interactive species-environment relations still need to be described (see discussions below).

Table 4.1. A DCA ordination for the “annual” herbaceous composition, showing eigenvalues and species-environment relations for the first four axes, as well as the environmental and passive variables explaining most of the species-environment relation for the first two axes. Variables explaining most of the variance are indicated in **bold**.

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.523	0.365	0.245	0.176
Lengths of gradient	3.016	3.617	2.941	2.391
Species-environment correlations	0.743	0.49	0.541	0.599
Cumulative percentage variance				
of species data	17	28.9	36.9	42.6
of species-environment relation (environmental)	38.2	49.5	0	0
of species-environment relation (passive data)	28.1	41.5	0	0

Environmental data	**SPEC AX1**	**SPEC AX2**	**Passive data**	**SPEC AX1**	**SPEC AX2**
Commercial	0.4008	-0.1227	BE/HA	-0.2629	0.4048
Tribal	**-0.7258**	0.2264	Bushcov	-0.2918	0.3794
Reserve	0.3186	-0.1017	Bush num/ha	-0.401	0.3141
Good	-0.1602	**-0.4163**	VCSAGRAZ	-0.2659	**-0.5502**
Poor	**0.1602**	**0.4163**	VCSPGRAZ	-0.2478	**-0.5683**
Com*Good	0.2047	-0.2698	DM/HA	-0.285	-0.4126
Com*Poor	0.3017	0.1085	VCSAECOL	-0.2556	**-0.5709**
Tri*Poor	-0.3918	0.2671	VCSPECOL	-0.225	**-0.6017**
Tri*Good	**-0.5283**	0.023	ANNrich	**-0.7774**	0.0036
Res*Good	0.1112	-0.3123	ANNeve	-0.2253	0.0275
Res*Poor	0.2899	0.1849	ANNdiv	**-0.5872**	0.0234
			Bsh.div	-0.341	0.0286

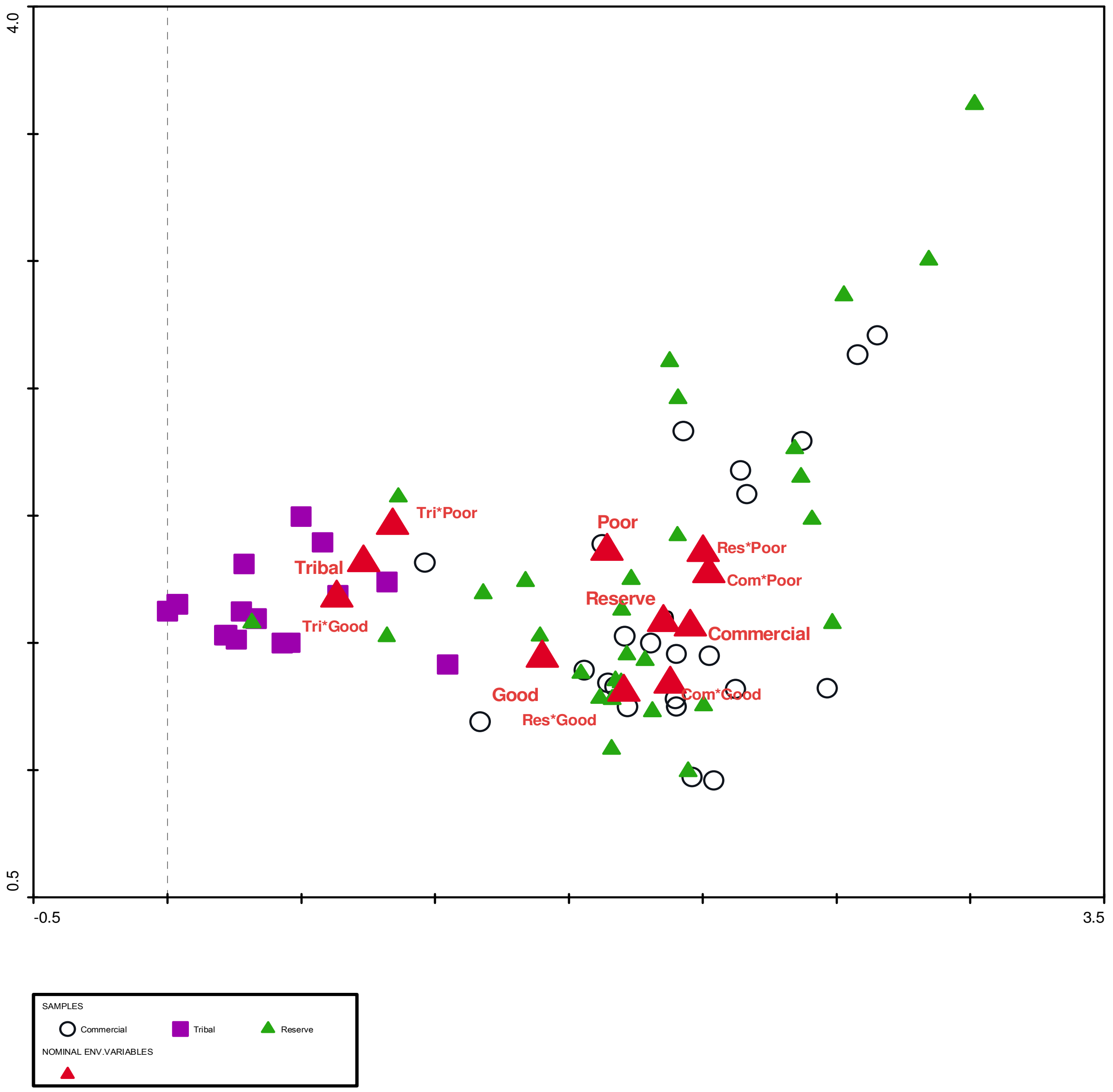


Fig. 4.6. A DCA ordination illustrating the main land use distributional patterns for the “annual” herbaceous species composition along the first two axes.

Species most strongly associated with the first ordination axis and most abundant at the Commercial and Reserve land uses were *Schmidtia kalahariensis, Tragus racemosus, Schmidtia pappophoroides, Stipagrostis ciliata, Antephora pubescens* and forb species (Fig. 4.7*)*. *Tragus koeleroides, Aristida congesta, Cymbopogon plurinoides, Tragus berteronianus, Digitaria erianthra, Aristida stipitata, Melinis repens, Eragrostis tricophora, Eragrostis biflora, Triraphis andropogonoides, Chloris virgata, Eleusine corocana, Perotis patens* and *Eragrostis lehmanniana* were more strongly associated with the Tribal land use (Fig 4.7).

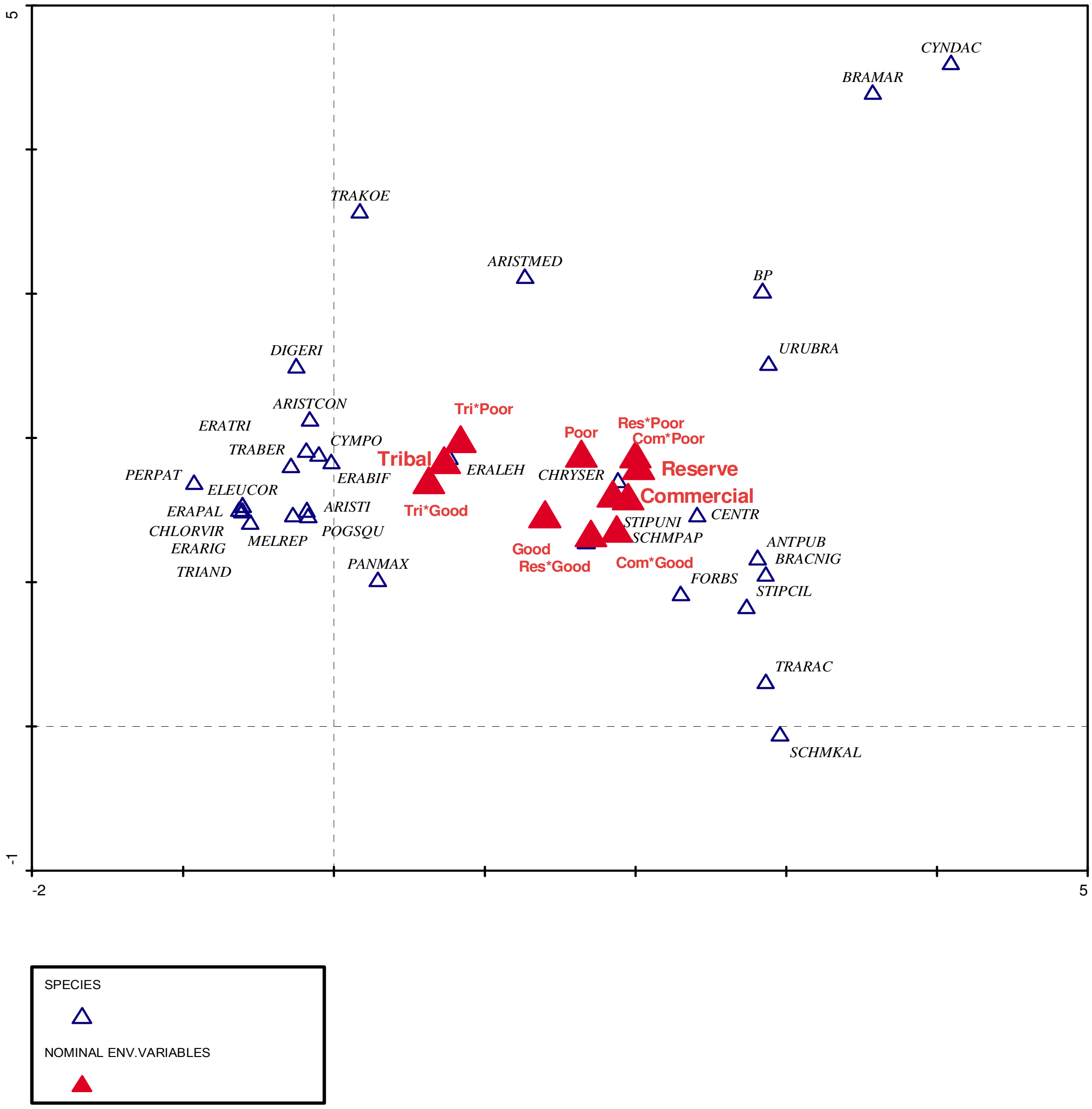


Fig. 4.7. A DCA ordination displaying the “annual” herbaceous species composition distributional patterns along the first two CCA axes.

With the indirect DCA ordination (“annual” interpretation), most of the species-environment correlations were explained by the first axis (r = 0.743) (Table 4.1). Species and environmental variables based on the first two axes explained 28.9% of the variance in the species data, 49.5% of the variance of the species-environment relation and 41.5% of the variance in the species-supplementary (passive) data relation (Table 4.1).

Environmental variables most strongly associated with the first axis, were the Tribal variable (r = -0.7258), Tribal-Good variable (r = -0.5283) and Commercial variable (r = 0.4008). Environmental variables best representing the second axis, were the “Good” (r = -0.4163) and “Poor” (r = 0.4163) variables (Table 4.1). Passive variables most strongly associated with the first axis were the species richness (ANNrich) (r = -0.7444) and species diversity (ANNdiv) (r = -0.5872), followed by the bush numbers/ha (r = -0.401)

(Table 4.1). The passive rangeland condition indices' scores (VCS…) most strongly represented the second axis (r > -0.55), and were associated with the "Good" environmental variable (Fig. 4.8). The woody components (BE/ha, bush numbers/ha and bush cover m^2/ha) were strongly associated with the Tribal land-use. Hence, the Tribal land use displayed a more complex and heterogeneous woody structure.

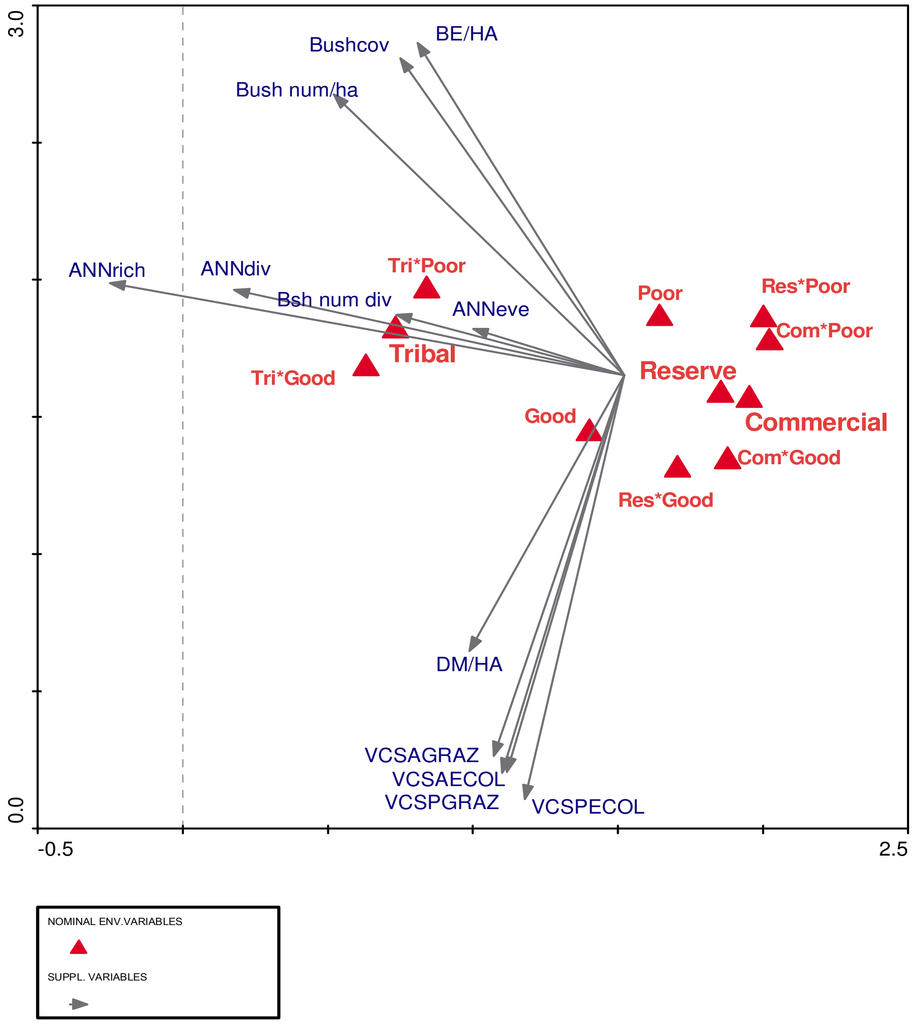


Fig. 4.8. A DCA ordination biplot displaying the environmental and passive variables explaining the species-environment relation for the "annual" interpretation.

The relationships between the land uses, relative condition groups (all employed as environmental variables) and herbaceous compositional data were directly examined by canonical correspondence analysis (CCA). CCA extracted gradients in the herbaceous community composition that were constrained to be a function of the environmental variables (Ter Braak & Šmilauer 1998) and allows species that are most responsive to the explanatory variables to be identified. The effect of these environmental variables on the species composition was then tested with a Monte Carlo permutation test (N = 499) (Manly 1997).

A CCA incorporating environmental and passive variables, revealed significant patterns related to these variables for both the first (F-ratio = 10.225, P < 0.005) and all canonical axes (F-ratio = 4.679, P < 0.005). The first two axes represented 80.7% of the species-environment relation for the environmental data. The fourth axis described 25.1% of the cumulative variance of the species data, 96.1% of the species-environment relation for the environmental variables and 65.7% of the species-supplementary variables relation (Table 4.2, Fig. 4.9). Species-data percentages are usually quite low, in particular when analysed with a CCA. This is normal since species data are often noisy, and an ordination diagram explaining only a low percentage might be very informative (Ter Braak & Šmilauer 1998).

Table 4.2. The eigenvalues, species-environment correlation and cumulative variances explained for the species data and species-environment relation for the CCA ordination for the "annual" herbaceous species composition.

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.412	0.237	0.069	0.055
Species-environment correlations	0.903	0.726	0.534	0.559
Cumulative percentage variance				
of species data	13.4	21.1	23.4	25.1
of species-environment relation (environmental)	51.3	80.7	89.2	96.1
of species-environment relation (passive data)	28.8	56.5	61.5	65.7

For the environmental variables, the Tribal land use (r = 0.8442), Tribal-Poor interaction (r = 0.5645), Tribal-Good interaction (r = 0.5081) (all associated with the fourth quadrant) and Reserve land use (r = 0.4483; second quadrant) were most strongly associated with CCA axis 1 (Table 4.3; Fig. 4.9). The CCA axis 2 strongly represented variability primarily associated with the environmental variables "Good" (relative condition) (r = -0.6331; third quadrant), "Poor" (relative condition) (r = 0.6331; first quadrant), Commercial-Poor interaction (r = 0.5; second quadrant) and Reserve-Poor interaction (r = 0.38; second quadrant) (Table 4.3; Fig. 4.9). Among the passive variables, CCA axis 1 was strongly associated with annual species composition richness (Annrich) (r = 0.7; fourth quadrant), Bush numbers/ha (r = 0.58; first quadrant), Bush cover (r =0.53; first quadrant) and Annual species diversity (Anndiv) (r = 0.54; fourth quadrant) (Table 4.3; Fig. 4.9).

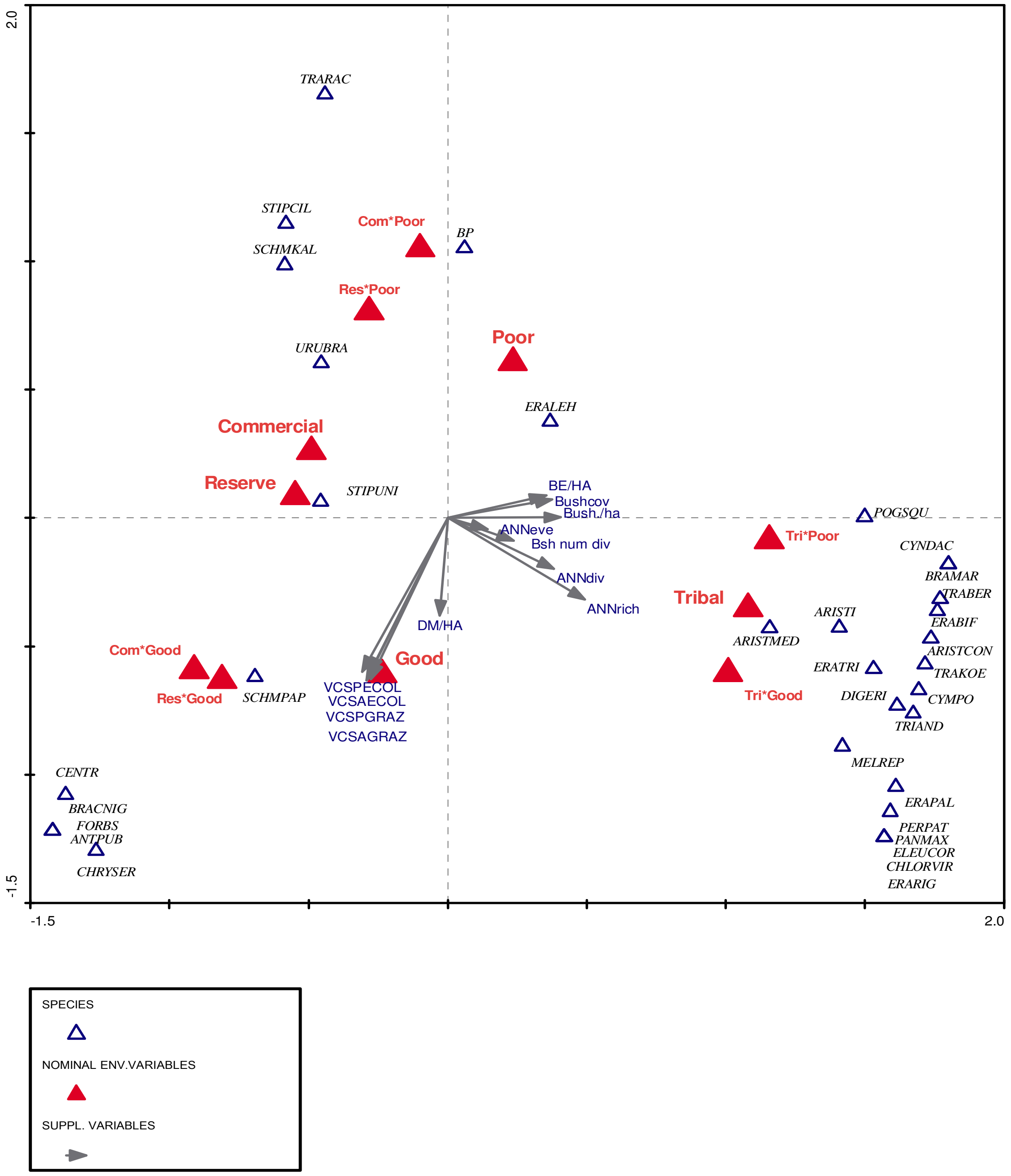


Fig. 4.9. A CCA ordination triplot displaying the environmental and passive variables significantly accounting for the largest proportion of the species-environment variance for the “annual” interpretation.

Table 4.3. Correlation coefficients (r-values) for the environmental and passive data associated with the first two canonical axes of the CCA ordination for the "annual' interpretation, as well as the environmental variables in order of importance, accounting for most of the species-environment variance as indicated by the Monte Carlo permutation test. Variables explaining most of the variance are indicated in **bold**.

Environmental data	**SPEC AX1**	**SPEC AX2**	**Passive data**	**SPEC AX1**	**SPEC AX2**
Commercial	-0.3877	0.1899	BE/HA	0.504	0.1165
Tribal	**0.8442**	-0.2549	Bushcov	0.5328	0.0945
Reserve	-0.4483	0.0633	Bush num/ha	**0.5773**	0.003
Good	-0.2641	**-0.6331**	VCSAGRAZ	-0.3931	**-0.8221**
Poor	0.2641	**0.6331**	VCSPGRAZ	-0.3994	**-0.7909**
Com*Good	-0.4466	-0.2679	DM/HA	-0.0418	-0.5002
Com*Poor	-0.0507	0.4967	VCSAECOL	-0.4135	**-0.8284**
Tri*Poor	0.5645	-0.0395	VCSPECOL	-0.4363	**-0.7853**
Tri*Good	0.5081	-0.2816	ANNrich	**0.6991**	-0.4161
Res*Good	-0.4185	-0.3006	ANNeve	0.2037	-0.0565
Res*Poor	-0.1453	0.3811	ANNdiv	0.5432	-0.2586

Monte Carlo permutation test

Variable	**P**	**F**
Tribal	0.002	10.16
Good /Poor	0.002	6.33
Tri*Poor/Tri*Good	0.002	2.51
Com*Good/Res*Good	0.022	1.89
Commercial	0.402	1.06

With the direct CCA ordination, it was evident that these diversity indices and woody components were indicative of the Tribal land use's more complex heterogeneous structure. These results from the ordination are consistent with the ANOSIM results, based on the diversity indices, as discussed in Section 4.3.1.2. The different rangeland condition indices' scores ($r > -0.78$, third quadrant) showed among the passive variables the strongest association with the second axis (Table 4.3; Fig. 4.9), and were positively associated with the "Good", Reserve-Good and Commercial-Good variables. The range condition scores thus reflected a gradient related to the species composition, but were not correlated with species richness and diversity.

Forward selection to show the order of inclusion of environmental variables indicative of the Monte Carlo permutation model (hence, including the combined effect of all environmental variables), as well as the significance of the variables (P-value) and test statistics (F-value) is also presented in Table 4.3. Environmental variables that contributed most significantly towards the species-environment relation are: Tribal Land use, "Good" and "Poor" relative condition variables, Tribal-Good and Tribal-Poor interactions (with $P < 0.005$ for all of these environmental variables) and the Commercial-Good and Reserve-Good interactions ($P < 0.05$).

The rangeland condition scores as calculated for the both the "annual" and "perennial" interpretation for the grazing – and ecological indices, were strongly associated with the second axis and third quadrant (r > -0.78), and correlated with the "Good" environmental variable and the dry material yield (DM yield) passive variable (Fig. 4.9). Herbaceous species most strongly associated with these environmental and passive variables within the third quadrant were *Anthephora pubescens, Brachiaria nigropedata, Chrysopogon serrulatus, Schmidtia pappophoriodes* and *Centropoidea glauca*. *Stipagrostis uniplumis* was typical of the Reserve and Commercial land uses (first axis, second quadrant) (Fig 4.9). These species were primarily associated with the Reserve, Reserve-/Commercial-Good environmental interactions.

The passive bush property variables (BE/ha; bush number/ha and area cover/ha) were strongly associated with the first axis and were distributed within the first quadrant, near to the fourth quadrant, showing a very strong association, with especially the Tribal-Poor as well as the Tribal and Tribal-Good environmental variables (which were strongly associated with the first axes). The passive variables indicating herbaceous species richness (ANNrich) (r = -0.4161), -diversity and –evenness of the "annual" interpretation were also strongly correlated with the fourth quadrant and its associated environmental and passive variables.

Pogonarthria squarosa, Brachiaria marlothii and *Cynodon dactylon* were strongly related to the first axis, woody variables and the Tribal-Poor interaction, whereas *Arisitida stipitata, Tragus berteronianus, Aristida meriodinalis* and *Aristida congesta* were closely related to the "Tribal" environmental variable. The Tribal-Good environmental variable - which was correlated with the species richness (ANNrich) passive variables - was characterised by *Digitaria erianthra, Melinis repens, Egragrostis pallens, Perotis patens, Panicum maximum, Eragrositis rigidior, Chloris virgata and Eleusine corocana* (Fig. 4.9).

A LOESS attribute plot (Fig. 4.10), with the "Good" nominal environmental value as predictor, displays contour levels ranging from sites associated with relative poor rangeland conditions (CCA environmental response contour level of -0.1), increasing towards sites associated with relative good rangeland conditions (CCA environmental response contour level of 1.2). An interesting observation is that the Reserve-/Commercial-Good and Reserve-/Commercial-Poor environmental interactions were negatively correlated with each other and associated with the third and second quadrant respectively, compared to the Tribal, Tribal-Good and Tribal-Poor interactions that were not markedly negatively correlated, and which all were associated with the fourth quadrant. Hence, the length of the degradation gradient within the Reserve- and Commercial land uses was more pronounced than within the Tribal land use, with the former land uses showing more extreme associations for both the Poor as well as the Good environmental variables (Fig. 4.10). However, the Reserve-/Commercial-Good variables were better correlated with the "Good" variable than the Tribal-variables were correlated with the "Good" variable, with the Tribal variables showing a low to mid-rangeland positioning on the larger study area degradation gradient (Fig. 4.10). The implication is that the Reserve-/Commercial-Poor variables represented sites with very low condition scores, and the Reserve-/Commercial-Good variables sites with very high range condition scores, thus displaying a clear degradation gradient. The Tribal-land use with its relative "Good" and "Poor" extremes were all comparable, being indicative of a total "shift" in species composition towards a low-mid range condition state. This is discussed in Section 4.3.1.7.

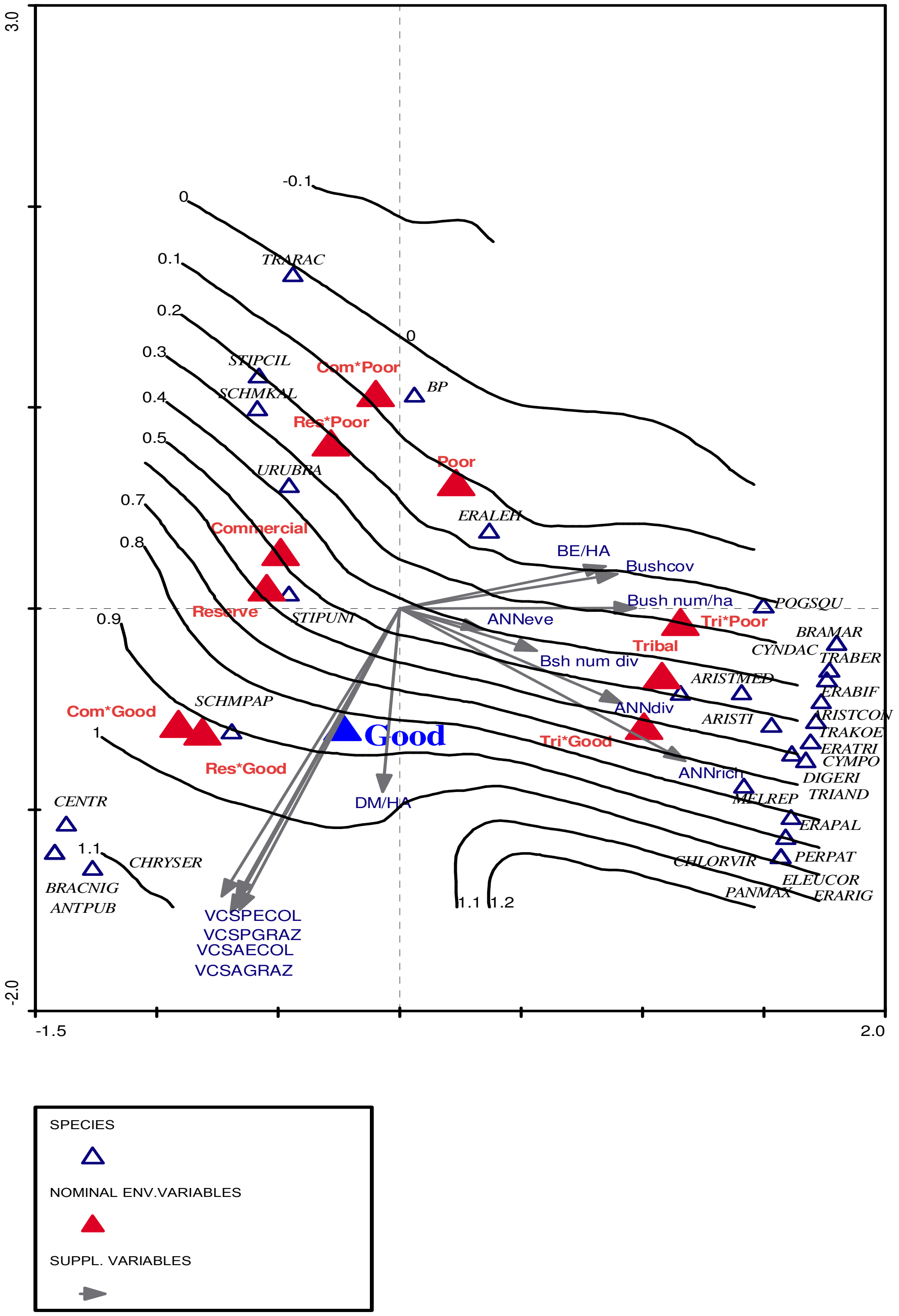


Fig. 4.10. A CCA ordination LOESS plot, with the "Good" environmental variable as predictor (indicated in blue) for the "annual" interpretation.

B. “Perennial” interpretation

A DCA of the species composition data indicated that the fourth axis accounted for 45.1% of the species variance (Table 4.4), opposed to the 42.6% of the “annual” interpretation (Table 4.1). The first two axes represented similar compositional patterns as the “annual” interpretation, and hence are not presented again. Environmental variables strongly associated with the first axis were the “Good” (r = 0.6474) and “Poor” (r = -0.6474) environmental variables and the “Commercial-Good” (r = 0.5010) and “Reserve-Good” (r = 0.5069) interactions (Table 4.4). The second axis was best represented by the “Good” (r = 0.4388) and “Poor” (r = -0.4388) environmental variables, followed by the “Reserve-Poor”- (r = -0.344), “Commercial-Poor”- interactions (r = -0.33) and by the Tribal variable (r = 0.3279) (Table 4.4).

Table 4.4. A DCA ordination for the “perennial” herbaceous composition, showing eigenvalues and species-environment relations for the first four axes, as well as the environmental and passive variables explaining most of the species-environment relation for the first two axes. Variables explaining most of the variance are indicated in **bold**.

Axes	**1**	**2**	**3**	**4**	
Eigenvalues	0.503	0.328	0.174	0.112	
Lengths of gradient	3.047	2.628	2.414	2.103	
Species-environment correlations	0.818	0.567	0.614	0.487	
Cumulative percentage variance					
of species data	20.3	33.6	40.6	45.1	
of species-environment relation (environmental)	47.8	59.4	0	0	
of species-environment relation (passive data)	39.9	48.3	0	0	
Environmental data	**SPEC AX1**	**SPEC AX2**	**Passive data**	**SPEC AX1**	**SPEC AX2**
Commercial	0.0978	-0.224	BE/HA	-0.4236	0.0872
Tribal	-0.3752	0.3279	Bushcov	-0.4327	0.1759
Reserve	0.2745	-0.1025	Bush num/ha	-0.3812	0.1085
Good	**0.6474**	**0.4388**	VCSAGRAZ	**0.9085**	0.3101
Poor	**-0.6474**	**-0.4388**	VCSPGRAZ	**0.9172**	0.2929
Com*Good	0.501	0.0525	DM/HA	0.4406	**0.438**
Com*Poor	-0.3629	-0.33	VCSAECOL	**0.9346**	0.303
Tri*Poor	-0.3432	0.0936	VCSPECOL	**0.9491**	0.277
Tri*Good	-0.1345	0.3201	PERrich	0.0236	-0.0269
Res*Good	0.5069	0.214	PEReve	-0.0507	0.176
Res*Poor	-0.1619	-0.344	PERdiv	-0.0428	0.084
			Bsh.div	-0.0988	0.1347

Most of the species-environment correlation for the environmental variables was explained by the first axis (r = 0.818), and 59.4% of the cumulative species-environment relation by the second axis (Table 4.4). The species-environment relation was 48.3% as explained cumulatively by the second axis, with the different rangeland condition indices' scores very strongly representing the first axis (VCSAGRA, r = 0.9085; VCSPGRA, r = 9172; VCSAECOL, r = 0.9346; VCAPECOL, r = 0.9491). The dry material yield (DM/ha) was best correlated with the second axis (r = 0.4380) (Table 4). This is similar to the pattern of the "annual" interpretation.

A CCA employing environmental and supplementary variables revealed significant patterns related to the first (F-ratio = 12.298, P < 0.005) and all canonical axes (F-ratio = 5.46, P < 0.005). The first two axes represented 84.1% of the species-environment relation and 98.4% of the species-environment relation by the fourth axis (Table 4.5). These statistics were an improvement on that of the "annual" interpretation. Twenty-four-point-six percent (24.6%) of the cumulative species data was accounted for by the first two axes and 28.8% by the fourth axis (Table 4.5).

Table 4.5. The eigenvalues, species-environment correlation and cumulative variances explained for the species data and species-environment relation for the CCA ordination for the "perennial" herbaceous species composition.

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.389	0.221	0.064	0.04
Species-environment correlations	0.888	0.703	0.492	0.512
Cumulative percentage variance				
of species data	15.7	24.6	27.2	28.8
of species-environment relation (environmental)	53.7	84.1	92.9	98.4
of species-environment relation (passive data)	32.7	62.1	68	72

The first axis was strongly associated with the Tribal land use (r = -0.6781, second quadrant), Commercial-Good (r = 0.53) and Reserve-Good interactions (r = 0.506, both first quadrant). The "Good" (r = 0.5453, first quadrant) and "Poor" (r = -0.5453, third quadrant) variables were the environmental variables that were the strongest associated with the second axis (Table 4.6; Fig. 4.11). The Tribal, Tribal-Good and Tribal-Poor interactions were associated with the second quadrant, whereas the Reserve-Poor, Commercial-Poor and Poor interactions were associated with the third quadrant and the Reserve-Good, Commercial-Good interactions and Good variables correlated with the first quadrant. Although the species-environment variance explained by the Monte Carlo test was higher than in the "annual" interpretation, the correlation coefficients between the environmental variables and axes were lower.

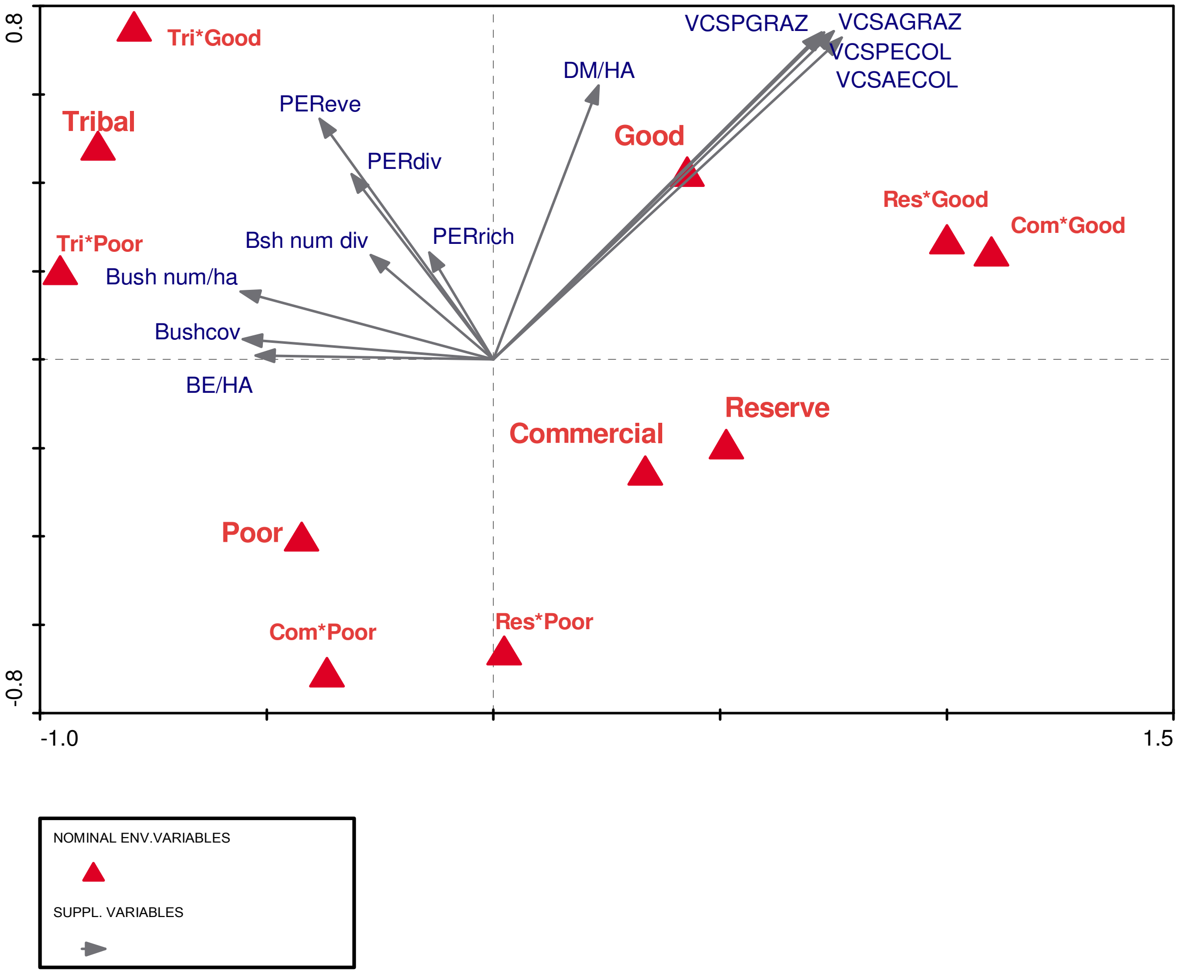


Fig. 4.11. A CCA biplot for the "perennial" interpretation, displaying the environmental and supplementary variables explaining most of the species-environment variance.

Passive variables associated with the species compositional patterns and environmental variables were similar to the "annual" interpretation, except that no annual species were included in the analysis (as explained under "Material and methods"). Perennial species richness, -evenness and -diversity, as well as the different woody property variables, were best correlated with the Tribal-, Tribal-Good and Tribal-Poor variables of the second quadrant, whereas the rangeland condition scores calculated from the different rangeland condition indices were associated with the first quadrant and the Good, Reserve-Good and Commercial-Good environmental variables (Fig. 4.11). These rangeland condition variables showed the strongest association for both the first and the second species-environment axis for passive variables ($r > 0.62$) (Table 4.6). The environmental and passive variables were associated with the same herbaceous species, barring the annual species, as discussed under the "annual" interpretation. The passive variables also showed less strong correlations with the axes than the "annual" interpretation did.

Table 4.6. Correlation coefficients (r-values) for the environmental and passive data associated with the first two canonical axes of the CCA ordination for the "perennial' interpretation, as well as the environmental variables in order of importance, accounting for most of the species-environment variance as indicated by the Monte Carlo permutation test. Variables explaining most of the variance are indicated in **bold**.

Environmental data	SPEC AX1	SPEC AX2	Passive data	SPEC AX1	SPEC AX2
Commercial	0.2619	-0.2427	BE/HA	-0.4875	0.0083
Tribal	-0.6781	0.4371	Bushcov	-0.5137	0.04
Reserve	0.4117	-0.1921	Bush num/ha	-0.5181	0.1329
Good	0.4726	**0.5453**	VCSAGRAZ	0.6714	**0.6396**
Poor	-0.4726	**-0.5453**	VCSPGRAZ	0.6775	**0.6391**
Com*Good	**0.5300**	0.1340	DM/HA	0.2153	0.5364
Com*Poor	-0.1864	-0.4322	VCSAECOL	0.6967	**0.6418**
Tri*Poor	-0.4646	0.1108	VCSPECOL	**0.7134**	**0.6295**
Tri*Good	-0.3959	0.4404	PERrich	-0.1320	0.2094
Res*Good	**0.5060**	0.157	PEReve	-0.3564	0.4706
Res*Poor	0.0121	-0.3999	PERdiv	-0.2906	0.3625
			Bsh.div	-0.2517	0.2039

Monte Carlo permutation test

Variable	P	F
Tribal	0.002	10.11
Good/Poor	0.002	8.95
Tri*Poor/Tri*Good	0.002	2.87
Com*Good/Res*Good	0.012	2.36
Commercial	0.554	0.88

Environmental variables that contributed most towards explaining the species-environment relation, in order of inclusion in the model, were the same as those discussed in the annual interpretation, although the F-values varied slightly (Table 4.6 vs. Table 4.3).

A LOESS plot for the CCA ordination, incorporating the "Good" variable as predictor, indicated a gradient running from the "Poor" to "Good" variable for the entire study area (Fig. 4.12). The countour level showing the lowest score (zero in this case) was associated with rangelands in relative poor condition, whereas contour levels associated with the highest scores (based on CCA environmental response contours) (contour level = 1.2) were associated with relative good rangeland conditions. It was evident that a gradient for relative condition existed for the entire area and within each land use, although the significance of these within land use gradients will be tested in the remainder of the chapter. The Commercial- and Reserve land uses were distributed over rangeland conditions stretching from very poor to very good for this study area. The entire Tribal land use occupied low to intermediate rangeland conditions (see section on rangeland condition scores, Section 4.3.5).

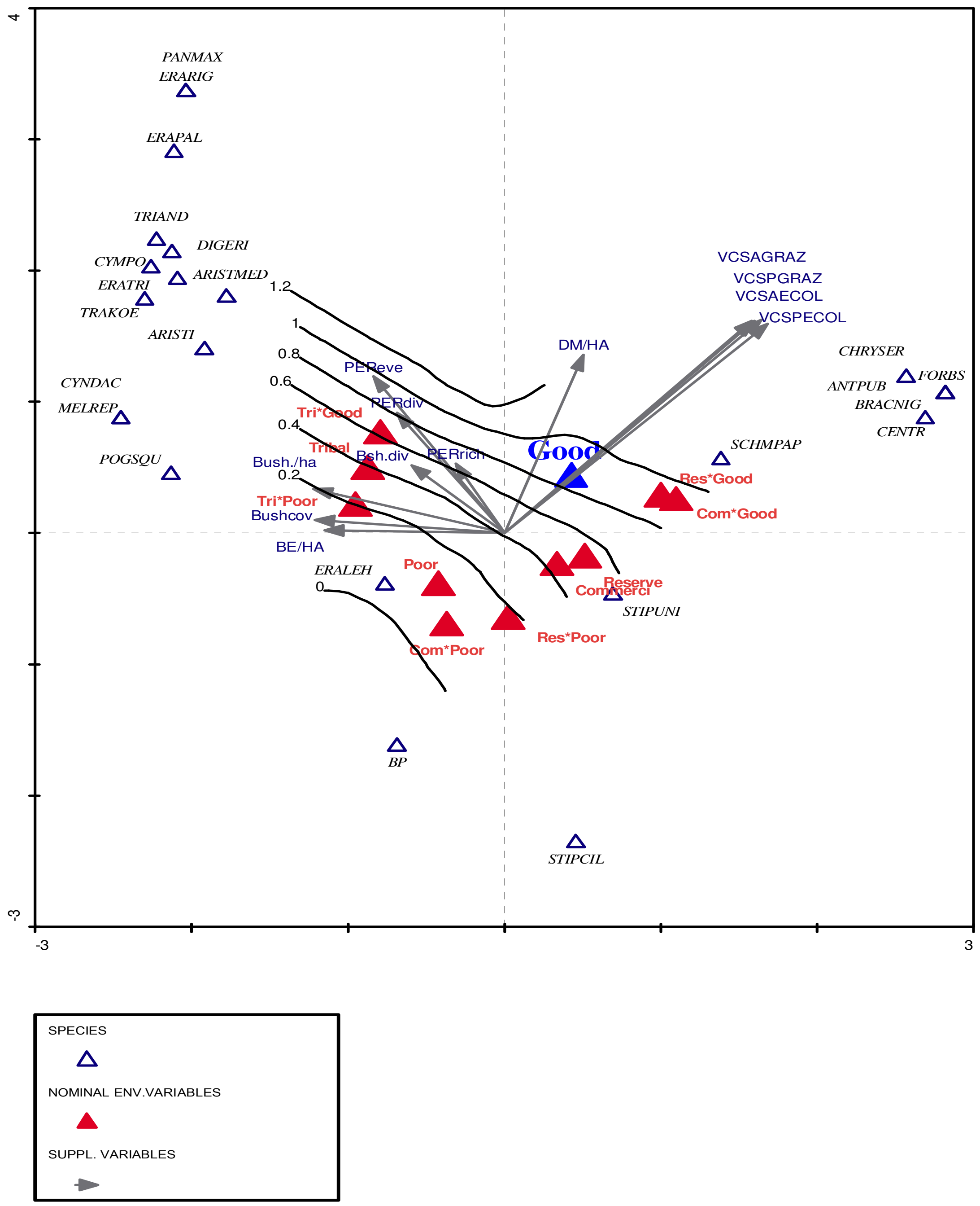


Fig. 4.12. A CCA ordination LOESS plot with the “Good” variable as predictor, illustrating a gradient running from the “Poor” to the “Good’ variable for the “perennial” interpretation.

C. Summary of two interpretation methods

Both the “annual” and “perennial” interpretations significantly explained the first and all canonical axes for the species-environment relation, with the Tribal-variables followed by the rangeland condition variables (relative “Good/Poor” variables) significantly explaining the species-environment variance. The higher species-environment variance explained by the “perennial” interpretation was informative and confirms the applicability of this interpretation technique to reflect on the longer-term ecological status of the

Molopo semi-arid system (as opposed to the "climatic" induced effects reflected by the "annual" interpretation). The species-environment patterns differed slightly in statistics from each other, but not in patterns. These results suggest that for this particular survey year, the seasonal rainfall variability did not result in significant differences between the two interpretation methods. These patterns will be investigated and verified more in depth in the remainder of the document.

D. Cumulative contribution to species variance

Species having 10% and higher of their ranges being accounted for by the CCA ordination's first two axes for both interpretation methods, were determined as a potential "instrument" towards identifying species that best represent each axis (Morris 2006, pers. comm.). Hence, it is suggested that these species could consistently act as potential indicators of rangeland condition within each land use and as indicators of the different land uses. Results are presented in Fig. 4.13 for the "annual" interpretation and Fig. 4.14 for the "perennial" interpretation (Appendix 4.3). These results are complementary to that of Section 4.3.1.4, and are incorporated into the "Key assessment matrix", presented in Chapter 9.

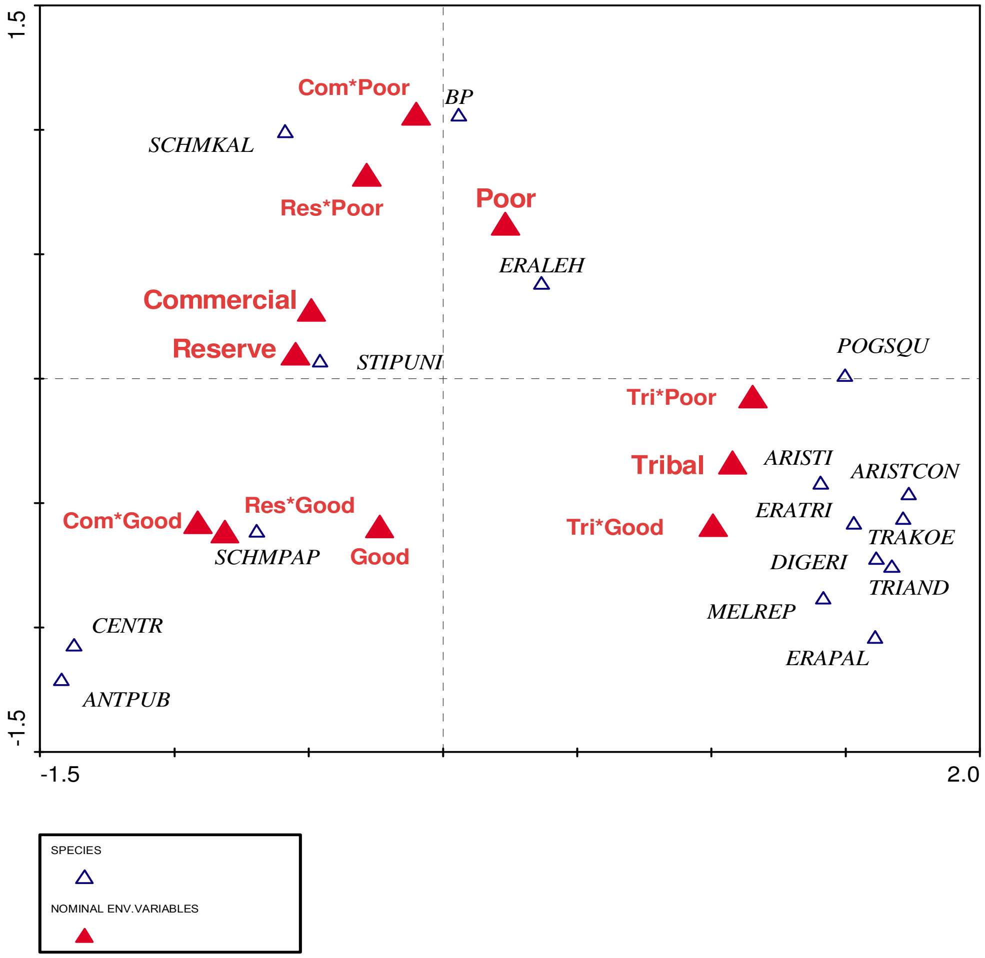


Fig. 4.13. A CCA ordination biplot for the "annual" interpretation, displaying herbaceous species with ranges 10% and higher being explained constrained by the first two axes.

Sixteen species (including BP) were included in the "annual" interpretation (Fig. 4.13). *Antephora pubescens*, *Schmidtia pappophoroides* and *Centropodia glauca* were associated with the Reserve-/Commercial-Good variables. *Stipagrostis uniplumis* was associated with intermediate ranges within the Reserve and Commercial land uses, and *Schmidtia kalahariensis* and BP with the Commercial-Poor and to a lesser extent with the Reserve-Poor variable. *Eragrostis lehmanniana* was associated with the relative "Poor" conditions, showing a distribution associated with all three land uses. The Tribal land use was represented by nine species. Although a rangeland condition gradient was not significant within the Tribal land uses, species associated with the Tribal-Good and Tribal-Poor variables are presented in Fig. 4.13. However, these variables did not necessarily contribute consistently to the species composition within all sites. This is discussed in Section 4.3.1.4.

Only 12 species were included in the "perennial" interpretation, and are presented in Fig. 4.14. These species accounted for 10% or higher of the species-environment relation, as constrained function of the first two axes. This means that monitoring of these 10% and higher contributing species for both interpretations is more informative than the monitoring of the total species compositional set, and that changes in these species will be informative of habitat modification (density dependent coupling) and climatic events (non-equilibrium events). These species will be used in the "Key assessment matrix", presented in Chapter 9.

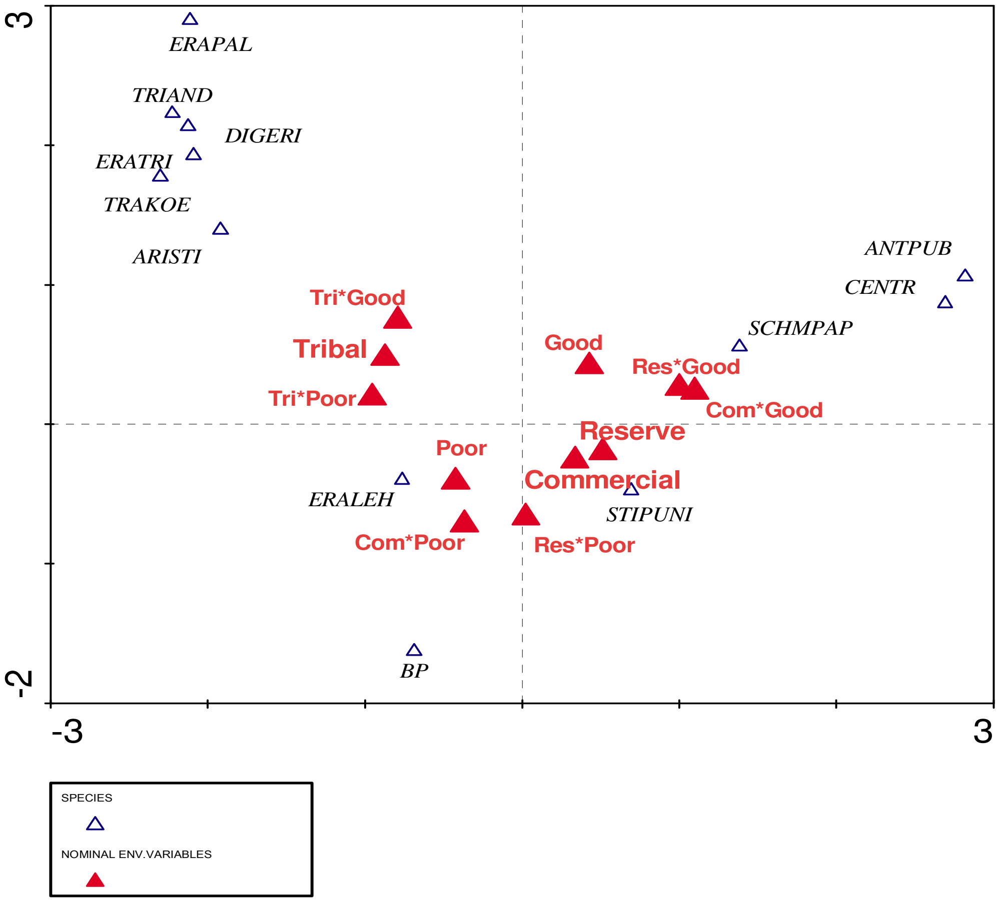


Fig. 4.14. A CCA ordination biplot for the "perennial" interpretation, displaying herbaceous species with ranges 10% and higher being constrained by the first two axes.

4.3.1.4 SIMPER analysis for general species composition matrix between land uses

SIMPER analyses were performed to identify which species primarily account for the observed assemblage similarities within and differences between the land uses as well as within and between the general relative condition groups. Individual species' contributions to the separation of the groups can be examined with the SIMPER procedure. It is an explanatory rather than a statistical framework (See Chapter 3, Material and Methods). Species identified in this manner (including typical and discriminant species; Chapter 3 – Material and Methods) are most effectively viewed together with an ordination, and hence are complementary to the results discussed above.

A. "Annual" interpretation

Species were listed in decreasing order of their importance in contributing to similarities within (Table 4.7) and discriminating between two sets of land uses (Table 4.8). The Commercial land use had an overall average similarity of 33.8%, the Tribal land use 39.31% and the Reserve land use 49%.

The following species (including bare patches - BP) accounted for 90% or higher of the similarities within the Commercial land use group (irrespective of the relative condition): *Schmidtia pappophoroides*, BP*, Eragrostis lehmanniana, Stipagrostis uniplumis* and *Schmidtia kalahariensis*. *Schmidtia pappophoroides* was the most abundant species, and contributed to 44.08% of the similarity (Table 4.7). Bare patches were the second most abundant group, followed by *Eragrostis lehmanniana*. These three species accounted for 75.61% of the total similarity. If *Stipagrostis uniplumis* and *Schmidtia kalahariensis* are added, 95.45% of the similarity is accounted for. *Schmidtia pappophoroides* (Sim/SD = 0.77), followed by *Stipagrosits uniplumis* (Sim/SD = 0.66), were consistently the most typical species of this land use (irrespective of relative condition types, although not that strong indicators with the Sim/SD < 1.0). Typical species are found in consistent abundances within a group, resulting in the standard deviation to be low, so that the Sim/SD ratio is low (Clarke & Warwick 2001). This means that these species were not consistently distributed throughout all sites, which will necessitate that species typical of each relative condition group need to be established. Since a rangeland condition gradient was indicated to be significant (Sections 3.1.1 and 3.1.3), the weak Sim/SD values could possibly be ascribed to the occurrence of these species at this level of analysis being averaged across all relative condition groups (Table 4.7).

Consistent *typical* species representative of the general Tribal land use spectrum were: *Aristida stipitata, Egragrostis lehmanniana* and *Aristida congesta*. These species are all typical of overgrazed rangelands (Van Oudtshoorn 2002). However, the first two species mentioned for this land use, followed by *Schmidtia pappophoroides*, were in that order the three most abundant species, and contributed to 73.68% of the similarity. These species, together with *Eragrostis pallens*, BP and *Digitaria eriantha* contributed to 92.46% of the Tribal land use's similarity (Table 4.7).

Table 4.7. SIMPER analyses for the "annual" herbaceous species composition, displaying species that contributed to the average similarities within each land use and rangeland condition group.

Group Commercial Average similarity: 33.8

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
SCHM PAP	31.01	14.9	*0.77	44.08	44.08
BP	19.34	6.55	0.53	19.39	63.47
ERA LEH	14.03	4.1	*0.57	12.14	75.61
STI PUNI	9.79	3.97	*0.66	11.76	87.37
SCHM KAL	11.66	2.73	0.45	8.08	95.45

Group Tribal Average similarity: 39.31

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
ARI STI	22.98	12.26	*1.21	31.19	31.19
ERA LEH	18.23	10.2	*1.15	25.95	57.14
SCHM PAP	13.23	6.5	*0.99	16.53	73.68
ERA PAL	7.21	2.33	0.54	5.93	79.61
BP	11.12	2.27	0.34	5.78	85.39
ARIST CON	4.06	1.73	*0.79	4.4	89.78
DIG ERI	3.81	1.05	0.51	2.68	92.46

Group Reserve Average similarity: 49

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
SCHM PAP	43.87	26.08	*1.11	53.23	53.23
STIP UNI	16.4	10.48	*1.62	21.38	74.62
BP	18.56	6.28	0.62	12.82	87.44
ERA LEH	12	4.13	0.63	8.43	95.87

Group Poor Average similarity: 32.74

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
BP	27.24	12.27	*0.76	37.49	37.49
ERA LEH	19.54	7.83	*0.69	23.93	61.41
SCHM PAP	13.99	5.13	*0.69	15.66	77.07
STIP UNI	9.59	3.37	0.56	10.3	87.37
ARI STI	9.72	1.98	0.3	6.04	93.42

Group Good Average similarity: 44.83

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
SCHM PAP	44.74	29.18	*1.37	65.09	65.09
STIP UNI	11.21	5.49	*0.87	12.24	77.33
ERA LEH	9.96	4.79	*0.92	10.68	88.01
ARI STI	7.93	1.84	0.4	4.11	92.12

The Reserve land use was consistently best **typified** by *Schmidtia pappophoroides* and *Stipagrostis uniplumis*. These two species accounted for 74.62% of this land use's similarity, and together with BP and *Eragrostis lehmanniana* accounted for 95.87% of the similarity (Table 4.7).

Species typical of the overall/general relative "Good" environmental variable, with average similarity of 44.83%, were: *Schmidtia pappohoroides, Stipagrostis uniplumis* and *Eragrostis lehmanniana*. These three species, together with *Aristida stipitata* contributed to 92.12% of the similarity. The relative "Poor" extreme was best typified by BP, *Schmidtia pappohoroides* and *Eragrostis lehmanniana* that accounted for 77.07% of the similarity. The last two mentioned species were typical of both "condition" groups when averaged over all land uses. However, the average abundance of these two groups differed between the two land uses, and should serve as further directive to distinguish between the relative condition groups *within* each land use (Table 4.7).

Average dissimilarities between the Commercial- and Tribal land uses were 76.61%, 74.21% for the Reserve-Tribal land uses, 59.27% between the Commercial-Reserve land uses and 71.74% between the relative Good-Poor variables. Discriminating species consistently contribute to the dissimilarity between inter-comparisons of all samples between two groups (if average contribution of species S_i to overall dissimilarity is large and the standard deviation SDS_i of the species is small, hence the S_i/SDS_i ratio large) (Table 4.8).

Discriminating species between the Commercial-Tribal land uses were *Schmidtia pappophoroides, Aristida stipitata*, *Eragrostis lehmanniana* and *Stipagrostis uniplumis*. Twelve species contributed to 91.31% of the dissimilarities. *Schmidtia pappohoroides*, BP and *Stipagrostis uniplumis* were the most consistent discriminating species between the Commercial- and Reserve land uses, even though *Stipagrostis uniplumis* contributed to less of the average dissimilarities and cumulative dissimilarities than *Eragrostis lehmanniana* and *Schmidtia kalahariensis* did (Table 4.8).

Six species listed in Table 4.8 contributed to 91.73% of the dissimilarities between the Reserve-Tribal land uses. *Aristida stipitata, Schmidtia pappophoroides*, *Eragrostis lehmanniana* and *Stipagrostis uniplumis* were discriminating species between the Reserve- and Tribal land uses. Even though BP contributed to the third highest average dissimilarity and cumulative contribution (av. diss = 10.69%, contribution = 14.41%), it was not indicated as being a consistent "discriminating species". Ten species contributed to 91.47% of the dissimilarities between these two land uses (Table 4.8).

Dissimilarities between the general Good-Poor relative condition groups were consistently best represented by *Schmidtia pappophoroides*, BP, *Eragrostis lehmanniana* and *Stipagrostis uniplumis*. Although only ranked fifth in terms of dissimilarity contribution, *Stipagrostis uniplumis* was the second strongest discriminating species. Ten species contributed to 90.65% of the dissimilarities (Table 4.8).

Table 4.8. SIMPER analyses for the “annual” herbaceous species composition, displaying species that contributed to the average dissimilarities between the different land uses and rangeland condition groups.

Groups Commercial & Tribal Average dissimilarity: 76.61

	Group Commercial	Group Tribal				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
SCHM PAP	31.01	13.23	13.58	*1.24	17.73	17.73
ARI STI	2.69	22.98	11.17	*1.16	14.58	32.3
BP	19.34	11.12	11.04	0.94	14.41	46.71
ERA LEH	14.03	18.23	9.44	*1.06	12.33	59.04
SCHM KAL	11.66	0	5.83	0.56	7.61	66.65
STIP UNI	9.79	5	5.24	*1.04	6.84	73.49
ERA PAL	0	7.21	3.61	0.71	4.71	78.2
ANT PUB	6.61	0	3.31	0.5	4.31	82.51
ARIST CON	0	4.06	2.03	0.95	2.65	85.16
DIG ERI	0.08	3.81	1.89	0.64	2.47	87.64
ERA TRI	0.03	3.11	1.56	0.49	2.03	89.67
MEL REP	0	2.52	1.26	0.7	1.64	91.31

Groups Commercial & Reserve Average dissimilarity: 59.27

	Group Commercial	Group Reserve				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
SCHM PAP	31.01	43.87	17.22	*1.39	29.06	29.06
BP	19.34	18.56	12.11	*1.01	20.43	49.5
ERA LEH	14.03	12	8.6	0.84	14.51	64.01
SCHM KAL	11.66	6.56	6.71	0.7	11.32	75.33
STIP UNI	9.79	16.4	6.41	*1.34	10.82	86.15
ANT PUB	6.61	0	3.31	0.5	5.58	91.73

Groups Tribal & Reserve Average dissimilarity: 74.21

	Group Tribal	Group Reserve				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
SCHM PAP	13.23	43.87	17.89	*1.36	24.1	24.1
ARI STI	22.98	0.8	11.16	*1.14	15.04	39.14
BP	11.12	18.56	10.69	0.87	14.41 5	3.55
ERA LEH	18.23	12	8.42	*1.19	11.34	64.89
STIP UNI	5	16.4	7.31	*1.41	9.85	74.74
ERA PAL	7.21	0	3.6	0.71	4.86 7	9.6
SCHM KAL	0	6.56	3.28	0.73	4.42 8	4.02
ARIST CON	4.06	0	2.03	0.95	2.74 8	6.76
DIG ERI	3.81	0	1.9	0.64	2.57 8	9.32
ERA TRI	3.11	0.2	1.59	0.51	2.15 9	1.47

Groups Poor & Good Average dissimilarity: 71.74

	Group Poor	Group Good				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
SCHM PAP	13.99	44.74	18.41	*1.48	25.67	25.67
BP	27.24	5.44	12.92	*1.02	18.01	43.67
ERA LEH	19.54	9.96	9.06	*0.99	12.62	56.3
ARI STI	9.72	7.93	6.88	0.76	9.59	65.88
STIP UNI	9.59	11.21	5.97	*1.20	8.33	74.21
SCHM KAL	8.36	3.79	5.04	0.58	7.03	81.24
ERA PAL	0.88	3.93	2.21	0.51	3.08	84.31
ANT PUB	0	4.41	2.2	0.39	3.07	87.38
ARIST CON	1.97	0.74	1.18	0.62	1.65	89.03
DIG ERI	1.25	1.34	1.16	0.47	1.62	90.65

B. “Perennial” interpretation

SIMPER similarity/dissimilarity analyses within and between groups, indicated that the Commercial land use had an overall similarity of 35.94%, 41.53% for the Tribal- and 51.57% for the Reserve land uses (averaged across all relative condition types) (Table 4.9). This did not differ much from the “annual” interpretation, and is thus consistent with the deductions made in Section C above.

Table 4.9. SIMPER analyses for the “perennial” herbaceous species composition, displaying species that contributed to the average similarities within each land use and rangeland condition group.

Group Commercial Average similarity: 35.94

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
SCHM PAP	34.08	16.02	*0.77	44.57	44.57
BP	26.2	9.46	0.57	26.31	70.88
ERA LEH	15.62	4.59	0.56	12.76	83.65
STIP UNI	11.24	4.47	*0.68	12.43	96.08

Group Tribal Average similarity: 41.53

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
ARI STI	22.99	12.27	*1.21	29.56	29.56
ERA LEH	20.41	11.07	*1.13	26.67	56.22
SCHM PAP	14.34	7.14	*1.00	17.18	73.4
BP	15.31	5.12	0.68	12.33	85.73
ERA PAL	8.06	2.64	0.55	6.36	92.09

Group Reserve Average similarity: 51.57

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
SCHM PAP	46.48	28.45	1.13	55.16	55.16
STIP UNI	17.75	11.45	1.57	22.21	77.36
BP	20.33	6.92	0.59	13.42	90.79

Group Poor Average similarity: 38.40

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
BP	34.9	17.68	0.92	46.05	46.05
ERA LEH	21.96	8.81	0.69	22.94	69
SCHM PAP	14.94	5.73	0.72	14.92	83.92
STIP UNI	10.78	3.75	0.55	9.76	93.67

Group Good Average similarity: 47.70

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
SCHM PAP	48.33	31.57	1.35	66.19	66.19
STIP UNI	11.96	5.9	0.87	12.37	78.57
ERA LEH	10.76	5.14	0.91	10.78	89.35
ARI STI	8	1.89	0.4	3.95	93.3

Only the species contributing to 90% or higher of the similarities/dissimilarities were listed. Typical species within land-use groups remained similar to that of the "annual" interpretation, since no annual species were indicated as primary typical or discriminant species in the "annual" interpretation. However, the average abundances of the perennial species contributing to 90% or higher of the similarities of the "perennial" interpretation, were slightly higher. However, it is worthwhile to mention that the species contributing to the average similarity of the Commercial land use had low Sim/SD ratios (Table 4.9). *Schmidtia pappophoroides* had the highest average abundance (34.08%) as well as contribution (44.57%), followed by BP. However, *Schmidtia pappophoroides* was not ranked as the primary *typical* species, whereas *Stipagrostis uniplumis*, which was ranked fourth in terms of contribution, was a stronger discriminant species than BP and *Eragrostis lehmanniana* (ranked third in terms of contribution). Hence, highest average abundance is not a measure of consistent distribution throughout all survey sites. Species compositional structures were indicated to be significantly correlated with range condition (and hence the gradient, as indicated in the results discussed in Sections 4.3.1.1 and 4.3.1.3). This suggests that patterns within a land use should be identified to establish whether this will result in highly abundant species to be more typical and hence consistent when related to either the relative "Good" or "Poor" range conditions. *Schmidtia pappophoroides* is a perennial palatable grass regarded as a valuable grazing grass. It is also considered to be drought-resistant and can endure reasonably heavy grazing (Van Oudtshoorn 2002). *Stipagrostis uniplumis* is regarded as an important species in semi-arid ecosystems, especially in terms of a relatively palatable grazing grass and for its soil stabilising characteristics (Van Oudtshoorn 2002).

The Tribal group was most typically represented by *Aristida stipitata*, which was also the most abundant species (av. abund = 22.99%, contribution = 29.58%), followed by *Eragrostis lehmanniana*, *Schmidtia pappophoroides*, BP and *Eragrostis pallens*. These species cumulatively contributed to 92.09% of the similarity (Table 4.9). *Aristida stipitata* grows mainly in deep, sandy soil in disturbed places such as overgrazed rangelands (Van Oudtshoorn 2002).

The Reserve was best represented by *Schmidtia pappophoroides* (av. abund = 46.48%), followed by *Stipagrositis uniplumis*, which was consistently most typical of this land use, and BP. These species and the BP contributed to 90.79% of the cumulative similarity (Table 4.9).

The relative "Poor" group had a similarity of 38.4% and the relative "Good" group 47.7% when averaged over all land uses, which was also slightly higher than in the "annual" interpretation. Typical species of the similarities within each relative condition group, as well as discriminating species of dissimilarities (69.78%) (Table 4.10) between these two groups, remained similar as in the "annual" interpretation, although their average abundances were slightly higher (Table 4.9).

Table 4.10. SIMPER analyses for the “perennial” herbaceous species composition, displaying species that contributed to the average dissimilarities between each land use and rangeland condition group.

Groups Commercial & Tribal Average dissimilarity: 72.23

	Group Commercial	Group Tribal				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
SCHM PAP	34.08	14.34	14.87	1.2	20.59	20.59
BP	26.2	15.31	13.87	1	19.21	39.8
ARI STI	3.34	22.99	11.34	1.16	15.7	55.5
ERA LEH	15.62	20.41	10.67	1.06	14.77	70.27
STIP UNI	11.24	5.12	5.86	1.01	8.11	78.38
ERA PAL	0	8.06	4.03	0.74	5.58	83.96
ANT PUB	6.73	0	3.36	0.5	4.66	88.62
DIG ERI	0.09	4.1	2.04	0.67	2.82	91.44

Groups Commercial & Reserve Average dissimilarity: 57.09

	Group Commercial	Group Reserve				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
SCHM PAP	34.08	46.48	18.31	1.4	32.07	32.07
BP	26.2	20.33	14.77	1.06	25.88	57.94
ERA LEH	15.62	13.06	9.44	0.84	16.53	74.47
STIP UNI	11.24	17.75	7.1	1.37	12.43	86.9
ANT PUB	6.73	0	3.36	0.5	5.89	92.79

Groups Tribal & Reserve Average dissimilarity: 70.35

	Group Tribal	Group Reserve				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
SCHM PAP	14.34	46.48	18.76	1.4	26.67	26.67
BP	15.31	20.33	11.56	0.89	16.44	43.11
ARI STI	22.99	0.91	11.15	1.14	15.85	58.95
ERA LEH	20.41	13.06	9.37	1.16	13.32	72.27
STIP UNI	5.12	17.75	7.87	1.46	11.19	83.46
ERA PAL	8.06	0	4.03	0.74	5.73	89.18
DIG ERI	4.1	0	2.05	0.67	2.91	92.09

Groups Poor & Good Average dissimilarity: 69.78

	Group Poor	Group Good				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
SCHM PAP	14.94	48.33	19.69	1.47	28.22	28.22
BP	34.9	6.32	15.91	1.09	22.79	51.01
ERA LEH	21.96	10.76	10.11	0.98	14.48	65.49
ARI STI	10.15	8	7.08	0.76	10.15	75.64
STIP UNI	10.78	11.96	6.54	1.21	9.38	85.02
ERA PAL	1	4.37	2.46	0.52	3.53	88.55
ANT PUB	0	4.49	2.24	0.39	3.21	91.77

The average dissimilarities between the Commercial and Tribal land uses were 72.23%, 57.09% for the Commercial-Reserve land uses and 70.35% for the Tribal-Reserve land uses (Table 4.10). The most important discriminating species between the Commercial-Tribal uses were *Schmidtia pappophoroides* (Diss/SD = 1.2), followed by *Aristida stipitata* (Diss/SD = 1.16) and *Eragrostis lehmanniana* (Diss/SD = 1.06) (Table 4.10). *Schmidtia pappophoroides* (Diss/SD = 1.4), followed by *Stipagrosits uniplumis* (Diss/SD = 1.37) were the strongest discriminating species between the Commercial-Reserve land uses. The differences in average abundance for *Schmidtia pappophoroides* can serve as further aid to distinguish between these two land uses (Table 4.10). The dissimilarity between the Tribal-Reserve land uses was primarily contributed by *Schmidtia pappophoroides*, which was the second most important discriminating species (Diss/SD = 1.4), BP, *Aristida stipitata* and *Eragrostis lehmanniana*, which cumulatively contributed to 72.27% of the dissimilarity. *Stipagrosits uniplumis* (Diss/SD = 1.46) was indicated as consistently the most important discriminating species (Table 4.10).

C. Remarks

SIMPER analyses were informative in terms of the following:

- Complementary explanatory analyses in addition to that of the MDS, DCA and CCA ordinations;
- Listing of species contributing to 90% or higher of the similarities within each land use according to each interpretation method, rendering comparisons possible for adaptive management purposes easier between land uses and between analysis techniques;
- Average relative frequency of each species within each land use is presented;
- Reliable indication of consistent typical species within each land use according to both interpretation methods;
- Reliable indication of discriminating species between land uses;
- Reliable indication of consistent distribution of species within and between land uses

SIMPER procedures for both methods displayed roughly similar patterns for the similarity groups *within* each land use and dissimilarity patterns between land uses. However, some typical species for a general land use were not very strong (low Sim/SD < 1.0), suggesting as supported by the analyses of Sections 4.3.1.1 and 4.3.1.3, that species typical of each land use's relative condition groups *within* each land use need to be established, owing to a significant range condition gradient being evident not only for the total survey area, but also within the Commercial and Reserve land uses. No significant gradient was visible within the Tribal land use, and further explanatory procedures to illustrate this, can be informative as to decide up to which level rangeland monitoring within a land use should be conducted. Such results can form the basis for adaptive management procedures.

The congruent patterns between the "annual" and "perennial" interpretations are consistent with previous discussions in this chapter. For this particular survey season discussed in the study, climatic variability did not result in large differences between the two interpretation methods. However, both interpretations are necessary in order to establish whether differences are more pronounced at different levels of analyses, which may result in either an “over-“ or “under”-estimation of range condition related to certain relative condition groups (“Good” vs. “Poor”) pertaining to the different land uses. This is discussed in Section 4.3.5.

4.3.1.5 Cumulative k-dominance plot

A. “Annual” interpretation

Rank-abundance curves for species abundance data for each of the land uses are illustrated in Fig. 4.15. Dominance by certain species was most pronounced in the Reserve land use (*Schmidtia pappohoroides*) (Table 4.13, Appendix 4.2). Dominance was less pronounced in the Commercial- (*Schmidtia pappohoides*) (Table 4.11, Appendix 4.2) and Tribal (*Aristida stipitata*) land uses (Table 4.12, Appendix 4.2). Thus both the Reserve and Commercial land uses were dominated by *Schmidtia pappophoroides* although the average abundance was highest in the Reserve. The high dominance within especially the Reserve, followed by that within the Commercial land use, can be ascribed to these systems attaining a stable, less complex herbaceous composition primarily dominated by a climax grass species. The Tribal land use on the other hand is characterised by more species (species richness) representing a heterogeneous system not dominated by a single species (refer to Fig. 4.3).

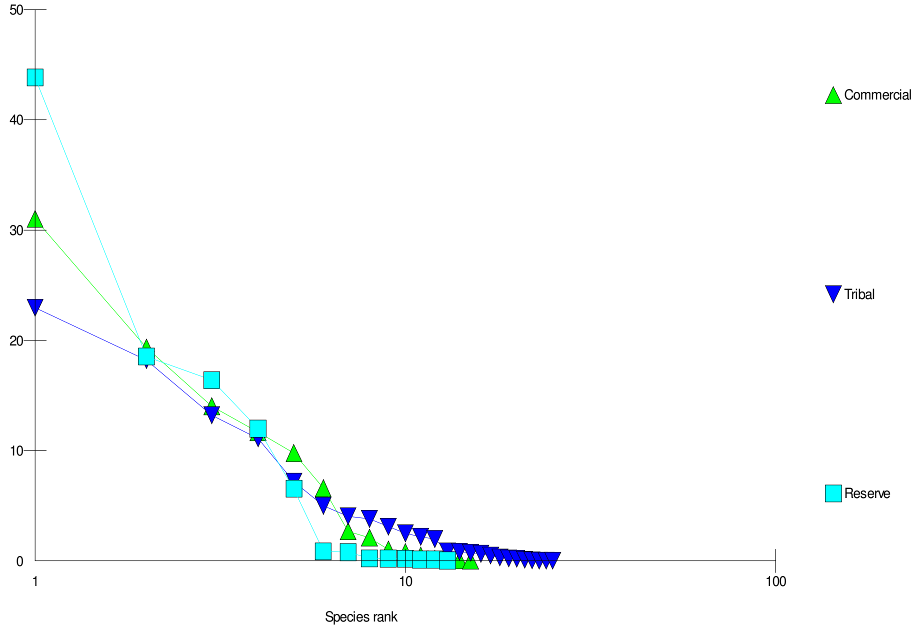


Fig. 4.15. Rank-abundance curves, displaying species-dominance for the three land uses for the “annual” herbaceous species interpretation.

Cumulative k-dominance plots for the three land uses, indicating cumulative relative abundance (y-axis) against species rank (x-axis) are presented in Fig. 4.16. It can be seen that the species rank of all three land uses reached a cumulative dominance of 100%, although the Reserve, followed by the Commercial and then Tribal land uses, reached it first.

Species accumulation curves reached their respective asymptotes for the Reserve and Commercial land uses, but possibly not completely for the Tribal land use (Fig. 4.16). This is often the case, even though sampling might be very intensive (Gotelli & Colwell 2001). The Tribal area reached (or nearly reached) it after the other two land uses, owing to the larger species richness and -diversity (Fig. 4.4 and Fig. 4.5).

The high dominance, indicated by the high abundances of certain species in the Reserve and Commercial land uses, is consistent with those patterns discussed for ants in Chapter 8, Section 8.2.5, which state that increasing habitat complexity may result in high diversity and reduced dominance (hence abundance) in ants (Room 1975; Majer 1985; MacKay *et al.* 1991; Perfecto & Snelling 1995), and thus *vice versa*. It is also stated that high dominance (and hence abundance) of ant species in highly productive systems results in a decline in diversity (Majer 1985; Andersen 1992). These patterns suggest, in support of the species richness results discussed in Section 4.3.1.2, that herbaceous composition and ant communities reflect congruent diversity (including richness) patterns. Both the herbaceous component and ant diversity measures reflect disturbance, i.e. habitat modification as a result of different land use management practices. Hence, land use is considered as primary structuring agent of herbaceous and ant species compositional patterns. For the herbaceous species component, this statement is discussed in the remainder of this chapter, as well as in Chapter 7, where it is integrated with other biotic and abiotic variables in support of this statement. Ant functional and compositional patterns are discussed in Chapter 8.

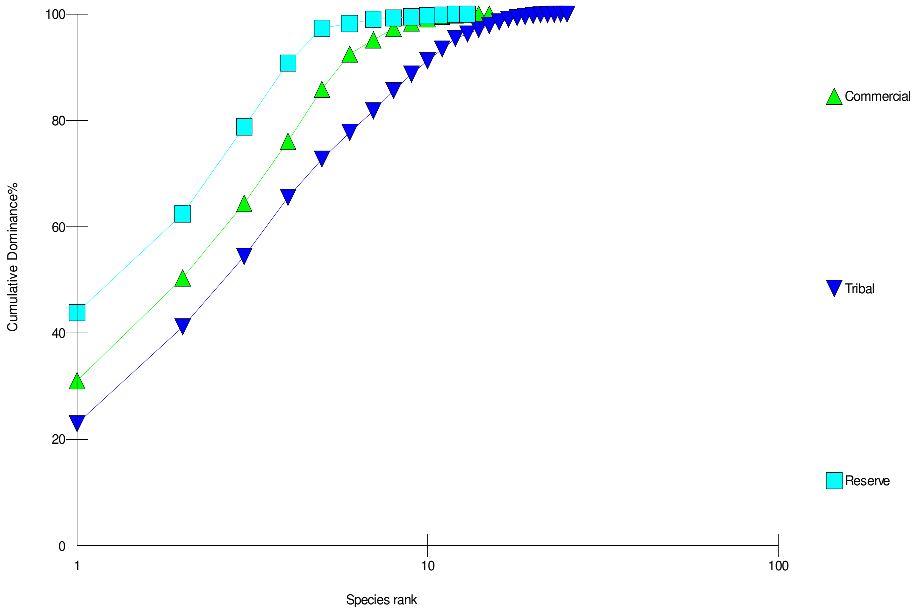


Fig. 4.16. Cumulative species-accumulation curves for the three land uses for the “annual” herbaceous interpretation method.

B. “Perennial” interpretation

The ranked species abundance plots (cumulative k-dominance plots) for the three land uses, indicating cumulative relative abundance (y-axis) against species rank (x-axis), were similar to the “annual” interpretation and are not presented again.

The similar patterns can be ascribed to the perennial and weak perennial species discussed in the SIMPER analyses, Section 4.3.1.4, being most abundant in all three land uses. Hence, the “removal” of the annual life-form in the nearest-point perennial plant survey only resulted in the average abundances of these dominant life-forms within each land use to increase.

4.3.1.6 ANOSIM and SIMPER for relative condition groups *within* each land use

One-way ANOSIM tests for differences between the relative “Good” and “Poor” variables *within* each land use were done. Hence, at a more in-depth level, this section seeks to establish whether a range condition gradient, based on the species compositional data, existed within the respective land uses, and whether these patterns are congruent among the different land uses. This holds important implications for rangeland monitoring and assessment models, for both the scientist and the land owner/manager. SIMPER analyses as explanatory procedures are presented as complement to the ANOSIM tests.

A. “Annual” interpretation

There were intermediate differences between the relative “Good” and “Poor” range condition variables for the Commercial (r = 0.463, P < 0.001) and the Reserve land uses (r = 0.564, P < 0.001). There was no significant difference between these two condition groups for the Tribal land use (r = 0.053, P > 0.1). These results further confirm results by the CCA ordination that a pronounced degradation gradient based on the species composition was visible within the Reserve and Commercial land uses, with the composition of these two land uses associated with both relative condition extremes, agreeing with each other. The length of the range condition gradient was most pronounced within the Commercial and the Reserve land uses, indicating that these land uses showed the largest differences between the relative condition groups. This corresponds with Fig. 4.10, as indicated by the CCA ordination. Based on species composition, the Tribal land use still did not show any rangeland condition gradient, implicating that the “state of health” for all sites were relatively similar, which were of relative low-intermediate rangeland condition ranges. This further supports the argument that the Tribal land use’s species composition showed a transitional shift towards another range and species composition state (Fig. 4.10).

Table 4.11. Average similarities and dissimilarities within and between the Commercial rangeland condition “Good” and “Poor” groups for the “annual” herbaceous interpretation.

Groups Poor & Good Average dissimilarity: 74.78

	Group Poor	Group Good				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
SCHM PAP	13.81	48.22	20.43	1.97	27.32	27.32
BP	33.13	5.55	15.29	1.28	20.44	47.76
ERA LEH	20.83	7.23	10.37	0.85	13.87	61.63
SCHM KAL	17.4	5.93	8.96	0.72	11.99	73.61
ANT PUB	0	13.23	6.61	0.81	8.84	82.45
STIP UNI	6.58	13	5.97	1.26	7.98	90.43

Group Poor Average similarity: 32.64

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
BP	33.13	17.74	1	54.35	54.35
ERA LEH	20.83	5.51	0.46	16.88	71.23
SCHM KAL	17.4	4.11	0.5	12.6	83.83
SCHM PAP	13.81	2.75	0.44	8.42	92.26

Group Good Average similarity: 53.71

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
SCHM PAP	48.22	36.44	2.09	67.86	67.86
STIP UNI	13	6.31	0.88	11.76	79.62
ANT PUB	13.23	4.17	0.53	7.76	87.38
ERA LEH	7.23	3.66	0.96	6.81	94.19

These significant differences were further explored by means of the explanatory SIMPER analyses for each land use. The Commercial "Good" variable had an average similarity of 53.71%, with *Schmidtia pappophoroides* being the most abundant species contributing to 67.86% of the similarity, followed by *Stipagrostis uniplumis* (although only third in terms of average abundance), *Anthephora pubescens* and *Eragrostis lehmanninana* contributing cumulatively to 94.19% of the similarity (Table 4.11). *Schmidita pappophorioides* was a very strong typical species for the Commercial-Good group (Sim/SD = 2.09). The "Poor" group had an overall similarity of 32.64%, being best typified by BP, which was also the most abundant group contributing to 54.35% of the similarities*. Eragostis lehmanniana* was the second most abundant and contributing group, followed by *Schmidtia kalahariensis* and then *Schmidtia pappophoroides* (Table 4.11). The cumulative percentage contribution towards the similarity of the Commercial "Poor" group was 92.26%. The average dissimilarity between these two groups was 74.78%, with *Schmidtia pappophoroides* contributing to 27.23% of the differences. BP was the second highest contributor to the differences (av. dissimilarity = 15.29%, contributing 20.44%), followed by *Eragrostis lehmanniana, Schmidtia kalahariensis, Antephora pubescens* and *Stipagrotis uniplumis*. These six species contributed to 90.43% of the cumulative differences (Table 4.11). *Schmidtia pappophoroides*, BP and *Stipagrostis uniplumis* were the most important discriminant species.

The Tribal relative "Good" group had an overall similarity of 44.59%. The most abundant species were *Aristida stipitata*, followed by *Schmidtia pappophoroides* and *Eragrostis lehmanniana*. These three species contributed to 73.35% of the similarity. Six species contributed to 92.12% of the similarities (Table 4.12*). Aristida stipitata* (Sim/SD = 2.65), *Schmidtia pappophoroides* and *Eragrostis lehmanniana* were consistently the three most typical species of this group. The average similarity for the "Poor" group was 36.26%, with *Aristida stipitata* being the most abundant and highest contributing species, followed by *Eragrostis lehmanniana* and *Schmidtia pappophoroides*, with these species contributing to 70.87% of the similarities. Although BP had the third highest abundance, it had the fourth highest contribution (9.73%). Six species explained 90.87% of the similarities. Emphasis should be placed on these results, since irrespective of the relative condition, species contributing to most of the differences, were similar and overlapping for the Tribal land use. These results are supported by the DCA and CCA discussed in the section above, suggesting that the Tribal land use statistically showed only one "state of health", based on herbaceous species composition. However, the Tribal-Poor group was consistently best typified by *Eragrostis lehmanniana* (Sim/SD = 1.11), followed by *Aristida congesta* (with a less important Sim/SD = 0.96) (Table 4.12). The average dissimilarity between the "Good" and "Poor" groups were 61.72%, with *Aristida stipitata*, followed by BP, *Eragrostis lehmanniana, Schmidtia pappophoroides, Eragrostis pallens, Stipagrostis uniplumis, Digitaria eriantha* and *Eragrostis tricophora* contributing to 79.53% of the differences (Table 4.12). The most consistent discriminant species were *Eragrostis lehmanniana* (Diss/SD = 1.28), *Aristida stipitata, Schmidtia pappophoroides* and *Aristida congesta*, with 90.32% of the differences being explained by 11 species.

Table 4.12. Average similarities and dissimilarities within and between the Tribal rangeland condition "Good" and "Poor" groups for the "annual" herbaceous interpretation.

Group Poor Average similarity: 36.26

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
ARI STI	23.85	11.08	0.83	30.56	30.56
ERA LEH	20.1	10.96	1.11	30.24	60.8
SCHM PAP	8.8	3.65	0.82	10.06	70.87
BP	15.43	3.53	0.42	9.73	80.6
ARIST CON	5.91	2.9	0.96	8	88.6
DIG ERI	3.75	0.82	0.58	2.27	90.87

Group Good Average similarity: 44.59

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
ARI STI	22.11	13.67	2.65	30.67	30.67
SCHM PAP	17.65	10.02	1.39	22.47	53.14
ERA LEH	16.35	9.02	1.23	20.22	73.35
ERA PAL	11.78	5.24	0.83	11.75	85.1
MEL REP	3.2	1.62	1	3.63	88.73
STIP UNI	7.46	1.51	0.38	3.39	92.12

Groups Poor & Good Average dissimilarity: 61.72

	Group Poor	Group Good				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
ARI STI	23.85	22.11	10.81	1.23	17.52	17.52
BP	15.43	6.82	8.78	0.75	14.22	31.74
ERA LEH	20.1	16.35	7.83	1.28	12.69	44.43
SCHM PAP	8.8	17.65	7.02	1.19	11.38	55.81
ERA PAL	2.64	11.78	5.45	0.96	8.83	64.64
STIP UNI	2.54	7.46	4	0.74	6.47	71.11
DIG ERI	3.75	3.87	2.68	0.83	4.34	75.45
ERA TRI	2.83	3.38	2.52	0.68	4.08	79.53
ARIST CON	5.91	2.22	2.5	1.16	4.05	83.57
CYN DAC	4.38	0	2.18	0.3	3.54	87.11
BRA MAR	3.97	0	1.98	0.48	3.21	90.32

The Reserve relative "Good" group had an overall similarity of 74.72%, and was best represented by *Schmidtia pappophoroides* and *Stipagrostis uniplumis*, with both of these species being typical species contributing to 92.24% of the group's similarity (Table 4.13). The average similarity of the "Poor" group was 46.27%, with BP being the most abundant and highest contributing group, followed by *Stipagrostis uniplumis, Schmidtia pappophoroides* and *Eragrostis lehmanniana*, which cumulatively contributed to 95.22% of the similarity. *Stipagrostis uniplumis* and *Schmidtia pappophoroides*, both also representative of the "Good" group, as well as BP, were the most typical species of this group. These four species contributed to 95.22% of the similarities (Table 4.13). The average dissimilarity between the "Good" and "Poor" groups was 61.54%, with *Schmidtia pappophoroides*, BP, *Eragrostis lehmanniana, Stipagrostis uniplumis* and *Schmidtia kalahariensis* contributing to 95.88% of the differences. *Schmidtia papphoroides* was the most important discriminant species (Diss/SD = 2.35), followed by *Stipagrostis uniplumis* (Diss/SD = 1.41) and BP (Diss/SD = 1.1) (Table 4.13).

The SIMPER results suggest that typical species indicative of the Commercial-Poor and –Good groups differed from each other. The Commercial-Good group was indicated by palatable grazing grasses, whereas the Commercial-Poor group was indicated by BP and species typical of overgrazing. The species contributing to the similarities of the Tribal-Good and –Poor groups were relatively similar, supporting arguments already discussed that this land use had statistically relatively similar "state of health/range conditions" throughout all the sites. However, typical species of each rangeland condition group differed, and can serve as explanatory indicators to potentially distinguish between the relative condition patterns within the Tribal land use. Similarities for the Reserve-Good group were explained by only two species, indicating the relative stability of these sites. Although species contributing to the similarities within each relative group differed, *Schmidtia pappophoroides* and *Stipagrostis uniplumis* occurred consistently throughout both range condition groups, being typical species of both groups. Hence, the discriminating species presented in Table 4.13 were informative indicators to distinguish between these two relative condition groups within the Reserve.

Table 4.13. Average similarities and dissimilarities within and between the Reserve rangeland condition "Good" and "Poor" groups for the "annual" herbaceous interpretation.

Group Poor Average similarity: 46.27

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
BP	33.18	16.96	1.09	36.66	36.66
STIP UNI	19.63	11.58	1.21	25.04	61.7
SCHM PAP	19.38	9.27	1.12	20.03	81.73
ERA LEH	17.7	6.24	0.63	13.49	95.22

Group Good Average similarity: 74.72

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
SCHM PAP	68.36	58.82	4.89	78.72	78.72
STIP UNI	13.18	10.1	2.88	13.52	92.24

Groups Poor & Good Average dissimilarity: 61.54

Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
SCHM PAP	19.38	68.36	25.06	2.35	40.72	40.72
BP	33.18	3.94	14.96	1.1	24.31	65.03
ERA LEH	17.7	6.29	8.18	0.94	13.29	78.32
STIP UNI	19.63	13.18	6.25	1.41	10.16	88.48
SCHM KAL	7.68	5.44	4.55	1	7.4	95.88

B. Perennial classification

One-way ANOSIM tests showed that there were intermediate to intermediate-high differences between the relative "Good" and "Poor" samples for the Commercial (r = 0.563, P < 0.001) and Reserve (r = 0.599, P < 0.001) land uses, but no significant differences for the Tribal land use (r = 0.045, P > 0.1). These results are consistent with that of the "annual" interpretation, although the statistics improved with the "perennial" interpretation. This implicates that differences between the relative "Good" and "Poor" extremes within the Commercial and Reserve land use are actually more pronounced than discussed in the "annual" interpretation.

Simper analyses were employed to investigate which species contributed to 90% or more of the differences between the relative "Good" and "Poor" condition groups within each land use.

Table 4.14. Average similarities and dissimilarities within and between the Commercial rangeland condition "Good" and "Poor" groups for the "perennial" herbaceous interpretation.

Group Poor Average similarity: 40.07

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
BP	46.28	27.63	1.25	68.95	68.95
ERA LEH	23.67	6.52	0.46	16.26	85.22
SCHM PAP	14.53	3.12	0.46	7.79	93.01

Group Good Average similarity: 55.38

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
SCHM PAP	53.62	38.67	2.04	69.83	69.83
STIP UNI	13.94	6.94	0.92	12.53	82.35
ANT PUB	13.46	4.3	0.54	7.76	90.11

Commercial Average dissimilarity: 74.87

	Group Poor	Group Good				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
SCHM PAP	14.53	53.62	22.52	1.79	30.08	30.08
BP	46.28	6.12	21.15	1.43	28.25	58.34
ERA LEH	23.67	7.58	11.58	0.85	15.47	73.81
STIP UNI	8.53	13.94	6.89	1.24	9.2	83.01
ANT PUB	0	13.46	6.73	0.81	8.99	91.99

The Commercial "Poor" variable had an overall similarity of 40.07%, and was represented by BP, *Eragrostis lehmanniana* and *Schmidtia pappophoroides*, with the cumulative contribution to the similarity being 93.01% (Table 14). BP was indicated as the most typical class for the Commercial "Poor" group (Sim/SD = 1.25), as opposed to Sim/SD = 0.46 of the other two species. The Commercial "Good" group had an overall similarity of 55.38%, and was best represented by the following species, in order of abundance and contribution: *Schmidtia pappophoroides*, *Stipagrostis uniplumis* and *Antephora* *pubscens*. These three species contributed to 90.11% of the “Good” group’s similarities (Table 4.14). *Schmidtia papphophoroides* was the most typical species (Sim/SD = 2.04) with Sim/SD = 0.9 for *Stipagrostis uniplumis* and Sim/SD = 0.54 for *Antephora pubescens*. The average dissimilarity between these two groups was 74.87%, with the following species contributing, in order of the highest to lowest average dissimilarity, contributing to 91.99% of the cumulative difference: *Schmidtia pappophoroides*, BP, *Eragrostis lehmanniana*, *Stipagrostis uniplumis* and *Antephora pubescens* (Table 4.14). The most important discriminating species were *Schmidtia papphophoroides* (Diss/SD = 1.79), BP (Diss/SD = 1.43) and *Stipagrostis uniplumis* (Diss/SD = 1.24%) (Table 4.14). An important observation is that *Schmidtia pappophoroides* was indicated as a species that occurs within both relative condition groups, but was typical of only the relative “Good” group, indicating its consistent distribution throughout the relative “Good” sites.

Table 4.15. Average similarities and dissimilarities within and between the Tribal rangeland condition “Good” and “Poor” groups for the “perennial” herbaceous interpretation.

Group Poor - Average similarity: 38.48

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
ERA LEH	22.87	11.80	1.08	30.68	30.68
ARI STI	23.87	11.11	0.83	28.86	59.54
BP	21.94	8.01	0.78	20.83	80.37
SCHM PAP	9.81	4.02	0.82	10.46	90.83

Group Good - Average similarity: 46.62

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
ARI STI	22.11	13.67	2.65	29.33	29.33
SCHM PAP	18.87	10.87	1.41	23.31	52.65
ERA LEH	17.95	9.89	1.19	21.21	73.85
ERA PAL	13.12	5.86	0.82	12.58	86.43
BP	8.68	2.70	1.05	5.79	92.22

Groups Poor & Good - Average dissimilarity: 59.40

..	Group Poor	Group Good				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
ARI STI	23.87	22.11	10.80	1.23	18.19	18.19
BP	21.94	8.68	10.40	0.82	17.50	35.69
ERA LEH	22.87	17.95	9.11	1.24	15.34	51.03
SCHM PAP	9.81	18.87	7.47	1.21	12.58	63.61
ERA PAL	3.01	13.12	6.05	1.02	10.19	73.80
STIP UNI	2.54	7.69	4.10	0.75	6.91	80.71
CYN DAC	6.05	0.00	3.02	0.30	5.09	85.79
ERA TRI	3.20	3.99	2.88	0.70	4.85	90.64

The Tribal "Poor" group had an average similarity of 38.48%, and 90.83% of the similarities was represented, in order of contribution, by *Eragrosits lehmanniana*, *Aristida stipitata*, BP and *Schmidtia pappophoroides* (Table 4.15). *Eragrostis lehmanniana* (Sim/SD = 1.08), followed by *Aristida stipitata* (Sim/SD = 0.83) were consistently the most typical species of this group. The Tribal "Good" group had an average similarity of 46.62%, and was characterised by the following species, in order of abundance as well as contribution: *Aristida stipitata*, *Schmidtia pappophoroides, Eragrostis lehmanniana*, *Eragrostis pallens* and BP (Table 4.15). *Aristida stipitata* (Sim/SD = 2.65), *Schmidtia pappophoroides* (Sim/SD = 1.41) and *Eragrosits lehmanniana* (Sim/SD = 1.19) were consistently most typical of the Tribal "Good" group. The average dissimilarity between these two groups was 59.4%, with *Aristida stipitata,* BP, *Eragrostis lehmanniana, Schmidtia pappophoroides, Eragrostis pallens, Stipagrostis uniplumis, Cynodon dactylon* and *Eragrostis tricophora*, in this order of average dissimilarity cumulative contributing to the 90.64% of the dissimilarity. *Aristida stipitata, Eragrostis lehmanniana, Schmidtia pappophoroides and Eragrostis pallens* were found to be the best discriminating species between these two relative condition groups. Species such as *Schmidtia pappophoroides* and *Eragrostis lehmanniana* that share both condition groups indicate that these condition groups have an overlapping or mid-rangeland condition, as can also be seen from the CCA (Fig. 4.12) presented in Section 4.3.1.3. However, the average abundances of the species for the different relative condition groups, can serve as directive to establish/discriminate of which group they are most representative (Table 4.15).

The average similarity of the Reserve "Poor" group was 49.76%, with 99.81% of the similarities being accounted for by BP, *Stipagrostis uniplumis*, *Schmidtia pappophoroides* and *Eragrostis lehmanniana* (Table 4.16). *Stipagrostis uniplumis* (Sim/SD = 1.24), followed by *Schmidtia pappophoroides* (Sim/SD = 1.18) and BP (Sim/SD = 1.05) were consistently most typical of this group. The relative "Good" group had an average similarity of 79.95%, with 94.12% of the similarities being accounted for by *Schmidtia pappophoroides* and *Stipagrosits uniplumis* (Table 4.16). *Schmidtia pappophoroides* was a very strong typical species (Sim/SD = 5.58), followed by *Stipagrostis uniplumis* (Sim/SD = 2.69). Results showed that the "Good" group appeared to have a more "stable" state in the sense that only two species contributed to most of the similarities. The Reserve relative condition groups had an average dissimilarity of 60.6%, with *Schmidtia pappophoides* having the largest average dissimilarity (26.28%) and contributing to 43.36% of the dissimilarities, with BP, *Eragrostis lehmanniana* and *Stipagrostis uniplumis* cumulatively explaining 96.21% of the dissimilarities. *Schmidtia pappohoroides* (Diss/SD = 2.52), followed by *Stipagrostis uniplumis* (Diss/SD = 1.48) and BP (Sim/Diss = 1.15) were, in that order, the most important discriminant species. As explained above, the average abundances of species shared across the relative condition groups within a land use, can serve as directive of which group they are more representative (Table 4.16).

Table 4.16. Average similarities and dissimilarities within and between the Reserve rangeland condition "Good" and "Poor" groups for the "perennial" herbaceous interpretation.

Group Poor - Average similarity: 49.76

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
BP	36.48	19.08	1.05	38.35	38.35
STI PUNI	21.25	13.06	1.24	26.25	64.60
SCHM PAP	20.48	10.37	1.18	20.84	85.44
ERA LEH	19.36	7.15	0.65	14.37	99.81

Group Good - Average similarity: 79.95

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
SCHM PAP	72.49	64.55	5.58	80.74	80.74
STI PUNI	14.26	10.70	2.69	13.38	94.12

Groups Poor & Good - Average dissimilarity: 60.60

	Group Poor	Group Good				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
SCHM PAP	20.48	72.49	26.28	2.52	43.36	43.36
BP	36.48	4.17	16.52	1.15	27.26	70.62
ERA LEH	19.36	6.77	8.83	0.95	14.56	85.18
STIP UNI	21.25	14.26	6.69	1.48	11.03	96.21

C. Remarks

The ANOSIM test for both the "annual" and "perennial" interpretation indicated the existence of a range condition gradient within the Commercial and Reserve land uses. Differences between the relative "Poor" and "Good" condition groups for both interpretation methods were most pronounced in the Reserve land use. However, the lengths of these rangeland condition gradients (i.e degradation gradients) were more pronounced with the "perennial" interpretation, indicating larger differences (based on the longer-term ecological status of the system) between the relative condition groups than the "annual" interpretation did. In none of the interpretation techniques, the Tribal land uses showed a rangeland condition gradient. Patterns for the two interpretations were similar, but the differences in average relative abundance of species associated with the longer-term rangeland condition versus the climatic induced species composition ("annual" interpretation), can serve as departure point not only within this study, but also for future studies including variable rainfall patterns over years.

4.3.1.7 Discussion of herbaceous species composition

The improvement of statistics done by a two-way crossed ANOSIM as opposed to the one-way ANOSIM for land uses and relative condition indicated that the combination of these variables contributed to patterns/gradients and differences identified within and between land uses, as was also indicated by the Monte Carlo permutation test for both interpretation methods.

Differences between the general “Good” and “Poor” groups were significant, with statistics varying from intermediate-low (“annual” interpretation) to intermediate (“perennial” interpretation) significance when averaged across all land uses.

Differences between the Commercial-Tribal and Reserve-Tribal land uses for both the “annual” and “perennial” interpretations were of intermediate to intermediate-high ranges and displayed similar patterns. An important observation was that the ANOSIM test across all land uses showed larger differences between the land uses for the “annual” than the “perennial” interpretation (Section 4.3.1.1) method. However, the rangeland condition gradient was more pronounced within the “perennial” interpretation method than for the “annual” interpretation for the general data set. The larger dissimilarities between the land uses for the “annual” interpretation method can be ascribed to the inclusion of the annual life-form, which was associated with the Reserve-/Commercial-Poor variables. The longer degradation gradient within the “perennial” survey method is ascribed to the inclusion of the nearest-perennial life-form when an annual life-form was pointed out. This resulted in larger differences between the relative “Good” and “Poor” groups, as is illustrated and discussed in Section 4.3.5.

Differences between the Reserve-Tribal land uses were more pronounced than between the Commercial-Tribal groups, indicating a larger degree of similarity between the Commercial-Tribal groups when averaged across the relative condition groups. There were no significant differences for both interpretations between the Commercial-Reserve groups, indicating a similarity in species compositional patterns averaged across all relative condition groups for these two land uses.

Within a land use, these rangeland condition gradients were more pronounced (higher significant r-statistics) within the Commercial and Reserve land use, but were insignificant within the Tribal land use. Although no significant differences between the Tribal relative condition groups were visible, species and sites were dispersed along the condition sites, ranging from relatively poor to intermediate-good rangeland condition ranges. The total Tribal land use was thus associated with the low-intermediate to relatively high ranges along the rangeland condition gradient, whereas the Reserve-/Commercial-Good groups were associated with the relative “Good” extreme and the Reserve-/Commercial-Poor groups with the relative “Poor” variable. This will be discussed in more detail in the rest of this section. These observations indicated a rangeland condition gradient stretching across the relative “Poor” to “Good” rangeland condition ranges for the entire study area. Such a rangeland condition gradient thus reflects a degradation gradient (Jordaan *et al.* 1997). However, studying and comparing the effects of herbivore grazing regimes in arid and semi-arid rangelands can be problematic, for the following reasons discussed below.

Unsustainable agricultural activities and wind erosion are considered among the principal mechanisms of land degradation in arid and semi-arid rangelands (Okin *et al.* 2001), with heavy grazing resulting in a dramatic decline of plant diversity, vegetation cover and primary production (Fensham & Holman 1998; Fensham & Skull 1999). It has been well documented that an increase in grazing pressure in the semi-arid savannas cause changes in soil nutrients, vegetation structure, composition and productivity (Moleele & Perkins 1998; Walker *et al.* 1989), resulting in vegetation and soil degradation in the Sahel (Lusigi & Glaser 1984; Warren & Khogali 1992). According to Dregne *et al.* (1991b), dry-land ecosystems are very fragile.

However, climatic events are described as important driving forces of vegetation change in semi-arid rangelands, due to the high spatio-temporal variability in precipitation with low predictability (Noy-Meir 1973, Ellis & Swift 1988). Such systems are called non-equilibrium systems, which lack the density-dependence (equilibrium systems) between vegetation and herbivore populations (Behnke & Scoones 1992). A new paradigm shift towards the non-equilibrium conception of dryland ecological dynamics acknowledges the inherent resilience and often reversible changes of these systems, often previously classified as degraded, following good rainfall after drought (Perkins & Thomas 1993a; Scoones 1995; Warren 1995). Hence, non-equilibrium systems are thought *not* to result in long-term degradation due to the impact of livestock densities (Behnke & Scoones 1992). The usefulness of the Clementsian successional model has been questioned by several authors (Westoby *et al.* 1989), especially with regard to utility of it in arid and semi-arid rangelands (Friedel 1991; Westoby *et al*. 1989). The plant succession theory (Clements 1916) states that rangelands are equilibrium systems driven by biotic effects along a series of successive stages until reaching a climax stage. A non-equilibrium system does not show vegetation succession patterns from pioneer to climax states, but rather shows a transition towards another vegetation state as the result of a triggering event.

Such changes in these systems are described by the state-and-transition model (Westoby et *al.* 1989). These changes to another vegetation state may either persist for a considerable time or can even be irreversible (Westoby *et al.* 1989). Hence, the state-and-transition model describes rangelands by means of catalogues of alternative states and transitions between states (Westoby *et al*. 1989). Continuous and reversible vegetation dynamics prevail within stable vegetation states, but are irreversible and discontinued when thresholds are surpassed and one stable state replaces another. Hence, this new paradigm shift results in an increasing criticism of the applicability of the carrying capacity concept (density-dependent), which is mostly based on the primary productivity within a rangeland (Smet & Ward 2005). This is supported by the findings of Kruger and Rethman (1999), who indicated that rainfall variability appeared to have greater impact on the productivity of Kalahari rangeland (eastern Namibia) and livestock, than stocking rate alone did.

The CCA ordinations for the species-environment data sets for both the “annual” and “perennial” interpretations for this study showed an improvement of the species-environment relations compared to the indirect DCA ordinations, indicating that the correct environmental variables explaining the largest proportion of the species-environment patterns have been selected. Both the first and all the canonical axes adequately represented the main pattern of compositional variation among the three land uses. The CCA ordinations for both interpretations showed that all the Tribal variables (Tribal-Good and Tribal-Poor) were closely correlated. The Tribal variables were all associated with the same quadrant, suggesting their relatively similar characteristics with regard to species composition. The Reserve and Commercial land uses were closely correlated, with the Reserve-Poor and Commercial-Poor interactions being closely associated with each other and the “Poor” variable within one quadrant, whereas the Reserve-Good and Commercial-Good variables were closely related with each other and the “Good” variable within another quadrant (though associated with the same axis). This indicates the presence of a rangeland condition gradient. For both the “annual “and “perennial” interpretations, the Monte Carlo test indicated that the Tribal land use, followed by the “Good/Poor” rangeland condition variables, Tribal-Poor/Tribal-Good interactions and the Reserve-/Commercial-Good variables significantly contributed towards explaining the species compositional patterns. This suggests that land use is a primary determinant of the species compositional structures within these semi-arid rangelands. This argument is continued in Chapter 7, where all vegetation properties (biotic) and abiotic variables are interrelated and analysed by means of ordinations and partial ordinations to ascertain that land use and not other environmental variables, is the primary determinant of the observed herbaceous compositional patterns.

For both the interpretations, species richness showed the strongest association with the Tribal variables, with the woody properties being interrelated with these variables, showing the second highest association with the Tribal land use (Fig. 4.9 and Fig. 4.11). The woody properties were most strongly associated with the Tribal-Poor variable. The rangeland condition indices’ scores, followed by the dry material yield variable were for both interpretation methods positively correlated with the “Good” and Reserve-/Commercial-Good variables (Fig. 4.9 and Fig. 4.11). These results are in contrast to the findings by Ward *et al.* (1998) that indicated that communal areas in Namibia did not differ in a number of vegetation and soil variables from commercial farms, reflecting on the resilience of arid environments in response to high stocking rates and the driving influence of abiotic factors on environmental quality. Results from this study suggest that species richness and diversity were positively correlated with Tribal land use, and also served as indicator of the heterogeneous complexity of this land use, but not as indicator of rangeland condition. The rangeland condition gradient reflected the significant distribution of Commercial and Reserve sites along a degradation gradient, with high rangeland condition scores being positively associated with the Reserve-/Commercial-Good sites, which were also associated with sites being dominated by a few climax species, notably *Schmidtia pappophoroides*. According to Zimmerman *et al.* (2001), sites with a good rangeland condition in the eastern Namibia were dominated by *Schmidtia pappophoroides*, whereas intermediate sites were dominated by *Stipagrostis uniplumis* and poorer sites by bare patches. These authors selected these as key species indicative of rangeland in different conditions. As discussed, the relative “Poor” rangeland condition scores were associated with the

Reserve-/Commercial-Poor groups (primarily bare patches), while the Tribal land use was associated with low to intermediate-high rangeland condition scores (comprised of primarily weak perennial species) along the total study area's rangeland condition gradient. However, the Tribal land use's species composition differed significantly from that of the other two land uses. This is reflected in terms of differences in range condition scores, presented in Section 4.3.5. Bai *et al.* (2001) found that although herbaceous species richness did not differ significantly between sites in Saskatchewan grasslands, species composition may differ between rangelands. Following this rationale the Tribal land use was primarily represented by herbaceous species indicative of low to intermediate rangeland condition ranges along the larger degradation gradient for the study area. However, these species were primarily weak perennial, less palatable species, characteristic of species establishing in response to continuously grazed rangelands, whereas the species representing the intermediate ranges of the Reserve and Commercial land uses, were perennial more palatable species. Hence, species compositions of the Reserve and Commercial land uses associated with low to intermediate rangeland positions along the rangeland condition gradient, differed from that of the Tribal land use associated with the same ranges.

This study indicated that the Tribal land use primarily, as well as the rangeland condition ("Good/Poor") significantly contributed towards explaining species compositional patterns, followed by the contributions of the other two land uses. Based on the results of both interpretations, it is suggested that the Molopo study area is not solely driven by abiotic factors (e.g. climate). Results of this study agree with those of Smet and Ward (2005) that found that management (land use) type had an important impact on the vegetation condition, with evident differences and patterns in degradation among the different management types. This study also concurs with arguments by Illius and O'Connor (1999) and Smet and Ward (2005), namely that these rangelands are not exclusively a true non-equilibrium system (climatic driven, independent of stocking density), implicating that density-dependent coupling of herbivores to key resources does occur and impact on the rangeland condition. Kruger (1998) and Legget *et al.* (2003a) reported that changes in seasonal rainfall appeared to have a significantly greater impact on basal cover and grass species than stocking rates for domestic stock appeared to have in Namibian rangelands. However, Du Plessis *et al.* (1998a, b) could not distinguish between climatic cycling and wildlife grazing intensity in the Etosha National Park, Namibia. Recent studies have indicated that most arid and semi-arid rangelands encompass elements of both the equilibrium and non-equilibrium systems at different scales (Vetter 2005). However, this dichotomy is a complex relation, and should take into consideration temporal variability and spatial heterogeneity (Vetter 2005). Rainfall and stocking rate interact, with low rainfall exacerbating the effects of high stocking rate, while high rainfall mitigates it (Vetter 2005). These observations have resulted in the development of the state-and-transition model (Westoby *et al.* 1989), though characterising rangeland at non-equilbrium, also being applied to succession-based rangeland models.

For this study, the proposed dichotomy between the non-equilibrium and equilibrium models are possibly best described by the state-and-transition model, resulting in a rangeland condition gradient and differences in species compositional patterns between the land uses. This suggestion is further motivated in the discussion below.

The absence of significant differences between the Commercial and Reserve land uses can be ascribed according to this dichotomy between the non-equilibrium and equilibrium (density-dependent) theory. The Reserve-/Commercial-Poor sites are areas, although not within the immediate vicinity of water resources, that historically were and still are being associated with density-dependent coupling, being characterised by a transitional shift in herbaceous species composition. For the farms and also the Reserve (previously commercial farms), these areas were either historically relatively continuously used by dairy cattle (commercial farmers 2004, pers. comm.) or by livestock kept relatively near to the farm houses/"kraals". Some of these sites were historically, or are currently situated relatively near water resources. The "annual" interpretation method (reflects species composition as result of climatic variability) and the "perennial" interpretation (longer-term ecological rangeland condition) methods both reflected a rangeland condition gradient, suggesting the existence of density-dependent coupling. Historical management patterns (density-dependent coupling between livestock density and key resources e.g. water provisioning), together with the effect of variable rainfall (non-equilibrium system), may mask small pastoralism impacts. It is thus not necessarily indicative of the absence of long-term degradation caused by herbivory (Ward *et al.* 1998). Irrespective if which interpretation method was employed, a rangeland condition gradient was evident for the larger study area, suggesting that density-dependent factors resulted in a degradation gradient that is also reflected by the longer-term ecological status of the herbaceous composition (as indicated by the "perennial" interpretation), and not completely "masked" by the climatic events ("annual" interpretation). However, the relatively intermediate (and not high) differences in rangeland condition between the relative "Good" and "Poor" sites within the Commercial and Reserve land use, reflect the resilience of these semi-arid rangelands, indicative of the non-equilibrium theory. Movement by wildlife into and out of the Hobatere Game Park (Hoanib River Catchment) in Namibia reduced the pressure on the vegetation resources close to the water sources during drought (and/or dry seasons), resulting in higher vegetation abundance at that point of time (Leggett *et. al.* 2003a), hence showing a density-dependence related to herbivory. Behnke and Scoones (1993) stated that management strategies pertaining to non-equilibrium systems should allow movement of herbivores to prevent stress induced by herbivory.

The existence of a more pronounced degradation gradient within the Commercial and to some extent the Reserve land use, can probably be ascribed to the long-term density-dependent coupling of the livestock (farms and historically the Reserve as well) and game (Reserve primarily) associated with these key resources (being ranching areas with a water provisioning system for several decades), especially during drought periods, as was also discussed in the paragraph above. These pressures on the key resources become more pronounced if the management type is an enterprise farming with cattle only, resulting in the selection of only one part of the vegetation instead of the occupation of different niches by a diverse herbivore composition (Ritchie & Olff 1999). High grazing pressure can exacerbate drought mortality of grasses and prevent the post-drought establishment of seedlings (O'Conner 1991b). Compositional changes of perennial grasses following drought may be higher under heavy grazing than under light or no grazing (O'Connor 1995b). Pronounced changes in vegetation abundance and species richness occurred near water resources for studies conducted in the Hoanib river catchment (Legget *et al.* 2003a). These areas, termed "sacrifice zones" (Perkins & Thomas 1993a, b), form a distinct vegetation zone primarily dominated by annual grass species and forbs (Leggett *et al.* 2003a, b).

Smet and Ward (2005) indicated that game ranching showed the least signs of rangeland degradation, owing to the higher diversity of game species all having their own feeding strategies adapted to the digestive system of the particular herbivore, resulting in a more efficient exploitation of the rangeland, and the minimisation of selective feeding (Owen-Smith 1999). Although high herbivore diversity in a game ranch described by Smet and Ward (2005) positively impacted on rangeland condition, for this study it was true for the Reserve relative "Good" extreme, but not for the Reserve-Poor extreme. This can possibly be attributed to several factors. The Reserve was proclaimed only in 1987 (Newbery 2006, pers. comm.), consisting of several commercial beef-ranching and cropping areas. Livestock are dependent on key resources, hence, showing a density-dependent coupling with the vegetation. Degraded areas within the Reserve may thus reflect historical impacts, as well as current grazing impacts linked to the key resources, showing density-dependant patterns. Although the "Poor" sites were not selected to indicate piosphere gradients as motivated in Chapter 3, the only true degraded areas in the Reserve were found to be in the proximity of water resources and were characterised by *Acacia mellifera* bush encroachment (see Chapter 5). Hence, this degradation within the Reserve and Commercial areas are possibly the result of long-term degradation events (density-dependent on these key resources), with small disturbances being masked by non-equilibrium climatic events, rendering this system resilient to such disturbances up to some point. This has resulted in significant differences in the species composition (hence ecological and palatability classes as well) most consistently typifying these relative condition extremes. It should also be emphasised that such typical and discriminating species between two groups, are not necessarily the most abundant species/classes.

The CCA ordination indicated that the entire Tribal land use significantly contributed towards explaining the species-environment relation. It was evident that the species composition of the Tribal management type significantly differed from that of the Commercial and Reserve land uses, even though the soil and climate for the total study area are being described as similar (Soil classification working group 1991; Low & Rebelo 1996; Chapter 2). It was further evident from the results that there were no significant differences between the Tribal relative "Good" and "Poor" extremes, suggesting that no rangeland condition gradient existed within this land use. Based on the non-equilibrium theory, it can be argued that climatic events might alleviate the continuous grazing impact of livestock linked to the key resources (e.g. livestock being kept in proximity of water resources and settlements), while also masking the long-term degradation caused by the pastoralism (Ward *et al.* 1998), indicative of the reversible and resilient nature of these degraded systems. Some of the Tribal study areas were only more recently equipped with permanent water provisioning (less than 10 years; Gasealahwe 2006, pers. comm.), hence resulting in a shorter historical period of density-dependent coupling of livestock to these water resources, masking the effect of a more pronounced rangeland condition gradient *within* this land use. This, together with the larger diversity of livestock (cattle, goats, donkeys, horses) exploiting the different Tribal resource niches, the impacts on the environment can be further alleviated. However, it can not be ignored that the *entire* Tribal land use as such, significantly differed from the other two land uses, as is supported by the differences in species composition typifying this land use. This was indicated by both interpretations for the herbaceous composition, ecological and grazing indices, as well as by the herbaceous life-form.

These results indicated that the Tribal land use's sites were dispersed along low to intermediate-high rangeland condition scores, with most species being less palatable/less desirable and being weak perennial life-forms. Impact of livestock on vegetation in the Molopo Tribal areas is also determined by the distribution of other key resources such as kraals and the proximity of settlements. Such management practices result in livestock being kept in and near kraals (or paddocks) very often near settlements, causing continuous grazing of the rangelands. Thus, often these major parts are being intensively grazed, resulting in a poor differentiation (and hence uniform structure) between relative "Good" and "Poor" sites within a Tribal area. Such observations, in addition to the congruent patterns among the two interpretation methods, suggest that the non-equilibrium model (climatic effects) is not the only model governing species compositional patterns in these rangelands. In addition, density-dependent impacts and management strategies (or the absence thereof), as related to limited Tribal key resources, have probably resulted in a total shift of Tribal land use's species composition to another compositional state. This transition is best described by the state-and-transitional model (Westoby *et al*. 1989), which encompasses both the equilibrium and non-equilibrium systems (Phelps & Bosch 2002) and includes rangeland condition models (Briske *et al*. 2005). This compositional state was associated with low to mid-high rangeland condition sites along the degradation gradient for the larger study area, hence also masking smaller internal gradients. Studies conducted by Leggett *et al*. (2003a, b) for communal areas around Otjokavare and Palmfontein, Namibia, indicated that grazing pressure is maintained throughout the year by domestic stock. Domestic stock is kept near villages for monitoring purposes during wet seasons, and during dry periods movement of livestock is limited by water availability. As a result the vegetation does not get the chance to recover, resulting in lower cover abundance (Leggett *et al.* 2003a). The total species compositional shift of the Tribal area for this study is concurrent with these authors' findings.

Rainfall events may further alleviate/mask any patterns. However, for this survey year, the "annual" interpretation (primarily climatic induced) in general did not differ significantly from the "perennial" interpretation, which reflects the general resilience and resistance of these ecosystems to disturbance. The results and arguments also suggest that favourable climatic conditions are unlikely to result in the Tribal species composition to "shift" back to its former state, showing more congruent patterns with the other two land uses. These species composition patterns need to be studied in conjunction with seed bank studies (Coetzee, *in prep. I*). Research by Fuls and Bosch (1991) indicated that for some southern African semi-arid rangelands, heavy grazing might result in a shift between vegetation states, or domains, hence supporting the state-and-transition model (Westoby *et al*. 1989). According to Fuls and Bosch

(1991), the impact of drought on ungrazed patches that were historically subjected to light grazing and had high perennial basal cover, resulted in non-significant vegetation changes. However, patches that were historically subjected to heavy grazing, and had a low perennial grass cover, showed a continual movement away from a perennial-dominated grass sward. It is suggested that the Tribal species compositional patterns are consistent with this theory by Fuls and Bosch (1991), showing a movement away to a weak perennial-dominant grass sward.

Results from this study are further supported by findings by Nsinamwa *et al.* (2005) for the hard and sandy rangelands of Botswana. They found that grazing pressure, together with soil nitrogen, were the major determinants of herbaceous species patterns. They also found that intense grazing (density-dependent impacts) resulted in the removal of most palatable species, mostly being perennial grasses, causing a reduction in ground cover and ultimately opening the way for fast establishing annual – and less palatable species. Leggett *et al.* (2003a) also found that in communal areas (Namibia), livestock were limited in their movements during the dry season, causing a concentration of the domestic stock around key resources, and hence resulting in vegetation to have lower cover abundance due to the lack of rest and recovery.

Climatic induced events (non-equilibrium events) may mask degradation effects, displaying the inherent resilience of these semi-arid rangelands, up to the point where density-dependent events such as a lack of rest and recovery may result in an irreversible shift towards another domain.

The purpose of this study was not to discuss species response curves within and between land uses, but rather to reflect on species being consistently typical of the relative condition groups within and between land uses to serve as indicators in an adaptive management tool.

The Commercial land use had, in general across all relative condition groups, no strong typical species (hence, species occurring consistently throughout all sites), although it was best indicated by *Schmidtia pappophoroides*, which was also the most abundant and highest contributing species (Tables 4.4 & 4.12). *Aristida stipitata* was most consistently indicative of the Tribal land use, and also had the highest average abundance and contribution towards the similarities. The Reserve-Poor group was consistently best typified by *Stipagrostis uniplumis*, although *Schmidtia pappophoroides* had for both interpretations the highest average abundance. *Schmidtia pappophoroides* and *Aristida stipitata* were then also the most important discriminating species, also contributing to the highest dissimilarities, between the Commercial-Tribal and Tribal-Reserve land uses (Table 4.8) for the "annual" interpretation. For the "perennial" interpretation, these species were also indicated as the most important discriminating species, although *Aristida stipitata* only had the third most contribution to the dissimilarities, and was preceded by bare patches (Table 4.10). This can be ascribed to the fact that a bare patch was indicated in the "perennial" interpretation method if no perennial species within a radius of 45 cm grew from the pointed annual species.

The “Good” rangeland condition group for both interpretations was consistently best typified by *Schmidtia pappophoroides*, which was also the most abundant and highest contributing species (Tables 4.7, 4.9). The “Poor” group for both interpretations was best typified by BP followed by *Eragrostis lehmanniana*, with both of these contributing most to the differences and being the most abundant species/group. *Schmidtia pappohoroides* and BP were the most important discriminating species/class, and also had the highest contribution to the dissimilarity. The average dissimilarities of these two discriminators were higher for the “perennial” interpretation, for the same reasons mentioned above. Bare soil is then also known to be a good indicator of poor rangeland health (De Soyza *et al.* 2000).

The two-way crossed ANOSIMS, as well as the CCA ordinations, indicated that relative conditions (“Good/Poor”) are important variables in explaining the species distributional patterns. It was also clear from the analyses that the relative “Good/Poor” rangeland condition groups for the different land uses did not occupy the same place on the degradation gradient for the larger study area. These findings necessitated further analyses to establish which species were typical of each relative condition group within each land use. The ANOSIM tests and explanatory SIMPER analyses (averaged either across all land uses or across all relative condition groups) to investigate similarities/dissimilarities between land uses and relative condition groups, were too robust and masked differences *within* land uses related to the degradation gradient (rangeland condition gradient) (Fig. 4.10 and Fig. 4.12). ANOSIM tests indicated intermediate to intermediate-high differences between the “Good” and “Poor” variables within the Commercial and Reserve land uses for both interpretations, being slightly more pronounced in the “perennial” interpretation, but no significant differences between the relative condition groups for the Tribal land use. This supports results from the CCA ordinations (Fig. 4.10 and Fig. 4.12). Hence, the Commercial and Reserve land uses were represented by a rangeland condition gradient with species ranging from the relative “Poor” end of the rangeland condition gradient to the relative “Good” (high) end of the gradient. However, species representing the Tribal-variables were dispersed along low to medium-high ranges of the rangeland condition gradient (Fig. 4.10 and Fig. 4.12), with no significant gradient within the land use.

An interesting observation was the presence of *Cynodon dactylon* only in Tribal site T1, which is continuously heavily grazed (“poor” site). *Cynodon dactylon* is a creeping grass species that is found in disturbed places and can endure heavy grazing (Van Oudtshoorn 2002). The benchmark exclosure near this sampling site was not grazed for the previous four years (erected in 1999), with the result that the species composition shifted towards a sward dominated by the weak perennial *Aristida stipitata* (following the state-and-transition model, Westoby *et al.* 1989). Studies have showed that long-term intensive grazing has resulted in persistent and resilient vegetation communities being dominated by grazing-resistant plant species (Vetter 2005). According to Friedel (1987), *Cynodon dactylon* was found to be the dominant grass in trampled areas in the Potchefstroom area (Agricultural Research Farm, Scientific Technical Support Services, South Africa). These dynamics for the Molopo study area reflect the resilient nature of these rangelands (non-equilibrium state), but also illustrate the density-dependent coupling effect of livestock to key resources, suggesting that the Molopo rangelands are best described by the state-and-transition model (Westoby *et al*. 1989), which includes both of the equilibrium and non-equilibrium concepts.

4.3.2 Grazing classification and -index

Species were classified according to four palatability classes (HD, DE, LD, UD), and in addition to it, into BP and forbs for both the "annual" and "perennial" interpretation methods (Appendix 4.4). Based on the palatability groups, differences within and between land uses were investigated, with reference to the rangeland condition. The appropriateness of using the grazing index as a measure to distinguish between the environmental variables for monitoring and management purposes is investigated in this section.

Patterns between land uses averaged across all relative condition groups, as well as between relative condition groups averaged across all land uses, were statistically tested. Based on these results, evaluations of the grazing index as a reliable indicator for rangeland management purposes were made for both interpretation methods.

4.3.2.1 ANOSIM between land uses - "Annual" interpretation and "Perennial" interpretation

A two-way crossed ANOSIM for the "annual" interpretation to test for differences between land use groups (averaged across all condition groups), was of intermediate significance between the Commercial-Tribal land uses ($r = 0.414$, $P < 0.001$) and between the Tribal-Reserve land uses ($r = 0.513$, $P < 0.001$). There was no significant difference between the Commercial-Reserve land uses ($r = -0.011$, $P > 0.1$). The test for differences between relative condition groups, averaged across all land-use groups, was significant and improved with the two-way crossed ANOSIM, although still low ($r = 0.355$, $P < 0.001$). For the grazing index classification, the same tendency as discussed in the previous sections for the species compositional data could be observed. The Reserve and Commercial groups were very similar in terms of the palatability of the herbaceous composition, but differed significantly from that of the Tribal land use (Fig. 4.17). The Commercial land use showed characteristics related more to the Tribal land use (lower r-statistics) than the Reserve did, although it was not significant.

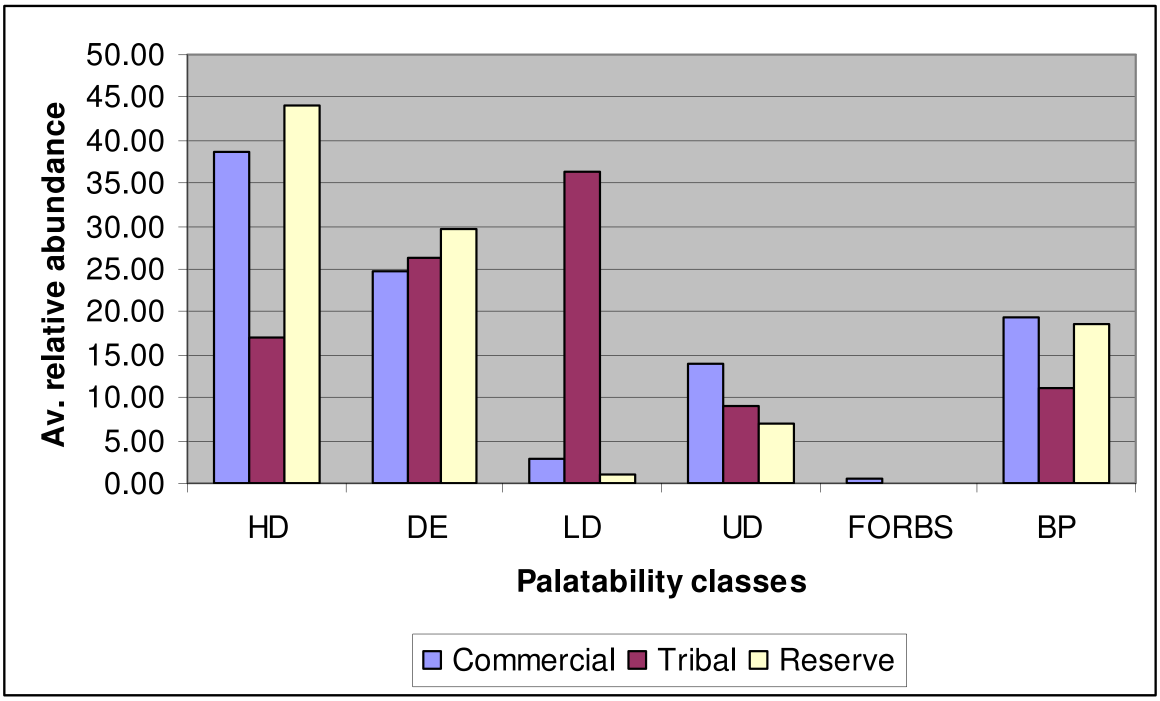


Fig. 4.17. Average relative abundances of the different palatability classes for each land use for the "annual" herbaceous interpretation.

The two-way crossed ANOSIM analysis for the "perennial" interpretation showed significant intermediate-low differences between condition groups (averaged across all land uses, r = 0.364, P < 0.001). When averaged across all condition groups, the Commercial-Tribal land uses differed significantly, though the statistics were relatively low (r = 0.339, P < 0.001), with an intermediate difference between the Tribal-Reserve land uses (r = 0.469, P < 0.001). There was no significant difference between the Commercial and Reserve land uses (r = 0.014, P > 0.1). These patterns are consistent with that of the "annual" interpretation, although the correlation coefficients (r-statistics) indicated smaller differences between the land uses than the "annual" interpretation did, while the statistics indicating differences between the relative condition groups were higher. This is consistent with the results discussed in Section 4.3.1, and hence the same arguments apply.

The significance of the ANOSIM tests suggested that ordinations employing the palatability groups should be conducted, for the following reasons. Firstly, to establish compositional patterns by means of a PCA based on the palatability groups by relating the observed patterns to the environmental variables. Then establish the direct species-environmental relations and the significance of the environmental variables explaining the cumulative variance. An improvement in the species-environment relations in the RDA as opposed to the PCA will indicate that the correct environmental variables explaining the largest proportion of the variance have been selected. The ordinations are also useful in illustrating patterns. Hence, it will be used as a procedure to make comparisons between the two interpretation methods.

4.3.2.2 PCA and RDA with environment and supplementary variables between land uses

A. “Annual” interpretation

The first two axes of the PCA ordination explained most of the species-environment correlations (r = 0.801 for first axis; r = 0.634 for second axis), with 69.4% of the cumulative species data and 92.2% of the species-environment relation for the environmental data being explained by the second axis (Table 4.17). The “Good” (r = 0.638, fourth quadrant) and “Poor (r = -0.638, second quadrant) variables best represented the first axis, followed by the Reserve-Good (r = 0.5371, first quadrant) and Commercial-Good (r = 0.463, first quadrant) interactions (Table 4.17, Fig. 4.18). The second axis was best explained by the Tribal (r = -0.6051, third quadrant) and Tribal-Good (r = -0.4536, third quadrant) interactions (Fig. 4.18).

For the passive data, 82.4% of the species-environment relation was explained by the first two axes (Table 4.17). The rangeland condition scores derived from the various indices (VCS…, r > 0.86) were strongly associated with the first axis. The species richness (ANNrich) (r = 0.6844) and diversity (ANNdiv) (r = -0.5349) were most strongly associated with the second axis and the Tribal variables (Table 4.17). The Commercial-Good and Reserve-Good variables were strongly correlated with the highly desirable (HD) class. Bare patches (BP) were associated with the Poor, Commercial-Poor and Reserve-Poor variables. The Undesirable class (UD) was associated with the first axis with the “Poor” variable, whereas the desirable (DE) and less desirable (LD) classes showed a strong affinity with the Tribal variables. The PCA ordination based on the palatability groups showed that the Reserve-/Commercial-Good clustered together and the Reserve-/Commercial-Poor variables clustered together (Fig. 4.18). These two clusters were negatively correlated, showing a gradient from “Poor” to “Good”. Thus, the Reserve-/Commercial-Poor variables showed the poorest composition (BP) of all three land uses at the relative “Poor” extreme end of the gradient, but also the most favourable palatability composition (HD) associated with the relative “Good” extreme of the range condition gradient. The Tribal variables showed low-intermediate palatability composition (favourability), comprised of the LD, and DE species. Hence, based on this classification, the palatability classes of the Tribal land use did not show a correlation with the range condition gradient, indicating a large similarity among all its sites in terms of palatability (Fig. 4.18).

Table 4.17. A PCA ordination for the "annual" grazing index, showing eigenvalues and species-environment relations for the first four axes, as well as the environmental and passive variables explaining most of the species-environment relation for the first two axes. Variables explaining most of the variance are indicated in **bold**.

Axes	**1**	**2**	**3**	**4**	
Eigenvalues	0.441	0.253	0.212	0.093	
Species-environment correlations	0.801	0.634	0.333	0.309	
Cumulative percentage variance					
of species data	44.1	69.4	90.6	99.9	
of species-environment relation (environmental)	67.9	92.2	97.9	100	
of species-environment relation (passive data)	59.1	82.4	94.6	100	
Environmental data	**SPEC AX1**	**SPEC AX2**	**Passive data**	**SPEC AX1**	**SPEC AX2**
Commercial	0.1165	0.2951	BE/HA	-0.4369	-0.1139
Tribal	-0.3446	**-0.6051**	Bushcov	-0.4339	-0.1757
Reserve	0.2282	0.31	Bush num/ha	-0.3846	-0.2458
Good	**0.638**	-0.1851	VCSAGRAZ	**0.884**	-0.2495
Poor	**-0.638**	0.1851	VCSPGRAZ	**0.8696**	-0.2451
Com*Good	0.463	0.1121	DM/HA	0.4139	-0.3163
Com*Poor	-0.3157	0.2611	VCSAECOL	**0.8966**	-0.2609
Tri*Good	-0.1442	**-0.4536**	VCSPECOL	**0.8804**	-0.2422
Tri*Poor	-0.2917	-0.3118	ANNrich	-0.1724	**-0.6844**
Res*Poor	-0.2485	0.299	ANNeve	-0.1855	-0.229
Res*Good	0.5371	0.0932	ANNdiv	-0.2329	**-0.5349**
			Bsh.div	-0.0885	-0.2704

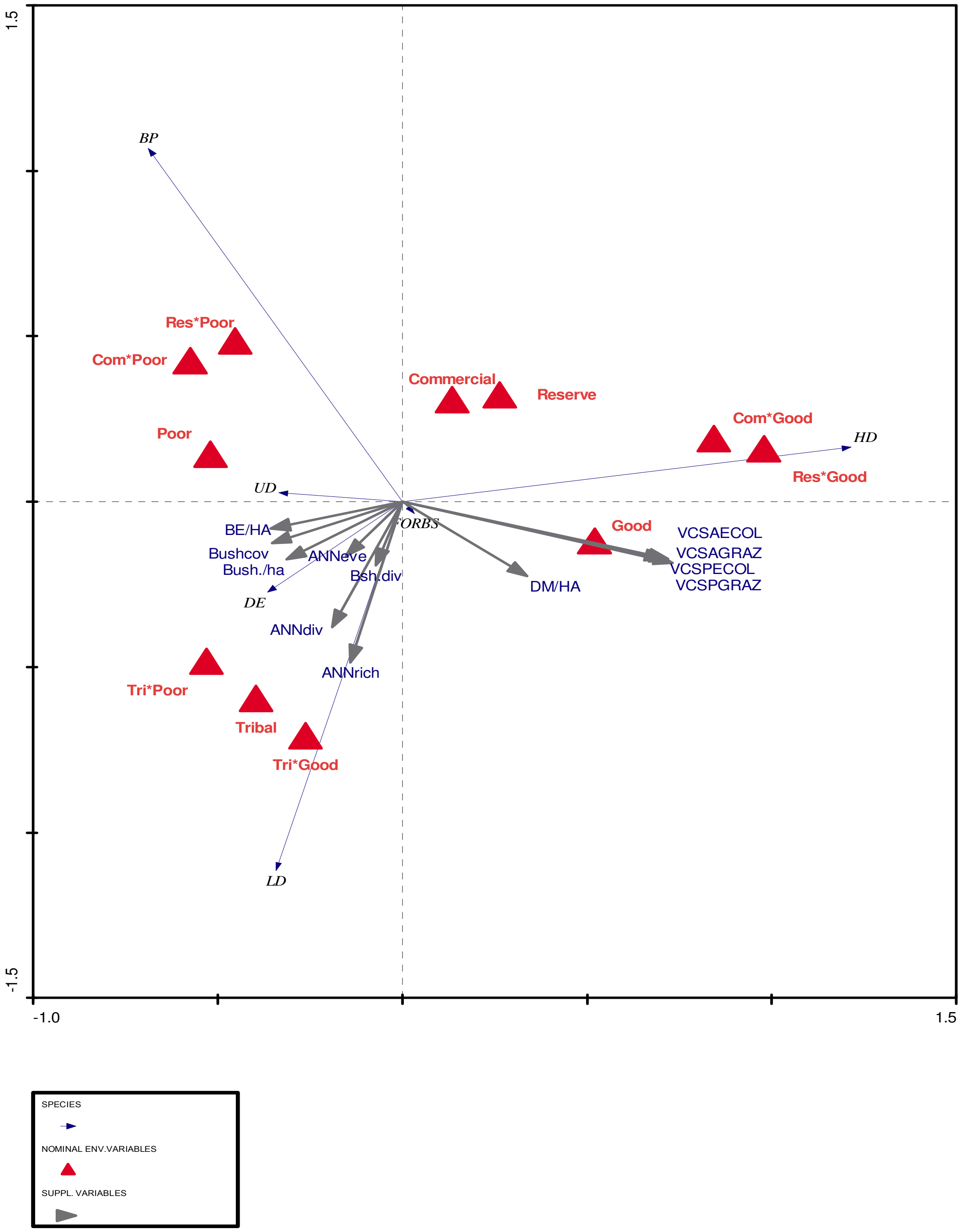


Fig. 4.18. A PCA ordination triplot displaying the species-environment relations for the environmental, passive and grazing index data for the “annual” grazing index.

A RDA ordination and Monte Carlo test showed significant species-environment correlations, with 97.2% of the species-environment relation and 40.6% of the species data being explained by the first two axes (Table 4.18). Patterns related to the first canonical axis (F = 26.98, P < 0.005) and all the canonical axes (F = 9.445, P < 0.005) were statistically significant. Hence, the improvement of the species-environment relation of the RDA ordination compared to the PCA ordination, indicates that the correct environmental variables explaining the largest proportion of the species-environment variance, have been selected. The first axis was best described by the “Good” (r = 0.604, first quadrant) and “Poor” (r = -0.604, third quadrant) variables, followed by the Reserve-Good variable (r = 0.5454, first quadrant) (Table 4.19, Fig. 4.19). The Tribal variable was most informative about the second axis (r = 0.5675, second quadrant), followed by the Tribal-Good variable (r = 0.4417, second quadrant). The distribution patterns of the species (palatability classes) in relation to the environmental variables varied in some respects from that of the PCA ordination. This can be ascribed to a PCA ordination being an indirect species-environment relation, and the composition of the grazing classes as a *function* of the environmental variables should be studied by the direct RDA ordination. Hence, the species (palatability classes) are constrained to be a function of the environmental variables. However, the species-environment correlations and relations for both techniques are informative and comparable in terms of the correct selection of the environmental variables explaining the largest proportion of the species-environment variance.

Table 4.18. The eigenvalues, species-environment correlation and cumulative variances explained for the species data and species-environment relation for the RDA ordination for the “annual” grazing index.

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.29	0.116	0.011	0
Species-environment correlations	0.817	0.679	0.285	0.038
Cumulative percentage variance				
of species data	29	40.6	41.7	41.7
of species-environment relation (environmental)	69.4	97.2	99.9	100
of species-environment relation (passive data)	57.8	82.8	91.6	98.7

The passive rangeland condition scores (r > 0.84, first quadrant) representing the grazing- and ecological indices (for the “annual” and “perennial” interpretation) were still associated with the “Good”, Reserve-Good and Commercial-Good environmental variables, as well as with the passive DM/ha-yield variable. The HD class was associated with these variables. The LD class was associated best with the various Tribal variables (second quadrant), and the DE, BP and UD classes with the “Poor”, Reserve-Poor and Commercial-Poor variables (third quadrant) (Fig. 4.19).

The HD palatability class represented rangeland in the best relative condition (“Good”), as opposed to BP primarily representing “Poor” rangeland condition. Species richness (r = 0.5954; second quadrant) was the variable showing the strongest affinity with the second axis (Table 4.19), and was correlated with the Tribal variables. Herbaceous diversity was also positively correlated with the Tribal variables (Fig. 4.19).

Table 4.19. Correlation coefficients (r-values) for the environmental and passive data associated with the first two canonical axes of the RDA ordination for the "annual" grazing index, as well as the environmental variables in order of importance, accounting for most of the species-environment variance as indicated by the Monte Carlo permutation test. Variables explaining most of the variance are indicated in **bold**.

Environmental data	SPEC AX1	SPEC AX2	Passive data	SPEC AX1	SPEC AX2
Commercial	0.1594	-0.2766	BE/HA	-0.4617	0.0834
Tribal	-0.4376	**0.5675**	Bushcov	-0.4716	0.1682
Reserve	0.2782	-0.2909	Bush num/ha	-0.4242	0.1975
Good	**0.604**	0.3499	VCSAGRAZ	**0.8581**	0.3626
Poor	**-0.604**	-0.3499	VCSPGRAZ	**0.8461**	0.344
Com*Good	0.4776	-0.0134	DM/HA	0.3664	0.4031
Com*Poor	-0.276	-0.3365	VCSAECOL	**0.8711**	0.3641
Tri*Good	-0.2127	0.4417	VCSPECOL	**0.8601**	0.3262
Tri*Poor	-0.3409	0.2761	ANNrich	-0.2624	**0.5954**
Res*Poor	-0.1935	-0.4091	ANNeve	-0.1975	0.0711
Res*Good	0.5454	0.0411	ANNdiv	-0.2916	0.379
			Bsh.div	-0.1239	0.2273

Monte Carlo permutation test

Variable	P	F
Good/Poor	0.002	16.35
Tribal	0.002	17.51
Tri*Good	0.002	5.78
Com*Poor	0.294	1.34

Environmental variables that statistically significantly explained most of the species-environment relation, in order of inclusion to the Monte-Carlo model, were the following variables: "Good/Poor" (F = 16.35; P < 0.005), Tribal (F = 17.51, P < 0.005), Tribal-Good/-Poor (F = 5.78, P < 0.005) and Commercial-Poor (F = 1.38, P > 0.1) (Table 4.19).

Hence, there was a significant degradation gradient represented by the "Good/Poor" environmental variables, as indicated by the passive range condition indices scores. The gradient is similar to that of the species composition's gradient, with the Reserve-/Commercial Poor variables indicating rangeland having the "poorest" relative condition, characterised primarily by BP, UD and to a lesser extent DE species (Fig. 4.19). Rangeland in the best condition, as predicted by the range condition score indices (red arrows), was related to the "Good" and Reserve-/Commercial-Good environmental variables and the HD grazing class. Rangeland in low to moderate condition was best represented by UD, DE and LD classes. This ordination not only identified which palatability classes were associated with each land use, but also which classes represented the different extremes of the rangeland condition gradient.

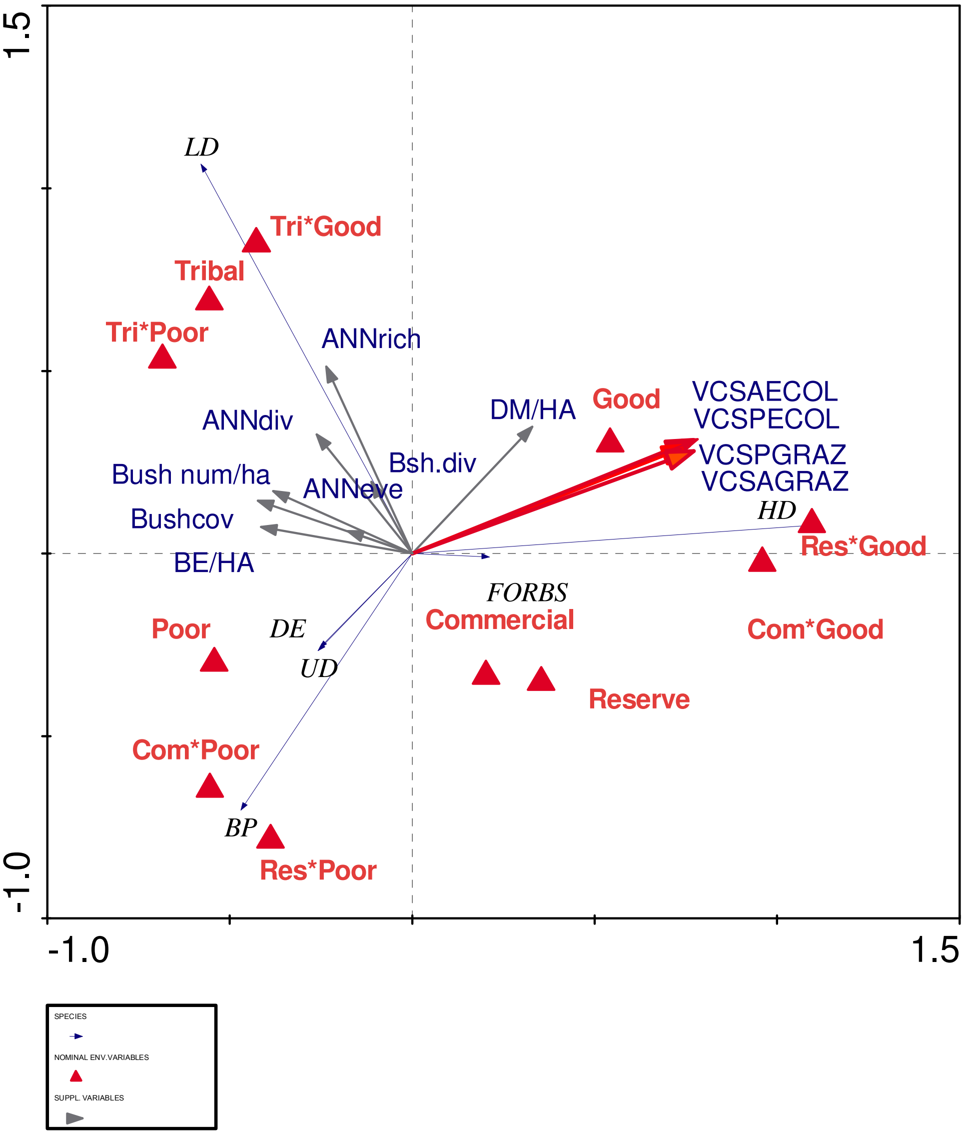


Fig. 4.19. RDA ordination triplot displaying the species-environment relations for the environmental, passive and grazing index data for the "annual" grazing index.

B. "Perennial" interpretation

The first axis of the PCA was best represented by the "Good" (r = 0.6405; fourth quadrant) and "Poor" (-0.6405; second quadrant) environmental variables, which agrees with the "annual" interpretation, whereas the second axis was best explained by the Tribal variable (r = -0.3233), although more weakly correlated with this axis and third quadrant (Table 4.20; Fig. 4.20). The larger part of the species-environment correlation was explained by the first axis (r = 0.758), with 77.7% of the species-environment relation and 76.8% of the cumulative species data being explained by the second axis (Table 4.20). These statistics explaining the species-environment variance, were lower than that of the "annual" interpretation.

Table 4.20. A PCA ordination for the “perennial” grazing index, showing eigenvalues and species-environment relations for the first four axes, as well as the environmental and passive variables explaining most of the species-environment relation for the first two axes. Variables explaining most of the variance are indicated in **bold**.

Environmental data	SPEC AX1	SPEC AX2	Passive data	SPEC AX1	SPEC AX2
Commercial	0.0201	0.2191	BE/HA	-0.3551	-0.055
Tribal	-0.2265	-0.3233	Bushcov	-0.3516	-0.0567
Reserve	0.2064	0.1043	Bush num/ha	-0.2961	-0.1564
Good	**0.6405**	-0.0345	VCSAGRAZ	**0.8844**	-0.2525
Poor	**-0.6405**	0.0345	VCSPGRAZ	**0.8931**	-0.28
Com*Good	0.3957	0.1065	DM/HA	0.4965	-0.1656
Com*Poor	-0.3702	0.1706	VCSAECOL	**0.9014**	-0.2848
Tri*Poor	-0.2289	-0.1284	VCSPECOL	**0.9074**	-0.3119
Tri*Good	-0.0576	-0.2806	PERrich	-0.0806	-0.4841
Res*Good	0.5212	0.1278	PEReve	-0.0903	**-0.5878**
Res*Poor	-0.2602	0.0041	PERdiv	-0.1129	**-0.5665**
			Bsh.div	0.0239	-0.2036
Axes	**1**	**2**	**3**	**4**	
Eigenvalues	0.492	0.276	0.228	0.003	
Species-environment correlations	0.758	0.356	0.631	0.359	
Cumulative percentage variance					
of species data	49.2	76.8	99.6	99.9	
of species-environment relation (environmental)	69.1	77.7	99.9	100	
of species-environment relation (passive data)	62.9	82.2	99.9	100	

The passive rangeland condition indices’ scores best explained the first axis (r > 0.88, fourth quadrant) and hence the “Good” environmental variable. The perennial species diversity (r = -0.5665), evenness (r = -0.5878) and richness (r = -0.4841) best explained the second axis and third quadrant (Table 4.20; Fig. 4.20), and were associated with the Tribal land use (Fig. 4.20). The first two axes explained 82.2% of the cumulative species-environment relation for the passive variables (Table 4.20).

The HD group was strongly associated with the Reserve-Good and Commercial-Good variables in the first quadrant (first axis) and with the range condition indices, the BP (strongly) and UD groups with the second quadrant and Reserve-Poor and Commercial-Poor variables. The LD and DE, as in the “annual” interpretation, showed an association with the Tribal variables. The DM/ha passive variable was correlated with the rangeland condition indices’ scores and the Reserve-/Commercial-Good groups (Fig. 4.20).

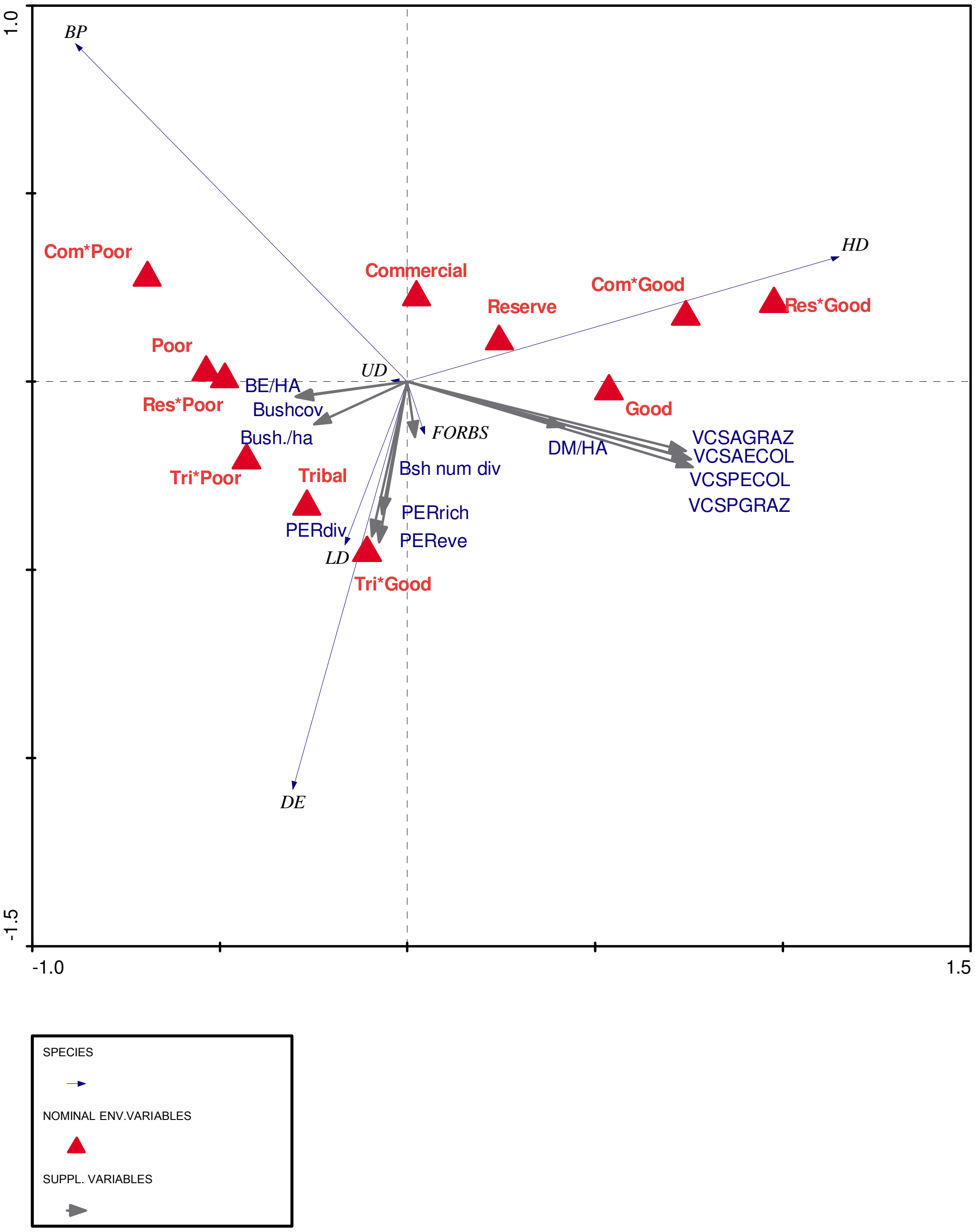


Fig. 4.20. A PCA ordination triplot displaying the species-environment relations for the environmental, passive and grazing index data for the “perennial” grazing index.

Direct RDA ordination revealed significant species-environment patterns for both the first (F = 27.221, P < 0.005) and all canonical axes (F = 9.129, P < 0.005). The first axis captured most of the species environment correlations (r = 0.78), with 98% of the species-environment being explained by the second axis for the environmental data, 40.1% of the cumulative species data and 82.8% of the species-environment relation for the passive data (Table 4.21). The environmental variables that most significantly explained the model, in order of inclusion, were the “Good/Poor” - (F = 17.92, P < 0.005), Tribal- (F = 14.79, $P < 0.005$), Tribal-Poor/-Good (F = 5.9, $P < 0.1$) and Commercial-Poor (F = 0.97, $P < 0.05$) variables. The species-environment relation is presented in Fig. 4.21.

Table 4.21. Correlation coefficients (r-values) for the environmental and passive data associated with the first two canonical axes of the RDA ordination for the “perennial’ grazing index, as well as the eigenvalues, species-environment correlation and cumulative variances explained for the species data and species-environment relation for the first four axes. Variables explaining most of the variance are indicated in **bold**.

Environmental data	**SPEC AX1**	**SPEC AX2**	**Passive data**	**SPEC AX1**	**SPEC AX2**
Commercial	0.0742	-0.31	BE/HA	-0.3872	0.1232
Tribal	-0.3328	**0.5904**	Bushcov	-0.3985	0.2225
Reserve	0.2586	-0.2804	Bush num/ha	-0.3404	0.1966
Good	**0.6189**	0.2809	VCSAGRAZ	**0.8625**	0.2913
Poor	**-0.6189**	-0.2809	VCSPGRAZ	**0.8705**	0.2926
Com*Good	0.4235	-0.0741	DM/HA	0.4512	0.3785
Com*Poor	-0.3297	-0.3181	VCSAECOL	**0.878**	0.2983
Tri*Poor	-0.2838	0.2884	VCSPECOL	**0.8865**	0.2779
Tri*Good	-0.1371	0.4584	PERrich	-0.125	0.1769
Res*Good	0.5439	-0.0074	PEReve	-0.18	**0.4556**
Res*Poor	-0.2168	-0.3472	PERdiv	-0.187	0.3511
Axes	**1**	**2**	**3**	**4**	
Eigenvalues	0.292	0.109	0.008	0	
Species-environment correlations	0.78	0.659	0.173	0.237	
Cumulative percentage variance					
of species data	29.2	40.1	40.9	40.9	
of species-environment relation (environmental)	71.4	98	100	100	
of species-environment relation (passive data)	60.5	82.8	99.8	99.9	

The HD was associated with the Reserve-/Commercial-Good variable within the fourth quadrant. The UD and especially the LD groups were strongly associated with the Tribal land use, and were associated with intermediate rangeland condition ranges (Fig. 4.21). The UD thus showed a stronger association with the Tribal land use than indicated in the PCA. This can be ascribed to the direct species-environment correlation within the RDA analysis as opposed to the indirect species-environment relation examined in Fig. 4.20 in the PCA analysis. Both the BP and the DE classes were associated with the Reserve-/Commercial-Poor groups, with the DE class showing an intermediate positioning along the rangeland condition gradient for the larger study area (Fig. 4.21). The DE class was thus not associated only with the Tribal land use. Although it was indicated to have higher abundances in the Reserve-/Commercial-Poor groups, its intermediate positioning along the rangeland condition gradient suggests that it is representative of all three land uses, as was also indicated in Fig. 4.17.

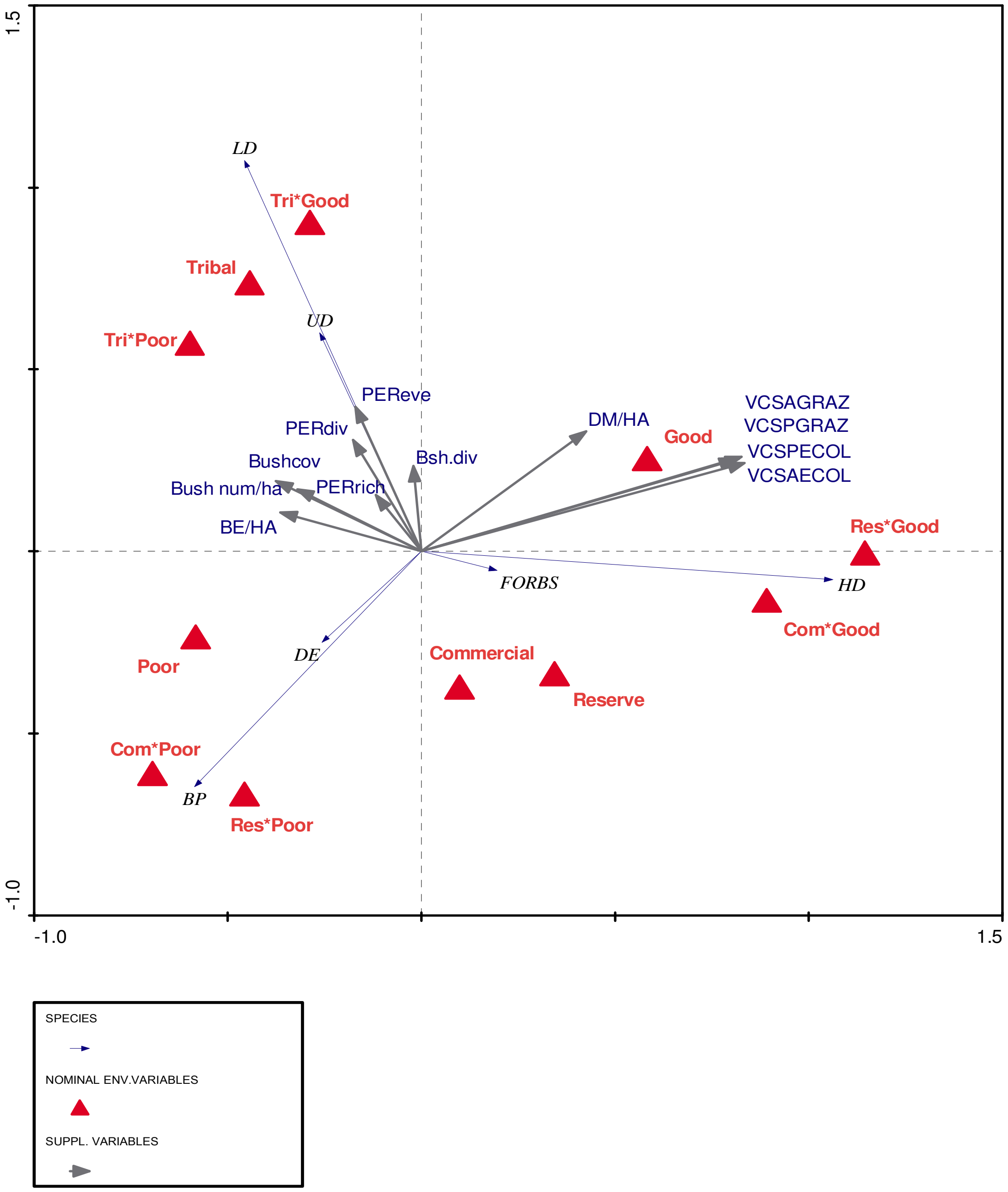


Fig. 4.21. A RDA ordination triplot displaying the species-environment relations for the environmental, passive and grazing index data for the "perennial" grazing index.

C. Remarks

The direct RDA ordination for the linear data for both interpretations improved from the statistics of the indirect PCA ordinations, indicating that the correct environmental patterns explaining the largest proportion of the species-environment correlation have been included in the ordination. Both interpretation methods significantly explained most of the species environment-relation, which is encouraging since this suggests that the grazing index classification is an useful measure of explaining the observed species-environment patterns. The comparatively small differences between the two interpretation methods, further support previous arguments that for this particular year, the climatic-induced species compositional pattern (“annual” interpretation) reflected that of the longer-term ecological compositional patterns (“perennial” interpretation), indicating a dichotomy between non-equilibrium and equilibrium events.

4.3.2.3 SIMPER analyses between land uses averaged across all relative condition groups and between relative condition groups averaged across all land uses

Since the ANOSIM results (Section 4.3.2.1) and RDA ordination species-environment relations (Section 4.3.2.2) were found to be significant, SIMPER analyses were done as explanatory complement to these results.

A. “Annual” interpretation

SIMPER analyses showed that the average similarities, based on the “annual” species composition interpretation, for the Commercial group were 42.39%, 54.32% for the Tribal group and 52.99% for the Reserve (Table 4.22). The average dissimilarities between the Commercial-Tribal uses were 63.9%, 51.69% between the Commercial-Reserve groups and 61% between the Tribal-Reserve land uses (Table 4.23).

Table 4.22. SIMPER analyses for the “annual” grazing index, displaying grazing classes that contributed to the average similarities within each land.

Group Commercial- Average similarity: 42.39

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
HD	38.74	19.27	0.79	45.46	45.46
DE	24.67	11.41	0.80	26.91	72.38
BP	19.34	6.55	0.53	15.46	87.84
UD	14.03	4.91	0.73	11.59	99.43

Group Tribal- Average similarity: 54.32

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
LD	36.38	22.45	1.31	41.34	41.34
DE	26.39	15.82	1.34	29.12	70.46
HD	17.07	9.14	1.07	16.83	87.29
UD	9.08	4.58	0.98	8.43	95.72

Group Reserve - Average similarity: 52.99

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
HD	44.11	26.20	1.11	49.45	49.45
DE	29.52	18.33	1.58	34.59	84.04
BP	18.56	6.28	0.62	11.86	95.90

The order of contribution by the palatability classes to the similarities of the Commercial land use corresponded with their average abundances, with the HD class being the most abundant, followed by the DE, BP and UD classes (Fig. 4.17). The DE (Sim/SD = 0.8) and HD (Sim/SD = 0.79) were consistently the most, although not that strong, typical classes (Sim/SD < 1.0). Hence, these classes did not occur that consistently throughout the Commercial land use when averaged across all relative condition groups. This indicates, as supported by the ANOSIM and RDA ordination results (Sections 4.3.2.1 and 4.3.2.), that SIMPER analysis between the relative condition groups *within* this land use will be more informative as to establish whether there are stronger typical classes related to the relative "Good" vs. "Poor" groups (see Section 4.3.2.5).

The Tribal group was best represented, in the following order of abundance and contribution, by the LD class, followed by the DE, HD and UD classes. These palatability groups explained 95.72% of the similarity, with the LD (Sim/SD = 1.31) and DE classes (Sim/SD = 1.34) consistently being the most typical classes (Table 4.22, Fig. 4.17).

The Reserve land use was best represented by the HD class, followed by the DE, and BP classes. These classes accounted for 95.5% of the similarity, with the DE (Sim/SD = 1.58) and HD (Sim/SD = 1.11) consistently being the most typical classes (Table 4.22, Fig. 4.17).

The Commercial-Tribal land uses had an average dissimilarity of 63.9%, with the LD and HD classes contributing to 53.34% of the cumulative dissimilarities. The DE and BP classes contributed to 89.02% of the cumulative dissimilarities, and the UD class to 99.63% of the cumulative dissimilarities (Table 4.23). The LD- (Diss/SD = 1.51), HD- (Dis/SD = 1.33) and DE- (Diss/SD = 1.3) classes were consistently the best discriminant classes between these two land uses, with the HD being most abundant in the Commercial land use and the LD within the Tribal land use (Table 4.23).

The Commercial and Reserve land uses had and overall dissimilarity of 51.69%, with the HD class and DE contributing to 59.1% of the dissimilarities, followed by BP and the UD class cumulatively accounting for 96.33% of the dissimilarities (Table 4.23). The HD class (Diss/SD = 1.41), followed by the DE class (Diss/SD = 1.29) were the strongest discriminant classes between these two land uses (Table 4.23). These two classes were also typical of each of these land uses, indicating that these land uses are closely correlated, as was indicated in the PCA and RDA discussed above. The average abundance of these typical classes was higher in the Reserve, and serves as distinction between these two land uses.

The LD followed by the HD contributed to 57.26% of the dissimilarity between the Tribal-Reserve land uses. These two classes followed by the BP and UD classes accounted for 92.18% of the dissimilarities (Table 4.23). The LD (Diss/SD = 1.52), followed by HD- (Diss/SD = 1.37) and DE (Diss/SD = 1.25) were consistently the best discriminant species between the Tribal-Reserve groups. The LD class was typical of the Tribal land use and the HD class of the Reserve land use (Table 4.23).

Table 4.23. SIMPER analyses for the "annual" grazing index, displaying grazing classes that contributed to the average dissimilarities between land uses.

Groups Commercial & Tribal Average dissimilarity: 63.90

	Group Commercial	Group Tribal				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
LD	2.77	36.38	17.4	1.51	27.24	27.24
HD	38.74	17.07	16.68	1.33	26.1	53.34
DE	24.67	26.39	11.78	1.3	18.43	71.77
BP	19.34	11.16	11.03	0.94	17.26	89.02
UD	14.03	9.08	6.78	0.76	10.61	99.63

Groups Commercial & Reserve Average dissimilarity: 51.69

	Group Commercial	Group Reserve				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
HD	38.74	44.11	18.27	1.41	35.33	35.33
DE	24.67	29.52	12.28	1.29	23.76	59.1
BP	19.34	18.56	12.11	1.01	23.42	82.52
UD	14.03	6.84	7.14	0.76	13.81	96.33

Groups Tribal & Reserve Average dissimilarity: 61.00

	Group Tribal	Group Reserve				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
LD	36.38	1.02	17.7	1.52	29.02	29.02
HD	17.07	44.11	17.22	1.37	28.24	57.26
BP	11.16	18.56	10.68	0.87	17.51	74.76
DE	26.39	29.52	10.62	1.25	17.41	92.18

Groups Poor & Good Average dissimilarity: 61.84

	Group Poor	Group Good				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
HD	15.24	51.37	20.59	1.58	33.29	33.29
BP	27.27	5.44	12.91	1.02	20.88	54.17
DE	30.76	22.96	11.76	1.28	19.1	73.19
LD	13.27	13.51	10.06	0.87	16.26	89.45
UD	13.52	6.45	6.37	0.79	10.29	99.75

The "Poor" group (averaged across all land uses) had an average similarity of 43.31%, and was best characterised by, in this order, the DE class, followed by the BP, HD and UD classes, which cumulatively accounted for 93.35% of the similarities (Table 4.24). The DE (Sim/SD = 1.03) class was the most typical class occurring consistently throughout the sites, followed by the BP. However, these results suggest that analyses within land uses should be done to establish which relative condition group each palatability class is more typical of, instead of averaging it across all land uses.

Table 4.24. SIMPER analyses for the "annual" grazing index, displaying grazing classes that contributed to the average similarities within and dissimilarities between the "Good" and "Poor" rangeland condition groups.

Group Poor - Average similarity: 43.31

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
DE	30.76	16.79	1.03	38.76	38.76
BP	27.27	12.32	0.76	28.44	67.20
HD	15.24	5.97	0.73	13.79	80.98
UD	13.52	5.36	0.75	12.37	93.35

Group Good - Average similarity: 56.60

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
HD	51.37	35.44	1.58	62.62	62.62
DE	22.96	14.06	1.37	24.84	87.46
LD	13.51	3.39	0.37	5.99	93.44

Groups Poor & Good - Average dissimilarity: 61.84

	Group Poor	Group Good				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
HD	15.24	51.37	20.59	1.58	33.29	33.29
BP	27.27	5.44	12.91	1.02	20.88	54.17
DE	30.76	22.96	11.76	1.28	19.01	73.19
LD	13.27	13.51	10.06	0.87	16.26	89.45
UD	13.52	6.45	6.37	0.79	10.29	99.75

The "Good" group (averaged across all land uses) had an average similarity of 56.6%, with the HD, DE and LD (av. abund = 13.51%) classes accounting for 93.44% of the similarities. The HD class (Sim/SD = 1.58), followed by the DE class (Sim/SD = 1.37), were the most typical classes of this group (Table 4.24).

The relative "Good" and "Poor" groups had and average dissimilarity of 61.84%, with the HD class, followed by the BP, DE and LD classes accounting for 89.45% of the dissimilarity, and in addition the UD class contributing to 99.75% of the cumulative dissimilarities (Table 4.24). The HD class (Diss/SD = 1.58), followed by the DE class (Diss/SD = 1.28) and BP (Diss/SD = 1.02) were the strongest discriminant classes. The HD class was typical of the "Good" condition, the BP of the "Poor" condition with the DE class belonging to both condition groups, with the DE being slightly more abundant in the "Poor" groups, suggesting that it is indicative of intermediate relative rangeland conditions (Table 4.24). However, the results presented for the relative "Good" and "Poor" groups were averaged across all land uses, and it is suggested that SIMPER analyses exploring similarity and dissimilarity patterns with regard to the rangeland condition, will be more informative.

The results of the SIMPER analyses were congruent with that of the RDA ordination, indicating the existence of a range condition gradient across the entire study area, with the Reserve and Commercial land uses being represented by different palatability classes associated with the relative "Good" and

"Poor" extremes along a rangeland condition gradient. The Tribal land use was represented by classes of intermediate palatability (LD). Thus the direct RDA ordination as well as the SIMPER analyses both indicated the same palatability classes representative of each land use and palatability classes representative of the two rangeland condition gradient' extremes (relative "Good" vs. "Poor"), and were complementary to each other. The RDA ordination and Monte Carlo test were useful in that the significance of the environmental explaining the species-environment variance, was given (it was significant, see Section 4.3.2.2 above), as well as the cumulative species-environment variance being explained, which was very high. The ordination is also a visual indication of the species-environment relations. In addition, the SIMPER analyses were informative as explanatory procedure by presenting the average abundances and contributions to the similarities within groups and dissimilarities between groups. The quantification of these similarities/dissimilarities is particularly useful in the application of current and future rangeland monitoring and assessment techniques.

B. "Perennial" interpretation

Average relative abundances for the palatability classes for each land use is illustrated in Fig. 4.22.

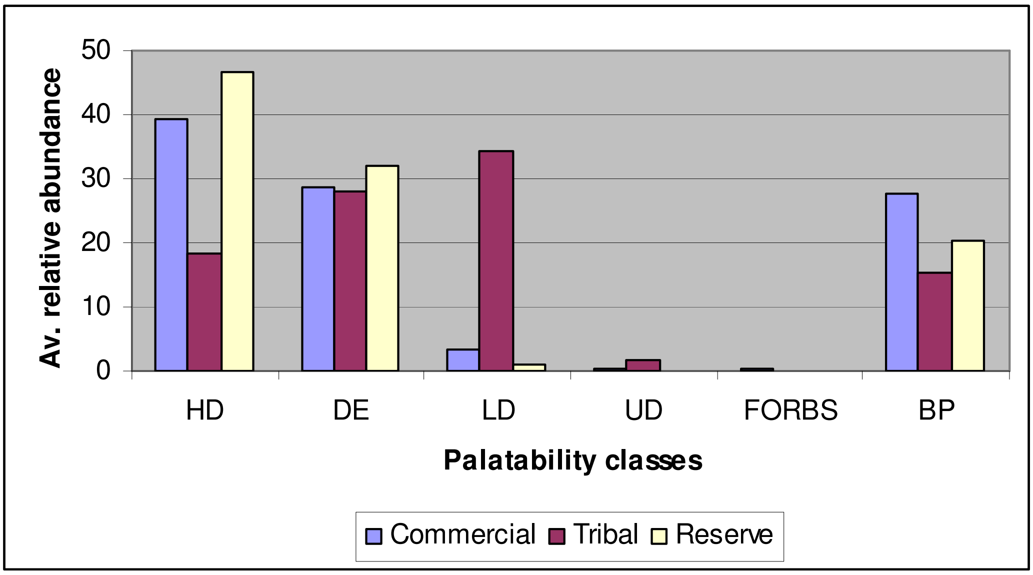


Fig. 4.22. Average relative abundances for the palatability classes within each land use for the "perennial" grazing index.

SIMPER analysis for the "perennial" interpretation showed that the Commercial group had an average similarity of 42.55%, with the HD class, followed by the DE and BP classes contributing to 99.38% of the similarity. There were no strong typical species (Sim/SD < 1.0), with the DE class being slightly more consistent (Sim/SD = 0.79) followed by the HD (Sim/SD = 0.71) and BP (Sim/SD = 0.6) classes (Table 4.25). This is very similar to the "annual" interpretation's results.

Table 4.25. SIMPER analyses for the "perennial" grazing index, displaying grazing classes that contributed to the average similarities within each land.

Group Commercial - Average similarity: 42.55

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
HD	39.46	18.30	0.71	43.00	43.00
DE	28.67	13.37	0.79	31.43	74.43
BP	27.74	10.62	0.60	24.96	99.38

Group Tribal - Average similarity: 51.31

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
LD	34.30	19.99	1.11	38.96	38.96
DE	28.03	15.51	1.04	30.23	69.20
HD	18.47	10.11	1.10	19.71	88.90
BP	15.31	5.36	0.65	10.45	99.35

Group Reserve - Average similarity: 55.67

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
HD	46.73	28.62	1.12	51.42	51.42
DE	32.09	20.06	1.56	36.03	87.44
BP	20.33	6.92	0.59	12.43	99.88

The Tribal group had an overall similarity of 51.31%, with the LD, followed by the DE-, HD- and BP classes accounting for 99.35% of the similarity. The LD group (Sim/SD = 1.11) was the most typical class (Table 4.25). The overall average similarity is lower than that of the "annual" classification, due to the exclusion of the annual life-form, but the patterns were similar for the "perennial" interpretation.

The Reserve had an average similarity of 55.67%, with the HD class, followed by the DE and BP accounting for 99.88% of the similarity (Table 4.25). The DE class (Sim/SD = 1.56) was the most typical class, followed by the HD class (Sim/SD = 1.12). The average similarity of this group was higher than for the "annual" interpretation, owing to the inclusion of the nearest perennial species when an annual life-form was pointed out.

The average dissimilarity between the Commercial-Tribal land uses was 63.91%, with the HD, followed by the LD, BP and DE classes contributing to 98.32% of the dissimilarity (Table 4.26). The LD class (Diss/SD = 1.35) was consistently the most important discriminating class, followed by the DE and the HD classes. This is consistent with the patterns displayed in the "annual" interpretation.

Table 4.26. SIMPER analyses for the "perennial" grazing index, displaying grazing classes that contributed to the average dissimilarities between land uses.

Groups Commercial & Tribal- Average dissimilarity: 63.91

	Group Commercial	Group Tribal				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
HD	39.46	18.47	17.74	1.27	27.75	27.75
LD	3.45	34.30	16.68	1.36	26.09	53.84
BP	27.74	15.31	14.61	1.05	22.85	76.70
DE	28.67	28.03	13.82	1.32	21.63	98.32

Groups Commercial & Reserve - Average dissimilarity: 50.79

	Group Commercial	Group Reserve				
Species	*Av.Abund*	*Av.Abund*	*Av.Diss*	*Diss/SD*	*Contrib%*	*Cum.%*
HD	39.46	46.73	19.57	1.42	38.53	38.53
BP	27.74	20.33	15.14	1.09	29.82	68.35
DE	28.67	32.09	13.72	1.35	27.01	95.36

Groups Tribal & Reserve - Average dissimilarity: 60.20

	Group Tribal	Group Reserve				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
HD	18.47	46.73	18.33	1.40	30.45	30.45
LD	34.30	0.91	16.90	1.37	28.08	58.53
DE	28.03	32.09	12.41	1.31	20.62	79.15
BP	15.31	20.33	11.79	0.89	19.58	98.73

The Commercial-Reserve groups had an average dissimilarity of 50.79%, with the HD class, followed by the BP and DE classes contributing to 95.35% of the dissimilarity. Results indicated that the HD class was consistently the most important discriminating class. Since the HD was consistently typical of the Reserve land use, being also more abundant than in the Commercial land use, *both* these characteristics should serve as directive to distinguish between the two land uses (Table 4.26). These results are congruent with those of the "annual" interpretation.

The average dissimilarity between the Tribal and Reserve land uses was 60.2%, with the HD class, followed by the LD, DE and BP classes accounting for 98.73% of the dissimilarity. The HD class was the most important discriminating class (Diss/SD = 1.4), followed by the LD and DE class (Table 4.26). These patterns agree with those of the "annual" interpretation, except that the LD class was the most important discriminating class, followed by the HD class.

The relative "Poor" group had an average similarity of 45.3%, with BP, the DE and HD classes accounting for 93.95% of the similarity. There was no strong typical class (Sim/SD < 1.0), with BP having the highest

Sim/SD (0.92). This also suggests that patterns within a land use as function of the rangeland condition, and not only averaged across all land uses, need to be established (Table 4.27).

The "Good" variable had an average similarity of 56.7%, with the HD- and DE classes accounting for 91.06% of the average similarity. The HD group was the most important typical class (Sim/SD = 1.42), which is congruent with the "annual" interpretation's results (Table 4.27).

The average dissimilarity between these two groups was 62.14%, with the HD group, followed by the BP, DE and LD classes accounting for 98.88% of the dissimilarity. The HD class (Diss/SD = 1.54), followed by the DE class and BP, were the most important discriminating classes (Table 4.27). This is similar to the "annual" interpretation's results.

Table 4.27. SIMPER analyses for the "perennial" grazing index, displaying grazing classes that contributed to the average similarities within and dissimilarities between the "Good" and "Poor" rangeland condition groups.

Group Poor - Average similarity: 45.30

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
BP	34.90	18.03	0.92	39.80	39.80
DE	33.82	17.85	0.91	39.41	79.20
HD	16.26	6.68	0.77	14.75	93.96

Group Good - Average similarity: 56.70

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
HD	53.51	36.09	1.42	63.65	63.65
DE	25.37	15.54	1.33	27.41	91.06

Groups Poor & Good - Average dissimilarity: 62.14

	Group Poor	Group Good				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
HD	16.26	53.51	21.72	1.54	34.96	34.96
BP	34.90	7.35	16.08	1.11	25.89	60.85
DE	33.82	25.37	13.61	1.36	21.90	82.75
LD	12.95	12.82	10.02	0.84	16.13	98.88

C. Remarks

Both interpretations showed similar patterns, barring one or two exceptions discussed above. Average abundances of especially the HD and DE classes were higher for the "perennial" interpretation due to the inclusion of the nearest perennial species if an annual species was pointed out. The "perennial" interpretation method is useful in that it reflects the longer-term "state of health" of the respective land uses, and is hence informative and complementary to the "annual" interpretation.

4.3.2.4 ANOSIM analyses between land uses for each separate palatability class

Differences *between* land uses for *each* palatability class were investigated by means of two-way crossed ANOSIMS. As discussed in the Sections above, the rangeland condition gradient was represented by different palatability groups. For example, the relative "Good" extreme was best represented by the HD class, being representative of the Commercial-Good and Reserve-Good extremes. The relative "Poor" rangeland extreme was reflected by the BP and UD classes, representative of the Reserve-Poor and Commercial-Poor sites. The intermediate ranges of the rangeland condition gradient were represented by the LD class (associated with Tribal land use) and to some extent, the DE class. Since the rangeland condition gradient was represented by classes typical of the different land uses, it was necessary to establish by means of a two-way crossed ANOSIM whether, based on *each* palatability class, differences *between* land uses were significant. This will give an indication whether a palatability class is a *significant* indicator of one land use, or associated with more than one land use (e.g. the Reserve-Commercial "complex"), as well as give an indication of its distribution (significance as related to relative "Good" and "Poor" groups) along the range condition gradient for the larger study area.

A. "Annual" interpretation

For the HD class, the pair-wise tests showed statistically significant but relatively low differences between the Commercial-Tribal groups ($r = 0.278$, $P < 0.001$), between the Tribal-Reserve groups ($r = 0.283$, $P < 0.001$) and no significant differences between the Commercial and Reserve groups ($r = 0.046$, $P > 0.1$). The test for differences between the condition groups (averaged across land use groups) was intermediate-low, with $r = 0.324$ ($P < 0.001$). These results indicate that the Reserve and Commercial land uses were statistically similar in terms of representation by the HD class, forming a "complex". The HD class was indicative of both of these land uses, whereas it was not indicative of the Tribal land use (see Section 4.3.2.2 – 3). The HD was significantly related to the relative "Good" condition group, as indicated by the significant rangeland condition gradient (and supported by Section 4.3.2.3, SIMPER analysis - HD class indicative of the relative "Good" range condition spectrum).

Pair-wise tests to investigate the differences between the land uses based on the DE class, were statistically insignificant, with $r = 0.029$ ($P > 0.1$) for the Commercial-Tribal groups, $r = 0.05$ ($P > 0.1$) for the Commercial-Reserve groups and $r = 0.028$ ($P > 0.1$) for the Tribal-Reserve land uses. The test for differences between the condition groups, when averaged across all land use groups, was neglectably low ($r = 0.073$, $P < 0.05$). These results are encouraging, since it confirms the results discussed in the two sections above that the DE is associated with all three land uses, occupying a relative intermediate distribution along the range condition gradient for the entire study area.

The LD class differed significantly intermediate-high between the Commercial-Tribal ($r = 0.672$, $P < 0.001$) and high between the Tribal-Reserve groups ($r = 0.779$, $P < 0.001$). There was no significant difference between the Commercial and Reserve land uses ($r = 0.068$, $P < 0.05$) or between the relative condition groups when averaged across all land uses (r = 0.062, P > 0.05). These results support the results discussed above in Sections 3.2.2 - 4. The LD group was indicated as a typical class associated with the Tribal land use, but was not typical or representative of the other two land uses, displaying the similarity of the Reserve and Commercial land uses in terms of this class as well (hence, low "dominance" or importance of the LD class). The association of the LD class with the Tribal land use, which is distributed along low-intermediate ranges along the range condition gradient, explains why this palatability class did not show significant differences between the relative "Good' and "Poor' groups (distributed half-way between these two extremes).

Based on the UD class, differences between the Commercial-Tribal (r = -0.031, P > 0.1), Commercial-Reserve (r = 0.018, P > 0.1) and Tribal-Reserve land uses (r = 0.074, P > 0.1) were not statistically significant. Differences between the condition groups were also not significant (r = -0.011, P > 0.1). Although the RDA ordination indicated that the UD class was associated more with the Reserve-/Commercial-Poor variables than with the Tribal land use, the association was not strong (length of arrow which represents the strength of the variable, was short). The UD class occupied a mid-range distribution along the range condition gradient, explaining why the relative condition extremes did not differ significantly. Due to its mid-range placement, it did not differ significantly between the different land uses. Hence, it was associated with the first axis which was best represented by the passive range condition score indices, occupying a mid-range position along the first axis and hence rangeland condition indices (Fig. 4.19). Though the abundance for this class was slightly higher in the Commercial use, explaining this variable's association with the third quadrant and the Commercial-/Reserve-Poor variables, it did not differ significantly between the three land uses.

There were no significant differences between the land use groups based on the BP class, with r = 0.062 (P > 0.05) for the Commercial-Tribal groups, r = - 0.015 (P > 0.1) for the Commercial-Reserve groups, and r = 0.067 (P > 0.05) for the Tribal-Reserve land uses. Based on the relative condition groups, there was only a small though significant difference between the "Good" and "Poor" extremes (r = 0.263, P < 0.001). The existence of a significant difference between the relative condition groups is encouraging. Bare patches were indicated as the class being typical of rangeland in "Poor" condition, hence explaining the significant difference between the relative rangeland condition indices. The RDA ordination (Fig. 4.19) indicated that the BP was not only associated with the "Poor" environmental variable, but also with the Reserve-/Commercial-Poor variables. Hence, both the Reserve and Commercial land uses were very similar in this regard (av. abund and % contribution to similarity; Table 4.22). The ANOSIM was further informative in that it indicated that the observed differences between the three land uses, based on the BP, was not significant, with the average abundance of this class differing significantly between the three land uses (Tables 4.22 – 4.23). Hence, BP was significantly indicative of poor rangeland condition, and though associated with all three land uses, it had a higher (though not significant) presence within the Reserve and Commercial land uses. Hence, the more in-depth level association of BP with each specific land use was informative in terms of the observed patterns, but indicated that the analyses were not significant.

B. “Perennial” interpretation

Based on the HD class, differences between the Commercial-Tribal (r = 0.234, P < 0.001) and the Tribal-Reserve (r = 0.305, P < 0.001) land uses were significant though low, and insignificant between the Commercial-Reserve land uses (r = 0.056, P > 0.05). The relative condition extremes for the HD class showed a significant though not a pronounced difference (r = 0.294, P < 0.001). In general, these statistics were very similar to that of the “annual” interpretation, with the r-statistics being slightly lower. The same explanations discussed under Section 4.3.2.5 A for the “annual” interpretation, apply here as well.

Pair-wise tests for differences between the various land uses, based on the DE class, averaged across all relative condition types were insignificant, with r = -0.44 (P > 0.1) for the Commercial-Tribal land uses, r = 0.043 (P > 0.1) for the Tribal-Reserve land uses and r = 0.02 (P > 0.1) for the Commercial-Reserve land uses. The differences between the relative “Good” and “Poor” groups, averaged across the different land uses, were neglectably low (r = 0.083, P < 0.05). These results are “consistent” with that of the “annual” interpretation.

For the LD class, pair-wise tests showed an intermediate-high difference between the Commercial-Tribal land uses (r = 0.591, P < 0.001), significant high differences between the Tribal-Reserve groups (r = 0.783, P < 0.001) but no differences between the Commercial-Reserve land uses (r = 0.032, P > 0.1). There were no significant differences (r = 0.043, P > 0.05), based on the relative “Good” and “Poor” groups, averaged across all land uses. These results are similar to those of the “annual” interpretation, except that the r-statistics were slightly lower. The same arguments presented for the “annual” interpretation (Section 4.3.2.5 A), apply here.

When averaged across all relative condition groups for the UD class, there was a neglectably low difference between the Commercial-Tribal groups (r = 0.052, P < 0.05), the Tribal-Reserve land uses (r = 0.084, P < 0.001), with no statistical differences between the Commercial-Tribal land uses (r = 0.0, P > 0.1). The relative “Good” and “Poor” variables showed insignificant differences (r = -0.015, P > 0.1), averaged across all land uses. These results are consistent with that of the “annual” interpretation.

Differences based on the BP class between the Commercial-Tribal land uses (r = 0.177, P < 0.001) were small but significant, whereas it was insignificant between the Commercial-Reserve (r = -0.005, P > 0.1) and the Tribal-Reserve (r = 0.011, P > 0.1) land uses. The test for differences between the “Good” and “Poor” groups was significant though low (r = 0.285, P < 0.001). Hence, according to the “perennial” interpretation, the Reserve and Commercial land uses were more similar in terms of the occurrence of BP. These results however need to be investigated more in depth, as to establish whether the BP class was associated with the relative “Poor” groups within the Reserve and Commercial land uses. This will be done within the next section.

C. Remarks

Interpretation at this level was informative and complementary to the SIMPER analyses discussed in Section 4.3.2.3. These results suggest that patterns need to be addressed at a more in-depth level within and not across land uses only. It is further suggested that both interpretations need to be verified and compared by future surveys including a wider spectrum of different seasonal rainfall distribution patterns. This should be done as to determine whether the differences between these two interpretation methods will be more pronounced during different climatic events.

4.3.2.5 ANOSIM and SIMPER analysis between relative condition groups *within* each land use across all grazing classes

The ANOSIM tests, RDA ordinations and the SIMPER analyses discussed above (Sections 3.2.1 - 4) indicated the existence of a rangeland gradient not only for the larger study area, but especially within the Commercial and Reserve land uses. Hence, a one-way ANOSIM based on the relative condition groups within each land use was done to establish whether significant differences existed, and hence whether the variable associated with the particular land use reflected the existence of a rangeland condition gradient. SIMPER analyses indicating typical classes associated with each relative condition group *within* each land use were done (Appendix 4.5 for the "perennial" interpretation). The rationale behind this was to identify palatability classes related to each condition type *within* each land use as measure for rangeland monitoring and adaptive management purposes.

A. "Annual" interpretation

There was a significant, though relatively low difference between the relative "Good" and "Poor" groups ($r = 0.295$, $P < 0.001$) for the Commercial land use. The "Poor" group had an average similarity of 38.7%, with BP being the most abundant, followed by the DE and UD classes, with 91.31% of the cumulative dissimilarity being accounted for (Table 4.28; Fig. 4.23). The BP was typical of this group (Sim/SD = 1.0). The "Good" group had an average similarity of 67.43%, and was best represented by the HD and the DE classes, with cumulative contribution of 94.19%. The HD class was the strongest typical class (Sim/SD = 3.62). The average dissimilarity between the "Good" and "Poor" variables were 67.4%, with the HD class, followed by the BP, DE and UD classes contributing to 95.43% of the dissimilarity. The HD class, followed by the DE and BP classes, were the most important discriminanting classes. Hence, a significant gradient, though not very strong, existed between the two relative rangeland condition extremes within the Commercial land use, with different palatability classes typical to the "Poor" and "Good" extremes.

Table 4.28. SIMPER analyses for the "annual" grazing index, displaying grazing classes that contributed to the average similarities within and dissimilarities between the Commercial "Good" and "Poor" rangeland condition groups.

Group Poor Average similarity: 38.70

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
BP	33.13	17.74	1	45.84	45.84
DE	27.48	10.46	0.63	27.02	72.86
UD	20.43	7.14	0.78	18.45	91.31

Group Good Average similarity: 67.43

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
HD	63.68	51.38	3.62	76.2	76.2
DE	21.87	12.13	1.02	17.99	94.19

Groups Poor & Good Average dissimilarity: 67.4

	Group Poor	Group Good				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
HD	13.81	63.68	26.61	2.2	39.48	39.48
BP	33.13	5.55	15.28	1.28	22.67	62.15
DE	27.48	21.87	13.15	1.29	19.52	81.66
UD	20.43	7.63	9.28	0.77	13.77	95.43

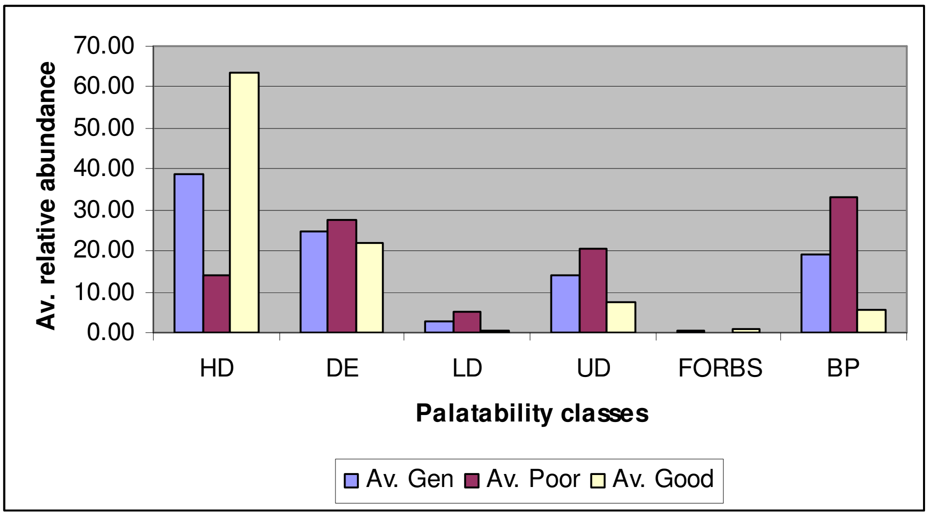


Fig. 4.23. Average relative abundances for the palatability classes of the Commercial land use for the "annual" interpretation method.

Table 4.29. SIMPER analyses for the "annual" grazing index, displaying grazing classes that contributed to the average similarities within and dissimilarities between the Tribal "Good" and "Poor" rangeland condition groups.

Group Poor Average similarity: 49.75

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
LD	34.33	18.04	0.93	36.26	36.26
DE	25.53	15.2	1.36	30.56	66.82
UD	12.17	7.14	1.27	14.35	81.16
HD	12.55	5.72	0.89	11.5	92.66

Group Good Average similarity: 59.13

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
LD	38.42	26.96	2.19	45.6	45.6
DE	27.24	15.65	1.35	26.47	72.08
HD	21.59	13.05	1.46	22.08	94.15

Groups Poor & Good Average dissimilarity: 45.8

	Group Poor	Group Good				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
LD	34.33	38.42	13.94	1.56	30.44	30.44
DE	25.53	27.24	10.2	1.28	22.28	52.71
BP	15.5	6.82	8.77	0.75	19.15	71.86
HD	12.55	21.59	8.14	1.3	17.77	89.62
UD	12.17	5.99	4.75	1.32	10.38	100

The Tribal "Good" and "Poor" variables did not differ significantly, with r = -0.009 (P > 0.1). It is supportive of the arguments based on the species composition and species richness ANOSIMS, as well as the ordinations that no significant degradation gradient existed within the Tribal land use, opposed to the other two land uses. The Tribal "Poor" group had an average similarity of 49.75%, with LD class being the most abundant and contributing most to the similarity, followed by the DE, UD and HD classes, with the HD class contributing to only 11.5% of the similarity (Table 4.29). The DE (Sim/SD = 1.36), followed by the UD class, were the most consistent typical classes. The "Good" group had an average similarity of 59.13%, and was also best represented by the LD class, followed by the DE and then HD class, with a cumulative contribution of 94.15% to the group's similarity. The LD class (Sim/SD = 2.19), followed by the HD class, were consistently the most typical classes. The abundance of the various palatability classes were very similar between the two range condition extremes, however, with the LD and DE classes being slightly higher in the Tribal-Good group compared to the Tribal-Poor group (Table 4.29; Fig. 4.24). The UD class also contributed to the Tribal-Poor group's similarity, but was not contributing to the Tribal-Good group's similarity. The LD group appeared more consistently throughout the Tribal-Good sites than in the Tribal-Poor sites. The HD group also was consistently most typical of the Tribal-Good group, further distinguishing it from the Tribal-Poor group. Although the DE group was consistently most typical in the Tribal-Poor group, its abundance was lower than in the Tribal-Good group, with its Sim/SD being approximately the same as the DE class within the Tribal-Good class. The average dissimilarity between the "Poor" and "Good" groups was 45.8%, with the LD contributing to most of the dissimilarities, followed by the DE-, BP-, HD- and UD classes. The most important discriminant class was the LD group, followed by the UD and then HD classes. The LD class was typical to both groups, supporting the PCA and RDA analyses that indicated that all the Tribal variables (Tribal, Tribal-Good and Tribal-Poor) were closely correlated and represented by the same quadrant (Fig. 4.21). This further supports the argument that the Tribal land use occupied a low-intermediate distributional range along the rangeland condition gradient for the entire study area. This applies irrespective if the Tribal land use is described according to species compositional level or according to palatability classes.

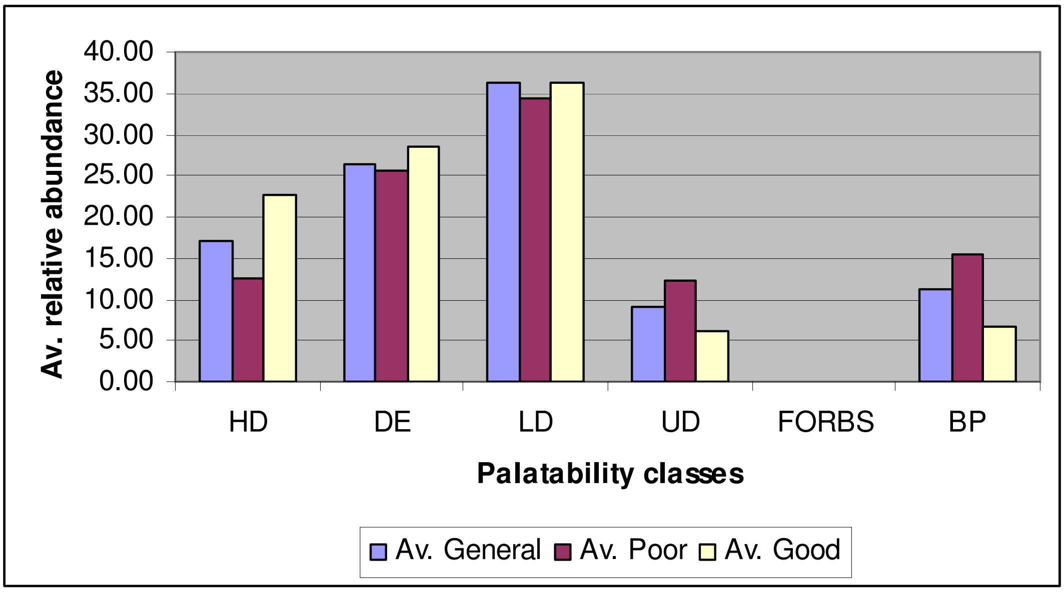


Fig. 4.24. Average relative abundances for the palatability classes of the Tribal land use for the "annual" interpretation method.

The one-way ANOSIM for the Reserve showed and intermediate-high difference between the relative "Good" and "Poor" variables (r = 0.59, P < 0.001). Hence, the differences were most pronounced within this land use. The "Poor" group had an average similarity of 53.8%, with the DE class, BP and HD classes accounting for 95.84% of the similarity. The DE class was most typical of this group, although the BP had a high average abundance (though lower than that of the DE class) (Fig. 4.25). However, it was rather localised in some sites, not being consistent throughout all sampling areas. The "Good" group had an average similarity of 76.74%, with the HD and DE class accounting for 95.56% of the similarity (Table 4.30). These were the only two classes that accounted for this high similarity, indicating the herbaceous homogeneity of the relative "Good" sites within this land use. The HD class was the most important typical class (Sim/SD = 4.81). The "Poor" and "Good" groups had an average dissimilarity of 58.26%, with the HD class (av. dissimilarity = 25.27%, contribution = 43.38%), followed by BP and the DE class accounting for 90.39% of the dissimilarity. The HD group was the most important discriminant class (Diss/SD = 2.36). Although this class belongs to both groups, it was not typical of the "Poor" group, and the average abundance within the "Good" group was much higher than within the "Poor" group.

Table 4.30. SIMPER analyses for the "annual" grazing index, displaying grazing classes that contributed to the average similarities within and dissimilarities between the Reserve "Good" and "Poor" rangeland condition groups.

Group Poor Average similarity: 53.80

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
DE	39.28	25.33	1.55	47.09	47.09
BP	33.18	16.96	1.09	31.52	78.61
HD	19.38	9.27	1.12	17.23	95.84

Group Good Average similarity: 76.74

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
HD	68.84	59.26	4.81	77.22	77.22
DE	19.77	14.07	2.39	18.34	95.56

Groups Poor & Good Average dissimilarity: 58.26

	Group Poor	Group Good				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
HD	19.38	68.84	25.27	2.36	43.38	43.38
BP	33.18	3.94	14.96	1.1	25.68	69.05
DE	39.28	19.77	12.43	1.29	21.34	90.39

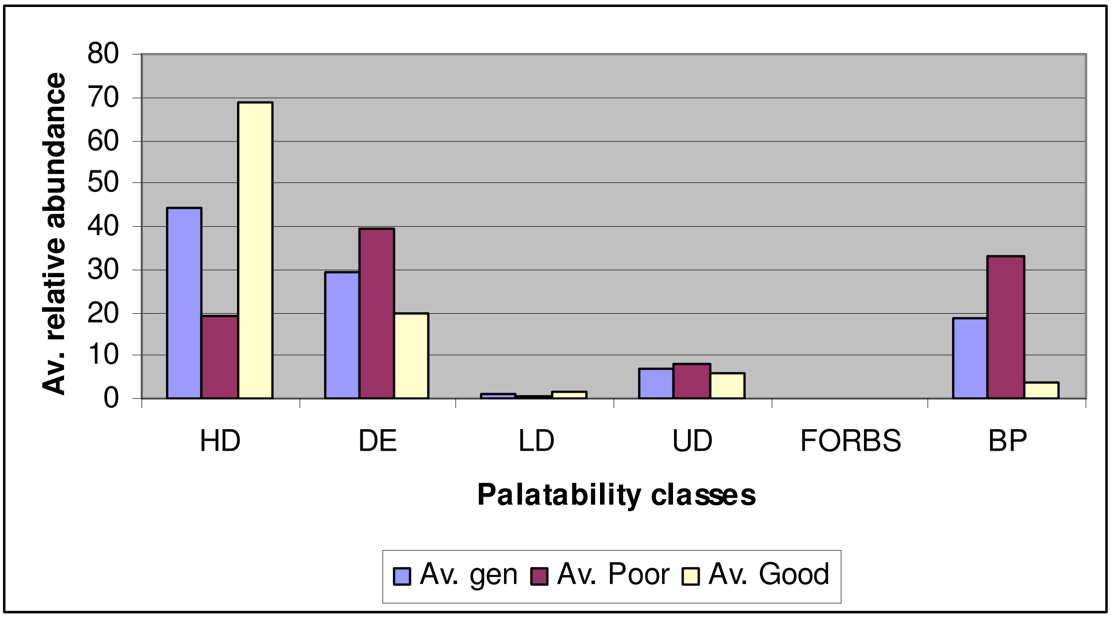


Fig. 4.25. Average relative abundances for the palatability classes of the Reserve land use for the "annual" interpretation method.

To summarise, ANOSIM and SIMPER analyses proved to be useful at this more in-depth level of monitoring, and should be included in a "Key rangeland condition assessment" matrix for adaptive rangeland monitoring and assessment purposes. Both the Reserve and Commercial groups displayed a degradation gradient based on the grazing index classification, while it was not significant within the Tribal land use, for the reasons discussed above. The Reserve and Commercial land uses displayed similar characteristics, which differed significantly from that of the Tribal land use. However, based on palatability classes, the differences between the relative "Good" and "Poor groups were most pronounced within the Reserve land use.

B. "Perennial" interpretation

The one-way ANOSIM test indicated an intermediate difference (employing all palatability classes) between the relative "Good" and "Poor" variables for the Commercial land use ($r = 0.448$, $P < 0.001$). Hence, the "perennial" interpretation indicated a much more pronounced rangeland condition gradient than the "annual" interpretation did within the Commercial land use, suggesting there were, based on the longer-term ecological range condition status, larger differences between the relative "Good" and "Poor" groups than indicated by the "annual" interpretation. The "Poor" variable had an overall similarity of 44.23%, with BP and the DE class contributing to 91.39% of this variable's similarity (Appendix 4.5). The BP was indicated as consistently typical of the group (Sim/SD = 1.25). The Commercial "Good" group had an overall similarity of 67.28%, with the HD class, followed by the DE class accounting for 97.67% of the "Good" group's similarity (Appendix 4.5). The HD class (Sim/SD = 1.75) was the strongest typical denominator of the "Good" group. The average dissimilarity between the "Poor" and "Good" groups was 67.28%, with 94.08% of the difference being accounted for by the HD-, BP- and DE classes, with the HD class being the most important discriminating class (Appendix 4.5).

There were no significant differences between the relative "Good" and "Poor" groups for the Tribal land use ($r = 0.019$, $P > 0.1$). The "Poor" group had an average similarity of 43.57%, and was best represented, in order of abundance and contribution, by the LD class, followed by the DE-, BP and HD classes which accounted for 99.37% of the similarities. Although the LD was the most abundant and highly contributing palatability class, the HD class (Sim/SD = 0.93) was consistently the most typical class (although not a strong typical class, with Sim/SD < 1.0) (Appendix 4.5). This differs from the "annual" interpretation, which indicated that the DE class was consistently the most typical class. It is suggested that the "annual" interpretation included more DE species associated with the season rainfall variability, whereas the "perennial" interpretation reflected on the "actual" ecological status and presence of the more stable, favourable HD species. However, since the Sim/SD was relatively low, this tendency is not very significant. The DE class (Sim/SD = 0.75) was the second best (though not strong) typical class (Appendix 4.5). The "Good" group had an average similarity of 59.9%, with the LD class, followed by the DE and HD class accounting for 94.93% of the similarities. The LD was the most important typical class (Sim/SD = 2.13). The average dissimilarity between the "Poor" and "Good" groups was 49.07%, with the LD class, followed by the DE-, BP and HD classes accounting for 97.56% of the dissimilarity. The LD was the most important discriminating class (Diss/SD = 1.58), followed by the DE and then HD classes. The average abundances within each relative condition group, in addition to the typical classes, can combined serve as directive of which rangeland condition group the discriminating class is more representative of. The overlapping classes of these relative condition groups complement results of the

PCA and RDA analyses, which showed that all the Tribal variables were relatively closely related and associated with the same quadrant. Hence, there was no significant rangeland condition gradient within the Tribal land use.

The one-way ANOSIM indicated intermediate-high differences between the "Good" and "Poor condition groups within the Reserve (r = 0.625, P < 0.001). These differences are also more pronounced than in the "annual" interpretation, suggesting that the longer-term ecological rangeland condition (thus "perennial" interpretation) between the relative "Poor" and "Good" groups was larger than indicated by the "annual" interpretation. The Reserve "Poor" group had an average similarity of 57.5%, with the DE class, followed by the BP and HD class contributing to 99.96% of the similarity (Appendix 4.5). The DE class consistently was the most typical class (Sim/SD = 1.59). The "Good" variable had an average similarity of 81.98%, with the HD and DE classes contributing to 97.94% of the group's similarity (Appendix 4.5). The average dissimilarity between the two groups was 57.3%, with the HD class, followed by the BP and DE classes contributing to 98.54% of the dissimilarities. The HD class was the most important discriminating class (Diss/SD = 2.54) (Appendix 4.5).

C. Remarks

The SIMPER and ANOSIM analyses discussed in this section were explanatory and complementary to the results discussed in Sections 4.3.2.1 – 4.3.2.4. Results from this section suggest that assessment and monitoring *within* and not only across all land uses, should be conducted. The "perennial" interpretation showed stronger r-statistics (hence larger differences between relative condition groups and a longer range condition gradient) than the "annual" interpretation did, indicating that this interpretation for the "perennial" technique at this level of analysis is essential and informative for land owners and scientists alike. The grazing classification index proved to be an informative comparative measure to reflect and compare the impacts of different land uses on rangeland herbaceous composition and condition. The Reserve land use showed with both interpretation methods the most pronounced differences between the relative "Good" and "Poor" groups. The pattern was similar in the Commercial land use, except that the differences were less pronounced. Both interpretations indicated no significant differences between the relative condition groups for the Tribal land use, strengthening the motivation that the longer-term ecological status of the rangeland as total, reflects a shift towards a low to midrange rangeland condition/"state of health".

4.3.2.6 ANOSIM within each land use between relative condition groups for each palatability class

Analysis of similarities *within* each land use for each palatability class was done to establish whether differences existed between the relative "Good" and "Poor" extremes. This section is thus additional to the SIMPER analyses discussed in Section 4.3.2.5. This section attempts to serve as directive for rangeland managers/owners by statistically establishing whether certain grazing classes are informative of certain range conditions, hence serving as departure point for an adaptive management tool not only across all land uses, but within a land use. Thus this section attempts not to generalise patterns across all land uses, but rather to establish patterns on a more detailed scale. This may be very essential, since the different land uses displayed different characteristics, and may need to be managed differently. These results will be presented in a final "Key assessment matrix" in Chapter 9.

A. "Annual" interpretation

For the Commercial land use, there was an intermediate difference for the HD palatability class ($r = 0.433$, $P < 0.001$) between the relative "Good" and "Poor" groups. There were no statistically significant differences between the "Good" and "Poor" variables for the DE ($r = 0.079$, $P > 0.1$), LD ($r = 0.047$, $P > 0.1$) and UD ($r = -0.031$, $P > 0.1$) classes. However, there was an intermediate difference between these two variables for the BP class ($r = 0.469$, $P < 0.001$). These results confirm the existence of a rangeland condition gradient within the Commercial land use, with the HD class being associated with rangeland "Good" condition sites, the DE, LD and UD with rangeland of intermediate condition and the BP with rangeland in poor condition.

For the Tribal palatability classes, differences based on the HD ($r = 0.037$, $P > 0.1$), DE ($r = -0.057$, $P > 0.1$), LD ($r = 0.058$, $P > 0.1$), UD ($r = 0.051$, $P > 0.1$) and BP ($r = 0.032$, $P > 0.1$) classes, were statistically insignificant. Thus, this land use was not associated with either "Poor" or "Good" range condition spectra, but further supporting the argument that the entire land use had a transitional shift in species composition towards a low-intermediate range condition state. Classification according to the grazing index is hence also a congruent reflection of the species compositional patterns.

Results for the Reserve showed an intermediate difference based on the HD class ($r = 0.503$, $P < 0.001$). The difference between the Reserve "Good" and "Poor" variables were low for the DE class ($r = 0.196$, $P < 0.05$), and statistically insignificant for the LD ($r = 0.08$, $P > 0.05$) and UD ($r = -0.03$, $P > 0.1$) classes. The difference between the Reserve rangeland condition groups was significant but lower than that of the Commercial land use for the BP class ($r = 0.289$, $P < 0.001$). The results show that a degradation gradient existed within the Reserve, with the HD group being very representative of rangeland in "Good' condition, with the DE class also being second most important in highlighting the differences between these two relative condition extremes, being associated more with the relative "Poor" sites. The LD and UD classes were indicative of intermediate rangeland condition and the BP of rangeland in "Poor" condition. The average dissimilarities between the "Good" and "Poor" groups were lower for the Reserve than for the Commercial land use, explaining the lower ANOSIM differences between these relative condition groups for the Reserve as opposed to the Commercial land use.

B. "Perennial" interpretation

The differences between the Commercial "Good" and "Poor" groups were significant though not very pronounced for the HD class ($r = 0.293$, $P < 0.001$), and insignificant for the DE ($r = 0.08$, $P > 0.1$), LD (r = 0.048, P > 0.1) and UD (r = 0, P > 1) classes. There was an intermediate difference between the "Good" and "Poor" variables for the BP class (r = 0.506, P < 0.001). The statistics for the HD group were lower than indicated by the "annual' presentation, and can be ascribed to the inclusion of the nearest perennial grass species when an annual life-form was pointed out. However, statistics for the "perennial" interpretation for the BP indicated larger differences between the relative condition groups. These results will be discussed in more detail in terms of the range condition scores calculated for each land use.

For the Tribal group, there were no statistically significant differences between these two condition extremes for the HD (r = 0.051, P > 0.1), LD (r = 0.08, P > 0.5), UD (r = -0.44, P > 0.1) or BP (r = 0.01, P > 0.1) classes. These results support previous arguments that the Tribal land use is distributed along low-intermediate ranges of the range condition gradient for the larger study area. Hence, for monitoring purposes in the Tribal land use only, classification according to the grazing index does not seem to be informative for either interpretation methods.

Results for the Reserve showed intermediate differences for the HD class (r = 0.537, P < 0.001). There were significant though low differences between these two relative condition extremes for the DE (r = 0.203, P < 0.05) and BP (r = 0.298, P < 0.001) classes. The differences were insignificant for the LD (r = -0.01, P > 0.1) and UD (r = 0, P > 0.1) classes. The r-statistics displaying significant differences for the HD, DE and BP classes were higher than in the "annual" interpretation, and will be reflected on by means of the range condition scores, discussed in Section 4.3.5.

C. Remarks

Analyses for both interpretation methods at this level proved to be informative, suggesting significant differences between certain palatability classes discussed above in the Reserve and Commercial land uses, which also reflect the rangeland gradient. Of all the land uses, the Reserve land use showed the largest differences between the relative "Good" and "Poor" range condition extremes as opposed to that of the Commercial land use. The Tribal land use did not show significant patterns for any of the palatability classes, confirming the ordination results that all the sites are relatively similar, and are associated with low-intermediate rangeland conditions (Fig. 4.21). Hence, no rangeland condition gradient, based on the grazing index classification, exists within the Tribal land use.

In general, the "perennial" interpretation method indicated larger differences between the relative condition groups within a land use than the "annual" interpretation did. Differences in the two interpretation methods will be discussed and compared further in the form of the range condition scores obtained for each interpretation method according to both the grazing- and ecological indices.

4.3.2.7 Discussion of the grazing index

ANOSIM tests for the grazing index showed similar patterns to the species compositional patterns, suggesting that it is an appropriate measure to differentiate between the impact of different land uses on species composition and rangeland condition. The differences between the Commercial-Tribal and Tribal-Reserve land uses were most pronounced with the “annual” interpretation method, due to the inclusion of the annual life-form, which most often contributed to the average abundances of the LD and UD palatability classes. However, the differences between the relative “Good” and “Poor” range condition groups were most pronounced within the “perennial” interpretation method.

The Monte Carlo test showed significant species-environment relations for the first as well as all the canonical axes for both interpretations. The “Good/Poor” relative condition variables, followed by the Tribal variables significantly explained the variance for both interpretation methods, though the F-values slightly differed between the two interpretation methods. For both interpretations, the “Good/Poor” variables were best explained by first axis and were associated with the Reserve and Commercial land uses, with the Tribal environmental variable best explaining the second axis. The first CCA axis, for the passive data, was most strongly associated with the rangeland condition indices’ scores, with increased range condition being associated with the Reserve-/Commercial-Good variables.

The HD class had the highest average abundance in general for the Reserve and Commercial land uses, as well as for the Reserve-/Commercial-Good groups for both interpretation methods. It was typical of only the Reserve-/Commercial-Good groups. Bare patches were most typical of the Commercial-Poor group with the DE class being typical of the Reserve-Poor land use. The LD class was typical and most abundant of the general Tribal land use, though it was typical of only the Tribal-Good group. Results presented further suggested that patterns within and between land uses for the general palatability data set, *as well* as for each separate grazing class, should be conducted to correctly identify typical and discriminating classes within and between land uses.

Results showed significant differences related to the range condition gradient (between the relative condition groups) for the total grazing classification index within the Reserve and Commercial land uses for both interpretations. Within the Reserve and Commercial land use, significant rangeland condition gradients pertaining to the classes discussed in the sections above were evident. None of the palatability classes within the Tribal land use showed significant differences between the relative condition groups. These results are supported by Fig. 4.19 and Fig. 4.21, indicating the Tribal-Poor/-Good variables to be closely associated, occupying a low- to medium rangeland on the degradation gradient. This is opposed to the Reserve and Commercial land uses, which reflected palatability classes associated with high to medium rangeland conditions, with BP being associated with low range condition ranges on the rangeland condition gradient (Fig. 4.19 and Fig. 4.21). Palatability classes contributing most to the average abundances of the respective relative condition groups within each land use for the two interpretation methods showed similar patterns. However, the abundances were higher for the HD, DE and BP classes, and lower for the LD and UD classes for the “perennial” interpretation as opposed to that of the “annual” interpretation.

4.3.3 Ecological classification and -index

Species were classified into four ecological classes (Decreasers, Increaser I, Increaser II and Increaser III), and in addition into BP and forbs, according to both the “annual” and “perennial” interpretation methods (Appendix 4.6). The purpose of this section was to determine whether the ecological classification corresponds with patterns at the species composition level. Thus, can the ecological classification index serve as a measure to indicate significant differences between ecological classes pertaining to the different land uses and rangeland condition extremes (relative “Good” vs. “Poor) within and between land uses?

This section seeks to establish whether the ecological classification serve as a practical and monitoring measure for rangeland assessment and management purposes within and between land uses. Consult Chapter 3 (Material and Methods), for more comments on the ecological classification, qualification of environmental variables and the difference between the “annual” vs. “perennial” interpretation methods. Results from the ecological index in the form of range condition scores will be compared to the rangeland condition scores of the grazing index in Section 4.3.5.

4.3.3.1 ANOSIM across different land uses

A two-way crossed ANOSIM for differences between the relative condition groups for the “annual” interpretation, showed an intermediate-low difference between the “Good” and “Poor” extremes when average across all land uses ($r = 0.332$, $P < 0.001$). The pair-wise tests for differences between land uses, averaged across all relative condition groups, showed intermediate differences between the Commercial-Tribal groups ($r = 0.538$, $P < 0.001$) and intermediate-high between the Tribal-Reserve land uses ($r = 0.646$, $P < 0.001$). There were still no statistically significant differences between the Commercial-Reserve land uses ($r = 0.001$, $P > 0.1$). According to the ecological classification, the same patterns as with the grazing classification and species composition were evident. However, the statistics (r-values) indicated that the ecological index showed slightly larger differences between the land uses than the grazing classification did. Thus, differences between the relative “Good” and “Poor” groups were most pronounced within the Reserve land use, followed by the Commercial land use, with no differences existing within the Tribal land use.

For the “perennial” interpretation, pair-wise tests for differences between land use groups, averaged across all relative condition groups, showed intermediate differences between the Commercial-Tribal groups ($r = 0.509$, $P < 0.001$), Tribal-Reserve land uses ($r = 0.617$, $P < 0.001$), but no differences between the Commercial-Reserve groups ($r = -0.006$, $P > 0.1$). A two-way crossed ANOSIM for differences between relative condition groups, averaged across all land use groups was of intermediate importance (r = 0.357, P < 0.001). These results were very similar to that of the “annual” interpretation, except that the range condition gradient was more pronounced in the “perennial” interpretation method, while differences between the Tribal-Reserve and Commercial-Tribal land uses were less pronounced.

The species-environmental (ecological classes-environment) relation was further investigated with indirect and direct ordinations, for the same reasons as discussed for the grazing classification (Section 4.3.2.2).

4.3.3.2 PCA and RDA with environmental and supplementary variables

A. “Annual” interpretation

Table 4.31. A PCA ordination for the “annual” ecological index, showing eigenvalues and species-environment relations for the first four axes, as well as the environmental and passive variables explaining most of the species-environment relation for the first two axes. Variables explaining most of the variance are indicated in **bold**.

Environmental data	SPEC AX1	SPEC AX2	Passive data	SPEC AX1	SPEC AX2
Commercial	-0.1932	0.2314	BE/HA	0.4032	0.0918
Tribal	**0.6242**	**-0.3897**	Bushcov	0.431	0.0594
Reserve	-0.431	0.1583	Bush num/ha	0.4529	-0.0608
Good	**-0.508**	**-0.397**	VCSAGRAZ	**-0.6796**	**-0.643**
Poor	**0.508**	**0.397**	VCSPGRAZ	**-0.6642**	**-0.635**
Com*Good	-0.483	-0.0795	DM/HA	-0.2963	-0.4026
Com*Poor	0.2386	0.3722	VCSAECOL	**-0.7066**	**-0.6627**
Tri*Poor	0.4687	-0.1639	VCSPECOL	**-0.7042**	**-0.6395**
Tri*Good	0.3209	-0.3291	ANNrich	0.4314	-0.5519
Res*Good	-0.5195	-0.124	ANNeve	0.118	-0.1708
Res*Poor	-0.0258	0.3243	ANNdiv	0.3399	-0.418
			Bsh.div	0.2292	-0.2254
Axes	**1**	**2**	**3**	**4**	
Eigenvalues	0.591	0.311	0.096	0.001	
Species-environment correlations	0.858	0.578	0.315	0.183	
Cumulative percentage variance					
of species data	59.1	90.2	99.8	100	
of species-environment relation (environmental)	79.3	98.2	100	100	
of species-environment relation (passive data)	62.8	95.5	100	100	

The indirect PCA ordination revealed that the first axis accounted for most of the species-environment correlations (r = 0.858) for the environmental variables, with 98.2% of the species-environmental relation and 90.2% of the species data being explained by the first two axes. The second axis explained 95.5% of the species-environment relation for the passive variables (Table 4.31).

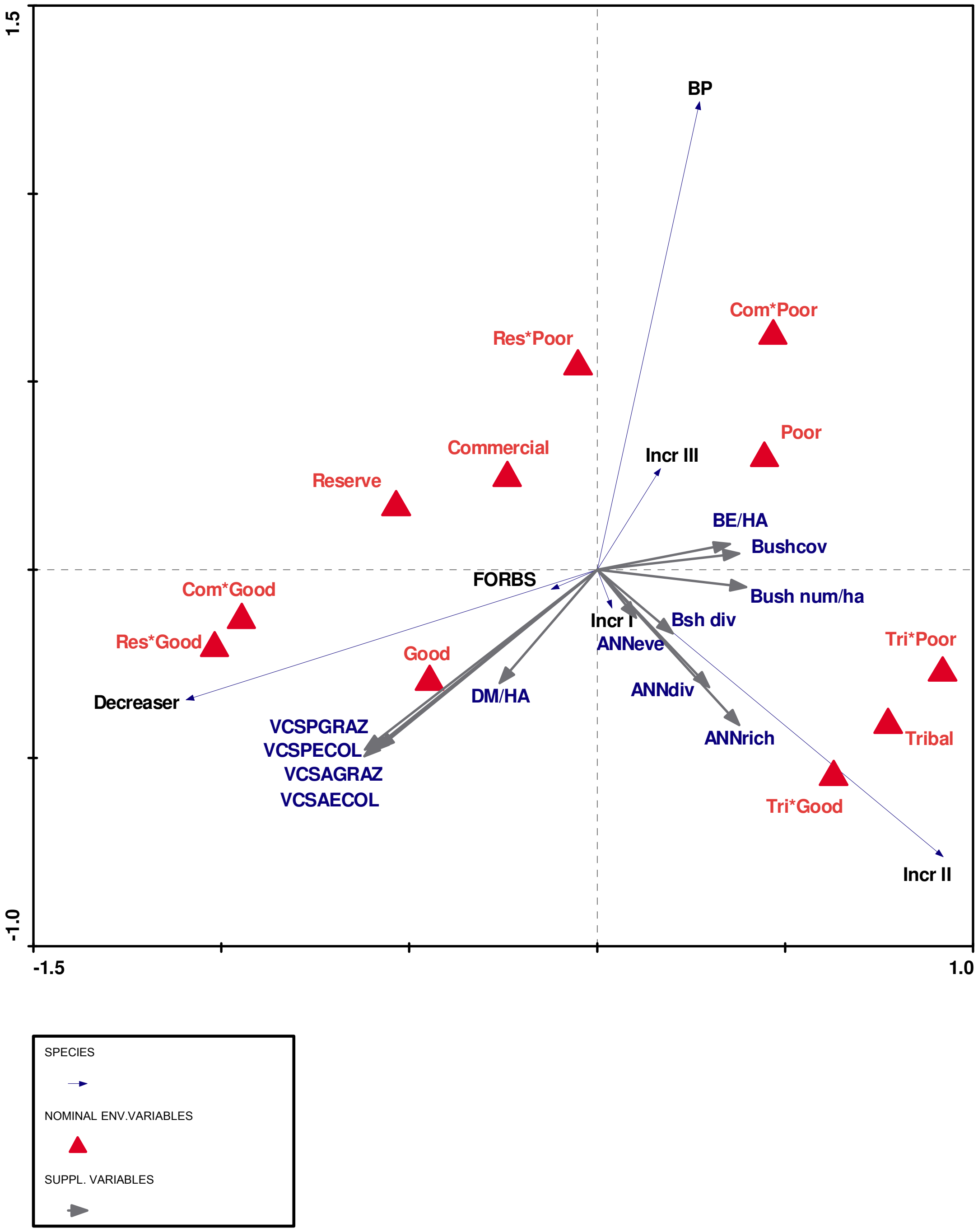


Fig. 4.26. A PCA ordination triplot illustrating indirect species-environmental correlations for the "annual" ecological classification.

The first axis was best represented by the Tribal (0.6242), "Good" (r = -0.508) and "Poor"(r = 0.508) variables, and the second axis by the Tribal (r = -0.3897), "Good" (r = -0.397) and "Poor" (r = 0.397) variables (Table 4.31). The passive rangeland condition indices scores (r > 0.66) were most strongly correlated with both the first axis and second axis (Fig. 4.26). The Decreaser group was strongly associated with the Reserve-Good and Commercial-Good. The Increaser III and BP groups were best correlated with the “Poor”, Reserve-Poor and Commercial-Poor variables. The Increaser II group was very strongly correlated with the different Tribal variables (Fig. 4.26) and the Increaser I group with the Tribal (notably Tribal-Good) land use (Fig. 4.26).

Table 4.32. A RDA ordination for the “annual” ecological index, showing eigenvalues and species-environment relations for the first four axes, as well as the environmental and passive variables explaining most of the species-environment relation for the first two axes. Variables explaining most of the variance are indicated in **bold**.

Environmental data	**SPEC AX1**	**SPEC AX2**	**Passive data**	**SPEC AX1**	**SPEC AX2**
Commercial	0.1958	0.2568	BE/HA	-0.4062	0.0608
Tribal	**-0.6262**	**-0.4035**	Bushcov	-0.4339	0.0303
Reserve	0.4304	0.1468	Bush num/ha	-0.4551	-0.0818
Good	0.5071	**-0.4064**	VCSAGRAZ	0.678	**-0.6589**
Poor	-0.5071	**0.4064**	VCSPGRAZ	0.6632	**-0.6444**
Com*Good	0.4835	-0.0762	DM/HA	0.2967	-0.397
Com*Poor	-0.2358	**0.4009**	VCSAECOL	**0.7051**	**-0.6774**
Tri*Good	-0.4695	-0.1678	VCSPECOL	**0.7034**	**-0.6464**
Tri*Poor	-0.3226	-0.3426	ANNrich	-0.4325	-0.5566
Res*Poor	**0.5194**	-0.1265	ANNeve	-0.1186	-0.1752
Res*Good	0.025	0.3121	ANNdiv	-0.3408	-0.4216
			Bsh.div	-0.2291	-0.2209

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.435	0.108	0.006	0
Species-environment correlations	0.858	0.595	0.232	0.176
Cumulative percentage variance				
of species data	43.5	54.3	54.8	54.8
of species-environment relation (environmental)	79.4	99	100	100
of species-environment relation (passive data)	62.7	95.7	100	100

Monte Carlo permutation test

Variable	**P**	**F**
Tribal	0.002	27.35
Good	0.002	26.96
Com*Poor	0.002	6.24
Tri*Poor	0.028	3.14
Commercial	0.96	0.11

As in the case of the grazing index and species composition analyses, the Reserve and Commercial land uses were strongly associated with each other, with the Tribal land use clustering separately. Similar to previous discussions, the Tribal land use did not show a range condition gradient, with both the Tribal-Good and Tribal-Poor variables not differing significantly (Fig. 4.26). However, the Reserve-/Commercial-Good variables (associated with each other) differed significantly from the Reserve-/Commercial-Poor variables (correlated with each other), with these two “clusters”’ being associated with different quadrants.

This illustrates the existence of a range condition gradient *within* these two land uses. These results were further investigated by means of the direct RDA ordination.

The RDA ordination, employing environmental and passive variables, explained 99% of the species-environment relation (environmental variables), 54.3% of the cumulative variance of the species data and 95.7% of the species-environment relation for the supplementary data by the second axis. This was an improvement on the indirect PCA species-environment variance, indicating that the correct environmental variables explaining the largest proportion of the species-environment variance have been included in the analysis. Both the first ($F = 50.848$, $P < 0.005$) and all the canonical axes ($F = 16.025$, $P < 0.005$) were statistically significant, with Tribal ($r = -0.6262$, third quadrant) and Reserve-Good ($r = 0.5194$, fourth quadrant) environmental variables representing the first axis the best, and the "Good" ($r = -0.4064$, fourth quadrant) and "Poor ($r = 0.4064$, second quadrant) the second axis best (Table 4.32, Fig. 4.27). Hence, the first axis was best represented by the land uses (secondly by the rangeland condition gradient associated with these land uses) and the second axis by the rangeland condition gradient (and secondly by the land uses associated with this gradient).

The first axis of the species-passive variable relation was best represented by the different ecological rangeland condition indices' scores ($r > 0.7$), which were also positively correlated with the "Good" variable and the Reserve-Good and Commercial-Good variables of the fourth quadrant. This tendency is similar to that of the PCA ordination. The species richness (ANNrich) and woody variables (BE/ha, Bush num/ha, Bushcov, Bsh div) were best associated with the Tribal variables (Fig. 4.27). The following variables most significantly revealed patterns related to the Monte Carlo permutation model: Tribal land use ($F = 27.35$, $P < 0.005$), Good/Poor ($F = 26.96$, $P < 0.005$) Tribal-Good/-Poor ($F = 3.14$, $P < 0.005$) and the Commercial-Poor /-Good ($F = 6.24$, $P < 0.005$) variables.

The Increaser II group, indicative of overgrazing, was best correlated with the Tribal land use, irrespective of range condition within *this* land use. The Decreaser group was strongly associated with the Reserve-/Commercial-Good variables, indicating the stable and functional ecological state of these sites. The Increaser I (underutilisation) group showed a correlation (though not strong- short arrow) with the "Good" environmental variable. The Increaser III and BP classes were associated with the Reserve-/Commercial-Poor groups. Increaser I species are most often relatively unpalatable climax species that can grow without defoliation (Van Oudthoorn 2002) (Fig. 4.27). However, the Increaser I and forb classes did not feature strongly within the study area, with the former being represented by only one species (*Cymbopogon plurinodis*), being associated with the Tribal land use. Thus, the appearance of Increaser I species in this land use, can possibly be ascribed to the animal behaviour of livestock displaying selective grazing behaviour, resulting in the selective grazing of other more palatable species above this relative unpalatable species. This is illustrative of patch dynamics (refer to Chapter 7). This species was recorded in both Tribal-Good and Tribal-Poor sites, although it had a slightly higher relative abundance within the Tribal-Poor sites. However, as discussed in the sections above, and as illustrated by Fig. 4.27, there were no significant differences between the Tribal-Good and Tribal-Poor rangeland condition groups. Refer to the discussion of Section 4.3.1.7.

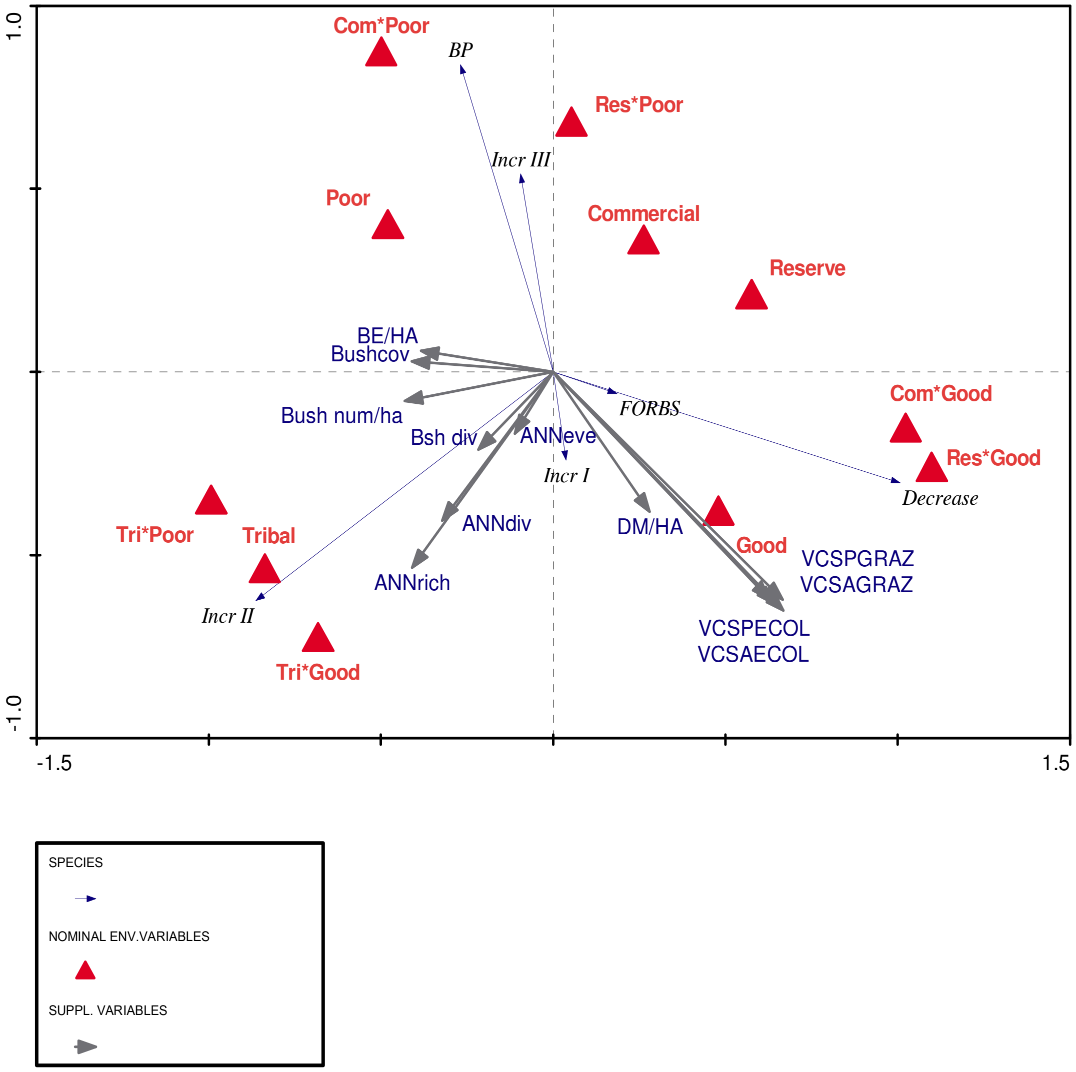


Fig. 4.27. A RDA ordination triplot illustrating indirect species-environment relation for the “annual” ecological classification.

B. Perennial interpretation

The second axis explained 100% of the species-environment relation for the environmental data, 99.8% of the cumulative variance of species data (Table 4.33) and 100% of the species-passive data relation for the PCA ordination. The same environmental and passive variables as discussed under the “annual” interpretation (Table 4.31), explained the first two axes, and will not be repeated again (Table 4.33). However, the Increaser I, II and III groups were all associated with the Tribal variables (fourth quadrant), and only the BP was associated with the Poor, Commercial-Poor and Reserve-Poor variables (first quadrant) (Fig. 4.28). The Decreaser group was still strongly associated with the Reserve, Commercial, Reserve-Good and Commercial-Good land uses (third quadrant). These patterns were verified with the direct RDA ordination, and will be discussed next.

Table 4.33. A PCA ordination for the "perennial" ecological index, showing eigenvalues and species-environment relations for the first four axes, as well as the environmental and passive variables explaining most of the species-environment relation for the first two axes. Variables explaining most of the variance are indicated in **bold**.

Environmental data	**SPEC AX1**	**SPEC AX2**	**Passive data**	**SPEC AX1**	**SPEC AX2**
Commercial	-0.1644	0.2398	BE/HA	0.3947	0.0434
Tribal	**0.5619**	**-0.4141**	Bushcov	0.4228	0.0058
Reserve	-0.3975	0.1743	Bush num/ha	0.4306	-0.1065
Good	**-0.5626**	-0.3205	VCSAGRAZ	**-0.7282**	**-0.5625**
Poor	**0.5626**	0.3205	VCSPGRAZ	**-0.7316**	**-0.5835**
Com*Poor	-0.4987	-0.028	DM/HA	-0.372	-0.3643
Com*Good	0.2907	0.3313	VCSAECOL	**-0.7626**	**-0.5814**
Tri*Good	0.4416	-0.1795	VCSPECOL	**-0.7779**	**-0.5898**
Tri*Poor	0.2692	-0.3444	PERrich	0.0264	-0.3062
Res*Poor	-0.5252	-0.0575	PEReve	0.2016	-0.5143
Res*Good	0.0225	0.2781	PERdiv	0.1568	-0.4388
			Bsh.div	0.1775	-0.2453
Axes	**1**	**2**	**3**	**4**	
Eigenvalues	0.631	0.367	0.001	0.001	
Species-environment correlations	0.855	0.534	0.253	0.311	
Cumulative percentage variance					
of species data	63.1	99.8	99.9	100	
of species-environment relation (environmental)	81.5	100	100	100	
of species-environment relation (passive data)	65.2	100	100	100	

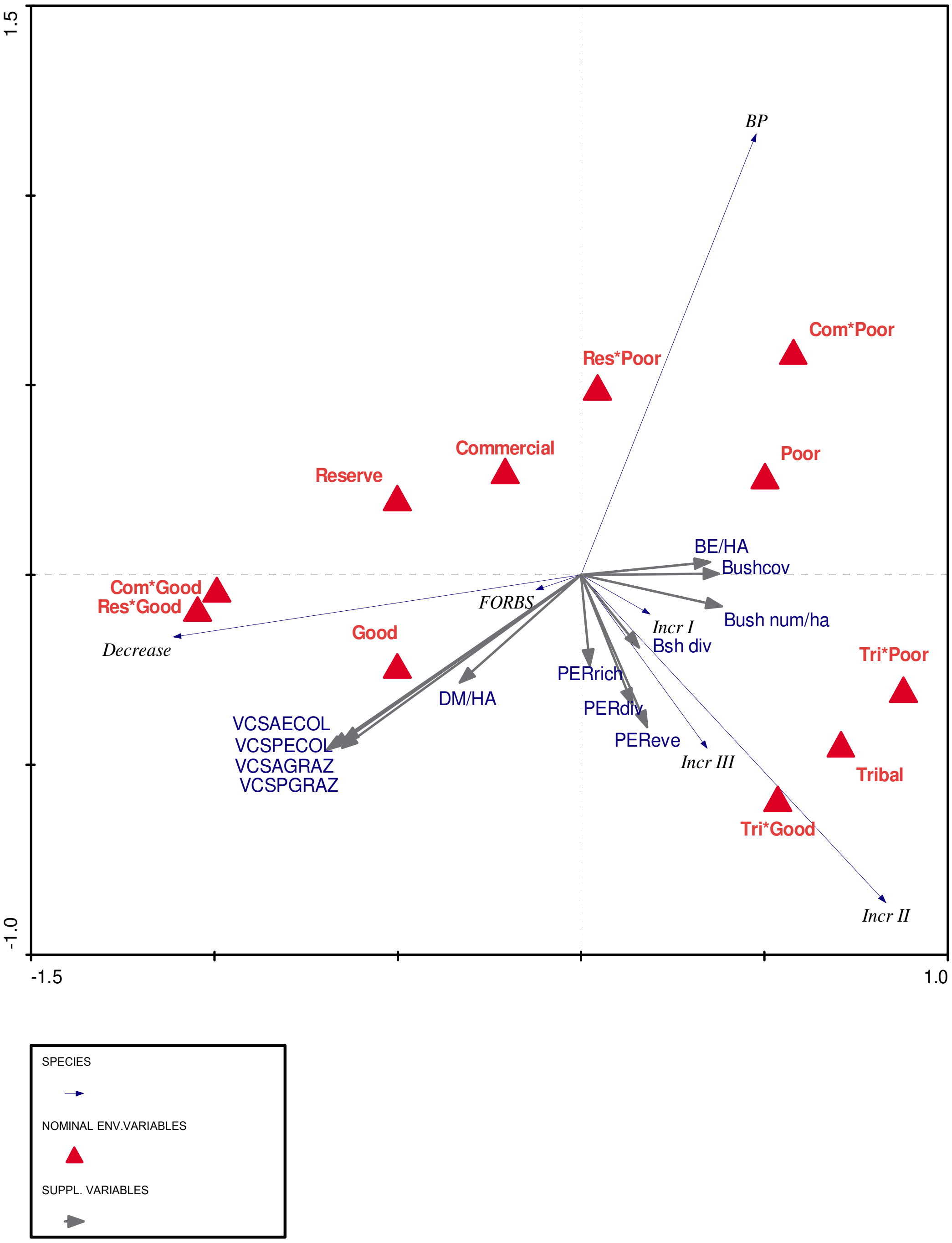


Fig. 4.28. A PCA ordination triplot showing the species-environment correlations for the "perennial" ecological interpretation.

The RDA revealed significant patterns for both the first (F = 56.563, P < 0.005) and all canonical axes (F = 17.216, P < 0.005) related to these environmental variables. The second axis explained 100% of the species-environmental relation (environmental data), 56.6% of the species data and 100% of the species-passive variables relation (Table 4.34). These statistics are a slight improvement from the "annual" interpretation. The first axis was most strongly represented by the "Good" (r = 0.5555), "Poor" (r = -0.5555) and Tribal (r = -0.5708) environmental variables, and the second axis with the same variables, although the r-values were lower (Fig. 4.29). Patterns between the two interpretation methods remained similar.

The passive variables that best explained the first axis were the rangeland condition indices' scores (r > 0.71) that were correlated with the "Good", Commercial-Good and Reserve-Good variables. These indices also had the highest r-values for the second axis (r > -0.58) (Table 4.34). The environmental variables, in order of inclusion in the Monte Carlo test, which significantly explained the species-environment relation, were: Tribal (F = 24.89, P < 0.005), "Good/Poor" (F = 32.75, P < 0.005), Tribal-Good/-Poor (F = 6.98, P < 0.005), Tribal (F = 7.06, P < 0.005) and Commercial-Poor/-Good (F = 2.99, P = 0.064).

Table 4.34. A RDA ordination for the "perennial" ecological index, showing eigenvalues and species-environment relations for the first four axes, as well as the environmental and passive variables explaining most of the species-environment relation for the first two axes. Variables explaining most of the variance are indicated in **bold**

Environmental data	**SPEC AX1**	**SPEC AX2**	**Passive data**	**SPEC AX1**	**SPEC AX2**
Commercial	0.1696	0.2336	BE/HA	-0.3937	0.0578
Tribal	**-0.5708**	**-0.3932**	Bushcov	-0.4226	0.0214
Reserve	0.4012	0.1596	Bush num/ha	-0.4328	-0.0906
Good	**0.5555**	-0.3412	VCSAGRAZ	**0.7159**	**-0.5892**
Poor	**-0.5555**	0.3412	VCSPGRAZ	**0.7188**	**-0.6104**
Com*Poor	0.498	-0.0466	DM/HA	0.364	-0.3779
Com*Good	-0.2835	0.3421	VCSAECOL	**0.7498**	**-0.6094**
Tri*Good	-0.4454	-0.1631	VCSPECOL	**0.765**	**-0.6183**
Tri*Poor	-0.2766	-0.3342	PERrich	-0.033	-0.3051
Res*Poor	0.5239	-0.077	PERreve	-0.2127	-0.5068
Res*Good	-0.0164	0.2788	PERdiv	-0.1663	-0.4329
			Bsh.div	-0.1828	-0.2385
Axes	**1**	**2**	**3**	**4**	
Eigenvalues	0.462	0.104	0	0	
Species-environment correlations	0.855	0.533	0.212	0.113	
Cumulative percentage variance					
of species data	46.2	56.6	56.6	56.6	
of species-environment relation (environmental)	81.5	100	100	100	
of species-environment relation (passive data)	64.4	100	100	100	

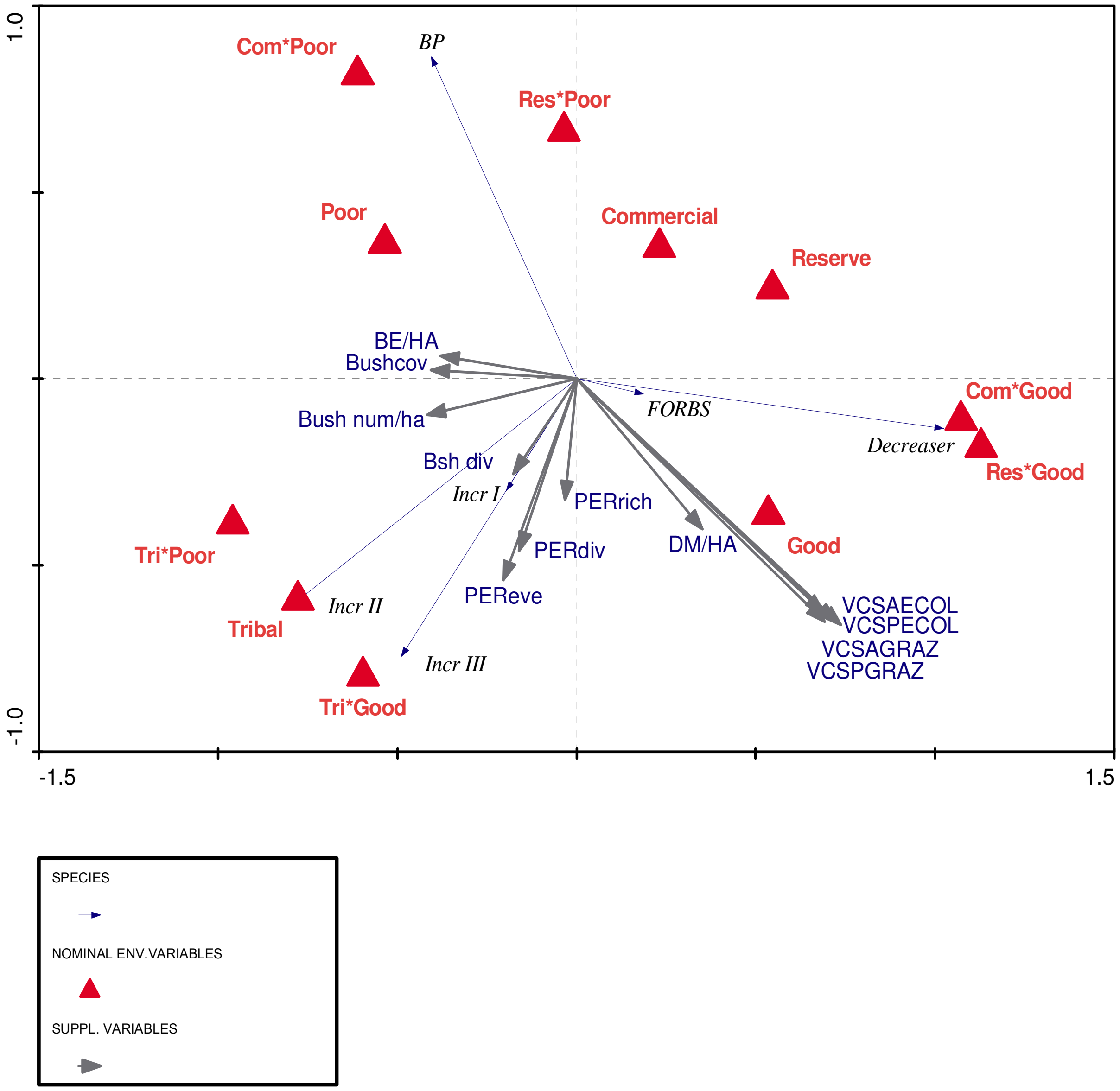


Fig. 4.29. A RDA ordination triplot showing the species-environment correlations for the "perennial" ecological interpretation**.**

C. Remarks

Statistics of the "perennial" interpretation were slightly higher than that of the "annual" interpretation, although both interpretations showed significantly high and similar species-environmental relations. These results will further be explored in the next section.

4.3.3.3 SIMPER analysis *between* land uses across all ecological classes

Since the ANOSIM tests (Section 4.3.3.1) and ordination (Section 4.3.3.2) patterns and species-environment relations were significant, SIMPER analyses were done in addition to the results of the ordinations. The SIMPER analysis as explanatory procedure indicated the classes contributing to most of the similarities within and dissimilarities between groups, as well as the average abundances of these ecological classes within a land use. The consistent distribution of these classes was used as measure to determine which of these classes could be identified as typical within a land use (hence an indicator classes associated within a land use) and as discriminating between land uses.

A. “Annual” interpretation

The classes contributing to 90% or higher of the similarities/dissimilarities within and between groups were established by means of the SIMPER analysis (Table 4.35). The Commercial land use had and average similarity of 44.58%, with the Decreasers and BP having the highest average abundances and contributing to 76.53% of cumulative similarity. These classes, followed by the Increaser II and Increaser III classes accounted for 100% of the similarity. The Decreaser (Sim/SD = 0.92) class was the most important typical class, though not that strong (Sim/SD < 1.0) (Table 4.35). The ecological classification showed that the Commercial sites were characterised by species indicative of a stable state (Decreasers) and BP characteristic of rangeland degradation (Fig. 4.27, Fig. 4.29, Fig. 4.30).

Table 4.35. SIMPER analyses for the “annual” ecological index, displaying ecological classes that contributed to the average similarities within each land.

Group Commercial - Average similarity: 44.58

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Decreaser	48.17	27.40	0.92	61.46	61.46
BP	19.34	6.72	0.53	15.06	76.53
Incr II	17.04	5.72	0.61	12.83	89.35
Incr III	13.78	4.75	0.67	10.65	100.00

Group Tribal - Average similarity: 68.63

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Incr II	61.46	51.42	3.20	74.93	74.93
Decreaser	22.07	12.51	1.19	18.23	93.16

Group Reserve - Average similarity: 57.99

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Decreaser	61.43	44.66	1.70	77.02	77.02
BP	18.56	6.28	0.62	10.84	87.86
Incr II	13.22	5.04	0.70	8.69	96.54

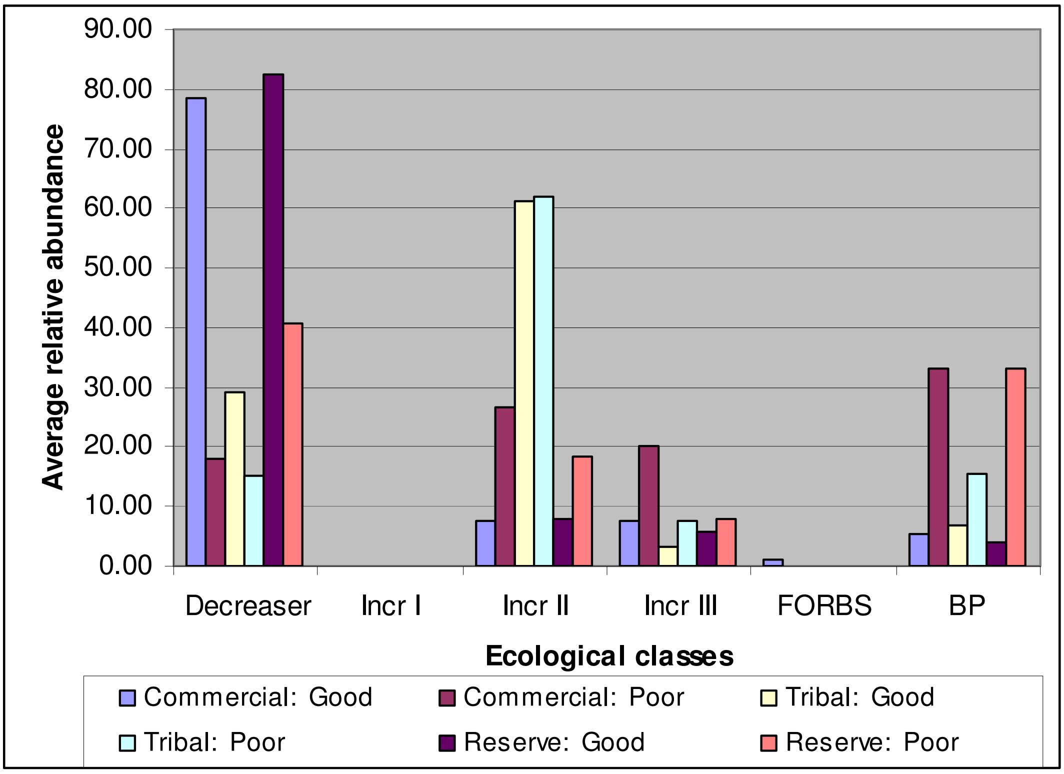


Fig. 4.30. Average relative abundances of the different ecological classes for the "annual" interpretation method.

The Tribal land use had an overall similarity of 68.63%, with Increaser II (abundant in relatively overgrazed rangeland) class being the most abundant, as well as being the most important typical class. This class, followed by the Decreaser class accounted for 93.16% of the similarity (Table 4.35, Fig. 4.30). Species associated with this land use was hence consistently (typical of overgrazed areas.

The Reserve land use had an average similarity of 57.99%, with the Decreaser group being the most abundant, followed by the BP and Increaser II classes, which accounted for 96.54% of the similarity. Results indicated that the Decreaser class was consistently the most typical class (Sim/SD = 1.7) (Table 4.35; Fig. 4.30). Decreaser species are typical of stable climax conditions.

The Commercial-Tribal groups had an average dissimilarity of 61.57%, 48.75% between the Commercial-Reserve groups and 61.32% between the Tribal-Reserve land uses. The Increaser II class was the most important discriminating class between the Commercial-Tribal groups, contributing to 39.27% of the dissimilarities, with an average dissimilarity of 24.18% (Table 4.36). The Increaser II class, followed by the Decreaser, BP and Increaser III classes contributed to 99.57% of the average dissimilarity. The Decreaser (Diss/SD = 1.46) class was the second most important discriminating class (Table 4.36).

For the Commercial-Reserve land uses, the Decreaser class not only had the highest average dissimilarity (19.5%), but also contributed to 40% of the cumulative difference, and was discriminating (Diss/SD = 1.39) between these two land uses. The Decreaser class, followed by the BP, Increaser II and Increaser III classes contributed to 99.46% of the dissimilarity. The BP was the second most important discriminating class (Diss/SD = 1.01). These results indicate that the discriminant classes were also the same as the typical classes within each land use, although the average abundance varied slightly. This supports results from the ordinations (Section 4.3.3.1 B) that these two land uses were closely correlated and did not differ significantly (Section 4.3.3.1 – ANOSIM) (Table 4.36).

The Increaser II class was discriminant between the Tribal-Reserve land uses (Diss/SD = 2.32), and contributed to 40.14% of the cumulative dissimilarities, and had the highest average dissimilarity (24.62%). It was followed by the Decreaser group (Diss/SD = 1.69) and BP (Diss/SD = 0.87) classes (Table 4.36).

Table4.36. SIMPER analyses for the "annual" ecological index, displaying ecological classes that contributed to the average dissimilarities between land uses.

Groups Commercial & Tribal - Average dissimilarity: 61.57

	Group Commercial	Group Tribal				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Incr II	17.04	61.46	24.18	2.16	39.27	39.27
Decreaser	48.17	22.07	19.46	1.46	31.60	70.87
BP	19.34	11.12	11.13	0.95	18.07	88.94
Incr III	13.78	5.35	6.55	0.68	10.63	99.57

Groups Commercial & Reserve - Average dissimilarity: 48.75

	Group Commercial	Group Reserve				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Decreaser	48.17	61.43	19.50	1.39	40.00	40.00
BP	19.34	18.56	12.19	1.01	25.01	65.01
Incr II	17.04	13.22	9.59	0.92	19.67	84.67
Incr III	13.78	6.84	7.21	0.76	14.79	99.46

Groups Tribal & Reserve - Average dissimilarity: 61.32

	Group Tribal	Group Reserve				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Incr II	61.46	13.22	24.62	2.32	40.14	40.14
Decreaser	22.07	61.43	22.04	1.69	35.95	76.09
BP	11.12	18.56	10.69	0.87	17.43	93.52

The “Poor” group had an average similarity of 46.54%, with the Increaser II class being the strongest typical class, as well as most abundant class contributing to 39.33% of the cumulative similarity. It was followed in contribution by the BP and Decreaser classes, which accounted cumulatively for 91.14% of the similarity (Table 4.37). These patterns will be investigated more in depth *within* each land use.

The “Good” group had and average similarity of 60.76%. The Decreaser class was the most typical class (Sim/SD = 1.74), with an average abundance of 63.22%, contributing to 77.25% of the cumulative similarities. It was followed by the Increaser II class, with cumulatively 94.81% of the similarity being explained (Table 4.37).

The two relative condition groups differed with 58.65%, with the Decreasers being the most important (Diss/SD = 1.66) discriminant class contributing to 39.2% of the cumulative dissimilarities. The Increaser II class was ranked as the second most important discriminant group (Diss/SD = 1.31), and contributed to 28.21% of the dissimilarities (Table 4.37).

Table 4.37. SIMPER analyses for the “annual” ecological index, displaying ecological classes that contributed to the average similarities within and dissimilarities between the “Good” and “Poor” rangeland condition groups.

Group Poor - Average similarity: 46.54

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Incr II	35.59	18.30	0.83	39.33	39.33
BP	27.24	12.42	0.76	26.69	66.01
Decreaser	24.56	11.69	0.88	25.13	91.14

Group Good - Average similarity: 60.76

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Decreaser	63.22	46.94	1.74	77.25	77.25
Incr II	25.55	10.67	0.69	17.56	94.81

Groups Poor & Good - Average dissimilarity: 58.65

	Group Poor	Group Good				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Decreaser	24.56	63.22	22.99	1.66	39.20	39.20
Incr II	35.59	25.55	16.54	1.31	28.21	67.41
BP	27.24	5.44	12.97	1.02	22.12	89.53
Incr III	11.85	5.46	5.95	0.72	10.14	99.67

B. “Perennial” interpretation

SIMPER analyses showed an average similarity of 48.48% for the Commercial land use, 67.99% for the Tribal group and 61.1% for the Reserve land use, which is slightly higher for the Commercial and Reserve land uses compared to the “annual” interpretation (see Appendix 4.7 for the “perennial” interpretation). This can be ascribed to the exclusion of the annual life-form from the analyses. The Tribal land use was primarily characterised by weak perennial life-forms, and hence did not show a significant change in similarity. The average dissimilarities between the Commercial-Tribal uses were 58.85%, 44.94% between the Commercial-Reserve groups and 59.21% between the Tribal-Reserve land uses (Appendix 4.7). Average relative abundances for the three land uses, displaying the different ecological classes for the “perennial” interpretation method, are illustrated in Fig. 4.31.

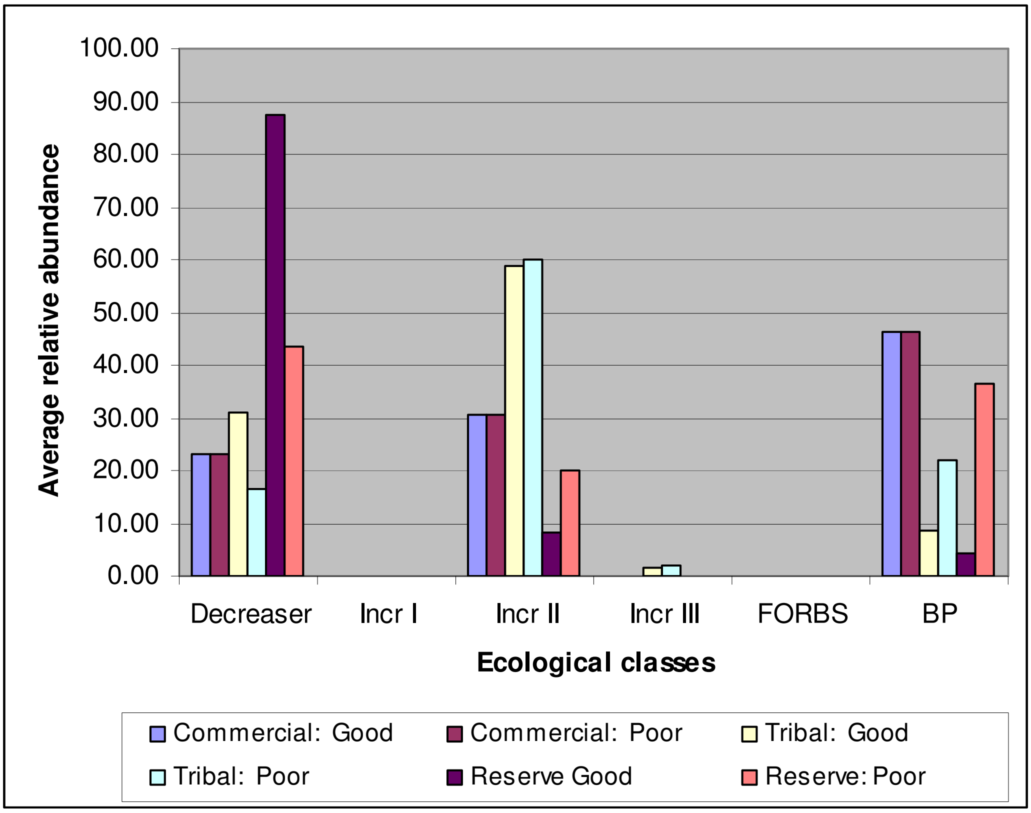


Fig. 4.31. Average relative abundances for the different ecological classes for the “perennial” interpretation method.

The Decreaser group had the highest abundance for the Commercial group, followed by the BP and Increaser II classes. Cumulatively, these groups contributed to 91.14% of the similarity. The Decreaser class was the most typical group (Sim/SD = 1.05) (Appendix 4.7). These results are consistent with those of the “annual” interpretation.

The Tribal group was best characterised by the Increaser II group, followed by the Decreaser class, which cumulatively accounted for 91.51% of the similarity. The Increaser II group was the most important typical class (Sim/SD = 2.72). These results are similar to that of the “annual” interpretation (Appendix 4.7).

The Reserve was best represented and typified by the Decreaser group (Sim/SD = 1.75) followed by the BP group, which cumulatively contributed to 91.15% of the similarity. Results between both interpretation methods were similar (Appendix 4.7).

The Decreaser class, followed by the Increaser II, BP and Increaser I classes contributed to 98.25% of the differences between the Commercial and Tribal land uses. The Increaser II class, although contributing second most to the dissimilarities, was consistently the most typical class (Diss/SD = 1.52), followed by the Decreaser group (Appendix 4.7).

The average dissimilarity between the Commercial and Tribal groups was best explained by the Increaser II class, followed by the Decreaser and BP classes which cumulatively contributed to 98.07% of the dissimilarity. The Increaser II group was indicated as the most important discriminating class (Diss/SD = 2.05) (Appendix 4.7).

Differences between the Tribal-Reserve land uses were primarily accounted for by the Increaser II group, followed by the Decreaser and BP classes. These groups cumulatively accounted for 98.51% of the dissimilarity. The Increaser II group was the most important discriminating class (Diss/SD = 2.14), followed by the Decreaser and then Increaser I class (Appendix 4.7).

The “Poor” group had an average similarity of 51.05%, with the Increaser II group being the most abundant, followed by the BP and the Decreaser class. These classes contributed to 99.85% of the similarity, with the Decreaser class consistently being the most important typical group, although not that pronounced (Sim/SD = 0.98, Sim/SD < 1.0) (Appendix 4.7).

The average similarity of the “Good” group was 63.53%, with the Decreaser class being the most abundant, highest contributing typical class (Sim/SD = 1.74), followed by the Increaser II class, which cumulatively accounted for 94.81% of the dissimilarity (Appendix 4.7). These results agree with that of the “annual’ interpretation, although the similarities of this group was higher. This can be ascribed to the exclusion of the annual life-form and the inclusion of the nearest perennial species when an annual species was pointed out.

The average dissimilarity between the “Good” and “Poor” groups was 59.21%, with the Increaser II class, followed by the Decreaser group and BP accounting for 98.51% of the dissimilarity. The Increaser II group was the most important discriminating class (Diss/SD = 2.14) (Appendix 4.7). This is similar to the “annual” interpretation results.

C. Remarks

Both interpretation methods were informative and complementary to the ANOSIM tests and ordinations presented in Sections 4.3.3.1 – 4.3.3.2. Statistics for the "perennial" interpretation were higher than that of the "annual" interpretation, ascribing this to the "removal" of the annual life-form and the indication of the nearest perennial species in its place. However, it was evident that SIMPER for the relative condition groups when averaged across all land uses, was not informative. Analyses within each land use as a function of the relative condition groups need to be done in order to identify whether different ecological classes are related to the different relative rangeland condition groups. The Increaser I, II and III classes were associated with low to intermediate conditions along the rangeland condition gradient for the larger study area.

4.3.3.4 ANOSIM for each separate ecological class *between* land uses

SIMPER analyses, as explanatory procedures, were performed in Section 4.3.3.3 to establish which ecological classes were associated with *each* land use. However, the *significance* of these results/patterns need to be verified, and are presented below.

A. "Annual" interpretation

The Decreaser class showed significant intermediate-low differences between the Commercial-Tribal groups (r = 0.328 P < 0.001), intermediate differences between the Tribal-Reserve (0.403, P < 0.001) land uses, and no significant difference between the Commercial-Reserve land uses (r = 0.065, P > 0.1). The "Good" and "Poor" condition groups differed significantly (r = 0.316, P < 0.001). Hence, results suggest that the Decreaser group was associated with the relative "Good" (Section 4.3.3.1 – 4.3.3.3) variable, which was related to the Reserve-/Commercial-Good variables. This explains why no difference existed between these two land uses based on the Decreaser class. The Tribal land use differed significantly from the other two land uses, suggesting and supporting previous results that this land use was not associated with the same distribution along the range condition gradient for the larger study area (Fig. 4.27).

There were statistically no significant differences between any of the land use groups (P > 0.1) based on the Increaser I class. The differences between the relative condition groups (r = -0.003, P > 0.1) were not significant. This indicates that the Increaser I class represents sites distributed along midranges on the range condition gradient for the larger study area (Fig. 4.27).

The Increaser II group showed significant intermediate differences between the Tribal-Reserve (r = 0.509, P < 0.001) and Commercial-Tribal (r = 0.447, P < 0.001) groups. There were no significant differences between the Commercial-Reserve land uses (r = -0.04, P > 0.1) or the relative condition groups (r = 0.002, P > 0.1). This ecological class also occupied a midrange position on the larger range condition gradient, but was more associated with the Tribal land use. This resulted in the large significant differences between the Tribal and other land uses. The Increaser II class was slightly more abundant in the Commercial than the Reserve land use, resulting in the smaller differences between the Commercial-Tribal land uses than the Reserve-Tribal land uses (Fig. 4.27).

For the Increaser III class, results showed no statistical significant differences between the Commercial-Tribal ($r = 0.027$, $P > 0.1$), Commercial-Reserve ($r = 0.005$, $P > 0.1$) or the Tribal-Reserve land uses ($r = 0.034$, $P > 0.1$). The test for differences between the relative condition groups also was not significant ($r = 0.009$, $P > 0.1$). Although this ecological class showed a stronger association with the Reserve and Commercial land uses (relative “Poor” sites), the differences between these two groups and between the Tribal land use were not significant (Fig. 4.27). The Increaser III class was thus less informative about differences between the relative “Good” and “Poor” extremes for the larger study area, suggesting that it was indicative of a low-intermediate rangeland condition range for the total study area.

The bare patches were discussed under the grazing index, and the same statistics discussed there apply within this section as well. Discussions will thus not be repeated again.

B. “Perennial” interpretation

Differences between the Commercial-Tribal ($r = 0.31$, $P < 0.001$) and Tribal-Reserve land uses ($r = 0.433$, $P < 0.001$) based on the Decreaser class were significant (intermediate-low), with no significant differences between the Commercial-Reserve groups ($r = 0.01$, $P > 0.1$). The test for differences between relative condition groups, when averaged across all land use groups, was significant but statistically relatively low ($r = 0.313$, $P < 0.001$). Patterns were similar to that of the “annual” interpretation.

For the Increaser I group, there was no statistical difference between any of the land uses ($P > 0.1$) or between the rangeland “Good” and “Poor” group ($r =-0.003$, $P > 1$). This is consistent with the “annual” interpretation’s results.

The Increaser II group showed intermediate differences between the Commercial-Tribal land uses ($r = 0.413$, $P < 0.001$), the Tribal-Reserve groups ($r = 0.464$, $P < 0.001$). There were no significant differences between the Commercial-Reserve land uses ($r = -0.025$, $P > 0.1$). There was no significant difference between the rangeland “Good” and “Poor” condition groups ($r = 0.01$, $P > 0.1$) when averaged across all land uses. The patterns are similar to that of the “annual” interpretation, with the statistics being lower for the “perennial” interpretation for the Tribal-Commercial land uses, but higher for the Reserve-Tribal land uses. This can be ascribed to the removal of the annual life-form, and inclusion of the nearest perennial/weak perennial species, resulting in the Commercial and Tribal land uses to be more similar in that regard (with the inclusion of Increaser II species for both land uses due to the nearest plant-point surveys), but with the Reserve showing more pronounced differences, possibly due to higher differences in the relative abundances of the Increaser II group (highest abundance in the Tribal land use) between these Reserve-Tribal land uses.

The Commercial-Tribal and Tribal-Reserve land uses ($r = 0.306$, $P < 0.001$) showed significant though relatively low differences based on the Increaser III class, while there was no significant difference for the Commercial-Reserve groups ($r = 0$, $P > 0.1$). The test for differences between the relative condition groups, was insignificant ($r = -0.01$, $P > 0.1$). These results differed significantly from that of the "annual" interpretation, which indicated no significant differences between the land uses or relative condition groups. These results suggest that the Commercial and Reserve land uses are very similar to each other based on this ecological class for the "perennial" interpretation, but both differed significantly from the Tribal land use. The Increaser III class, typical of overgrazing, was in this interpretation more strongly associated with the Tribal land use and not any more with the Reserve-/Commercial-Poor groups. The "perennial" interpretation, reflecting on the longer-term ecological state of the rangeland condition, hence indicated large differences due to the inclusion of the nearest perennial life-form (which was associated with the Commercial and Reserve land uses) when an annual life-form was pointed out. However, for the range condition gradient for the total study area, the Increaser III group was still associated with low-midrange conditions (Fig. 4.29). These results will be investigated in more detail in Section 4.3.3.5.

C. Remarks

The "perennial" interpretation method in general indicated larger differences between the Commercial-Tribal and Reserve-Tribal land uses, suggesting more pronounced dissimilarities between these land uses than indicated with the "annual" interpretation method. Based on range condition, the Decreaser class and the BP class (discussed in Section 4.3.2 – grazing index) represented the "Good" and "Poor" range condition extremes respectively. This gradient was only slightly more pronounced with the "perennial" interpretation than with the "annual" interpretation. Although the patterns between the two interpretation methods were very similar, the results suggest that the "perennial" interpretation gives a slightly more accurate indication of the actual "state of health" of the rangelands. Hence, climatic variability ("annual" interpretation) did not necessarily result in major differences between the two interpretation methods, but it did not reflect the slightly more pronounced range condition gradient and hence differences between the relative "Good" and "Poor" groups, averaged across all land uses, as the "perennial" interpretation did. The relative abundance of the Increaser III group did not differ significantly between the three land uses according to the "annual" interpretation method, although it was indicated by the ordination (Fig. 4.27 and Fig. 4.29) to be associated more with the Reserve-/Commercial-Poor groups. However, results differed significantly from that of the "perennial" survey method, which showed that the Increaser III group was consistently more typical of the Tribal land use. This can be ascribed to the inclusion of the nearest perennial species in the place of the annual species during the nearest plant-point survey technique, with these perennial species being relatively more abundant within the Commercial and Reserve land uses, and primarily being Decreaser species.

4.3.3.5 ANOSIM and SIMPER analyses *within* land uses across all the ecological classes, based on relative condition groups

From the analyses discussed above, a rangeland condition gradient for the larger study area was evident. Both the Reserve and Commercial land uses were represented at both the relative “Good” and “Poor” extremes. The Tribal land uses showed only one cluster associated with ecologically intermediate ranges. The purpose of this section is to establish *within* each land use, whether significant range condition gradients related to different ecological classes could be detected. Should this be the case, it should serve as directive that a “Key assessment matrix” (see Chapter 9, Concluding remarks) should include analyses at this level for rangeland assessment and monitoring purposes within the different land uses. This will imply that a generalised rangeland assessment model across all land uses, will not be appropriate.

A. “Annual” interpretation

Table 4.38. SIMPER analyses for the “annual” ecological index, displaying ecological classes that contributed to the average similarities within and dissimilarities between the Commercial “Good” and “Poor” rangeland condition groups.

Group Poor - Average similarity: 41.45

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
BP	33.13	18.27	1.01	44.08	44.08
Incr II	26.50	9.90	0.61	23.89	67.96
Incr III	20.01	6.87	0.68	16.59	84.55
Decreaser	18.03	6.40	0.75	15.45	100.00

Group Good - Average similarity: 77.90

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Decreaser	78.31	70.29	5.38	90.23	90.23

Groups Poor & Good - Average dissimilarity: 69.25

	Group Poor	Group Good				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Decreaser	18.03	78.31	31.35	2.57	45.26	45.26
BP	33.13	5.55	15.46	1.30	22.32	67.59
Incr II	26.50	7.58	12.43	1.01	17.95	85.54
Incr III	20.01	7.55	9.54	0.78	13.77	99.31

The one-way ANOSIM between the Commercial "Good" and "Poor" groups was of intermediate range (r = 0.575, P < 0.001) (Table 4.38; Fig. 4.32). The Commercial relative "Poor" group had an average similarity of 41.45%, with the BP, followed by the Increaser II, Increaser III and Decreaser classes contributing to 100% of the similarity. The BP was consistently the most typical group (Sim/SD = 1.01). The Commercial "Good" had an average similarity of 77.9%, and was best represented by the Decreaser class, which accounted for 90.23% of the similarity. The Decreaser class was thus typical (Sim/SD = 5.38) of the Commercial "Good" rangeland condition group. The Commercial "Good" and "Poor" groups had an average dissimilarity of 69.25%, with the Decreasers, followed by BP, Increaser II and Increaser III classes accounting for 99.31% of the dissimilarity. The Decreaser class Diss/SD = 2.57) was the most important discriminating class (Table 4.38; Fig. 4.32). The ANOSIM thus indicated that a rangeland condition gradient existed within the Commercial land use, with the different ecological classes discussed above being typical of each relative condition group.

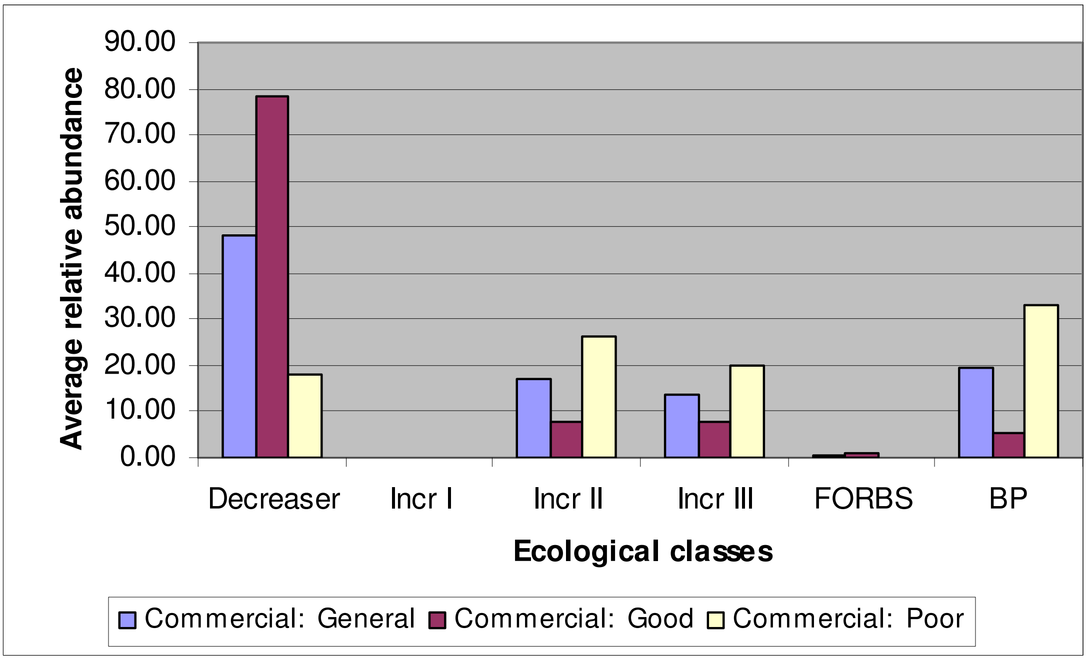


Fig. 4.32. Average relative abundances for the "annual" ecological classes for the Commercial land use.

The one-way ANOSIM indicated that the Tribal "Good" and "Poor" rangeland condition variables did not differ significantly (r = 0.009, P > 0.1). Hence, the SIMPER analyses are not discussed in depth but only presented in Table 4.39, since differences between these two groups were not significant. This supports previous results that sites within the Tribal land use had similar rangeland condition scores for both the relative "Poor" and "Good" sites, which were of intermediate rangeland condition for the total Tribal land use (Table 4.39). The Increaser II group, indicative of overgrazing, was both typical and discriminant within and between relative condition groups. The Decreaser class was the second most important discriminating class (Table 4.39). The ecological classes for the Tribal land use are illustrated in Fig. 4.33. Since the Increaser I class had neglectably low relative abundances, it is not visible in Fig. 4.33 (refer to Appendix 4.6).

Table 4.39. SIMPER analyses for the "annual" ecological index, displaying ecological classes that contributed to the average similarities within and dissimilarities between the Tribal "Good" and "Poor" rangeland condition groups.

Group Poor - Average similarity: 66.29

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Incr II	61.90	51.16	2.85	77.19	77.19
Decreaser	15.09	7.68	0.95	11.59	88.77
Incr III	7.58	3.91	0.99	5.90	94.68

Group Good - Average similarity: 71.68

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Incr II	61.03	50.98	3.69	71.13	71.13
Decreaser	29.05	18.48	1.66	25.78	96.91

Groups Poor & Good - Average dissimilarity: 31.69

	Group Poor	Group Good				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Decreaser	15.09	29.05	10.06	1.31	31.74	31.74
Incr II	61.90	61.03	9.69	1.33	30.57	62.31
BP	15.43	6.82	8.78	0.75	27.70	90.01

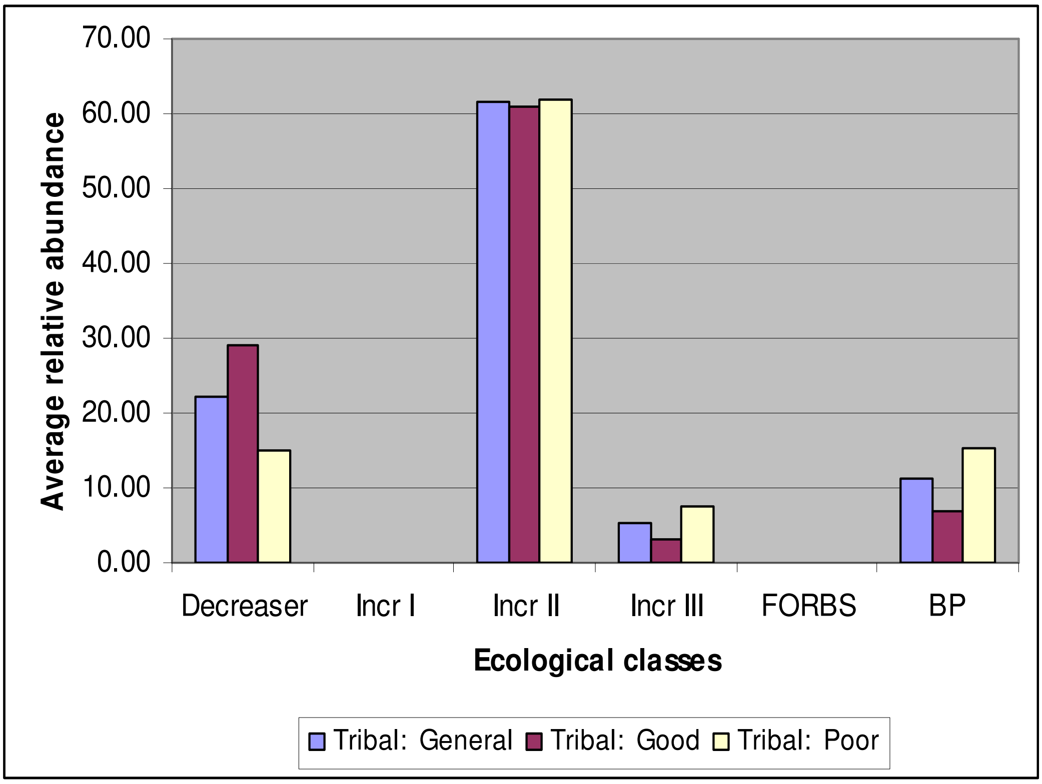


Fig. 4.33. Average relative abundances for the "annual" ecological classes for the Tribal land use.

The one-way ANOSIM for the Reserve indicated that intermediate-high differences existed between the relative "Good" and "Poor" variables (r = 0.412, P < 0.001). The Reserve "Poor" had an average similarity of 51.58%, with the Decreaser class, followed by the BP and Increaser II classes accounting for 95.7% of the similarity. The Decreaser class was the most important typical class (Sim/SD = 1.39). The Reserve "Good" group had an average similarity of 81.5%, and was indicated by the Decreaser group, which accounted for 91.37% of the similarity (Table 4.40; Fig. 4.34). The Decreaser class was thus most typical of this group (Sim/SD = 7.03). The average dissimilarity between the "Good" and "Poor" groups was 49.86%, with the Decreaser group accounting for 43.6% of the dissimilarity, followed by the BP and Increaser II groups, which cumulatively contributed to 90.46% of the dissimilarity. The Decreaser group was the most important discriminating class (Table 4.40). As with the Commercial land use, a significant range condition gradient existed within the Reserve land use, with the Decreaser class being typical of each rangeland condition group, although it was more strongly associated with the Reserve-Good group. The Decreaser class is characteristic of rangeland with stable climax grasses, which decrease with over- or undergrazing

Table 4.40. SIMPER analyses for the "annual" ecological index, displaying ecological classes that contributed to the average similarities within and dissimilarities between the Reserve "Good" and "Poor" rangeland condition groups.

Group Poor - Average similarity: 51.58

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Decreaser	40.55	25.80	1.39	50.03	50.03
BP	33.18	16.96	1.09	32.88	82.91
Incr II	18.38	6.60	0.63	12.79	95.70

Group Good - Average similarity: 81.50

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Decreaser	82.32	74.47	7.03	91.37	91.37

Groups Poor & Good - Average dissimilarity: 49.86

	Group Poor	Group Good				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Decreaser	40.55	82.32	21.74	1.78	43.60	43.60
BP	33.18	3.94	14.95	1.10	29.99	73.58
Incr II	18.38	8.05	8.41	1.00	16.87	90.46

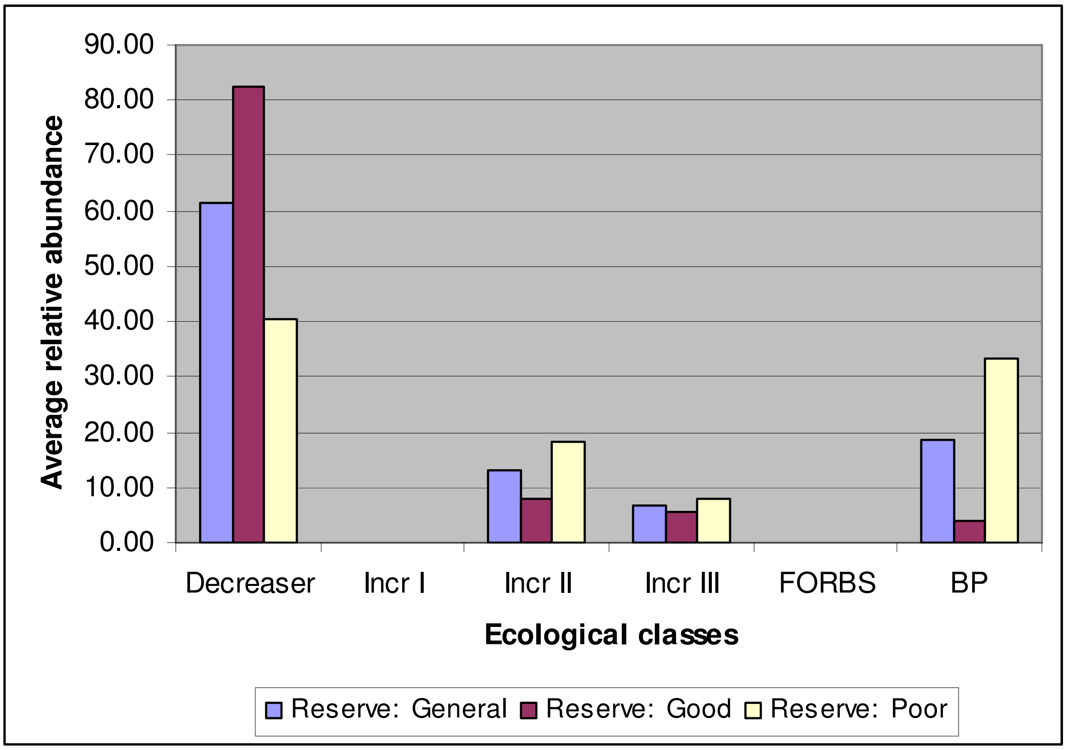


Fig. 4.34. Average relative abundances for the "annual" ecological classes for the Reserve land use.

The ecological index ANOSIM results were consistent with that of the grazing index, except that the differences between the relative condition groups across all ecological groups within a land use were higher than with the grazing classification index.

B. "Perennial" interpretation

The one-way ANOSIM indicated intermediate-high differences between the Commercial "Good" and "Poor" rangeland condition groups ($r = 0.623$, $P < 0.001$). This statistic is higher than the "annual" interpretation, indicating larger actual ecological (long-term degradation effects) differences between the relative condition extremes than the "annual" (seasonal) interpretation did. The average similarity of the Commercial "Poor" group was 49.37%, with the BP and Increaser II and Decreaser classes cumulatively contributing to 100% of the similarity (Appendix 4.8). The BP was the most important typical group (Sim/SD = 1.25). The "Good" group had an average similarity of 81.95%, with the Decreaser class contributing to 94.07% of the similarity. The Decreaser class was then also the most important typical class (Sim/SD = 5.49). The average dissimilarity between the Commercial "Good" and "Poor" groups was 67.27%, with the Decreaser group, followed by the BP and Increaser II groups, accounting for 94.31% of the dissimilarity. The Decreaser group was the strongest discriminant group (Diss/SD = 2.52) (Appendix 4.8). These results are similar to that of the "annual" interpretation. The ecological classes for the Commercial "perennial" interpretation are illustrated in Fig. 4.35.

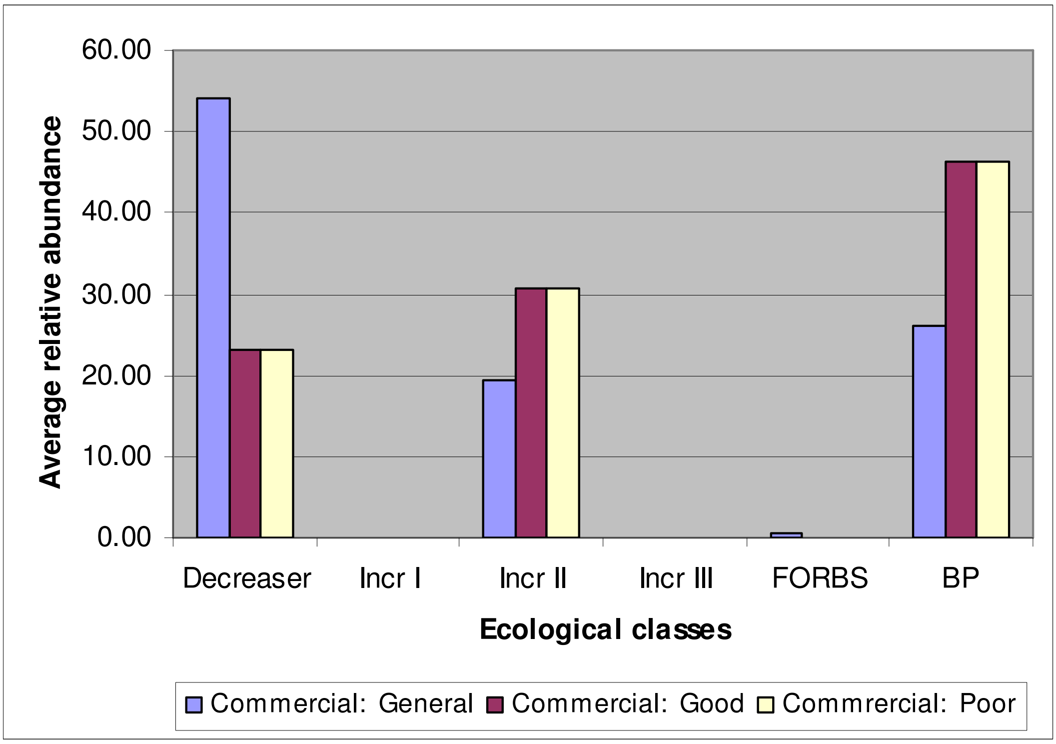


Fig. 4.35. Average relative abundances for the "perennial" ecological classes for the Commercial land use.

There was no significant difference between the relative "Good" and "Poor" Tribal groups ($r = 0.002$, $P > 0.1$). The Tribal ecological classes are presented in Fig. 4.36. The Tribal "Poor" group had an average similarity of 65.01%, with the Increaser II group, Decreaser and BP groups contributing to 98.85% of the similarity (Appendix 4.8). The Increaser II group, which had the highest abundance and contribution, was consistently the most typical group (Sim/SD = 2.28). The Tribal "Good" group had an average similarity of 72.08%. The Increaser II and Decreaser groups contributed to 95.59% of the similarity. The Increaser II group was indicated as the most important typical group (Sim/SD = 3.56). The average dissimilarity between the "Good" and "Poor" groups was 32.52%, with the Decreaser, Increaser II and BP classes contributing to 96.65% of the similarity. The Increaser II group (Diss/SD = 1.34) was consistently the strongest discriminant class. Hence, results are similar to that of the "annual" interpretation, showing that the relative rangeland condition groups were relatively similar between the "annual" and "perennial" interpretations when classified according to the ecological index.

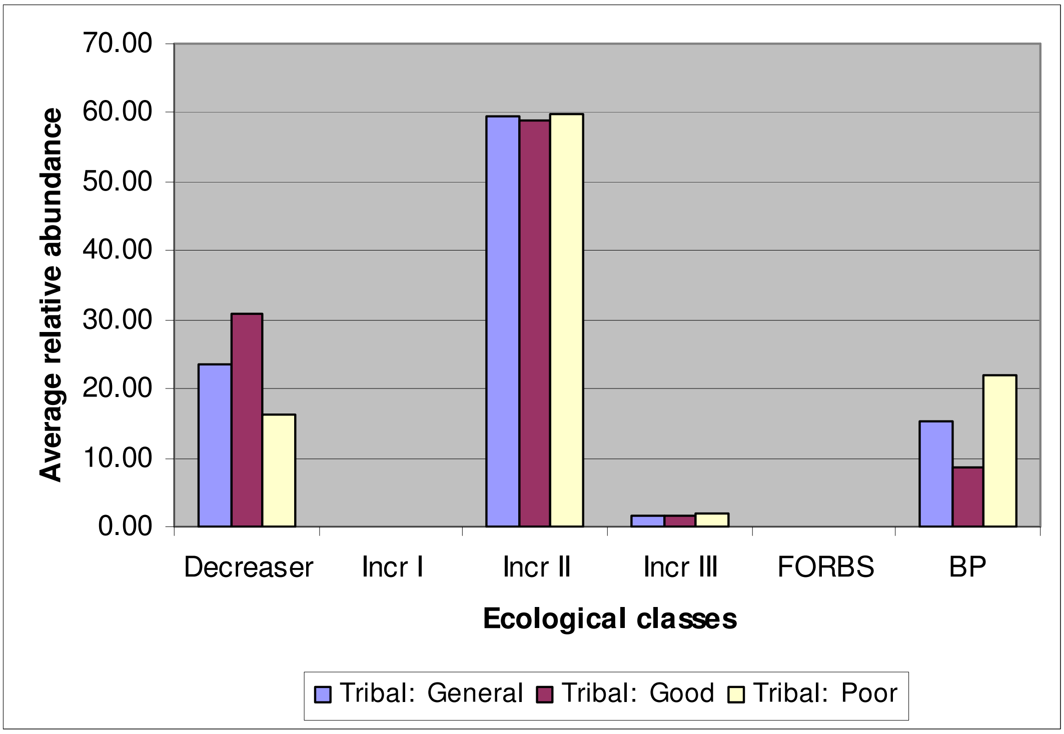


Fig. 4.36. Average relative abundances of the “perennial” ecological classes for the Tribal land use.

The Reserve differed intermediately between the relative “Good” and “Poor” groups, as indicated by the one-way ANOSIM (r = 0.446, P < 0.001), with the differences being more pronounced than in the “annual” interpretation, for the same reasons as discussed above for the Commercial land use. The Reserve “Poor” group had an average similarity of 55.03%, with the Decreaser, BP and Increaser II classes contributing to 100% of the similarity (Appendix 4.8). The Decreaser class was consistently most typical of this group (Sim/SD = 1.5). The Reserve “Good” group had and average similarity of 87.26%. The Decreaser class contributed to 93.64% of the similarity, with the Decreaser group thus being most typical (Sim/SD = 8.5) of the “Good” group. The average dissimilarity between the “Poor” and “Good” groups was 48.1%. The Decreaser class, BP and Increaser II classes contributed to 100% of the dissimilarity. The Decreaser group was the most important discriminating class between the “Good” and “Poor” groups (Appendix 4.8). These patterns are congruent with that of the “annual” interpretation. The Reserve “perennial” ecological classes are illustrated in Fig. 4.37.

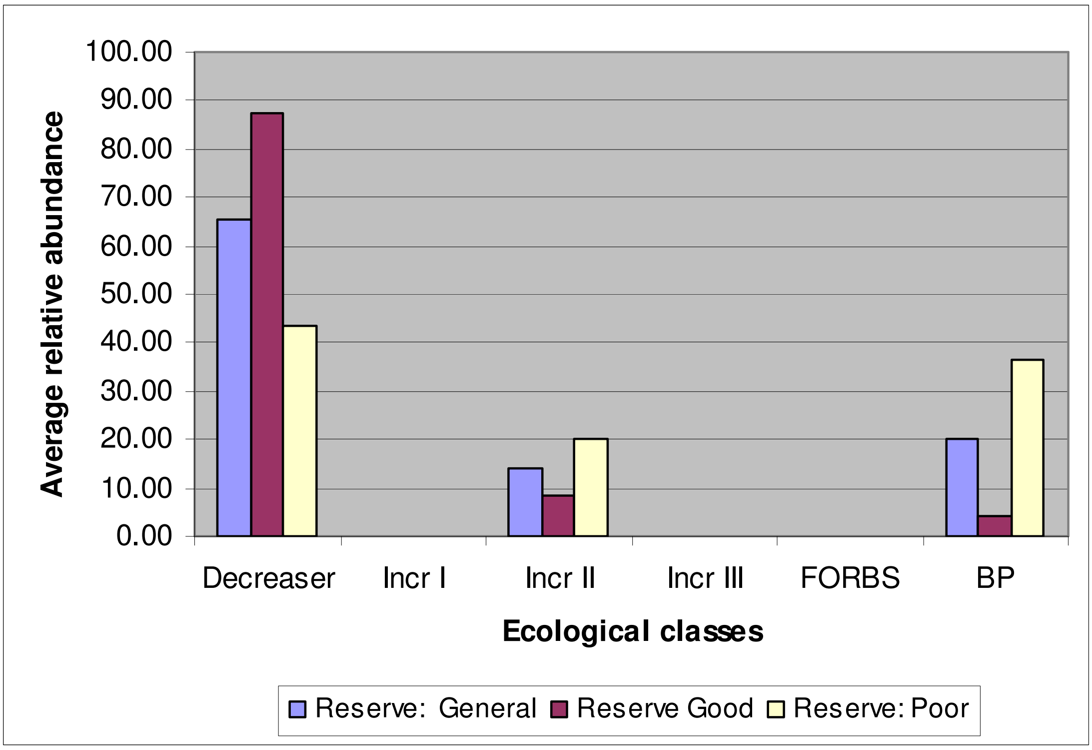


Fig. 4.37. Average relative abundances of the "perennial" ecological classes for the Reserve land use.

C. Remarks

Both interpretation methods showed congruent patterns. However, statistically the "perennial" interpretation displayed larger differences between the relative "Good" and "Poor" groups within the Commercial and Reserve land uses, compared to the "annual" interpretation method. This is indicative of a stronger range condition gradient as was indicated by the "perennial" interpretation, suggesting that this is possibly a more appropriate method of quantifying the longer-term rangeland condition. The statistics were also higher than with the grazing index. The most appropriate index method (if any) as reflected by the rangeland condition score, will be discussed in Section 4.3.5.

Both interpretation methods indicated that the Tribal land use was not correlated with the rangeland condition gradient, supporting the results discussed in previous sections that this land use is associated with the midranges of the larger rangeland condition gradient for the total study area, with no statistically significant differences between the relative "Good" and "Poor" groups within the Tribal land use.

It was further evident from both the "annual" and "perennial" interpretation methods that differences between the Commercial "Good" and "Poor" groups were most pronounced, indicative of the relatively most pronounced degradation gradient within this land use. This tendency was second most pronounced within the Reserve land use.

4.3.3.6 ANOSIM for each ecological class *within* each land use

Results (SIMPER and ANOSIM) for the different ecological classes confirmed that some of the ecological classes were positively related to a range condition gradient, as was discussed in the sections above. SIMPER analyses also indicated which ecological classes *within* a land use were typical of each relative condition. This is especially useful for rangeland monitoring purposes not only for the larger study area, but also within each land use, since the land uses statistically displayed different characteristics. It is important to embrace these differences, since it may be directive of different rangeland management strategies that need to be applied within the separate land uses. A generalised model across all land uses will simply ignore the different patterns and processes operating within each land use.

Hence, this section seeks to statistically verify the SIMPER results presented above (Section 4.3.3.5).

A. "Annual" interpretation

For the Commercial land use, differences between the relative condition groups were intermediate for the Decreaser class ($r = 0.383$, $P < 0.001$) and insignificant for the Increaser I ($r = 0.0$, $P > 0.1$, Increaser II ($r = 0.054$, $P > 0.1$) and Increaser III classes ($r = -0.028$, $P > 0.1$). However, there was an intermediate difference between the condition groups for the BP class ($r = 0.469$, $P < 0.001$). These results suggest that the Decreaser group (as supported by the SIMPER analyses and RDA ordination in the sections above) is indicative of the relative "Good" rangeland condition within this land use and the BP indicative of the relative "Poor" extreme. The other classes were associated with intermediate rangeland conditions for this land use.

Tests between the Tribal "Good" and "Poor" variables for the Decreaser ($r = 0.062$, $P > 0.1$), Increaser I ($r = -0.008$, $P > 0.1$), Increaser II ($r = -0.05$, $P > 0.1$), Increaser III ($r = 0.108$, $P > 0.05$) and the BP ($r = -0.006$, $P > 0.1$) classes were not significant. Once again it supports all the results discussed so far in this section, namely that the Tribal land use had only one rangeland condition type, which occupied low-intermediate places along the range condition gradient for the larger study area.

For the Reserve, the Decreaser group showed an intermediate difference between these two condition extremes ($r = 0.362$, $P < 0.001$), no significant differences between the rangeland condition extremes for the Increaser I class ($r = 0.0$, $P > 0.1$), and the BP ($r = 0.289$, $P < 0.001$) was intermediate-low. There was also no significant difference between the "Good" and "Poor" variables for the Increaser II ($r = 0.03$, $P > 0.1$) or Increaser III ($r = -0.053$, $P > 0.1$) classes. These results suggest that the Decreaser class was associated with the Reserve-Good extreme, and that the BP was indicative of the Reserve-Poor extreme. The Increaser II and III groups occupied intermediate ranges on the range condition gradient within this land use, hence being insignificant between the relative "Good" and "Poor" sites.

B. “Perennial” interpretation

Differences between the rangeland condition groups for the Commercial Decreaser class (r = 0.466, P < 0.001) and BP (r = 0.545, P < 0.001) were of intermediate ranges. The Increaser I (r = 0.0, P > 0.1), Increaser II (r = 0.068, P > 0.1) and Increaser III (r = 0.0, P > 0.1) classes showed no significant differences between the two rangeland condition extremes. Patterns were similar to that of the “annual” interpretation, although the higher r-statistics indicated that the rangeland gradient, reflecting the longer-term state of health of the rangelands, was longer within the “perennial” interpretation.

Differences between the Tribal condition groups were not significant for the Decreaser (0.063, P > 0.1), Increaser I (r = - 0.008, P > 0.1), Increaser II (r = -0.012, P > 0.1), Increaser III (r = -0.035, P > 0.1) or BP (r = 0.013, P > 0.1) classes. These results and patterns are consistent with the “annual” interpretation method.

The Reserve’s Decreaser class differed intermediately (r = 0.404, P < 0.001) between the relative condition groups, whereas the BP class (r = 0.298, P < 0.001) showed significant though relatively low differences. There were no significant differences between the “Good” and “Poor” groups for the Increaser I (r = 0.0, P > 0.1), Increaser II (r = -0.027, P > 0.1) and Increaser III (r = 0.0, P > 0.1) classes. These statistics were also an improvement to those of the “annual” interpretation, suggesting that the rangeland degradation was longer and the differences between the “Good” and “Poor” relative condition variables more pronounced when reflecting on this land use’s state of health.

C. Remarks

Patterns among both interpretation methods were congruent with each other. However, the “perennial” interpretation method showed larger differences between the relative “Good” and “Poor” extremes within the Commercial as well as the Reserve land uses, indicating a larger rangeland condition gradient. Ecological classes indicative of each of these relative condition groups within each land use, were presented above. The Tribal land use showed for both interpretation methods, as also discussed for the species compositional data and grazing index, no significant differences between the relative “Good” and “Poor” groups within this land use. It was associated with low-midrange conditions along the rangeland condition gradient for the larger study area. These results suggest that a rangeland condition assessment model, extrapolating/generalising across all land uses, is not appropriate. The ecological index will be compared with the grazing index in Section 4.3.5 according to the range condition scores.

4.3.3.7 Discussion of the ecological index

Semi-arid and arid regions with long evolutionary histories of grazing have been shown to be resilient to grazing (Milchunas *et al.* 1988), with the removal of grazing as opposed to increased stocking rates possibly resulting in larger disturbances (Ellis & Swift 1988, Milchunas *et al.* 1988, Ward *et al* 1988).

Fourie and Redelinghuys (1994) found that rangeland deterioration in the Northern Cape, South Africa, was the result of incorrect grazing management and over-estimation of the grazing capacity, hence indicating density-dependent coupling of livestock to key resources. Results presented for this study, have shown that overgrazing has resulted in Increaser II species to be dominant within the Tribal land use, which displayed a totally different species compositional structure than that of the other two land uses.

Differences based on the ecological index between the land uses and relative condition groups in this study, reflected similar patterns as the species compositional and grazing index, for both the "annual" and "perennial" interpretations.

Results from the ANOSIM tests and CCA ordinations indicated that differences *within* each land use between the relative condition groups may result in different interpretations, as when averaged across all land uses. This was evident within the Reserve and Commercial land uses. The ANOSIM results also indicated that the rangeland condition gradient was most pronounced within the Commercial land use. Once again, differences between the Tribal-Poor/-Good groups were not significant, although the observed patterns can be informative. For both interpretation methods, the general Reserve land use was best represented by Decreasers in terms of abundance and consistent distribution (typical class). The relative abundance of the Increaser III class did not differ significantly between the three land uses for the "annual" interpretation, although it was associated more with the Reserve- and Commercial-Poor land uses. However, with the "perennial" interpretation there were significant differences between the Commercial-Tribal and Reserve-Tribal land uses, with the Increaser III class being associated with the Tribal land use.

The order of groups contributing most to the average abundances of the relative "Good/Poor" groups within each land use remained similar for both interpretation methods, although the abundances for the Decreaser, Increaser II and BP were higher for both condition groups within all land uses in the "perennial" interpretation. Increaser III (unpalatable grasses commonly found in overgrazed rangeland) contribution was much lower for the "perennial" interpretation, being absent within the Reserve and Commercial land uses. This can be attributed to the recording of the nearest perennial species in the nearest plant-point survey technique if an annual species was pointed out.

4.3.4 Life-form

Patterns within and between land uses, as well as between the relative condition groups based on the "annual" and "perennial" interpretation life-form was conducted in this section (Appendix 4.9). This was done to establish whether life-form can be incorporated as a measure within a "Key assessment matrix" for rangeland monitoring and assessment purposes. This was done for both interpretation methods, for reasons already discussed. "Life-form" refers to either an annual, perennial or weak perennial herbaceous species.

4.3.4.1 General ANOSIM analysis between land uses

A. "Annual" interpretation

Based on the life-form, differences were less pronounced between the land uses and relative condition groups, as indicated by the grazing-, ecological classification and species composition matrix. However, the Reserve and Commercial land uses still appeared similar with regard to life-form. A significant rangeland gradient, though not that strong, was also apparent.

A two-way crossed ANOSIM showed significant though relatively small differences between the Commercial-Tribal groups ($r = 0.293$, $P < 0.001$), Tribal-Reserve groups ($r = 0.329$, $P < 0.001$) and insignificant for the Commercial-Reserve groups ($r = -0.022$, $P > 0.1$). The difference between the relative "Good" and "Poor" groups were significant though low ($r = 0.232$, $P < 0.001$). Based on the life-form, patterns were similar to that of the previous results, namely that the Commercial and Reserve groups were statistically similar with regard to life-form, which differed significantly from that of the Tribal land use.

Although a range condition gradient for the larger area was still significant and evident with regard to the life-form interpretation, the statistics were lower than for the grazing and ecological classifications. This suggests that this interpretation method is not as useful as the grazing and ecological indices to distinguish between land uses and range condition groups for the Molopo semi-arid rangelands. This statement will be verified in the sections below.

B. "Perennial" interpretation

A two-way crossed ANOSIM indicated low to intermediate significant differences between land uses: Commercial-Tribal groups ($r = 0.36$, $P < 0.001$), insignificant for the Commercial-Reserve groups ($r = -0.009$, $P > 0.1$) and an intermediate difference for the Tribal-Reserve groups ($r = 0.40$, $P < 0.001$). Differences between the relative condition groups averaged across all land uses were significant ($r = 0.389$, $P < 0.001$). Patterns between both interpretations remained similar. However, statistics for the "perennial" interpretation were higher than that of the "annual" interpretation, suggesting that a more pronounced rangeland condition gradient exists if the climatic induced effects are accounted for.

4.3.4.2 ANOSIM for each life-form between the land uses

A. "Annual" interpretation

Analyses of similarities for each life-form between land uses and relative condition groups were done to establish whether significant patterns existed at this more in-depth level. Once again this was done to identify (refine) to which level analyses need to be done for incorporation in a final "Key assessment matrix".

A two-way crossed ANOSIM showed significant though small differences (r = 0.159, P < 0.05) for the Commercial-Tribal groups and r = 0.23 (P < 0.001) for the Tribal-Reserve groups. There was no significant difference between the Commercial-Reserve land uses (r = -0.033, P > 0.1), and only a small difference between the "Good" and "Poor" variables (r = 0.172, P < 0.001). These results indicate that the Reserve and Commercial groups were similar with regard to this life-form, and that both differed from the Tribal land use. According to these results a range condition gradient was evident, with the perennial life-form differing between the relative "Good" and "Poor" sites when averaged across all land uses. However, the results were less informative (statistics were not as strong) than those of the grazing and ecological indices.

Based on the weak perennial life-form, differences were most pronounced between the Tribal-Reserve groups (r = 0.368, P < 0.001), followed by r = 0.224 (P < 0.001) for the Commercial-Tribal groups and r = 0.084 (P < 0.05) for the Commercial-Reserve groups. The test for differences between the relative condition groups averaged over all land uses was not significant (r = 0.058, P > 0.05). This life-form was associated with intermediate range conditions (no significant difference between the relative "Good" and "Poor" groups). The Commercial and Reserve land use had a small difference, with the Reserve showing a closer association with the Tribal land use, due to a lower r-statistic indicating smaller differences. However, it should be emphasised that the Tribal land use was still significantly different from the other two land uses based on this life-form.

Differences between the different land uses and relative condition groups for the annual life-form were very low and not significant as determined by the one-way analysis, and were also not significant for the two-way ANOSIM, with r = 0.01 (P > 0.1) for the Commercial-Tribal groups, r = 0.045 (P > 0.1) for the Tribal-Reserve groups and r = 0.005 (P > 0.1) for the Commercial-Reserve groups. The test for differences between the relative condition groups was not significant, with r = 0.037 (P > 0.1). Although the "annual life-form" was indicated to be associated more with the Reserve-/Commercial-Poor variables, it still did not differ significantly from the Tribal land use Hence, it was not exclusively associated and significantly indicative of the "Poor" rangeland condition variable for the study area.

B. "Perennial" interpretation

Two-way crossed ANOSIM (perennial life-form) tests for differences between land uses averaged across different land uses, were of intermediate-low significance for the Commercial-Tribal groups (r = 0.309, P < 0.001), Tribal-Reserve land uses (r = 0.281, P < 0.001) and not significant for the Commercial-Reserve groups (r = 0.04, P > 0.1). Tests for differences between the relative condition groups when averaged across all land uses, were low (r = 0.32, P < 0.001). The statistics were significantly higher than those of the "annual" interpretation, with the "perennial" interpretation showing similar patterns as the "annual" interpretation, but indicating a larger rangeland condition gradient for the total study area.

Two-way crossed ANOSIM tests indicated significant though low differences for the weak perennial groups for the Commercial-Tribal groups (r = 0.231, P < 0.001), non-significant for the Commercial-

Reserve land uses (r = 0.015, P > 0.1) and significant but intermediate-low (r = 0.366, P < 0.001) for the Tribal-Reserve groups. The difference between the relative "Good" and "Poor" condition groups, averaged over the land uses, was low with r = 0.054 (P < 0.05). These results were very similar to that of the "annual" interpretation.

4.3.4.3 SIMPER analysis between land uses for general data set

SIMPER analysis was done for explanatory purposes and complementary to the results discussed above in order to identify similarity within and dissimilarity between land uses, and which variables contributed to the observed patterns. These results are informative in adaptive management practices for both scientists and land managers/owners for rangeland monitoring and assessment purposes. This section seeks to investigate patterns between land uses, which will dictate whether more in-depth analyses need to be conducted for patterns within land uses.

A. "Annual" interpretation

The average relative abundances of the different life-forms for each land use are illustrated in Fig. 4.38.

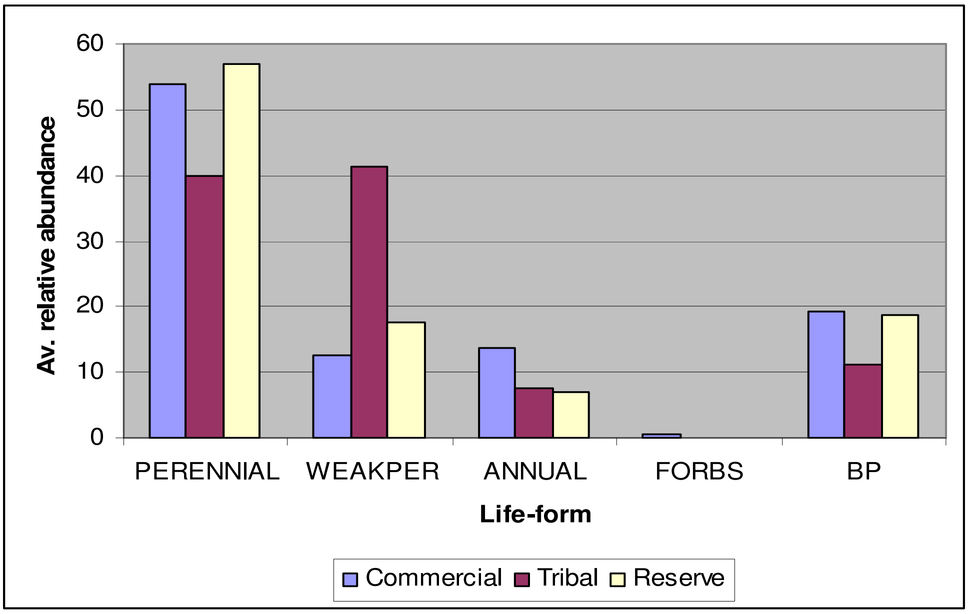


Fig. 4.38. Average relative abundances for the different life-forms for each land us for the "annual" interpretation.

The Commercial land use had an average similarity of 51.8%, with the perennial life-form being the most abundant (av.abund = 53.8%), and contributing to 68.81% of the similarity of this group. It was also the most consistent typical group (Sim/SD = 1.37). Followed by the BP (contribution = 12.66%) and weak perennial (9.74%) classes, it accounted for 91.1% of the similarity (Table 4.41).

The Tribal group had and average similarity of 60.8%, and was best typified by the perennial group (Sim/SD = 2.06), which contributed to 47.06% of the similarity, but did not have the highest average abundance (39.9% opposed to the 41.43% of the weak perennial group: Sim/SD = 1.34). Together these two groups contributed to 90.94% of the similarity (Table 4.41).

The Reserve land use had an average similarity of 61.02%, with the perennial life-form having the highest average abundance (57.03%) and contribution (67.49%), but with the weak perennial group being most consistent (Sim/SD = 1.7 opposed to the 1.58 of the perennial group). The weak perennial group had an average abundance of 17.63% and contribution of 18.92%. These two groups, followed by the BP class, contributed to 96.71% of the similarity (Table 4.41).

Table 4.41. SIMPER analyses for the "annual" life-form data, displaying life-form classes that contributed to the average similarities within each land use.

Group Commercial - Average similarity: 51.80

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
PERENNIAL	53.80	35.59	1.37	68.71	68.71
BP	19.34	6.55	0.53	12.66	81.36
WEAKPER	12.59	5.05	0.68	9.74	91.10

Group Tribal - Average similarity: 60.80

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
PERENNIAL	39.90	28.61	2.06	47.06	47.06
WEAKPER	41.43	26.68	1.34	43.89	90.94

Group Reserve - Average similarity: 61.02

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
PERENNIAL	57.03	41.19	1.58	67.49	67.49
WEAKPER	17.63	11.55	1.70	18.92	86.41
BP	18.56	6.28	0.62	10.30	96.71

Group Good - Average similarity: 67.66

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
PERENNIAL	62.95	50.23	2.69	74.23	74.23
WEAKPER	25.53	14.26	1.19	21.08	95.32

Group Poor - Average similarity: 49.48

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
PERENNIAL	37.53	22.43	1.23	45.32	45.32
BP	27.24	12.27	0.76	24.80	70.13
WEAKPER	22.23	9.86	0.80	19.93	90.06

The average dissimilarity between the Commercial-Tribal land uses was 50.75%, with the weak perennials (av. dissimilarity = 16.69%, contribution = 32.89%) followed by the perennials contributing to most of the dissimilarities (64.42%), although the perennials were a slightly better discriminant group than the weak perennials. The Commercial-Reserve groups differed with 43.27%, with the perennial life-form being the discriminating class (Diss/SD = 1.37) and contributing to 33.81% of the differences. The perennial class, followed by the BP, weak perennial and annual classes, accounted for 99.46% of the dissimilarity. The Tribal-Reserve groups differed with 45.73%, with the perennial life-form being the most important discriminant class (Diss/SD = 1.54), as well as the highest contributing (34.5%) class. Together with the weak perennial and BP classes, it accounted for 90.08% of the dissimilarity (Table 4.42).

Table 4.42. SIMPER analyses for the "annual" life-form data, displaying life-form classes that contributed to the average dissimilarities between land uses.

Groups Commercial & Tribal - Average dissimilarity: 50.75

	Group Commercial	**Group Tribal**				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
WEAKPER	12.59	41.43	16.69	1.47	32.89	32.89
PERENNIAL	53.80	39.90	16.00	1.49	31.52	64.42
BP	19.34	11.12	11.04	0.94	21.75	86.17
ANNUAL	13.78	7.61	6.79	0.74	13.37	99.54

Groups Commercial & Reserve - Average dissimilarity: 43.27

	Group Commercial	**Group Reserve**				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
PERENNIAL	53.80	57.03	16.58	1.37	38.31	38.31
BP	19.34	18.56	12.11	1.01	27.99	66.30
WEAKPER	12.59	17.63	7.24	1.31	16.74	83.03
ANNUAL	13.78	6.84	7.11	0.75	16.42	99.46

Groups Tribal & Reserve - Average dissimilarity: 45.73

	Group Tribal	**Group Reserve**				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
PERENNIAL	39.90	57.03	15.78	1.57	34.50	34.50
WEAKPER	41.43	17.63	14.72	1.44	32.20	66.70
BP	11.12	18.56	10.69	0.87	23.38	90.08

Groups Poor & Good - Average dissimilarity = 48.75

	Group Poor	**Group Good**				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
PERENNIAL	37.53	62.95	17.62	1.51	36.15	36.15
BP	27.24	5.44	12.92	1.02	26.50	62.65
WEAKPER	22.23	25.53	11.73	1.21	24.07	86.72
ANNUAL	13.04	5.78	6.32	0.77	12.96	99.68

The "Good" group had an overall average similarity of 67.66%, the "Poor" group 49.48% (Table 41), with an average dissimilarity of 48.75% between these two groups (Table 4.42). The perennial life-form was typical to both groups, with Sim/SD = 1.23 for the "Poor" group and Sim/SD = 2.69 for the "Good" group. It was also the most abundant and the highest contributing for both the "Poor" (av. abund = 37.53%, contribution = 36.15%) (Table 4.41) and "Good" groups (av. abund = 62.95%, contribution = 74.23%)

(Table 4.41), with the same class being discriminating (Diss/SD = 1.51) between the two relative condition groups (Table 4.42). However, the difference in the average abundance for the perennial life-form between the “Good” and “Poor” variables should serve as directive of which condition group is more indicative. The perennial-, BP (contribution = 24.8%) and weak perennial classes (contribution = 19.93%) accounted for 90.06% of the “Poor” group’s similarity. The perennial and weak perennial (contribution = 21.08%) accounted for 95.32% of the “Good” group’s similarity (Table 4.41).

However, these results suggest that patterns within land uses should be investigated, thus not averaging patterns across all relative condition groups.

B. “Perennial” interpretation

Results from this section are summarised in Appendix 4.10.

The Commercial land use had an average similarity of 45.23%, with the perennial life-form, followed by the weak perennial life-form and BP contributing to 100% of the similarity. There was no strong typical group (Sim/SD < 1.0), with both the perennial and weak perennial classes showing a Sim/SD = 0.8.

The Tribal group had an average similarity of 67.17%, with the weak perennial and perennial life-forms contributing to 92.37% of the similarity. The weak perennial group was the most important typical life-form (Sim/SD = 2.02).

The average similarity for the Reserve was 57.29%, with the perennial life-form, weak perennial life-form (contribution = 35.88%) and BP (contribution = 12.08%) accounting for 100% of the similarity. The weak perennial life-form was consistently most typical (Sim/SD = 1.67), followed by the perennial life-form (Sim/SD = 1.15).

The average dissimilarity between the Commercial-Tribal land uses was 52.95%. The weak perennial (av. dissimilarity = 20.58%, contribution = 38.87%), perennial life-form and BP contributed to 99.53% of the dissimilarity, with the weak perennial group being the most important discriminating class (Diss/SD = 1.67).

The Commercial-Reserve land uses had an average dissimilarity of 48.24%, with the perennial life-form, BP and weak perennial life-form resulting in 99.48% of the dissimilarity. The average dissimilarity between the Tribal-Reserve land uses was 47.97%, with 100% of it being accounted for by the weak perennial life-form, perennial life-form and BP. The weak perennial life-form was the most important discriminator class (Diss/SD = 1.78).

The average similarity of the “Poor” group was 53.73%, with the weak perennial life-form, followed by the BP and perennial life-form contributing to 100% of the similarity. The weak perennial life-form was the typical life-form (Sim/SD = 1.1).

The “Good” group had an average similarity of 64.62%, with 97.19% of the similarity being accounted for the by perennial and weak perennial life-forms. The perennial life-form was the strongest typical life-form (Sim/SD = 1.7). The average dissimilarity between the “Poor” and “Good” groups was 54.35%, with the perennial life-form, weak perennial life-form and BP contributing to 99.69% of the dissimilarity, with the perennial class being the most important discriminating life-form (Diss/SD = 1.62)

C. Remarks

Both interpretation methods were congruent with the results of the ordinations presented in Section 4.3.4.4. Results by both interpretation methods suggest that differences should be investigated within and not only across all land uses.

4.3.4.4 ANOSIM within each land use for each life-form across relative condition groups

One-way ANOSIMS were performed ***within*** each land use for each life-form separately as to determine whether any sifnificant differences between the relative “Good” vs. “Poor” condition group exist. This was done to establish whether the results discussed above, would improve when investigated more in depth, with the purpose of identifying to which extent analyses need to be done for application purposes in a “Key assessment matrix”.

A. “Annual” interpretation

For the Commercial land use, there was only a small difference between these two relative condition extremes for the perennial life-form ($r = 0.234$, $P < 0.001$), and no significant differences for the weak perennial - ($r = -0.006$, $P > 0.1$) or the annual life-form ($r = -0.028$, $P > 0.1$). It is suggested that the perennial life-form represented the Commercial-Good extreme (Section 3.4.6, Fig. 4.39), whereas the other two life-forms were associated with intermediate ranges of the rangeland condition gradient for the study area.

The perennial life-form composition did not differ significantly for the Tribal group ($r = 0.029$, $P > 0.1$). There were no significant differences for the weak perennial life-form ($r = 0.091$, $P > 0.05$) and only a small difference for the annual life-form ($r = 0.191$, $P < 0.05$). Based on life-form, only the annual life-form was indicative of a rangeland condition gradient with the Tribal land use, suggesting that it was associated more with the Tribal-Poor than Tribal-Good sites (Section 4.3.4.6, Fig. 4.39).

The Reserve showed significant though not large differences across the relative condition extremes for the perennial life-form ($r = 0.254$. $P < 0.001$), and only insignificant differences for the weak perennial- ($r = 0.089$, $P > 0.05$) and the annual life-forms ($r = -0.053$, $P > 0.1$). The same explaination discussed under the Commercial land use above, applies here.

Hence, these results suggest that the Tribal land use occupied a midrange position on the rangeland condition gradient, with the type of life-form being relatively similar throughout all sites, with only the "annual" life-form serving as "poor" indicator of differences between the Tribal-Poor and Tribal-Good sites. Within this land use, this life-form was better associated with the Tribal-Poor group. Both the Commercial and Reserve land uses showed only significant differences based on the perennial life-form between the relative condition groups.

These results suggest that life-form is not as good an indicator of differences within and between land uses as was the species compositional data, grazing- and ecological indices. This statement will be examined by direct and indirect ordinations.

B. "Perennial" interpretation

Results for the "perennial" interpretation were further interpreted on a finer scale by establishing whether any differences existed (hence a gradient) between the relative "Good" vs. "Poor" extremes within each land use for both the perennial and weak perennial life-forms.

For the Commercial group, there was an intermediate difference between the relative "Good" and "Poor" spectra ($r = 0.446$, $P < 0.001$) for the perennial life-form, but a neglectably small difference for the weak perennial life-form ($r = 0.074$, $P < 0.001$). The statistics showed an improvement to that of the "annual" interpretation, implicating that the rangeland condition gradient, based on the longer-term ecological status of the rangeland, was longer.

For the Tribal land use, there were no significant differences for the perennial- ($r = 0.029$, $P > 0.1$) or for the weak perennial life-forms ($r = -0.042$, $P > 0.1$) when compared across the relative "Good/Poor" extremes. These results are consistent with that of the "annual" interpretation.

The perennial life-form for the Reserve showed and intermediate difference ($r = 0.484$, $P < 0.001$) when the relative "Good/Poor" groups were compared, but the weak perennial life-form showed significant though low differences ($r = 0.124$, $P < 0.05$) between these two condition extremes. It can be ascribed to the explanation given above for the Commercial land use.

The "perennial" interpretation thus showed that a longer (and stronger) rangeland gradient existed between the relative "Poor" and "Good" groups, than was indicated by the "annual" interpretation.

However, this method is less informative, since only two life-forms are included in this interpretation indicator classes representative of the mid- and lower range condition ranges, are not possible.

Hence, BP as discussed in the grazing index should also be incorporated as indicator of rangeland condition. Since results for the BP were already presented, it will not be discussed again within the ANOSIMS for the life-forms (owing it not to be a life-form), but are included in the ordinations presented below.

4.3.4.5 SIMPER analysis within land uses across relative condition groups

SIMPER analyses as complementary procedure to the ANOSIM results discussed above, are presented below. This is useful for adaptive management purposes.

A. “Annual” interpretation

The Commercial “Poor” group had an average similarity of 45.23%, with the BP, followed by the perennial- and annual classes which cumulatively accounted for 92.56% of the similarity. The Perennial (Sim/SD = 1.02) and BP (Sim/SD = 1.0) were the most important typical life-forms. The Commercial “Good” group had an average similarity of 71.95%, with the perennial life-form (Sim/SD = 4.64) being the most abundant and contributing life-form, as well as the most typical life-form. Together with the weak perennial group (contribution = 9.02%), it contributed to 94.63% of the “Good” group’s similarity. The average dissimilarity between the Commercial “Good” and “Poor” groups was 54.44%, with the perennial life-form, followed by the BP, annual and weak perennial life-forms accounting for 99.14% of the dissimilarity. The perennial group was the most important discriminating life-form (Diss/SD = 1.73). It is advised that the difference in abundances related to each relative condition group for the perennial life-form should serve as further aid to distinguish between the “Good” and “Poor” groups (Appendix 4.11).

The Tribal “Poor” group had an average similarity of 52.04%, and was best represented, in this order of abundance and contribution, by the perennial life-form, followed by the weak perennial and annual, which cumulatively accounted for 93.22% of the similarity. The perennial life-form was the most important typical group (Sim/SD = 1.67). The average similarity of the “Good” group was 72.08%, with the weak perennial, followed by the perennial life-form contributing to 97.17% of the similarity. The perennial life-form was indicated as the strongest typical life-form (Sim/SD = 2.87) opposed to Sim/SD = 2.78 of the weak perennial life-form. The average dissimilarity between the Tribal “Good” and “Poor” groups was 40.36%, with the weak perennial life-form, perennial life-form and BP accounting for 88.02% of the dissimilarity. The weak perennial class was indicated as the strongest discriminating life-form (Diss/SD = 1.69) (Appendix 4.11).

The average similarity for the Reserve “Poor” group was 53.71%, with the perennial-, BP and weak perennial life-form accounting for 95.87% of the similarity. The weak perennial group (Sim/SD = 1.24) followed by the perennial life-form (Sim/SD = 1.16) were most consitently typical of the “Poor” group. The Reserve “Good” group had an average similarity of 82.84%, with the perennial- and weak perennial contributing to 96.35% of the similarity. The perennial life-form was the most important typical class (Sim/SD = 6.77), with Sim/SD = 2.9 for the weak perennial class. The average dissimilarity between the “Good” and “Poor” groups was 45.62%, with the perennial life-form, BP and weak perennial life-form accounting for 89.68% of the difference. The perennial life-form was the strongest discriminanting group (Diss/SD = 1.57), followed by the weak perennial life-form (Diss/SD = 1.34) (Appendix 4.11)

B. “Perennial” interpretation

SIMPER explanatory analyses are presented in this section for use in adaptive management matrices, in order to establish differences between the relative condition groups within a land use.

The Commercial “Poor” group had an average similarity of 48.18%, and 93.52% of the similarity was accounted for the typical BP class (av. abund = 46.28%, contribution = 57.34%, Sim/SD = 1.25) and the weak perennial life-form (contribution = 36.18%) (Appendix 4.12). The Commercial “Good” group had an average similarity of 72.02%. The typical perennial life-form and weak perennial life-form (contribution = 17.38%) accounted for 98.72% of the similarity. The average dissimilarity between the “Poor” and “Good” groups was 68.4%, with 99.27% of the dissimilarity being accounted for the by the perennial life-form, BP and the weak perennial life-form. The perennial life-form was also most discriminating (Diss/SD = 2.31) between these two condition groups (Appendix 4.12)

The Tribal “Poor” group had an average similarity of 59.18% and the Tribal “Good” group an average similarity of 75.17%. The “Good” and “Poor” groups had an average dissimilarity of 32.84%. Based on the ANOSIM, differences between the Tribal relative condition groups were not significant, and hence are only presented in Appendix 4.12.

The Reserve “Poor” group had an average similarity of 56.97%, with 100% of the similarity being accounted for by the weak perennial life-form, BP and the perennial life-form. The average similarity of the Reserve “Good” group was 83.56%, with the perennial and weak perennial life-forms (contribution = 19.56%) contributing to 98.11% of the similarity. The average dissimilarity between the “Poor” and “Good” group was 54.61%, with the perennial life-form, BP and weak perennial life-form contributing to 100% of the dissimilarity. The perennial life-form was the most important discriminating class (Diss/SD) between these two groups (Appendix 4.12).

4.3.4.6 PCA and RDA with environmental and supplementary variables

The results presented in Sections 4.3.4.1 – 4.3.4.5 were further investigated by means of direct and indirect ordinatons. The results presented below, were complementary to those discussed in the sections mentioned above, and can assist in rangeland monitoring and assessment not only across but within land uses. The ordinations also present a visual illustration of the species-environment relation.

A. “Annual” interpretation

According to the PCA, the “Good” (r = -0.5085) and “Poor” (r = 0.5085) environmental variables and the passive rangeland condition indices’ variables (r = 0.89) strongly represented the first axis (Table 4.43). The Tribal- (r = 0.5393), Tribal-Good (r = 0.4812) environmental variables and the passive variables species richness- (ANNrich) (r = 0.6420) and species diversity (ANNdiv) (r = 0.5589) best represented the second axis (Table 4.43).

Table 4.43. A PCA ordination for the “annual” life-form data, showing eigenvalues and species-environment relations for the first four axes, as well as the environmental and passive variables explaining most of the species-environment relation for the first two axes. Variables explaining most of the variance are indicated in **bold**.

Environmental data	SPEC AX1	SPEC AX2	Passive data	SPEC AX1	SPEC AX2
Commercial	-0.0585	-0.3282	BE/HA	0.4312	0.2132
Tribal	0.1828	**0.5393**	Bushcov	0.4473	0.2757
Reserve	-0.1244	-0.2111	Bush num/ha	0.3103	0.276
Good	**-0.5085**	0.1937	VCSAGRAZ	**-0.9032**	0.1595
Poor	**0.5085**	-0.1937	VCSPGRAZ	**-0.8985**	0.1448
Com*Good	-0.3604	-0.1253	DM/HA	-0.3435	0.333
Com*Poor	0.2865	-0.2899	VCSAECOL	**-0.9294**	0.1629
Tri*Poor	0.1486	0.201	VCSPECOL	**-0.9174**	0.1459
Tri*Good	0.0826	**0.4812**	ANNrich	-0.024	0.642
Res*Good	-0.4044	-0.096	ANNeve	0.0683	0.321
Res*Poor	0.2471	-0.171	ANNdiv	0.0384	**0.5589**
			Bsh.div	-0.0326	0.1923
Axes	**1**	**2**	**3**	**4**	
Eigenvalues	0.539	0.33	0.13	0.001	
Species-environment correlations	0.623	0.585	0.293	0.273	
Cumulative percentage variance					
of species data	53.9	86.9	99.9	100	
of species-environment relation (environmental)	62.8	96.6	100	100	
of species-environment relation (passive data)	68.3	93.6	100	100	

The cumulative variance explained by the second axis for the species-environment relation was 96.6%, 86.9% for the cumulative species data variance and 93.6% for the species-passive variable relation (Table 4.43). The perennial life-form was primarily associated with the third quadrant and the Commercial-, Reserve, Commercial-Good and Reserve-Good environmental variables. Weak perennials were associated with the Tribal variables and first quadrant, and the annual life-forms and BP with the fourth quadrant and Poor, Reserve-Poor and Commercial-Poor variables.

A Monte-Carlo test in the direct RDA ordination showed that the first (F = 17.557, P < 0.005) and all canonical axes (F = 6.59, P < 0.005) revealed significant patterns between the life-form data and environmental data, with the Good/Poor variables (F = 12.67, P < 0.005), Tribal-Good (F = 12.6, P < 0.005), Tribal (F = 3.85, P < 0.05) and Commercial-Poor (F = 0.99, P < 0.05), in this order, explaining most of the species-environment patterns. The second axis of the species-environment relation for the environmental data explained 97.9% of the variance, 32.6% of the cumulative species data and 94.6% of the species-passive variables' relation (Table 4.44). These RDA results improved from that of the PCA results, suggesting that the correct environmental variables, explaining most of the species-environment variance, were included in the analysis.

The first and second axes of the RDA ordination (Table 4.44, Fig. 4.39) were best described by the same environmental and passive variables discussed under the PCA ordination. The RDA ordination revealed that the different life-form classes were associated with the same environmental variables as discussed under the PCA analysis (Fig. 4.39).

Table 4.44. A RDA ordination for the "annual" life-form data, showing eigenvalues and species-environment relations for the first four axes, as well as the environmental and passive variables explaining most of the species-environment relation for the first two axes. Variables explaining most of the variance are indicated in **bold**.

Environmental data	**SPEC AX1**	**SPEC AX2**	**Passive data**	**SPEC AX1**	**SPEC AX2**
Commercial	0.0812	-0.343	BE/HA	-0.4434	0.1923
Tribal	-0.2226	**0.5213**	Bushcov	-0.4644	0.2507
Reserve	0.1414	-0.1783	Bush num/ha	-0.3287	0.2574
Good	**0.4934**	0.2643	VCSAGRAZ	**0.8903**	0.2872
Poor	**-0.4934**	-0.2643	VCSPGRAZ	**0.8861**	0.2639
Com*Good	0.3688	-0.0847	DM/HA	0.317	0.3687
Com*Poor	-0.266	-0.3491	VCSAECOL	**0.916**	0.2911
Tri*Poor	-0.164	0.1762	VCSPECOL	**0.9046**	0.2647
Tri*Good	-0.1176	0.4832	ANNrich	-0.0244	**0.6451**
Res*Good	0.4108	-0.0439	ANNeve	-0.0918	0.3173
Res*Poor	-0.232	-0.1816	ANNdiv	-0.0802	0.5543
			Bsh.div	0.0169	0.1845
Axes	**1**	**2**	**3**	**4**	
Eigenvalues	0.21	0.116	0.007	0	
Species-environment correlations	0.626	0.598	0.225	0.207	
Cumulative percentage variance					
of species data	21	32.6	33.3	33.3	
of species-environment relation (environmental)	63.1	97.9	100	100	
of species-environment relation (passive data)	67	94.6	100	100	

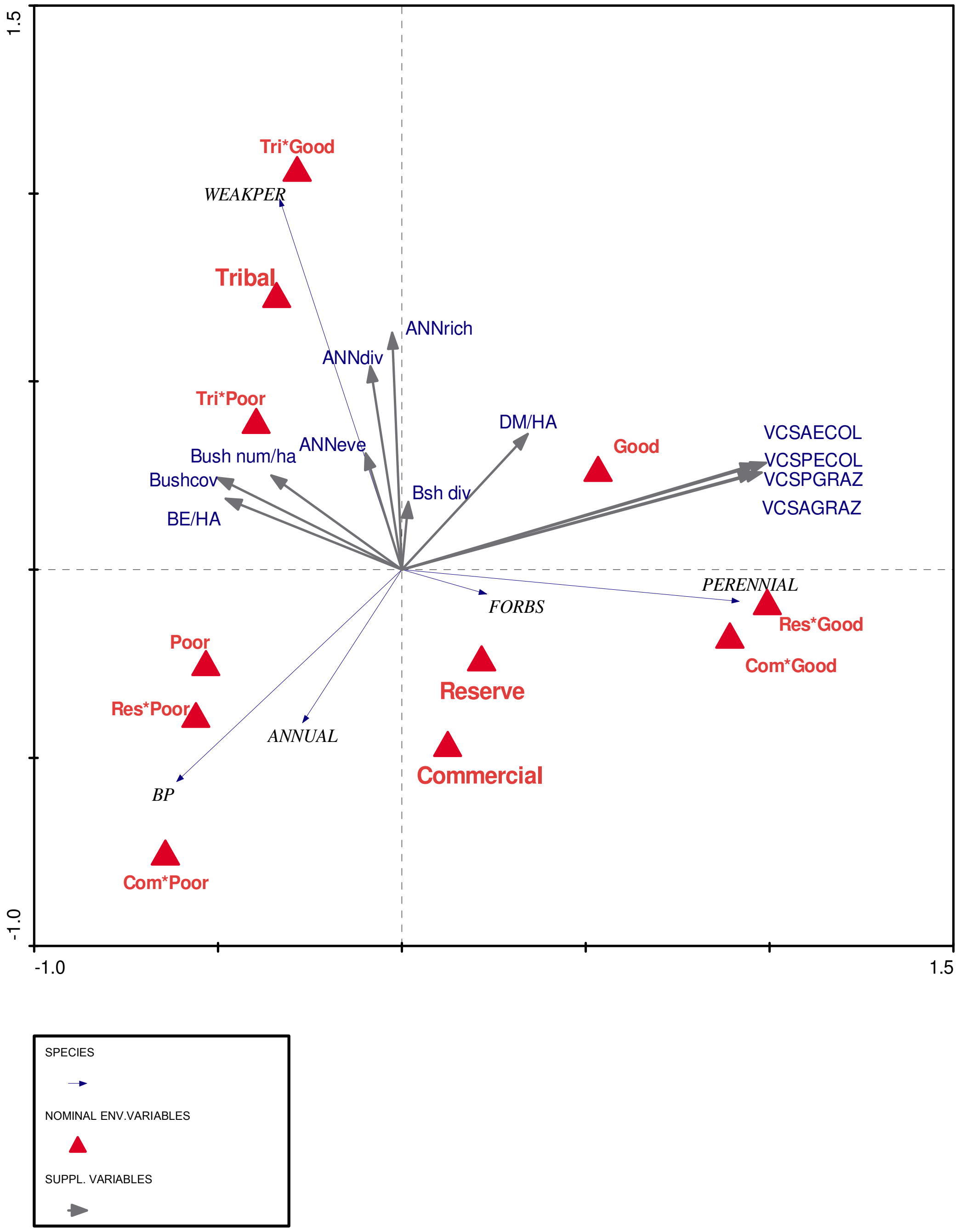


Fig. 4.39. A RDA ordination triplot illustrating the species-environment relation for the "annual" life-form interpretation.

B. "Perennial" interpretation

Indirect PCA ordination with environmental and supplementary values, explained 100% of the species-environment relation by the second axis and 99.9% of the cumulative species-data variance (Table 4.45). Hundred percent (100%) of the species-passive data relation was explained by the second axis. For the species-environment correlation, most of the variance was explained by the first axis (r = 0.783), followed by the second axis (r = 0.473) (Table 4.45).

The first axis was primarily being explained by the "Good" (r = 0.5724) and "Poor" (r = - 0.5724) environmental variables, followed by the Reserve-Good interaction (r = 0.5059) and Commercial-Good interaction (r = 0.4811) (Table 4.45). The second axis was best represented by the Tribal variable (r = -0.3426), followed by the Commercial-Poor interaction (r = 0.3291) (Table 4.45). Passive variables that were most strongly associated with the first axis, were the different rangeland condition indices' scores (r > 0.71) (Table 4.45). These variables also showed the strongest association with the second axis (r > 0.56), followed by the species evenness (PEReve) (r = -0.5645) and species diversity (PERdiv) (r = -0.5083) (Table 4.45).

Table 4.45. A PCA ordination for the "perennial" life-form data, showing eigenvalues and species-environment relations for the first four axes, as well as the environmental and passive variables explaining most of the species-environment relation for the first two axes. Variables explaining most of the variance are indicated in **bold**.

Environmental data	**SPEC AX1**	**SPEC AX2**	**Passive data**	**SPEC AX1**	**SPEC AX2**
Commercial	0.1451	0.2375	BE/HA	-0.4127	0.025
Tribal	-0.3817	**-0.3426**	Bushcov	-0.4201	-0.0014
Reserve	0.2365	0.1051	Bush num/ha	-0.3972	-0.102
Good	**0.5724**	-0.3101	VCSAGRAZ	**0.7175**	**-0.5607**
Poor	**-0.5724**	0.3101	VCSPGRAZ	**0.7222**	**-0.5808**
Com*Good	0.4811	-0.0286	DM/HA	0.3327	-0.3822
Com*Poor	-0.2975	0.3291	VCSAECOL	**0.749**	**-0.5804**
Tri*Poor	-0.2638	-0.1048	VCSPECOL	**0.7468**	**-0.5968**
Tri*Good	-0.219	**-0.3286**	PERrich	-0.2168	-0.4028
Res*Good	**0.5059**	-0.0588	PEReve	-0.2818	**-0.5645**
Res*Poor	-0.2067	0.1917	PERdiv	-0.2812	**-0.5083**
			Bsh.div	-0.0883	-0.2072
Axes	**1**	**2**	**3**	**4**	
Eigenvalues	0.585	0.414	0.001	0	
Species-environment correlations	0.783	0.473	0.257	0.167	
Cumulative percentage variance					
of species data	58.5	99.9	100	100	
of species-environment relation (environmental)	79.5	100	100	0	
of species-environment relation (passive data)	60.2	100	100	0	

The first two axes of the Monte Carlo test as performed in the direct RDA ordination (Table 4.46; Fig. 4.40) significantly explained the species-environmental variation, with F = 37.634 (P < 0.005) for the first axis and F = 10.868 (P < 0.005) for all canonical axes. Hundred percent (100%) of the species-environment relation for both the environmental as well as passive data was explained by the second axis, and 45.2% of the cumulative species-data variance. The first axis showed the strongest association with the "Good" (r = 0.6014, first quadrant) and "Poor" (r = -0.6014, third quadrant) variables, and the second axis with the Tribal (r = 0.3944, second quadrant) and Tribal-Good (r = 0.3569, second quadrant) variables.

For the passive data, the rangeland condition indices' scores (r > 0.77, first quadrant) showed the strongest correlation with the first axis, with the species evenness (r = 0.5994, second quadrant) and species richness (PERrich) (r = 0.5437, second quadrant) showing the strongest association with the second axis, followed by the rangeland condition indices (Fig. 4.40). The rangeland condition indices were associated with the "Good" variable.

The species richness – and species diversity variables (PERrich and PERdiv) were best associated with the Tribal land use and weak perennial life-form (Fig. 4.40). The perennial life-form was best associated with the first axis (first quadrant) and hence the Reserve-Good and Commercial-Good variables. BP was strongly related to the "Poor", Reserve-Poor and Commercial-Poor variables (Fig. 4.40). The following variables, in order of their inclusion to the Monte Carlo test, significantly explained most of the species-environment relation: "Good/Poor" (F = 21.09, P < 0.005), Tribal-Good (F = 21.68, P < 0.005) and Tribal (P < 0.05).

Table 4.46. A RDA ordination for the "perennial" life-form data, showing eigenvalues and species-environment relations for the first four axes, as well as the environmental and passive variables explaining most of the species-environment relation for the first two axes. Variables explaining most of the variance are indicated in **bold**.

Environmental data	**SPEC AX1**	**SPEC AX2**	**Passive data**	**SPEC AX1**	**SPEC AX2**
Commercial	0.1199	-0.2561	BE/HA	-0.4131	0.0351
Tribal	-0.3443	0.3944	Bushcov	-0.4178	0.0624
Reserve	0.2244	-0.1383	Bush num/ha	-0.3846	0.1586
Good	**0.6014**	0.2237	VCSAGRAZ	**0.7715**	0.4506
Poor	**-0.6014**	-0.2237	VCSPGRAZ	**0.7783**	0.4699
Com*Good	0.4815	-0.0416	DM/HA	0.3703	0.3299
Com*Poor	-0.3298	-0.2824	VCSAECOL	**0.8048**	0.4656
Tri*Poor	-0.2516	0.142	VCSPECOL	**0.8044**	0.4821
Tri*Good	-0.184	0.3569	PERrich	-0.174	0.4299
Res*Good	0.5092	-0.0152	PEReve	-0.222	**0.5994**
Res*Poor	-0.2254	-0.1597	PERdiv	-0.2272	0.5437
			Bsh.div	-0.0666	0.2179
Axes	**1**	**2**	**3**	**4**	
Eigenvalues	0.363	0.088	0	0	
Species-environment correlations	0.789	0.461	0.205	0	
Cumulative percentage variance					
of species data	36.3	45.2	45.2	0	
of species-environment relation (environmental)	80.4	100	100	0	
of species-environment relation (passive data)	63.6	100	100	0	

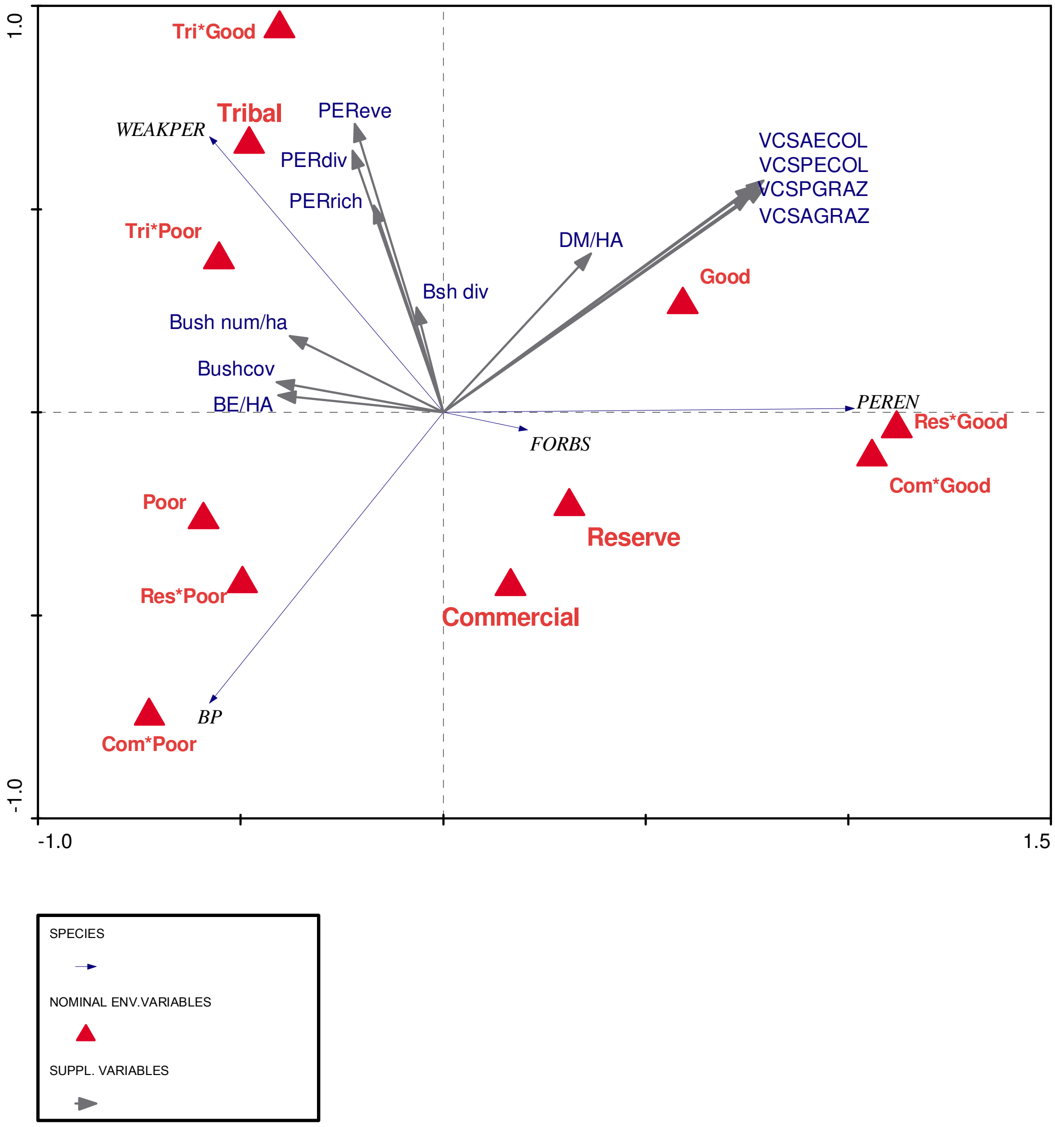


Fig. 4.40. A RDA ordination triplot illustrating the species-environment relation for the “perennial” life-form interpretation.

4.3.4.7 Discussion of herbaceous life-form

Abundance of perennial grasses and browse is said to increase ecosystem resilience and resistance to disturbance caused by drought and intensive grazing (Whitford *et al*. 1999a). Hence, a lack of perennial grasses indicates that the resilience and resistance capabilities of an ecosystem to disturbances caused by herbivory and drought, have been impaired (Leggett *et al*. 2003a). Following this statement, the Commercial and Reserve land uses, and particularly the Reserve-/Commercial good groups, being represented by perennial species, will be more drought resistant and flexible following drought periods under sustainable grazing practices, than the Tribal land use being represented primarily by weak perennial species or the Reserve-/Commercial-Poor areas being represented by annual species. The Molopo rangelands are considered to be resilient, however, the transitional shift in species composition displayed by the Tribal land use, as well as the Reserve-/Commercial-Poor areas, suggests that climatic events (non-equilibrium) may mask rangeland degradation, but that the resilience of these areas, as opposed to the Reserve-/Commercial-Good sites, may potentially be lower. According to O' Conner (1994), perennial, obligate seed reproducers may become locally extinct as a result of intensive grazing, whereas annual, less palatable grasses with prolific seed may increase under grazing and variable rainfall. The author ascribes this to heavy grazing of preferred grasses resulting in a decline in available seed and seedling recruitment. These observations may indicate that the Reserve-/Commercial Poor and the Tribal land use's capability of resistance and resilience to disturbances have potentially been impaired.

Bayer and Waters-Bayer (1994) state that higher grazing pressure can result in the replacement of perennial grasses by annuals, whereas Metzger *et al.* (2005) showed that bare ground was strongly associated with grazing impact during the dry season within the Serengeti, being independent of the wet season. This was evident in this study, with the annual life-form being associated with the "Poor", Reserve-Poor and Commercial-Poor sites, whereas the Tribal land use was characterised primarily by weak perennials. Long-term intensive grazing can influence herbaceous vegetation by resulting in reduced seed production of preferred or more grazing-exposed species, or by favouring species with short life-cycles or competitive advantages under low litter cover (Turner 1999). In this study, species were classified according to the life-form for both interpretation methods. Only differences between the Commercial-Tribal, Tribal-Reserve and "Good-Poor" variables were significant. Statistics based on life-form were lower than that of the grazing and ecological indices, suggesting that this interpretation method is less informative regarding differences between land uses and within land use.

The perennial and weak perennial life-forms showed significant differences between the Commercial-Tribal and Tribal-Reserve land uses for both interpretation methods. The RDA ordination for the "annual" interpretation indicated that the annual life-form was strongly associated with the "Poor", Commercial-/and Reserve-Poor variables. The Commercial-Poor land use had the highest average abundance for the annual life-form. However, a high average relative abundance for the annual life-form for the Commercial land use does not automatically imply that the annual species richness within this land use was high, but it is suggested that the contributions to the average abundance of the annual life-form by the few (number of species) annual species were very high opposed to the low contribution from a wider array of annual species associated with the Tribal land use to the average relative abundance within this land use. It is suggested that frequency of occurrence (absence/presence) data can be employed as a measure in addressing such scenarios. There were no differences between the Commercial-Reserve land uses, and the same arguments discussed under "Herbaceous species composition", can be applied.

When "annual" interpretation patterns related to the relative condition groups within a land use, with reference to the different life-forms were investigated, the annual life-form showed a small difference between the two condition groups for the Tribal "annual" interpretation. The perennial life-form showed small differences between the relative "Good-Poor" variables for the Reserve and Commercial land uses for both interpretation methods.

The "perennial" interpretation for the perennial life-form for the Commercial- and Reserve groups showed intermediate differences between the relative "Good-Poor" groups, and only small differences for the weak perennial group. There were no significant differences between the Tribal condition groups for these classes, and can be supported by the same arguments discussed in the sections above (Tribal variables showing a "fuzzy/weak distinguishable" distribution along the degradation gradient). Interesting though is that the weak perennial life-form contributed most to the average abundances as opposed to the other life-forms for all the land uses to the "perennial-Poor" interpretation, compared to the perennial life-form contributing most to the average abundance for all the land uses to the "annual-Poor" interpretation. This can be ascribed to methodology applied in the "perennial" interpretation.

Significant differences/patterns within and between the two interpretation methods, although of intermediate or low importance, can be informative in the respect that they can act as measure to reflect on the ecological status of a rangeland (density-dependent aspect), instead of reflecting possibly only on the masking effect of rainfall variability (non-equilibrium aspect). The relative small significant differences between the land uses (Commercial-Tribal and Reserve-Tribal) are quite informative, and reflect the inherent resilience and stability of the Molopo study area, indicating the non-equilibrium masking aspects of these rangelands. However, it is suggested that the species composition and abundances (hence, species level) contributing towards these life-form classes can not be ignored, since shifts in species composition contributing to these classes can be informative of density-dependent impacts, illustrating the dichotomy of the equilibrium and non-equilibrium nature of the study area.

The RDA ordinations and Monte Carlo tests for both interpretation methods, indicated similar variables explaining most of the species-environment relations, as related to the first two axes. The RDA ordination was quite informative, indicating that the Reserve-/Commercial-Poor variables were best represented by the annual life-form, although it did not differ significantly between the three land uses. The Tribal land use was best associated with the weak perennial life-form (hence, mid-rangeland on gradient) and the Reserve-/Commercial-Good with the perennial life-form (higher rangeland on the gradient).

4.3.5 Rangeland condition scores derived from the "annual" and "perennial" grazing- and ecological indices

A gradient with regard to the "state of health" of the rangeland, thus a rangeland condition gradient within land uses and across all land uses (for the larger study area) was compared by means of the ecological and grazing indices (Fig. 4.41 and Fig. 4.42). This was done for both the "annual" and "perennial" interpretation methods. This section aims to establish, for both interpretation methods, which range condition index (ecological vs. grazing) is more informative, if any, for the use in the "Key assessment matrix" (Chapter 9, Concluding remarks).

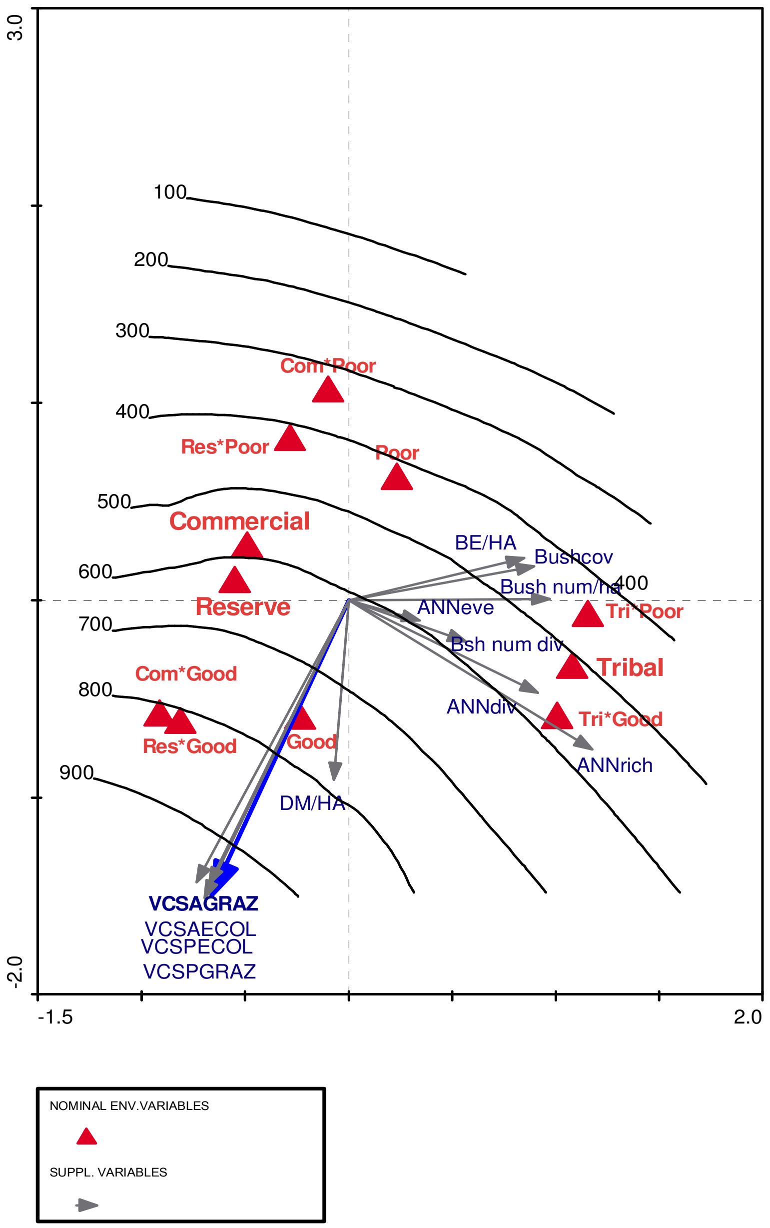


Fig. 4.41. A CCA ordination LOESS plot with rangeland condition score as predictor (blue arrow), indicating an increasing range condition gradient from the “Poor” to the “Good” variable, irrespective of the “annual” or “perennial” interpretation method.

Rangeland condition scores for both the “annual” and “perennial’ interpretations for both the grazing- and ecological indices are presented in the next section, and are illustrated in Fig. 4.42.

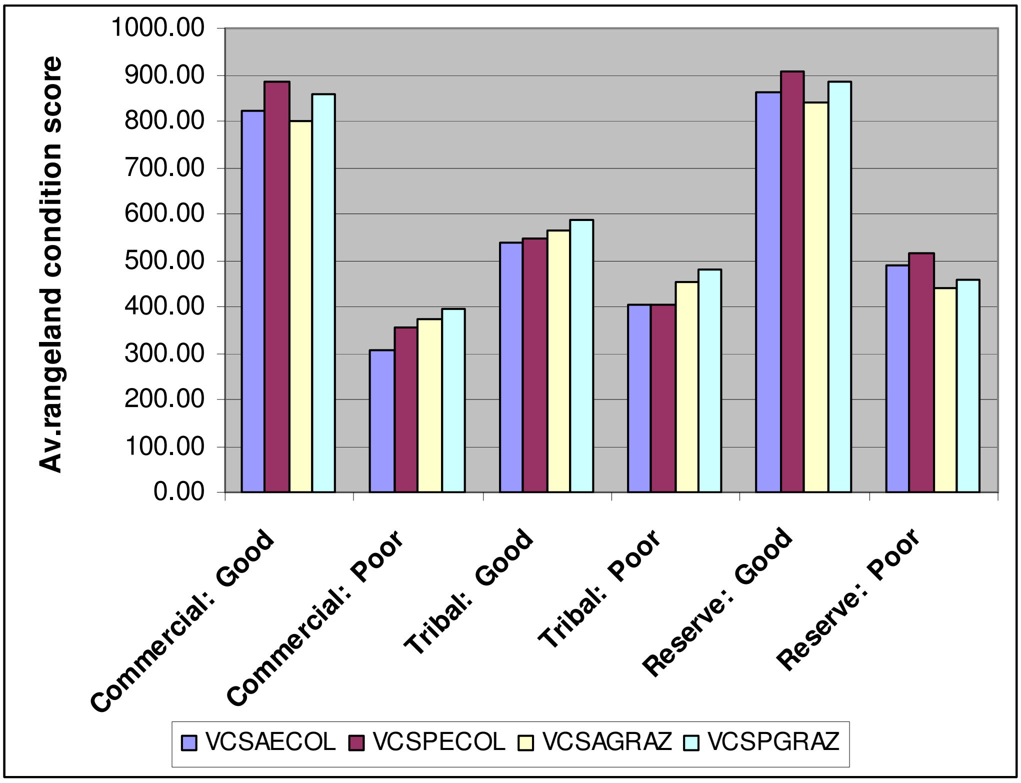


Fig. 4.42. Average rangeland condition scores according to the ecological and grazing indices, for both the "annual" and "perennial" interpretation for all three land uses.

4.3.5.1 Grazing and Ecological indices - Differences between land uses and between relative condition groups for the larger study area

Differences between land uses were established by means of two-way crossed ANOSIM tests.

A. Differences between land uses based on the grazing index

Differences between the three land uses, incorporating the rangeland condition scores derived from the "annual" and "perennial" grazing interpretations, were investigated by means of two-way crossed ANOSIM tests.

A two-way crossed ANOSIM for the "annual" interpretation indicated small but significant differences between the land uses, with $r = 0.251$ ($P < 0.001$) for the Commercial-Tribal groups and $r = 0.24$ ($P < 0.001$) for the Tribal-Reserve land uses. There was no significant difference between the Commercial-Reserve land uses ($r = -0.032$, $P > 0.1$). The test for differences between the relative rangeland condition groups, averaged across all land use types, was significant ($r = 0.264$, $P < 0.001$). From these analyses, it was evident that a rangeland condition/degradation gradient existed for the larger study area. However, according to the rangeland condition scores, the gradient was less pronounced as was indicated by the ANOSIM tests for the species compositional data, grazing- and ecological classifications. The Commercial and Reserve land uses were positively correlated and not associated with the Tribal land use, thus being consistent with the previous results.

Results from the two-way crossed ANOSIM for the "perennial" interpretation showed that there were significant but relatively small differences between the Commercial-Tribal (r = 0.217, P < 0.001) and the Tribal-Reserve (r = 0.317, P < 0.001) land uses and no significant differences between the Commercial-Reserve land uses (r = -0.019, P > 0.1). These statistics (r-coefficients) were higher than those for the "annual" interpretation, showing more pronounced differences between the land uses. The test for differences between the relative "Good" and "Poor" variables, representing the rangeland condition gradient, was significant and higher than that of the "annual" interpretation, with r = 0.297 (P < 0.001). Based on the perennial interpretation, the results indicated differences between the Commercial-Tribal and Reserve-Tribal land uses to be more pronounced (Table 4.47, Fig. 4.42), and the range condition gradient to be longer. Both interpretation methods though explained the similar significant patterns. These results will be discussed more in depth, together with the results of the ecological classification, in Section 4.3.5.3

Table. 4.47. Correlation coefficients (r-values) between the different rangeland condition indices, as indicated by the Pearson's coefficient, Draftsman plot.

Variable	Variable	Correlation
VCSAGRAZ	VCSPGRAZ	0.893
VCSAGRAZ	VCSAECOL	0.879
VCSAGRAZ	VCSPECOL	0.856
VCSPGRAZ	VCSAECOL	0.944
VCSPGRAZ	VCSPECOL	0.963
VCSAECOL	VCSPECOL	0.981

B. Differences between land uses based on the ecological index

The two-way crossed ANOSIM test for the "annual" interpretation indicated significant though low differences in the rangeland condition scores between the Commercial-Tribal groups (r = 0.262, P < 0.001) and intermediate between the Tribal-Reserve land uses (r = 0.287, P < 0.001) groups, but no significant differences between the Commercial-Reserve groups (r = 0.045, P > 0.1). The "Good" and "Poor" relative condition groups showed a significant though not very pronounced difference (r = 0.32, P < 0.001) when averaged across all land use types. Based on the ecological index, a degradation gradient was also significant, with the statistics being slightly higher than with the "annual" grazing index classification for the Commercial land use, and considerably higher for the Reserve land use.

Based on the "perennial" interpretation, there were significant though not very pronounced differences between the Commercial-Tribal (r = 0.278, P < 0.001) and the Tribal-Reserve land uses (r = 0.339, P < 0.001), but no significant differences between the Commercial and Reserve groups (r =0.019, P > 0.1). The difference between the relative “Good” and “Poor” groups, averaged across all land use groups, was significant (r = 0.334, P < 0.001). For the “perennial” interpretation, differences between the land uses and relative condition groups were more pronounced than with the “annual’ interpretation ecological classification. Hence, the degradation gradient was more pronounced in the “perennial” interpretation, due to the nearest plant-point survey technique, as was already discussed in the sections above. The implications of this statement will be discussed in Section 4.3.5.3.

C. Remarks

Tendencies between interpretation methods within and across the grazing and ecological indices remained similar, showing the strong correlation between the different range condition indices (Fig. 4.41). The correlation coefficients, calculated by the Draftsman plot (Clarke & Warwick 2001), between the different rangeland condition indices for both the “annual” and “perennial” interpretations, are presented in Table 4.47.

However, the “perennial” interpretation showed the largest differences between the relative “Good” and “Poor” groups for both the grazing and the ecological indices (Fig. 4.42). Statistics between the two indices were very similar, although the ecological index indicated more pronounced differences between the rangeland condition groups for both the “annual” and “perennial” interpretation methods. Differences with regard to the range condition scores, will be discussed in Section 4.3.5.3

4.3.5.2 Differences within land uses based on grazing and ecological indices

Differences based on the two indices were then investigated ***within*** each land use as to establish whether any significant differences and thus rangeland condition gradients existed between the relative “Good” and “Poor” extremes of a land use. These analyses were done to establish whether rangeland monitoring and assessment at this in-depth level is significant and can serve as directive for management purposes. One-way ANOSIMS were used to test for differences.

A. Differences within land uses based on the grazing index

Based on the “annual” interpretation, for the Commercial group there was significant intermediate differences (r = 0.492, P < 0.001) between the “Good” and “Poor” extremes for the grazing condition index. For the Tribal land use, based on the grazing condition index, the difference was statistically insignificant (r = 0.001, P > 0.1). There was a significant intermediate-low difference (r = 0.3, P < 0.001) between the relative “Good” and “Poor” extremes for the Reserve grazing index. These results, based on the “annual” interpretation grazing condition scores, suggest that the gradient was more pronounced within the Commercial land use, followed by the Reserve land uses. Hence, sites representative of very low as well as of very high range condition scores were prevalent with the Commercial land use, with this gradient being slightly less pronounced in the Reserve. No gradient was visible within the Tribal land use, which suggests that it was associated with an intermediate position on the rangeland condition gradient.

The one-way ANOSIM tests for differences between the relative "Good" and "Poor" samples for the "perennial" interpretation showed significant intermediate differences within the Commercial land use ($r = 0.442$, $P < 0.001$), and insignificant differences within the Tribal land use ($r = 0.028$, $P > 0.1$). The Reserve showed intermediate differences between the relative "Good" and "Poor" groups for the rangeland condition scores ($r = 0.42$, $P < 0.001$). The rangeland condition gradient was slightly more pronounced within the Commercial land use, followed by the Reserve land use (Fig. 4.41).

B. Differences within land uses based on the ecological index

Differences between the relative "Good" and "Poor" extremes for the Commercial land use were significant ($r = 0.592$, $P < 0.001$) for the "annual" ecological range condition index. Results on the differences between the condition groups for the Tribal rangeland condition index were insignificant ($r = 0.017$, $P > 0.1$). The difference between rangeland condition scores for the relative "Good' and "Poor" groups for the Reserve was low ($r = 0.35$, $P < 0.001$). These results are very similar to that of the grazing index, showing a more pronounced gradient within the Commercial land use.

Differences for the "perennial" interpretation, between the Commercial "Good" and "Poor" relative condition types were significant ($r = 0.569$, $P < 0.001$). Differences between the "Good" and "Poor" Tribal land use samples were not significant when using the rangeland condition index ($r = 0.012$, $P > 0.1$). Differences were significant of intermediate strength ($r = 0.42$, $P < 0.001$) between the Reserve's relative "Good" and "Poor" groups. Differences for the Commercial land use were lower than with the "annual" interpretation, but higher for the Reserve interpretation. This can be ascribed to the annual life-form, which showed a stronger association with the Commercial-Poor variable than the Reserve-Poor group being omitted. However, more perennials pointed out in this nearest plant-point survey method, were associated with the Reserve-Good group than with the Commercial-Good group. Hence, the Reserve-Good variable was associated with the highest range condition scores (due to the inclusion of higher "scoring" perennial species).

4.3.5.3 Average range condition scores for the grazing and ecological indices pertaining to the "annual" and "perennial" interpretations

The average grazing index' rangeland condition scores for the entire study area (72 subreplicates), for each separate land use (24 subreplicates each), for the average relative "Good" and "Poor" variables (36 replicates each), as well as for the relative "Good/Poor" conditions (12 replicates each) within each land use are presented in Table 4.48.

Table 4.48. Descriptive statistics for the mean rangeland condition scores.

	VCSAECOL	VCSPECOL	VCSAGRAZ	VCSPGRAZ
Total: General				
Mean	570.27	601.83	578.63	611.01
Standard Error	31.28	32.62	29.68	31.12
Minimum	0.00	0.00	0.00	0.00
Maximum	992.20	1001.00	996.10	996.10
Total: Good				
Mean	740.60	779.11	735.19	777.10
Standard Error	32.06	34.14	29.07	29.86
Minimum	232.00	232.00	235.00	235.00
Maximum	992.20	1001.00	996.10	996.10
Total: Poor				
Mean	399.94	424.56	422.07	444.93
Standard Error	35.83	36.82	36.45	38.21
Minimum	0.00	0.00	0.00	0.00
Maximum	908.00	908.00	840.50	840.50
Difference: Good/Poor	**340.66**	**354.55**	**313.12**	**332.16**
Commercial: General				
Mean	564.13	617.86	585.70	627.95
Standard Error	64.23	65.58	57.20	61.12
Minimum	57.50	0.00	97.80	0.00
Maximum	992.20	1001.00	996.10	996.10
Commercial: Good				
Mean	821.91	882.35	799.79	858.18
Standard Error	39.23	37.81	41.30	39.84
Minimum	480.70	525.80	482.80	528.20
Maximum	992.20	1001.00	996.10	996.10
Commercial: Poor				
Mean	306.34	353.37	371.60	397.72
Standard Error	60.24	61.95	60.37	66.30
Minimum	57.50	0.00	97.80	0.00
Maximum	853.80	861.00	831.30	838.50
Difference: Good/Poor	**515.57**	**528.98**	**428.19**	**460.46**
Tribal: General				
Mean	461.94	465.23	500.52	524.30
Standard Error	32.29	35.31	34.48	37.35
Minimum	106.20	67.40	103.50	103.40
Maximum	772.80	803.40	742.80	773.40
Tribal: Good				
Mean	538.06	546.19	566.25	587.78
Standard Error	41.31	42.14	39.22	40.18
Minimum	232.00	232.00	235.00	235.00
Maximum	772.80	803.40	742.80	773.40
Tribal: Poor				
Mean	406.50	404.73	453.73	477.97
Standard Error	44.17	50.32	53.09	59.10
Minimum	106.20	67.40	103.50	103.40
Maximum	576.60	613.90	696.60	737.40
Difference: Good/Poor	**131.56**	**141.47**	**112.51**	**109.81**
Reserve: General				
Mean	674.42	712.18	640.20	672.23
Standard Error	54.61	55.41	57.74	58.63
Minimum	0.00	0.00	0.00	0.00
Maximum	989.80	989.80	964.90	964.90
Reserve: Good				
Mean	861.84	908.78	839.53	885.33
Standard Error	29.97	22.15	29.27	19.69
Minimum	722.00	735.60	700.90	718.80
Maximum	989.80	989.80	964.90	964.90
Reserve: Poor				
Mean	486.99	515.58	440.88	459.12
Standard Error	72.02	72.94	76.56	75.70
Minimum	0.00	0.00	0.00	0.00
Maximum	908.00	908.00	840.50	840.50
Difference: Good/Poor	**374.85**	**393.20**	**398.66**	**426.22**

Rangeland condition indices indicated as most consistently typical by the SIMPER analyses of the relative condition groups (“Good” vs. “Poor) within each land use, are presented in Appendix 4.13. These analyses were done to determine whether some of the range condition indices were more applicable in surveys for the different relative condition groups pertaining to the different land uses. Hence, consistent contribution to similarities within a relative condition group within a land use is considered to be an appropriate measure for assessing which range condition index method need to be applied. This may provide to be useful in recommendations made for the “Key assessment matrix”, Chapter 9 (Concluding remarks).

The Commercial-Good group was best typified by the “annual” ecological and “annual” grazing indices, and not by the “perennial” interpretation, though the latter resulted in the highest average range condition scores. This can be attributed to less consistent congruent patterns within the “perennial” than the “annual” interpretations. Hence, perennial species included according to the “perennial’ interpretation, displayed localised patch/paddock patterns, being more abundant in certain relative “Good” sites than other. The Commercial-Poor group was consistently best typified by the “perennial” and “annual” grazing-indices (Appendix 4.13).

The Tribal-Poor group was consistently best typified by the “annual” ecological index and the Tribal-Good by the “perennial” and “annual” ecological indices (Appendix 4.13). The Reserve-Poor group was consistently best indicated by the “perennial” ecological index and the Reserve-Good group by the “perennial” grazing index (Appendix 4.13).

These results can serve as guidelines to be implemented in the “Key assessment matrix”. However, it is recommended that since the range condition indices were so closely correlated and the contributions to the similarities within relative condition groups within the respective land uses were very similar, these results should serve as baseline and departure point for future surveys across different seasons (in order to distinguish between equilibrium and non-equilibrium events). Such future surveys should include long-term monitoring to include long-term seasonal variability, to establish whether the different range condition indices for both the “annual” and “perennial’ interpretation yield different patterns (Appendix 4.13). This will contribute to explaining and statistically verifying the observed patterns.

However, from Table 4.48 it was evident that the Tribal land use was characterised by intermediate range condition scores for both relative rangeland condition groups, showing only relatively small differences between the Tribal-Good and Tribal-Poor groups (range condition scores differing between 109 and 142) for the all the rangeland condition indices. The Reserve-/Commercial-Poor relative condition groups were characterised by low scores and the Reserve-/Commercial-Good groups by high range condition scores, resulting in large differences between the rangeland condition groups within these two land uses for all the rangeland condition indices (between 428 and 516 for the Commercial land use and between 374 and 427 for the Reserve land use). The gradient was thus most pronounced and significant within the

Commercial land use, followed by the Reserve land use. This can be ascribed to the same arguments discussed in Section 4.3.1.7.

4.3.5.4 Rangeland condition ordination – LOESS presentation with range condition score as predictor

The CCA ordination for the “annual” grazing index was illustrated by means of an LOESS plot (Fig. 4.41), with the range condition score as predictor. It was evident that a rangeland condition gradient between the relative “Poor” to “Good” variable existed for the entire study area, with the gradient being most prevalent within the Commercial followed by the Reserve land uses. The Tribal land use occupied low-intermediate ranges. Hence, the Commercial and Reserve land uses were characterised by sites associated with very low range condition scores as well as with very high range condition scores, whereas the Tribal areas had low to intermediate-high range condition scores. The range condition scores for the different indices for both the “annual” and “perennial’ interpretations were highly correlated (Table 4.47), and hence the CCA LOESS gradients with range condition index as predictor, were all similar to that of Fig. 4.41.

4.3.5.5 Discussion of rangeland condition scores

Rangeland condition indices for both the “annual” and “perennial” interpretation methods, for both the grazing- and ecological indices, were highly correlated (Table 4.47). Differences, as established with the ANOSIM tests between the Commercial-Tribal and Reserve-Tribal land uses, were intermediate to intermediate-high, while indicating no differences between the Commercial-Reserve land uses, as supported by the CCA ordination (Fig. 4.41). Rangeland condition gradients for both the grazing and ecological indices were pronounced and significant within the Commercial and Reserve land uses, whereas differences between the relative “Good” and “Poor” groups were insignificant within the Tribal land use (Fig. 4.41). The length of the rangeland condition gradient was more pronounced for the “perennial” than the “annual” interpretation method for both the ecological and grazing indices. However, the average “Poor” and “Good” relative condition sites for both the Commercial and the Reserve land uses for the “perennial” interpretation were higher than that of the “annual” interpretation, showing that the longer (stronger) rangeland condition gradient for the “perennial” interpretation was characterised by a shift towards higher rangeland condition values for both the relative “Poor” and “Good” sites (Table 4.48). This implies that perennial life-forms were present within these sites and were pointed out in the place of the nearest annual life-form during the surveys. Hence, even the “Poor” sites were characterised by the relatively sparse presence of herbaceous perennial life-forms. The Tribal land use was associated with low to intermediate-high rangeland condition ranges. Although the differences between the Tribal-Poor and Tribal-Good groups were insignificant, the distributional patterns of the land use along the rangeland condition gradient for the larger study area can be informative (Table 4.48, Fig. 4.41).

According to the grazing index, for the relative “Poor” rangeland condition, the Tribal-Poor variable had the highest average rangeland condition scores for both the “annual” and “perennial” interpretation methods, followed by the Reserve-Poor land use. The average range condition score for the Commercial-Poor group was considerably lower than for the Tribal- and Reserve-Poor groups. For the grazing index, notably the “Good” rangeland condition group, the Reserve-Good group had the highest average grazing index rangeland condition scores for both interpretation methods, followed by the Commercial-Good group (Table 4.48).

For the ecological index, the Reserve land use had the highest average rangeland condition scores for both the “Good” and “Poor” groups (“annual” and “perennial” interpretations). The average rangeland condition scores for the Commercial “Poor” group for both ecological interpretations were considerably lower than that of the Tribal-Poor group, indicating that the Commercial-Poor sites were relatively more degraded than the Tribal sites. The Reserve-Good group, followed by the Commercial-Good land use, had the highest average rangeland condition scores for both the “annual” and “perennial” interpretation methods. These results further support the existence of a degradation gradient, and the fact that the gradient is much longer/stronger in the Commercial and Reserve land uses (with samples and species being associated with both extremes), as opposed to the Tribal land use being associated with the low- to mid-rangeland values of the gradient (Table 4.48, Fig. 4.41).

The grazing index method showed only a small increase in rangeland condition scores for the relative “Poor” group (all land uses) from the “annual” to the “perennial’ interpretation (Table 4.48). However, the increase from the “annual” to the “perennial” interpretation (grazing index) for the relative “Good” rangeland condition scores was much more pronounced for the Reserve-/Commercial Good groups, and only moderate for the Tribal-Good group (Table 4.48).

For the ecological index method, the rangeland condition scores for both the “perennial” “Good” and “Poor” rangeland condition groups were considerably higher than that of the “annual” interpretation method, except for the Tribal-Good group that did not show such a pronounced increase from the “annual” to “perennial” interpretation, while the Tribal-Poor group showed a small decrease in rangeland condition (Table 4.48).

In general, the ecological index for the “perennial” interpretation, resulted in higher rangeland condition scores for both the “Poor” and “Good” groups across all land uses (except for the Tribal-Poor land use, with the “perennial” grazing range condition score being highest for the relative “Poor” condition within this land use) for both indices (Table 4.48).

4.3.6 Integration of herbaceous species composition with other environmental and biotic variables

The integration of the herbaceous species composition data set with other biotic and abiotic variables to determine which variables contribute to the main compositional patterns between multivariate data sets, is discussed in Chapter 7. This was done to identify matching biotic to biotic/abiotic/environmental patterns and to confirm that land use was the primary determinant of species-environment relations.

4.4. CONCLUSION

Ellis and Swift (1988) and Ward *et al.* (1998) stated that degradation, as the result of high stocking rates within non-equilibrium systems, is a reversible process due to rainfall events, based on the low density-dependent effects of herbivores on the vegetation. Ward *et al.* (1998) conclude that although degradation and/or desertification can not be ignored, rainfall in arid regions are major driving factors masking the small impact by livestock in such areas, while also acknowledging that slow, long-term degradation has occurred in both commercial and communal land uses. However, Illius and O'Connor (1999) acknowledge that rainfall is an important driving factor in arid and semi-arid ecosystems, but that density-dependent coupling within these areas linked to key resources which provide forage during shortages, results in higher livestock activity and hence degradation in such areas. They further state that although climatic effects might be reversible, biotic effects such as grazing might cumulatively, over the long-term, impact on the vegetation component. Studies showed that increasing grazing pressure in the West African Sahel resulted in a decline of the following year's production of annual rangelands through the depletion of the seed bank, resulting in a decrease of up to 50% in the herbaceous production (Hiernaux & Turner 1996). Continuous livestock grazing in communal rangelands in Namibia resulted in vegetation cover not having the chance to recover and rest (Leggett *et al.* 2003a).

This study for the Molopo semi-arid rangelands acknowledges that abiotic factors such as rainfall events are major driving factors of vegetation change in the semi-arid rangelands (non-equilibrium theory) (Noy-Meir 1973; Ellis & Swift 1988), but suggests that these rangelands - whether Commercial, Tribal or Reserve - and the presence of key resources historically and currently do result in density-dependent processes (Illius & O'Connor 1999; Smet & Ward 2005) linked to these key resources, with the effect of degradation being masked by climatic events (non-equilibrium theory). However, relatively lower stocking densities applied on the "conservation" Commercial ranches as well as within the Reserve land use for this study, may result in more forage available during droughts. Leggett *et al.* (2003a) showed that grass species, trees and shrubs reflected intensive grazing by domestic stock, especially during drought years. According to Bayer and Waters-Bayer (1994), increased grazing pressure may result in the replacement of perennial grasses by annual species, hence impacting on the rangeland yield.

This dichotomy between the non-equilibrium processes and density-dependent factors renders these systems relatively resilient, possibly explaining the intermediate differences only between relative "Good" and “Poor” rangeland conditions for the Reserve and Commercial land uses, and intermediate differences between the Tribal-Reserve and Tribal-Commercial land uses. However, the transitional shift in species composition displayed by the Tribal land use, suggests that both the equilibrium (effect of continuous livestock grazing) and non-equilibrium systems (resilience following favourable climatic events) operate within these rangelands. If a shift towards a new domain has been reached, non-equilibrium events will not easily result in a transitional shift (flexibility) back towards the previous domain and range condition state. For this study, it is suggested that climatic events (non-equilibrium events) might mask density-dependent coupling effects within the new domain up to a certain point, whereafter the system may reflect the longer-term degradation events due to losing its flexibility (resilience). The abundance of perennial grasses and browse allows an ecosystem more resistance and resilience to disturbance caused by drought and grazing (Whitford *et al.* 1999a), but a lack of perennial grasses indicates that an ecosystem does not have a great degree of resistance and resilience to disturbance caused by drought and grazing by animals (Leggett *et al.* 2003a).

The debate regarding the sustainability and productivity of communal rangelands, in comparison to commercial ranching, is still under discussion. It is a common perception that overgrazing and poor management strategies are far greater in communal farming areas than in commercial farming areas (Archer *et al.* 1989), resulting in unproductive and degraded rangelands (Dahlberg 2000), with a lack of education being considered as a major cause of the perceived poor management practices of communal rangelands (Ellis & Swift 1988; Behnke & Scoones 1992). Hardin’s (1968) “tragedy of the commons” further states that multiple managers are one of the primary reasons for communal rangeland degradation. In response to this, the study suggests the following:

1. The existence of a degradation gradient for the larger Molopo study area, including all land uses.
2. A more pronounced degradation gradient with very low to very high rangeland condition scores within the Commercial and Reserve land use as opposed to the Tribal land use showing no rangeland condition gradient, with the entire land use being associated with low-intermediate rangeland condition ranges.
3. Possibly a transitional shift in species composition for the Tribal land use, ranging from low to intermediate-high rangeland condition ranges.

According to Zimmerman *et al.* (2001), perennial grasses in Camelthorn savanna of the eastern Namibia gave a better reflection of the range condition than the annual grasses. These authors found that due to good rains, perennial grasses had been sufficiently abundant and were good indicators of rangeland condition. However, in prolonged drought and continuous heavy grazing, the situation might be reversed and other indicators might be needed (Zimmerman *et al.* 2001). For this particular survey year, differences within and between land uses for the ecological and grazing indices for both the “perennial” and “annual” interpretation methods were not very pronounced, although some interesting observations were made, as were discussed in the results. However, the “perennial” interpretation was informative in that it did show a more pronounced rangeland condition gradient within the Commercial and Reserve land uses. These results suggest that the total study area is relatively resistant and resilient to disturbance caused by intensive livestock grazing and droughts. However, annual herbaceous life-forms were primarily associated with the relative "Poor" sites within the Commercial and Reserve land uses, suggesting that a lack of perennial grasses may result in a decreased rangeland condition and yield. The Tribal land use was primarily characterised by weak perennial grass species. Although no pronounced rangeland condition/degradation gradient was evident within the land use, the shift in species composition structure towards a poorer life-form, indicates that the Tribal ecosystem did not retain its full (long-term) potential with regard to resilience and resistance to disturbances. Arid and semi-arid areas where the mobility of pastoralists has been limited, and where high livestock number are increasingly maintained through the provision of supplementary feed, have the same effect as increasing the key resources. Thus it increases the risk of degradation by allowing high grazing pressure to be maintained in an area during a drought season (Vetter 2005). Hence, the ecological consequences of restricting herbivory and providing key resources (water and feed) in temporally variable environments, need to be fully quantified (Vetter 2005).

Monitoring over the long-term is essential to establish whether the state-and-transitional model, encompassing fluctuations in the proposed non-equilibrium vs. density-dependent dichotomous relationship, reflects significant differences within and between the rangeland condition index methods, and/or for both the "annual" vs. the "perennial" interpretation methods employed within this study.

In answer to the key questions stated for this chapter, the following. Land use was indicated as the primary determinant of structuring herbaceous compositional patterns, showing a rangeland condition gradient, and hence a degradation gradient, across the larger study area as well as significantly within the Reserve and Commercial land uses. The Tribal land use did not show a significant gradient within the land use, but was characterised by a transitional shift in species composition associated with low to intermediate-high range condition scores. Species richness and diversity were associated with the Tribal land use, suggesting that these diversity indices are indicators of complex heterogeneous systems and diversity. It is suggested that the diversity indices are indicators of environmental change and diversity rather than indicators of biodiversity (refer to Chapter 1 for definition) *per se*. This is congruent with ant functional and compositional patterns discussed in Chapter 8. Although Illius and O'Connor (1999) state that density-dependent processes are at the heart of both equilibrium and non-equilibrium dynamics, state-and-transition models may be most useful to describe vegetation dynamics pertaining to the semi-arid rangelands of the Molopo study area, and should include the respective ecological paradigms.

The implications for management from this study are the option that would include the appropriate distribution of water sources and management pertaining to other key sources (e.g. kraals, settlements etc.), together with a co-ordinated grazing and resting management system that is adaptive and flexible. Addition of more water resources (hence key resources resulting in density-dependent coupling by livestock/wildlife) in these rangelands may result in an intensifying of grazing and browsing, and if not regulated correctly, may result in increased "sacrifice" or "high impact" zones (Leggett *et al.* 2003a). Recommendations regarding the most appropriate land use practices toward range condition and diversity management will be presented in Chapter 9. A "Key assessment matrix" pertaining to both interpretations, will be presented in Chapter 9.

4.5. RECOMMENDATIONS FOR CHAPTER 4

This study acknowledges that only the "extreme condition spectra" of a rangeland condition/degradation gradient within each land use have been described, and that a complete gradient for the entire study area needs to be described. However, the purpose of this study and Chapter 4 was to establish some principles and correct indicators of rangeland condition within and between land uses as possible adaptive management tools for the different land users/owners and scientists alike. The applicability of benchmark exclosures, as motivated in Chapter 2, will prove to be useful in future as reference points for changes across survey seasons, since this was only the first survey season after erecting it (for the Reserve and Commercial land uses).

Both the "perennial" and "annual" interpretatation methods supplied essential baseline information for the Molopo semi-arid rangelands, which can be used as departure point for future long-term research, to distinguish between the effects of non-equilibrium vs. density-dependent events. More recommendations will be summarised in Chapter 9 (Concluding remarks) and Chapter 10 (Recommendations).

CHAPTER 5

Woody component

5.1. INTRODUCTION

Bush encroachment has long been recognised as a problem in the savanna areas of South Africa (Scott 1984), but is also a concern to rangeland managers around the world (Archer 1994). It is the phenomenon whereby trees and shrubs invade into open grassland or thicken up in already wooded areas (Barnes 1979; Trollope 1980; O'Connor & Crow 1999). Competitive interaction between the woody and herbaceous components of savanna, especially with regards to available soil moisture, has been reported worldwide (Donaldson & Kelk 1970; Walker *et al.* 1972; Donaldson 1978; Scholes 1987; Winter *et al.* 1989; Smit 1994; Smit & Swart 1994). Bush encroachment does not only involve *Acacia* species and species of thorn bush, but also non-thorny species (Moleele *et al.* 2002).

The model of woody encroachment in overgrazed rangelands (Noy-Meir 1982; Walker & Noy-Meir 1982) states that a decrease in the grass layer results in woody plants having access to soil water that could otherwise have been utilised by grasses (Walker & Noy-Meir 1982). However, this view is not always the only unconditional factor contributing to the process of bush encroachment (Smit 2004). Rainfall amount and frequency (Ward & Rochner 1997), as well as soils (Friedel 1987; Moleele & Perkins 1998), fire (Trollope 1980; Rutherford 1981; Trollope & Tainton 1986) and climate change (Ringrose *et al.* 2002) may also result in bush encroachment. Teague & Smit (1992) state that a knowledge regarding stability and resilience is necessary to calculate (and manage) long-term costs and benefits and the wider ecological aspects related to holistic conservation, productivity and sustainability of savannas. Teague and Smit (1992) further concur with the authors mentioned above that the relations between woody and herbaceous plants in savannas are primarily determined by soils, soil moisture and climate, and secondary by fire and herbivory. According to Ward and Rohner (1997), rainfall amount and frequency may be primary determinants of the occurrence of bush encroachment, since trees require more moisture to germinate than grasses do. These authors further state that large numbers of trees may germinate with or without grazing in rare, high rainfall years. Ringrose *et al.* (2002) stated that for the Botswana rangelands, the expected increased aridity would result in the transformation of vegetation from tree and shrub savanna to shrub and bush savanna.

A more recent primary factor put forward to explain bush encroachment, is the global increase of atmospheric carbon dioxide (CO_2) (Polley *et al.* 1994; Archer *et al.* 1995). These authors state that encroaching woody species exhibit a greater photosynthetic and growth response under elevated CO_2 conditions, than the predominantly C_4 grasslands being invaded.

Water is the main driving force of semi-arid ecosystems (Snyman *et al.* 1987; Snyman & Fouché 1991), with the suppressive effect of bush encroachment on herbaceous plants being largely through the competition for soil water (Dye & Spear 1982; Moore *et al.* 1988). Many savannas are recognised as water-limited ecosystems, and bush encroachment is considered to be a major factor contributing towards the low occurrence or even absence of herbaceous cover (Smit *et al.* 1999). An increase in woody plant density beyond a critical density causes the suppression of herbaceous plants, mainly through severe competition for available soil moisture, resulting in lower herbaceous yields and thus lowering the grazing capacity (Dye & Spear 1982; Moore 1989; O'Connor 1991a; Smit & Rethman 1998; Richter *et al.* 2001).

The natural savanna vegetation of Africa evolved in the presence of multiple species of herbivores with a wide range of diet preferences, making it reasonable to assume that these herbivores and vegetation were in a dynamic balance, with both the herbaceous and woody components being utilised (Kelly 1977). Owen-Smith (1989) stated that African savannas have an evolutionary history of high levels of browsing by herbivores, capable of modifying the woody structure and composition, with the consequence that the removal of browser ungulates may have contributed to bush encroachment (Smit 2004).

Livestock farming has often resulted in bush encroachment and a reduction of grazing capacity in many semi-arid grasslands and savannas (Donalson 1966; Archer *et al.* 1988; Asner *et al.* 2003). This can be ascribed to a change in the competitive balance between grass and bush (Friedel 1987). Friedel (1991) suggested that two transitions across thresholds could be recognised in arid and semi-arid rangelands: (i) a change from herbaceous to woody dominance, and (ii) irreversible changes in soil physical and chemical properties. The value of grazing may be completely destroyed by encroaching woody plants, while their eradication may cost more than the land is worth (Donaldson 1966). The grazing capacity of large areas of the southern African savannas has declined as a result of bush encroachment, resulting in many previously economic livestock properties no longer being economically viable (Smit 2004). Hence, the suppressive effect of bush encroachment on the herbaceous production has often resulted in the clearing of woody plants as a management option (Smit *et al.* 1996).

Woody plant control measures are widely applied in rangelands to increase forage for livestock and to create improved habitats for game species (Fulbright 1996). Research, however, has shown that woody plants form an essential component of certain savanna systems and total clearing can be detrimental to the livestock production potential of such areas. Furthermore, no economic advantages would be gained when the bush density in such areas is reduced below certain threshold values. Consequently, it is of great importance that the impacts of different densities of various woody species on the herbaceous layer should be quantified. This would help in determining the extent of thinning required. According to Kelly (1977), woody plants will have a competitive advantage in the absence of browsing since herbaceous plants are continuously being grazed. However, removal of woody plants may differ between vegetation types, resulting in negative or positive responses to tree removal (Teague & Smit 1992). Trees may have positive effects on the grass growth (Smit 2004), with trees creating a favourable micro-environment (e.g.

leaf litter, shade) for herbaceous yields (Stuart-Hill *et al.* 1987). This is consistent with research by other authors (Bosch & Van Wyk 1970; Belsky *et al.* 1989; Smit & Rethman 1992; Smit & Swart 1994). However, Grossman *et al.* (1980) found that biomass yield was greater in open grassland than under trees, but the quality of the forage was higher under the tree canopies. This is consistent with research conducted by Smit (1994), but Pieterse & Grunow (1985) found in contrast that clearing of woody plants in the Limpopo Province, South Africa, did not affect forage quality.

The Kalahari Thornveld is a water-limited ecosystem and bush encroachment invariably results in the suppression of herbaceous plants (Hagos & Smit 2005). Of importance though is the fact that the presence of woody plants is not just associated with negative consequences. Trees are known to create sub-habitats differing from that of open habitats, impacting differently on the herbaceous layer (Belsky *et al.* 1989; Smit & Swart 1994; Ludwig *et al*. 2004). In addition, several authors state that the ratio of trees to grass considerably influences the profitability of such systems (Du Toit 1972; Aucamp & Barnard 1980; Aucamp *et al.* 1983; Trollope 1983; Stuart-Hill 1987).

Bush encroachment is considered as a primary indicator of rangeland degradation within the North West Province (Hoffman *et al.* 1999). Within this study, the woody component was surveyed to establish whether the woody composition reflects a rangeland degradation gradient across the larger study area, or whether patterns were isolated to certain land uses. Woody compositional patterns were also related to soil and herbaceous species composition data (Chapter 7), and to ant compositional data (Chapter 8) to establish possible congruent patterns within and between these biotic and abiotic parameters pertaining to the rangeland condition, land use type and the diversity indices.

This chapter will address the following key questions. Do the three different land uses and hence their impacts result in different woody species compositions, densities, structures and diversity/richness patterns? Do woody composition and density reflect a rangeland condition/degradation gradient (expressed as relative “Good” vs. “Poor” rangeland condition extremes) as a result of environmental disturbance caused by the different land uses? Thus, does the woody component act as an indicator of rangeland degradation? Finally, which recommendations regarding the monitoring and management of the woody component for the semi-arid rangelands of the Molopo study area can be made?

5.2. OVERVIEW OF RESULTS AND DISCUSSION

In order to address the above-mentioned key questions, the Results and the discussion will be presented under the same headings due to the complexity of the data, and as motivated in the brackets next to each heading. ***For further clarification as to what the purpose of each analysis technique is, refer to Chapter 3, Material and Methods. Average relative abundances for woody composition, average absolute density, average number of individuals per species/ha, and average area coverage (m^2/ha) for each species within and between land uses are presented within the Tables and***

Appendices, as indicated by each relevant section. However, it should be emphasised that these GENERAL descriptive statistics, although informative, may result in major incorrect assumptions that do not reflect on spatial heterogeneity, complexity and gradients within and between land uses pertaining to rangeland degradation and biodiversity indices, neither does it reflect on the models operating within these rangelands. Neither does it reflect on key species that are consistently associated with particular land uses, rangeland conditions or other criteria. Hence, this may result in incorrect over-extrapolation of management and monitoring techniques between land uses and across different parameters, which might prove to be "development experiments" that might result in unfortunate implications for both the ecosystems and people (Ellis & Swift 1988).

Hence, it can not be emphasised enough that, although these different analyses techniques might result in the **incorrect** perception of over-analysing, the different procedures were all essential and complementary to each other. It was only after the in-dept analyses, using the different procedures that it was possible to establish the different multivariate spatial patterns, heterogeneity complexity and diversity- and rangeland gradients pertaining to the woody data, which exist within and between land uses due to different land use impacts (refer to Conclusions within each chapter and final Concluding Remarks in Chapter 9).

5.3. RESULTS AND DISCUSSION

5.3.1 General - Woody species composition and density (a general overview)

5.3.1.1 Relative abundance - Analysis of similarities (ANOSIM) and Multidimensional scaling (MDS iterative procedures, based on relative abundances of species, to establish whether removal of sites from further analyses are necessary)

5.3.1.2 Relative abundance - Species richness and diversity (based on relative abundance data – TE/ha: ANOSIM to establish patterns within and between land uses for the different diversity measures, and relate it to relative rangeland condition groups)

5.3.1.3 Relative abundance - Woody species community patterns (TE/ha)

A. Indirect DCA ordination (based on relative abundance data)

B. Direct CCA ordination and Monte Carlo test - establish species-environment relation (employing the land use, relative "Good" and relative "Poor" groups as environmental variables)

C. Cumulative contribution towards explaining species-environment variance (key species explaining 10% and higher of the species-environment variance)

D. Relative abundance compositional patterns

5.3.1.4 SIMPER analysis for general woody species composition matrix between land uses (Explanatory procedure as complement to Section 5.3.1.1 and Section 5.3.1.3 for adaptive management purposes)

5.3.1.5 ANOSIM and SIMPER for relative condition groups *within* each land use

5.3.1.6 Cumulative k-dominance plots (establish whether species accumulative asymptotes in respective land uses have been reached)

5.3.2 Woody structural form, density (actual TE/ha), numbers/ha and woody area coverage (m^2/ha)

5.3.3 Integration of herbaceous species composition with other environmental and biotic variables (recommendations pertaining to these multivariate analyses)

5.3. RESULTS AND DISCUSSION

5.3.1 General - Woody species composition

A total of 24 woody species were recorded across the entire study area (Appendix 5.1). Woody composition of these species is presented as relative abundances (percentage/frequency of occurrence within survey site/sub-replicate) for the TE/ha-matrix (Appendix 5.2), Bush numbers/ha-matrix (Appendix 5.3) and the Bush area coverage-matrix (m^2/ha) (Appendix 5.4). Relative abundances (Section 5.3.1) were informative regarding the frequency of occurrence of woody species (proportional occurrence), and hence woody compositional patterns within and between land uses.

The structural forms of woody species (average height and canopy diameter for each species; Section 5.3.2), as modified by the land tenure practices pertaining to the different land uses, are presented in Appendix 5.8. This was a useful comparative measure between land uses with regard to different land tenure impacts on the growth form of each woody species.

The actual density of woody species/ha (Section 5.3.3), is presented as TE/ha (Appendix 5.9), bush number/ha (Appendix 5.10) and area coverage (m^2/ha) (Appendix 5.11). These matrices were informative comparative measures regarding the density patterns of woody species within and between land uses.

The abbreviations for the woody species are summarised in Appendix 5.1, and should be consulted for the interpretation of the Tables, Figures and Appendices.

5.3.1.1 Relative abundance - Analysis of similarities (ANOSIM) and Multidimensional scaling (MDS) for the total woody species compositional matrix

The procedures for the interpretation of statistics pertaining to ANOSIM analyses and MDS ordinations are described in Chapter 3 (Material and Methods). Relative abundances were employed in the analyses for Section 5.3.1.

A. Tree equivalent/ha matrix (TE/ha-matrix)

A non-metric MDS algorithm, an iterative procedure based on Bray-Curtis dissimilarities, was employed to satisfy as closely as possible the dissimilarity relations between samples/sites for the TE-matrix relative abundances. The MDS ordination indicated site ScBG as being a possible outlier sample (Fig. 5.1). This site was removed from the analyses, resulting in the stress value to remain similar (Fig. 5.2). The stress value is an indication of the distortion between the dissimilarity rankings and the corresponding distance rankings in the ordination plot (Clarke & Warwick 2001). Hence, the fact that the stress value associated with the removal of the site did not increase, suggested that the outlier should be removed from further analyses (refer to Chapter 3), as was also confirmed by the ANOSIM tests presented below. The outlier site represented the benchmark or the relative "Good" rangeland condition within the Scheepers survey area (replicate) within the Commercial land use (refer to Chapter 3). Within this site, no woody species occurred. The significance of these MDS ordinations, and the removal of the outlier site, were tested by means of ANOSIM tests, and will be discussed next.

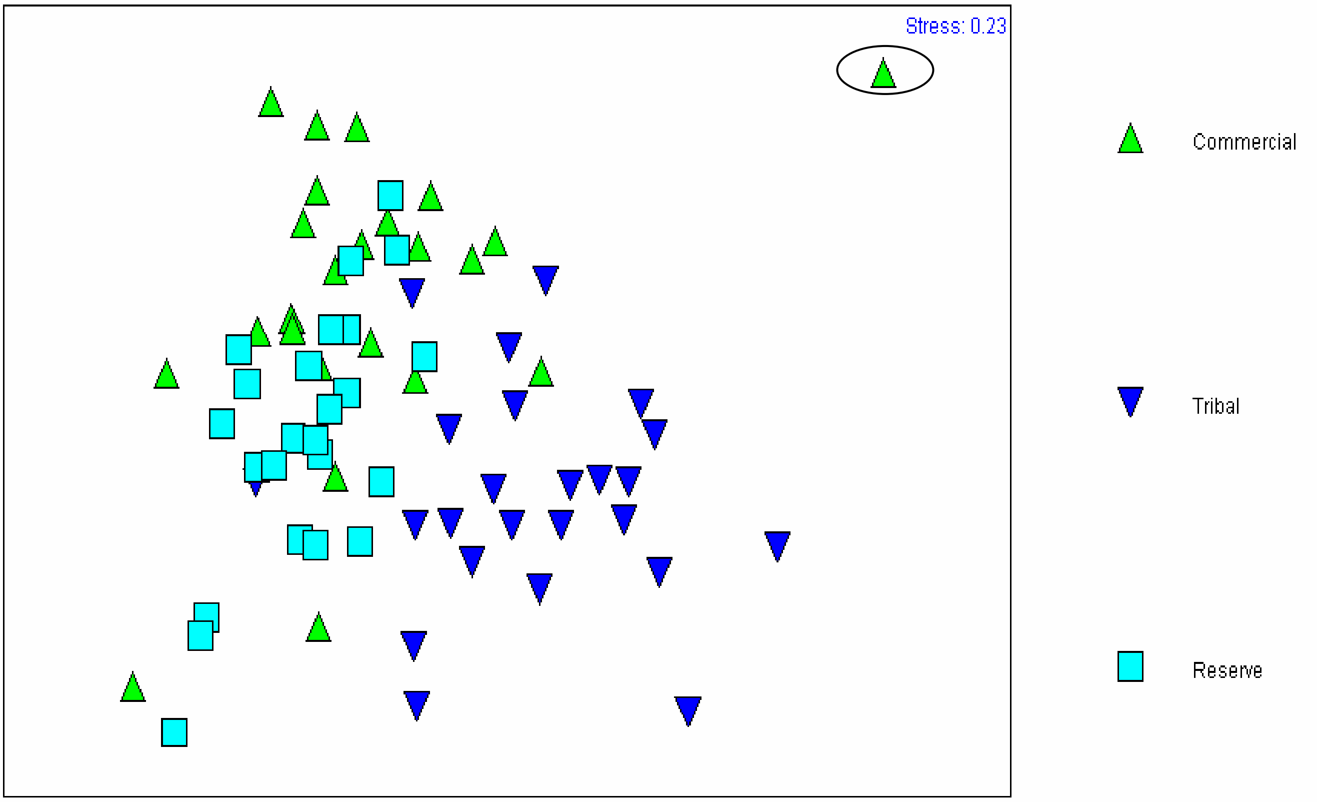


Fig. 5.1. A MDS plot for woody relative abundances (TE/ha matrix) displaying the outlier site, ScBG.

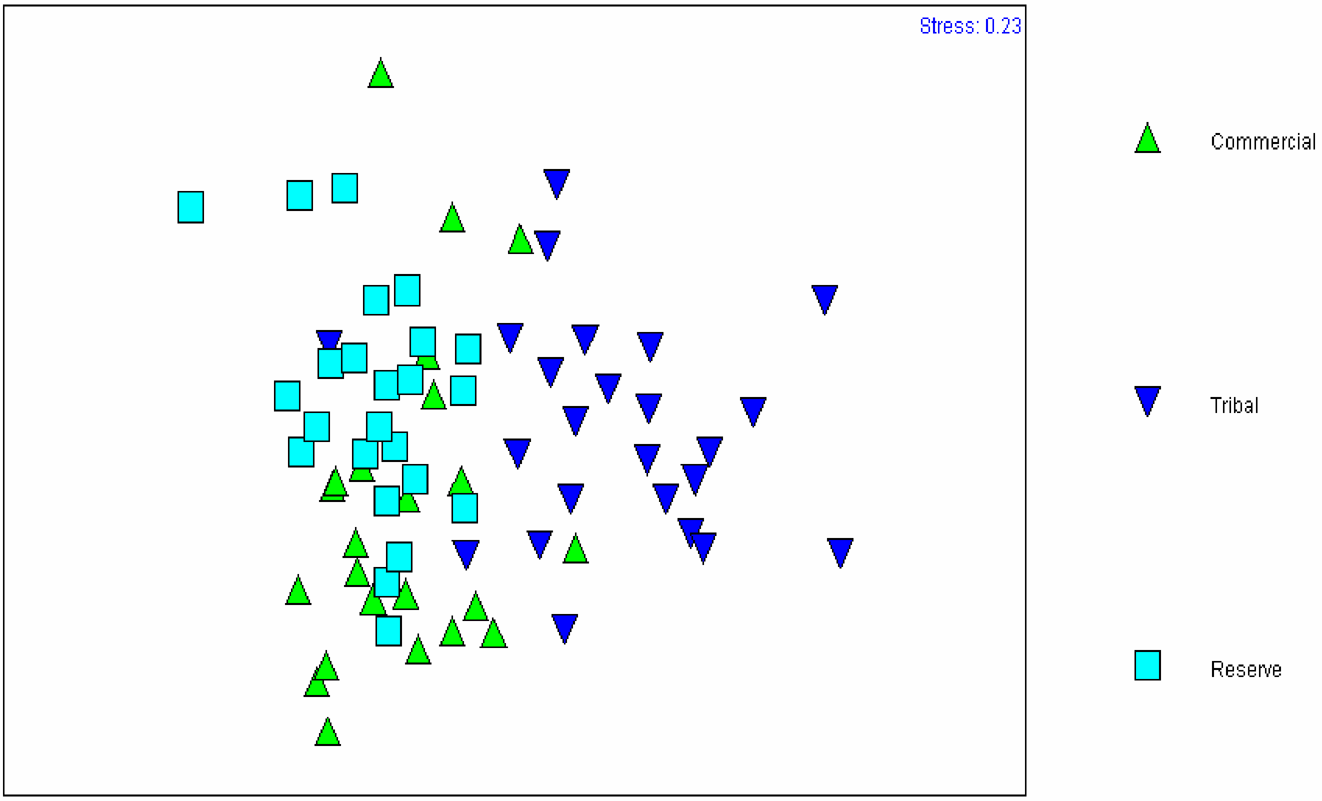


Fig. 5.2. A MDS plot for woody relative abundances (TE/ha matrix) after removal of the outlier site, ScBG.

When averaged across all relative rangeland condition areas, pair-wise tests from the two-way crossed ANOSIM showed significant differences of intermediate strength between the Commercial-Tribal land uses (r = 0.411, P < 0.001), the Tribal-Reserve land uses (r = 0.56, P < 0.001) and small but significant differences between the Commercial-Reserve land uses (r = 0.186, P < 0.001). The relative condition groups, averaged across all land uses, showed small but significant differences (r = 0.108, P < 0.001) between the “Good” and “Poor” groups.

With the removal of the outlier site (ScBG), the differences between the Tribal-Reserve land uses remained similar (r = 0.56, P < 0.001), but the r-values indicating differences between the Commercial-Reserve (r = 0.201, P < 0.001) and the Commercial-Tribal (r = 0.447, P < 0.001) land uses were higher. The differences between the relative condition groups, averaged across all land uses, were also higher (r = 0.117, P < 0.001). The improvement of the ANOSIM results, after removal of the outlier site, corresponds with the results of the MDS ordinations, suggesting that the outlier site should be omitted from the rest of the data analyses. The results further suggested that the Commercial and Reserve land uses were more similar with regard to woody species composition, than were the Commercial-Tribal or Reserve-Tribal land uses. A gradient between the relative “Poor” and “Good” groups, averaged across all land uses were significant, suggesting the existence of a degradation gradient across the total study area pertaining to the woody component (see Chapter 1, Introduction, for reference to degradation indicators). However, the degradation gradient (when averaged across all land uses) was not very pronounced, and patterns within land uses will be explored in the remainder of this chapter.

Research by Richter *et al.* (2001) showed that for semi-arid rangelands in the Northern Cape and North West Province, bush encroachment did not affect the grass species composition, implying that bush clearing will not necessarily result in improvement of herbaceous species composition. However, these authors found that above-ground herbaceous production was adversely affected by bush encroachment, with bush densities of 2500 TE/ha suppressing phytomass production during years of normal rainfall, which resulted in a decline of the grazing capacity of these areas. Results from this study showed that the woody component did result in differences in the herbaceous species composition, as was reflected by the existence of a rangeland condition/degradation gradient across the larger study area. Research results by Coetzee (unpublished report 2005) are presented in Section 5.3.1.5 in support of this statement.

Tendencies across the total study area will be compared with patterns within each land use in the remainder of this chapter. The relationship between the woody and herbaceous component was tested by means of multivariate analyses and results are presented in Chapter 7.

B. Bush numbers/ha - matrix

The explanation regarding the bush numbers (individuals) per species/ha is given in Chapter 3. The matrix is presented in Appendix 5.3.
The MDS ordination showed similar results to that discussed in Section 5.3.1.1 A (Fig. 5.1 and Fig. 5.2). Hence, only ANOSIM results after removal of the outlier site (ScBG) are presented.

The pair-wise tests from the two-way crossed ANOSIM showed similar tendencies as that of the TE/ha-matrix, with $r = 0.486$ ($P < 0.001$) for the Commercial-Tribal land uses, $r = 0.568$ between the Tribal-Reserve land uses and $r = 0.172$ ($P < 0.001$) between the Commercial-Reserve land uses. However, differences between the Commercial-Reserve land uses, and the gradient between the relative “Good” and “Poor” rangeland condition groups (averaged across all land uses) were less pronounced ($r = 0.084$, $P < 0.001$) than for the TE/ha matrix. The factors that are responsible for this phenomenon will be discussed in Section 5.3.2.

C. Bush area coverage matrix – relative abundances

The explanation pertaining to the bush area coverage matrix (m^2/ha) is discussed in Chapter 3. This matrix is presented in Appendix 5.4.

The MDS ordinations were similar to that of the TE/ha-matrix, although the placement of the outlier site (ScBG) was more pronounced (Fig. 5.3) than were indicated by the other two matrices. The outlier site was thus removed from further analyses.

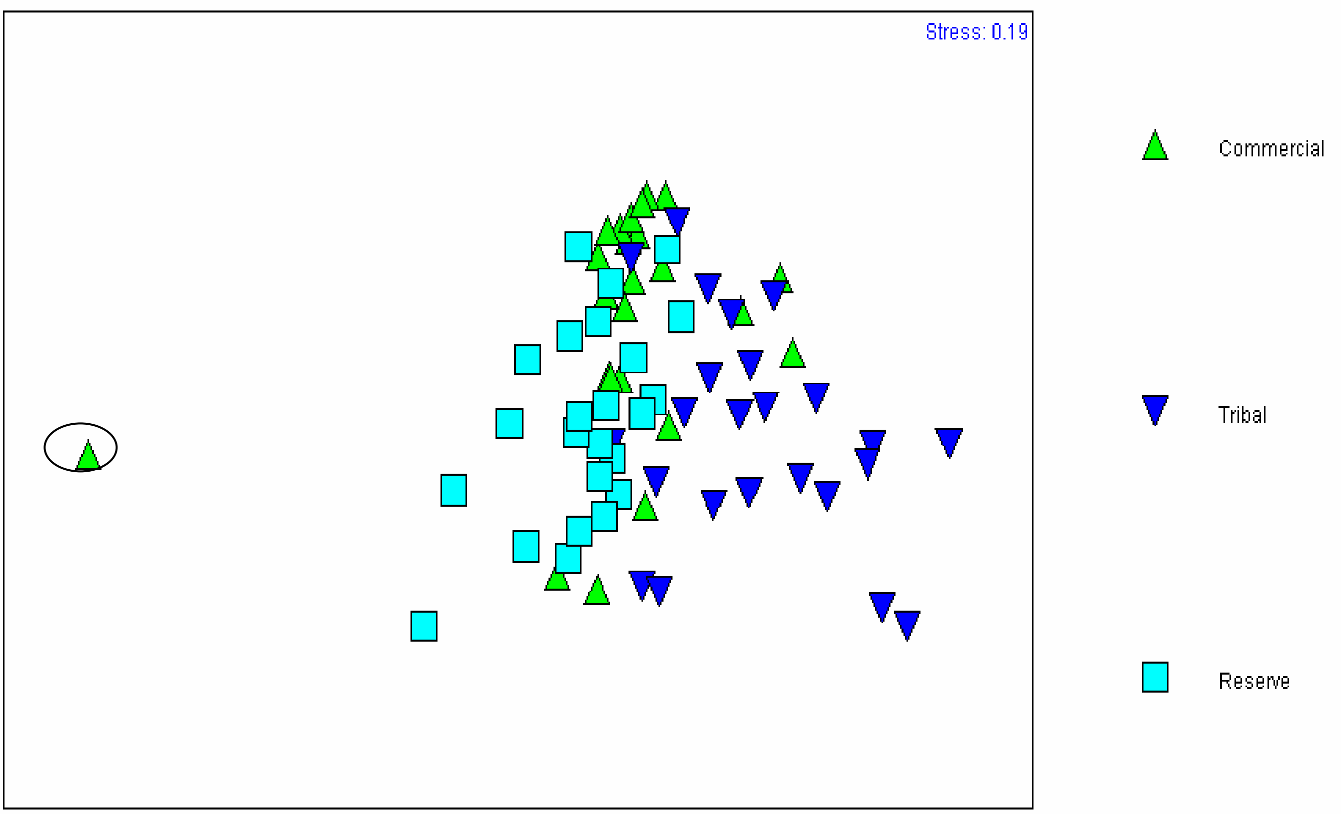


Fig. 5.3. A MDS plot for woody relative abundances (Bush area coverage matrix) displaying the outlier site, ScBG.

The pair-wise tests from the two-way crossed ANOSIM showed similar tendencies as that of Sections 5.3.1.1 A and 5.3.1.1 B, although differences were less pronounced between the Commercial-Tribal land uses (r = 0.346, P < 0.001) and the Tribal-Reserve land uses (r = 0.407, P < 0.001). Differences between the Commercial-Reserve land uses were very similar, although slightly more pronounced than that of the TE/ha-matrix (refer to Section 5.3.1.1 A). Differences between the relative “Good” and “Poor” rangeland condition groups (r = 0.158, P < 0.001) (indicating a rangeland condition/degradation gradient) were higher than that of the TE/ha-matrix, but less pronounced than that of the “Bush numbers” matrix. The factors that are responsible for this phenomenon will be discussed in Section 5.3.2.

5.3.1.2 Relative abundance - Species richness and diversity patterns

Due to the congruent patterns among the three woody matrices, only results and discussions following the TE/ha-matrix (BE-matrix – see Chapter 3) will be presented in the remainder of Chapter 5. Thus, bush density was standardised to tree equivalents per hectare (1TE = 1 tree of 1.5 m height) (Teague *et al.* 1981).

Diversity indices reduce the complexity of the multivariate data into a single index or a small number of indices evaluated for each sample, which can then be further employed in multivariate analyses (Clarke &

Warwick 2001). The purpose of the diversity indices was not only to reduce the woody structural complexity, but also to establish whether the diversity indices pertaining to the woody component were correlated or inversely related to rangeland condition and productivity of a system.

A total of 14 woody species (58.33% of the total woody component) occurred within each of the Commercial and Reserve land uses, and 22 species (91.67% of the total woody component) within the Tribal land use (Appendix 5.2).

Two-way crossed ANOSIM pair-wise tests, based on Margalef's species richness, Shannon's diversity index and Pielou's evenness, were conducted.

Based on all the diversity indices mentioned above, differences between the Commercial-Tribal ($r = 0.398$, $P < 0.001$) and the Commercial-Reserve land uses ($r = 0.216$, $P < 0.001$) were significant, but small between the Tribal-Reserve land uses ($r = 0.12$, $P < 0.001$). There were no significant differences between the relative "Good" and "Poor" rangeland condition groups ($r = 0.037$, $P > 0.1$) when averaged across all land uses. However, a one-way ANOSIM test for differences between the relative rangeland condition groups based on these diversity indices, was significant within the Commercial land use ($r = 0.16$, $P < 0.05$) only, suggesting that these combined woody diversity indices reflected the rangeland condition/degradation gradient within this land use. Species richness differed significantly between the Commercial-Good and –Poor rangeland condition groups ($r = 0.211$, $P < 0.001$). Differences between the Commercial-Good and –Poor groups based on species diversity were significant though less pronounced ($r = 0.129$, $P < 0.001$) than the species richness' results. Within the Commercial land use, species richness and diversity were higher in the "Poor" rangeland condition sites than in the "Good" rangeland condition sites, although Pielou's evenness, indicating the consistent (equitable) distribution of woody species (Clarke & Warwick 2001), was higher within the Commercial-Good rangeland condition sites (Table 5.1; Fig. 5.4). The lower species richness within the Commercial-Good rangeland condition group can be ascribed to the relatively homogeneous nature of these sites pertaining to the woody component, as will be discussed further below in this section. This is further illustrated in that Pielou's evenness indicated that woody species representative of the Commercial-Good land use group occurred consistently throughout all the sites associated with this rangeland condition group. This can mainly be ascribed to the uniform management actions with regards to woody eradication and management pertaining to this rangeland condition group within the Commercial land use.

Table 5.1. Average Margalef's species richness, Shannon's diversity and Pielou's evenness for the woody component (relative abundances – TE/ha matrix) for the different land use groups, being highest within the Tribal-Good land use, indicated in **bold**.

Land use type	**Margalef's richness**	**Pielou's evenness**	**Shannon diversity**
Total: General	1.39	0.76	1.44
Total: "Good"	1.31	0.79	1.42
Total: "Poor"	1.47	0.73	1.47
Commercial: General	0.82	0.77	1.11
Commercial: "Good"	0.67	0.79	0.94
Commercial: "Poor"	0.98	0.75	1.27
Tribal: General	1.95	0.77	1.75
Tribal: "Good"	**1.97**	**0.79**	**1.81**
Tribal: "Poor"	1.94	0.75	1.69
Reserve: General	1.39	0.75	1.47
Reserve: "Good"	1.28	0.80	1.50
Reserve: "Poor"	1.50	0.70	1.43

Based on the combined diversity indices (species richness, diversity and evenness), there were no significant differences between the rangeland condition groups (relative "Good" vs. "Poor" extremes) within the Tribal or Reserve land uses ($P > 0.1$). Neither were there differences between the "Good" and "Poor" rangeland condition groups when species richness, diversity and Pielou's evenness were tested separately.

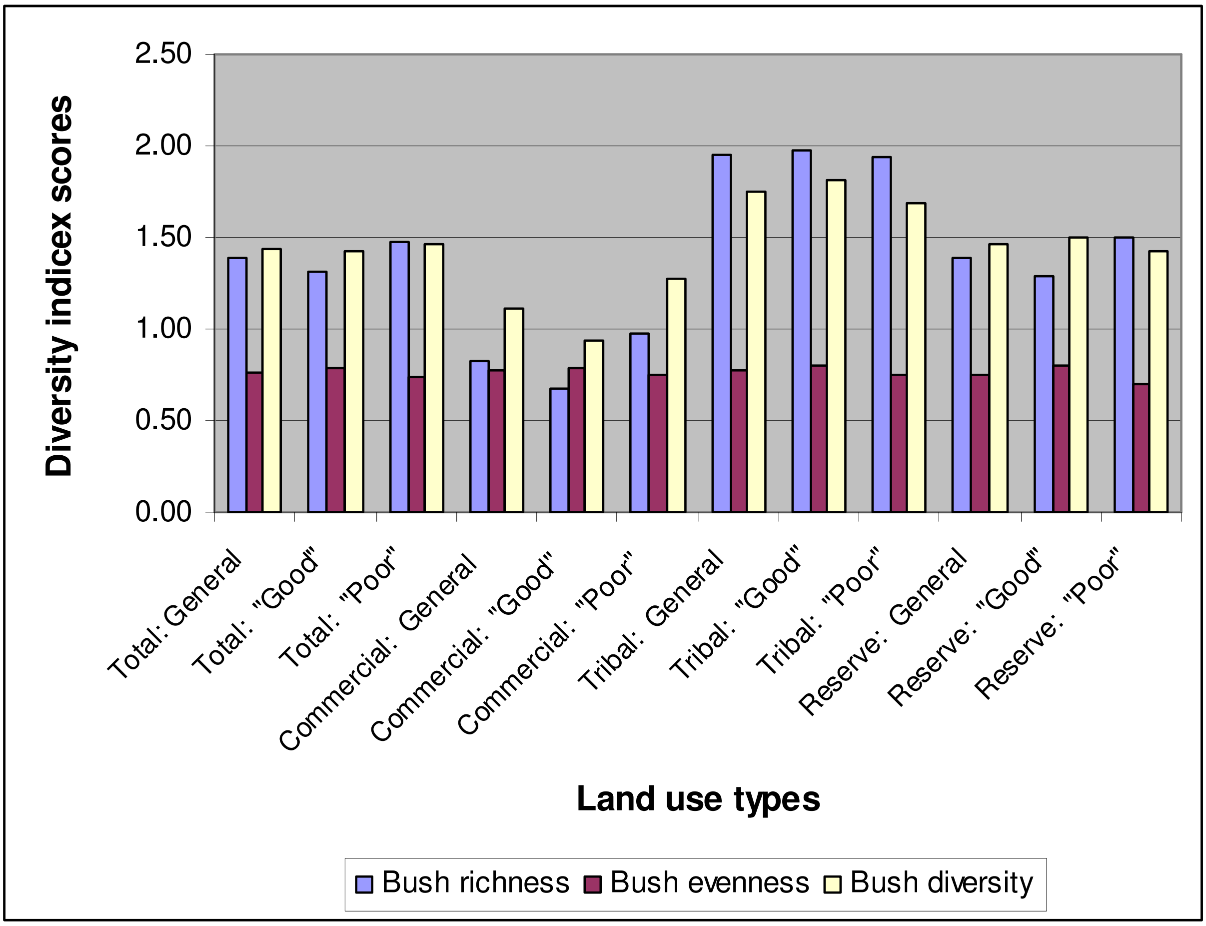


Fig. 5.4. Average Margalef's species richness, Shannon's diversity and Pielou's evenness for the woody component (relative abundance – TE/ha matrix) for the different land use groups.

Average woody species richness (Margalef's) and Shannon diversity were highest within the Tribal land use (specifically the Tribal-Good sites), with species richness and diversity being lowest within the Commercial land use, notably the Commercial-Poor sites (Table 5.1; Fig. 5.4). Species richness within the Reserve land use was highest within the Reserve-Poor sites, with species diversity being highest in the Reserve-Good sites. The Reserve species richness and diversity were intermediate between that of the other two land uses (Table 5.1; Fig. 5.4). Pielou's evenness had the highest mean within the Tribal land use, indicating that individuals among different woody species were distributed more evenly (Clarke & Warwick 2001) than within the Reserve and Commercial land uses (Table 5.1; Fig. 5.4). However, analyses at a more in-depth level to establish differences between rangeland condition groups (relative "Good" vs. "Poor") *within* each land use, indicated that the Reserve-Good had the highest average evenness for the total study area, with the Reserve-Poor group having the lowest average evenness (Table 5.1; Fig. 5.4).

A direct CCA ordination LOESS attribute plot displaying the environmental and passive variables associated with the first two canonical axes, is presented in Fig. 5.5. Margalef's species richness was incorporated as predictor. A gradient (illustrated by the contours) showed that Margalef's species richness was highest within the Tribal land use (Margalef's species richness contour levels: 1.6 – 1.8)

(Fig. 5.5). Species richness within the Reserve land uses was intermediate between that of the Tribal and Commercial land uses (contour levels 1.2 – 1.4) (Fig. 5.5). Margalef's species richness' levels varied between 0.6- 1.0 for the Commercial land use, with the Commercial-Poor sites falling within the 0.6 contour level, and the Commercial-Good sites within the 1.0 contour level (Fig. 5.5). The Tribal and Reserve land uses did not show any species richness gradients between the relative "Good" and "Poor" groups within each land use. These results are consistent with that of the ANOSIM results presented above, which showed that woody species richness reflected the rangeland condition/degradation gradient within the Commercial land use, but not within the other two land uses. The list of the abbreviations and descriptions for the passive and environmental data employed in the figures, are summarised in Table 3.1 (Chapter 3).

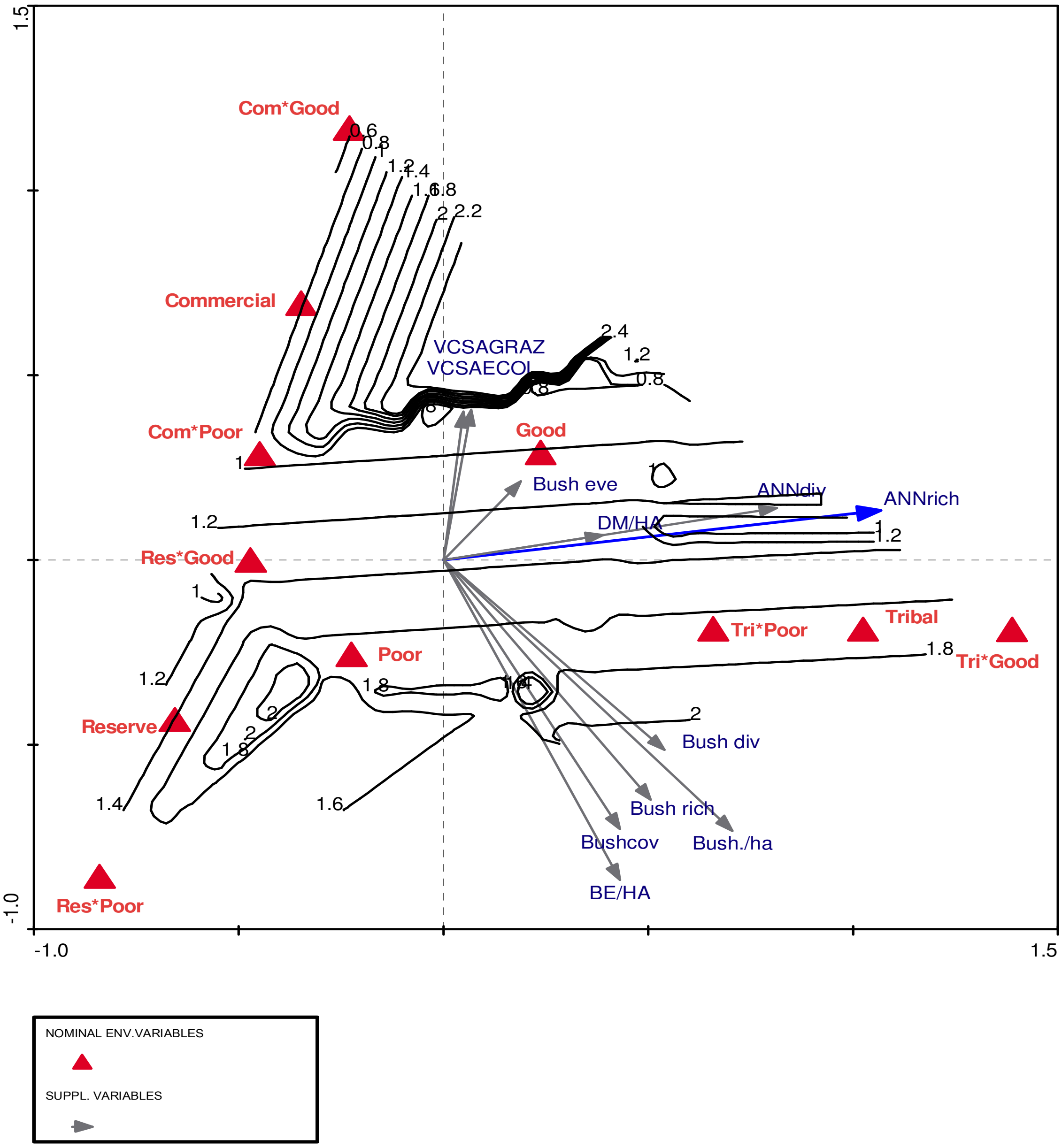


Fig. 5.5. A CCA ordination LOESS attribute plot (relative abundance – TE/ha matrix), incorporating Margalef's species richness (blue arrow) as predictor, being highest within the Tribal land use.

A CCA ordination LOESS attribute plot, incorporating Shannon diversity as predictor (Fig. 5.6), displayed similar tendencies as discussed above for species richness (Fig. 5.5). Thus, a small diversity gradient reflecting the rangeland condition/degradation gradient within the Commercial land use existed, whereas no Shannon diversity gradients existed within the Tribal and Reserve land uses (Fig. 5.6). Hence, woody species richness and diversity were highly correlated, as will be discussed in Section 5.3.1.3, Table 5.6.

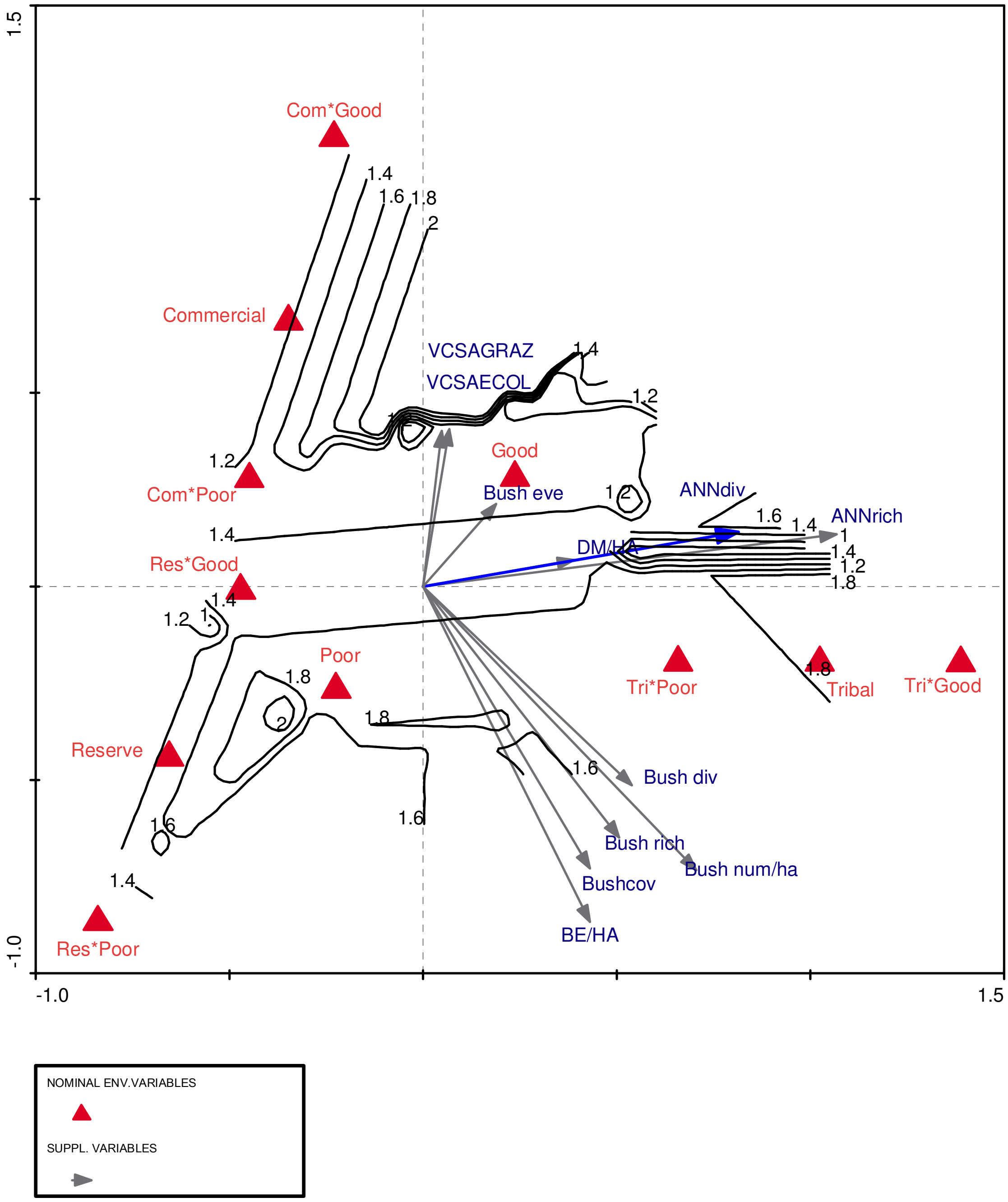


Fig. 5.6. A CCA ordination LOESS attribute plot (relative abundance – TE/ha matrix), incorporating Shannon's diversity (blue arrow) as predictor, being highest within the Tribal land use.

There is increasing concern regarding the effects of woody plant control on woody species richness and biodiversity (Lewis *et al.* 1988; West 1993), with improvement projects aiming at increasing livestock forage often resulting in reduced plant and faunal species diversity (Cooperrider 1991). One of the objectives of this chapter was to establish whether woody and herbaceous vegetation structures and ant communities display congruent diversity patterns. Results from this study indicated that woody species richness and diversity were lowest within the Commercial land use, with cattle beef-farming being the main farming enterprise within this land use. Within the Commercial land use, the natural habitat has been modified by woody control actions, reducing/eradicating the density of especially encroacher woody species. Hence, woody density (discussed in Section 5.3.3) and woody species diversity were lower within the Commercial land use compared to that of the Tribal and Reserve land uses. Woody species richness and diversity were intermediate within the Reserve land use in relation to the other two land uses. This is consistent with the results discussed for the herbaceous species composition (Chapter 4) and the ant species richness and diversity patterns (Chapter 8). The different types of land use tenures result in the diverse utilisation of the natural resources within the Tribal and Reserve land uses. Cattle farming, in addition to browsing by livestock (e.g. Boer goats and cattle-browsing) are common tenure practices within the Tribal land use, while both grazing and browsing by game are the norm within the Reserve land use. Results for the woody diversity indices are consistent with that of invertebrate studies that showed that ant species richness was almost always lower in farmlands than in natural vegetated areas as a result of habitat modification (Lobry de Bruyn 1999), with ant species richness being negatively affected by pastoralism (Woinarski *et al.* 2002). These results for the woody component were thus congruent with the herbaceous compositional patterns, which indicated that herbaceous diversity was lowest within the Commercial land use, but highest within the Tribal land use, and intermediate within the Reserve land use.

The role of plant diversity in ecosystem function and stability has been much debated (e.g. Tilman *et al.* 1997). Several authors state that local extinction of functionally redundant species is likely to have little effect on ecologically important processes (Walker 1992; Chapin *et al.* 1992) in the short-term. However, this may affect the long-term ability of the ecosystem to remain stable in a fluctuating environment (Johnson *et al.* 1996; Walker *et al.* 1999). Ecosystem functioning is likely to be detrimentally influenced by the loss of entire guilds (e.g. tree stratum, shrub stratum etc.), since functional groups and not species diversity largely determine ecosystem functioning (Cowling *et al.* 1994; Walker *et al.* 1999). Reduced functional complexity may result in a reduction of stability, since the ecosystem has lost some of its flexibility to respond to environmental fluctuations in the longer term (Van Voris *et al.* 1980). These statements suggests that a homogeneous woody stratum, whether a tree or shrub stratum only, may be detrimental to the stability of the ecosystem. Hence, woody eradication/control actions should attempt to maintain a few individuals representative of each guild. Thus, land tenure practices that result in the modification of the woody structure, can either have positive (ecologically and economically sound bush control practices) or negative effects (e.g. heavy browsing resulting in all trees to be shrub-like). However, the interaction between the woody component and the herbaceous and soil components was explored by means of multivariate analyses in Chapter 7, whereas the importance of the woody-ant relations was addressed in Chapter 8. The impact of different land use practices on the woody structural form is discussed in Section 5.3.3 of this Chapter.

The effects of woody plant control on plant species richness and diversity depend on spatial and temporal scale (Fulbright 1996). Fulbright (1996) stated that plant and vertebrate species richness and diversity within a patch created by woody control, may be similar, greater or lower than that of undisturbed rangeland. Woody plant control may either reduce species richness and diversity at patch level, but increases species richness and diversity at landscape scale and hence increase beta diversity (variation among habitats in the landscape) and landscape complexity (Fulbright 1996). Results from this section indicated that the diversity indices did not act as a good indicator of the rangeland condition/degradation gradient for the larger study area. This is consistent with the results of the herbaceous component (Chapter 4) and the ant diversity patterns (Chapter 8). However, the diversity indices did reflect a degradation gradient within the Commercial land use, with the diversity indices being highest within the Commercial-Poor (more woody encroached) rangeland condition group, indicative of the spatial heterogeneous patterns pertaining to the woody component. These results, in addition to the different diversity patterns observed within each land use, suggest that monitoring strategies of the woody component should take into consideration the complex spatial variable patterns at a finer scale (patch and paddock scale), and should not only extrapolate patterns for monitoring and management purposes across the landscape scale. Monitoring at the patch, paddock and landscape scale should be used complementary to each other. This is important, since studies by Smit and Rethman (2000) showed that complex inter-relationships between plants, soil and soil moisture exist.

For this study, woody diversity patterns, as in the case of the herbaceous species composition, did not reflect biodiversity patterns *per se*, but rather reflected changes in habitat structure and composition (McNaughton 1985; Belsky 1992) as a result of longer-term disturbances (modification) by the different land use practices. Neither did it reflect a rangeland condition/degradation gradient for the larger study area, although it did reflect a small though significant degradation gradient within the Commercial land use. Thus, these results suggest that the woody diversity patterns reflected different environmental changes (McGeoch 1998) induced by the different land uses, and that monitoring and management should take into account spatial variability at patch as well as landscape scale.

5.3.1.2 Relative abundance - Woody species community patterns

A. Detrended correspondence analysis (DCA)

The patterns of variation in the woody composition in relation to the different land uses and rangeland condition groups (relative “Good” vs. relative “Poor”) were examined by detrended correspondence analysis (DCA) using CANOCO 4 (Ter Braak & Šmilauer 1998). Detrending was required as an artificial “arch effect” was evident in the joint plot. The main gradients in composition (DCA axes) were related (indirect ordination) to measured environmental and vegetation variables by multiple regression to identify the main determinants of the woody composition. The distribution of the sub-replicates along the first two DCA axes after removal of the outlier site, are displayed in Fig. 5.7.

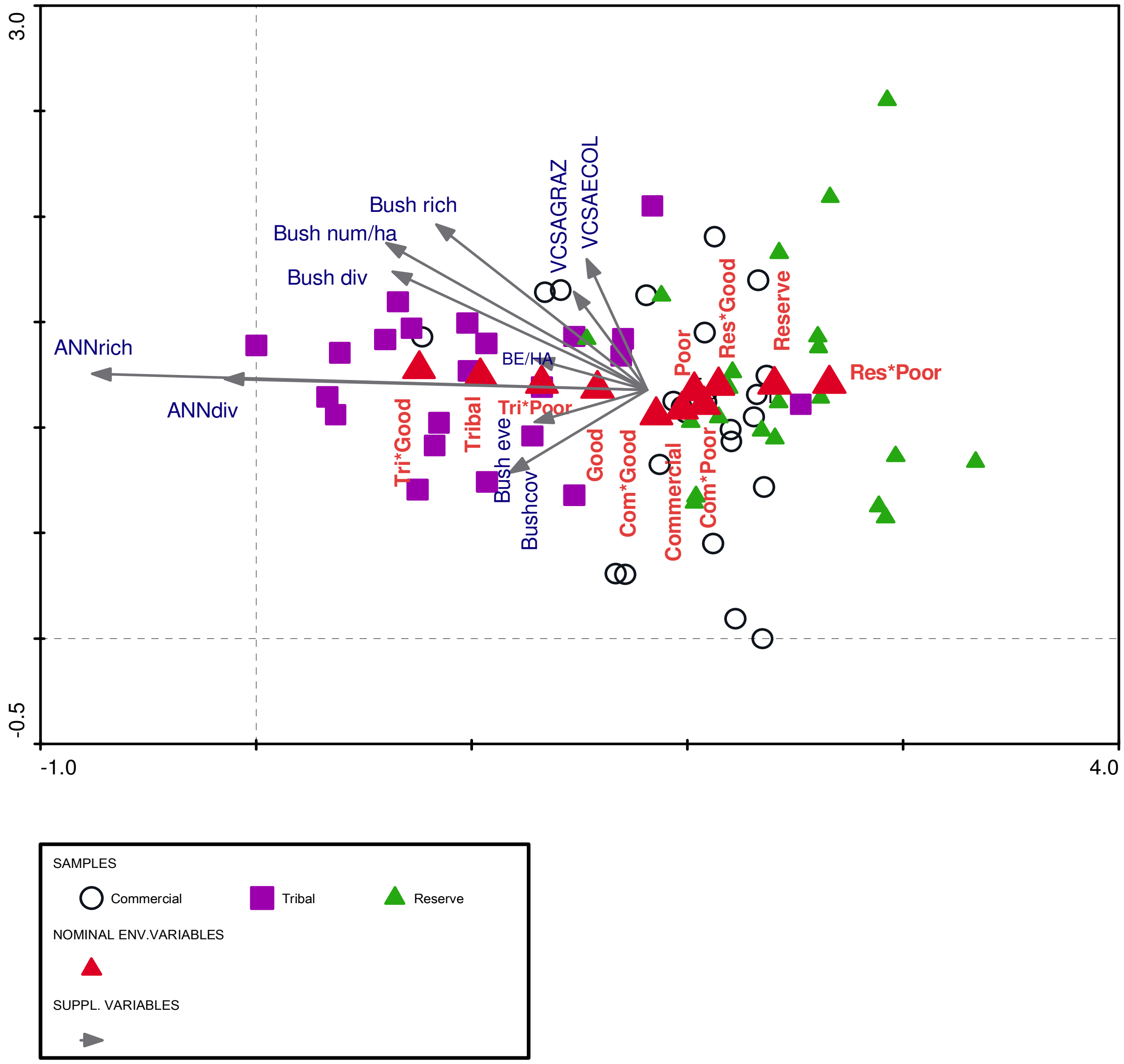


Fig. 5.7. Distribution of sites for the woody TE/ha matrix (relative abundances) along the first two DCA axes.

After removal of the outlier site from the relative abundance matrix (TE/ha), the second axis explained 25.9% of the species data and 37.5% by the fourth axis. For the species-environment relation, the second axis explained 52.4% of the variance (Table 5.2). The second axis explained 35.8% of the species-passive data (Table 5.2).

Environmental variables that showed the strongest association with the first axis were the Tribal land use (r = -0.7414) and the Tribal-Good variable (r = -0.6422) (Table 5.2). The second axis was best represented by the Commercial (r = -0.1476) and Commercial-Good (r = -0.1157) groups, although the correlation coefficients (r-values) were very low (Table 5.2). Hence, the land uses showed slightly separate clusters, but a direct CCA ordination should be employed to establish the species-environment relation.

Passive variables that showed the strongest association with the first axis, were herbaceous species richness (ANNdiv., r = -0.676) and herbaceous diversity (ANNdiv, r = -0.5144). The woody species richness (Bush rich, r = 0.2244) was best associated with the second axis, although the correlation coefficient (r-value) was low (Table 5.2).

Table 5.2. A DCA ordination based on relative abundances (TE/ha matrix) showing the eigenvalues, cumulative species data and species-environment variance for the first four axes. The correlation coefficients (r-values) for the environmental and passive variables associated with the first two DCA axes are given, with the variables showing the highest r-values, indicated in **bold**.

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.495	0.273	0.2	0.142
Lengths of gradient	3.335	2.552	2.663	1.583
Species-environment correlations	0.84	0.162	0.487	0.304
Cumulative percentage variance				
of species data	16.7	25.9	32.7	37.5
of species-environment relation (environmental)	51.3	52.4	0	0
of species-environment relation (passive data)	29.4	35.8	0	0

Environmental data	**SPEC AX1**	**SPEC AX2**	**Passive data**	**SPEC AX1**	**SPEC AX2**
Commercial	0.1507	**-0.1476**	BE/HA	-0.1375	0.046
Tribal	**-0.7414**	0.1038	Bushcov	-0.1643	-0.0978
Reserve	0.5855	0.0421	Bush num/ha	-0.3224	0.2031
Good	-0.3059	0.0098	VCSAGRAZ	-0.0925	0.1299
Poor	0.3059	-0.0098	DM/HA	-0.2503	0.1591
Com*Good	0.024	**-0.1157**	VCSAECOL	-0.0779	0.1711
Com*Poor	0.1636	-0.0736	ANNrich	**-0.676**	0.0538
Tri*Poor	-0.296	0.0303	ANNdiv	**-0.5144**	0.0395
Tri*Good	**-0.6422**	0.1009	Bush rich	-0.2625	**0.2244**
Res*Good	0.2056	0.0223	Bush eve	-0.1359	-0.0346
Res*Poor	0.5293	0.0306	Bush div	-0.3137	0.1663

Woody species that were best associated with the first axis were *Acacia luederitzii*, *Acacia haematoxylon*, *Boscia albitrunca*, *Cadaba aphylla*., *Lycium hirsitum* and *Rhigozum brevispinosum* (Table 5.3, Fig. 5.8). Hence, these species were more closely associated with the Tribal land and Reserve land uses that were associated with this axis (Table 5.2). Species that showed the strongest associations with the second axis were *Acacia tortilis*, *Ehretia rigida, Cadaba aphylla*., *Lycium hirsitum*, *Mundulea sericea*, *Protasparagus suleovons* and *Rhigozum brevispinosum* (Table 5.3, Fig. 5.8). These results indicate that some species were associated with both axes, thus, direct species-environmental patterns were investigated in Section 5.3.1.3 B.

Table 5.3. DCA ordination eigenvalues for the woody species (relative abundances) for the first two axes, with the axis with which each species is associated the best, indicated in **bold**.

	Eigenvalues	
Species	**AX1**	**AX2**
Ac hae	**2.9808**	-1.2536
Ac heb	1.5477	-0.4218
Ac lue	**4.0367**	-0.2163
Ac mel	2.8666	1.1615
Ac kar	0.3424	2.2638
Ac rob	0.6089	0.5981
Ac tor	0.2819	**2.3158**
Bos alb	**3.2275**	1.105
Dic cin	-0.3017	1.4607
Dio lyc	0.5031	1.9439
Ehr rig	1.4468	**2.3668**
Gre fla	1.89	0.9035
Gre flsc	0.7621	1.15
Gym bux	0.0244	1.2421
Cada ba	**3.4935**	**3.2938**
Lyc hir	**3.3315**	**2.4618**
Mun ser	0.7415	**2.3581**
Prot sul	1.0066	**2.3136**
Rhi bre	**3.0374**	**2.9932**
Rhu cil	0.8856	2.0796
Tar cam	-0.098	1.3861
Ter ser	-0.0447	1.2752
Ziz muc	0.8854	2.2105

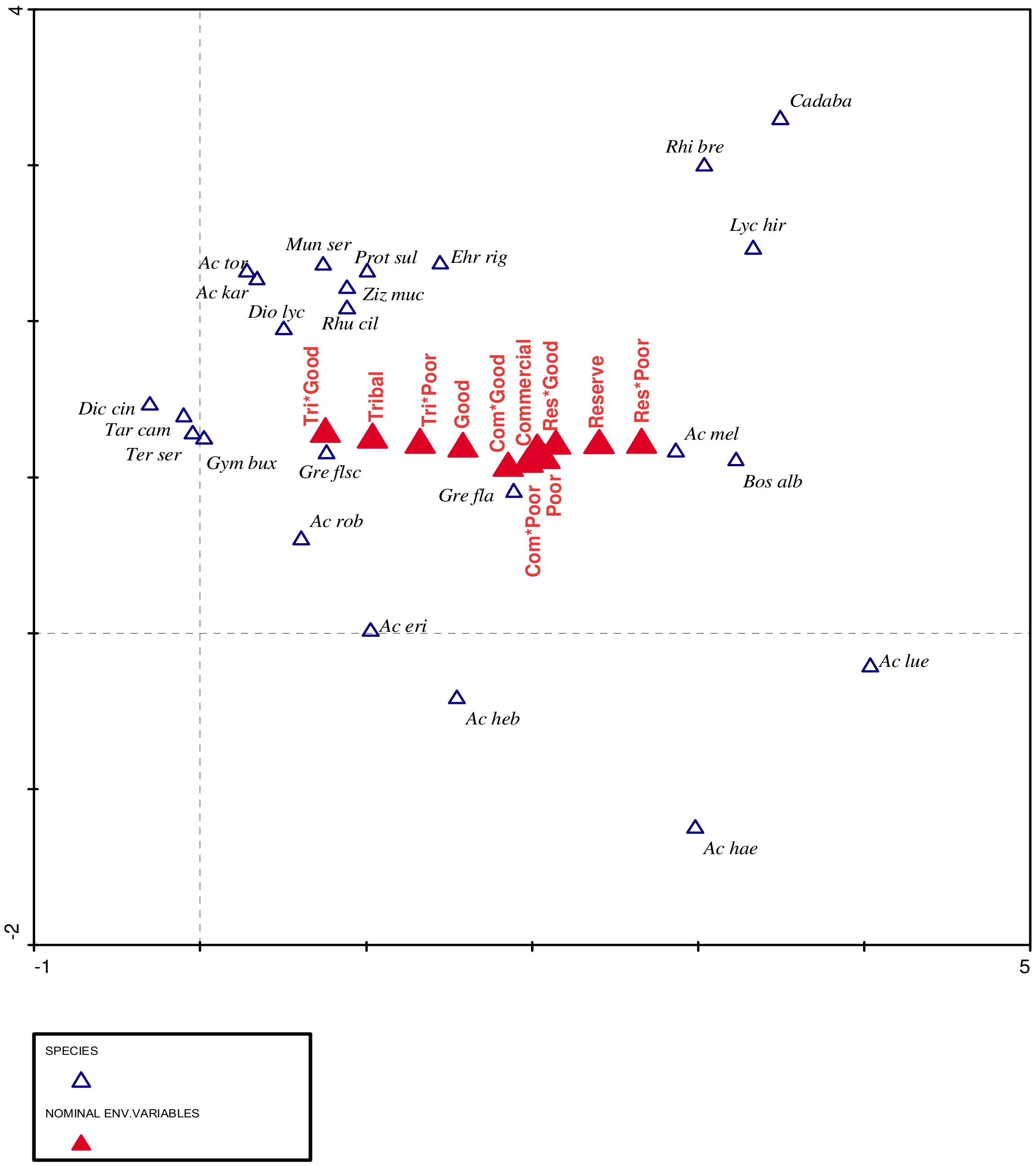


Fig. 5.8. A DCA ordination joint plot showing the woody species and environmental variables associated with the first two canonical axes.

B. Canonical correspondence analysis (CCA)

The direct CCA ordination, incorporating relative abundances (TE/ha matrix), explained 78.7% of the species-environment relation by the second axis, and 97.3% by the fourth axis (Table 5.4). These results suggest that most of the environmental data (land uses and relative “Good” and “Poor” rangeland condition groups) explaining the species-environmental relation, has been accounted for. The second axis explained 51.2% of the species-passive data relation (Table 5.4).

The Monte Carlo permutation test significantly explained the species-environment variance related to the first (F = 8.886, P < 0.005) and all canonical axes (F = 3.404, P < 0.005). These results from the Monte Carlo test support the motivation given above that the environmental variables primarily explaining the species-environment variance, have been accounted for. Environmental variables that best explained the species-environment relation, with order of inclusion being according to significance and importance, are presented in Table 5.4. The Tribal land use, followed by the Reserve-Poor and Commercial-Good groups significantly explained the species-environment relation.

Table 5.4. A CCA ordination for woody relative abundances (TE/ha) showing the eigenvalues, cumulative species data and species-environment variance for the first four axes, as well as the environmental variables that explained the species-environment relation in order of importance as indicated by the Monte Carlo permutation test.

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.356	0.127	0.064	0.05
Species-environment correlations	0.861	0.678	0.547	0.586
Cumulative percentage variance				
of species data	12	16.3	18.5	20.2
of species-environment relation (environmental)	58	78.7	89.1	97.3
of species-environment relation (passive data)	35.8	51.2	60.2	66

Monte Carlo permutation test

Variable	**P**	**F**
Tribal	0.002	8.34
Res*Poor	0.002	3.04
Com*Good	0.002	2.22
Commercial	0.064	1.57
Good	0.212	1.22

The environmental variable that showed the strongest association with the first axis was the Tribal land use (r = 0.8047, fourth quadrant) (Table 5.5, Fig. 5.9 and Fig. 5.10). The second axis was best represented by the Commercial land use (r = 0.5339, second quadrant) and Commercial-Good areas (r = 5487, second quadrant).

Table 5.5. CCA correlation coefficients (r-values) for the environmental and passive variables associated with the first two CCA axes for the partial CCA, with the variables showing the highest r-values being indicated in **bold**.

Environmental data	SPEC AX1	SPEC AX2	Passive data	SPEC AX1	SPEC AX2
Commercial	-0.2669	**0.5339**	BE/HA	0.2851	**-0.5858**
Tribal	**0.8047**	-0.1584	Bushcov	0.2859	**-0.4923**
Reserve	-0.5342	-0.3668	Bush num/ha	0.4673	-0.495
Good	0.2573	0.3104	VCSAGRAZ	0.045	0.2739
Poor	-0.2573	-0.3104	DM/HA	0.2584	0.0453
Com*Good	-0.1072	**0.5487**	VCSAECOL	0.0314	0.2707
Com*Poor	-0.2288	0.1437	ANNrich	**0.7079**	0.0899
Tri*Poor	0.3274	-0.0997	ANNdiv	0.5396	0.0943
Tri*Good	0.6909	-0.1008	Bush rich	0.3358	-0.4384
Res*Good	-0.2397	-0.006	Bush eve	0.1255	0.1436
Res*Poor	-0.4311	-0.4537	Bush div	0.3576	-0.3475

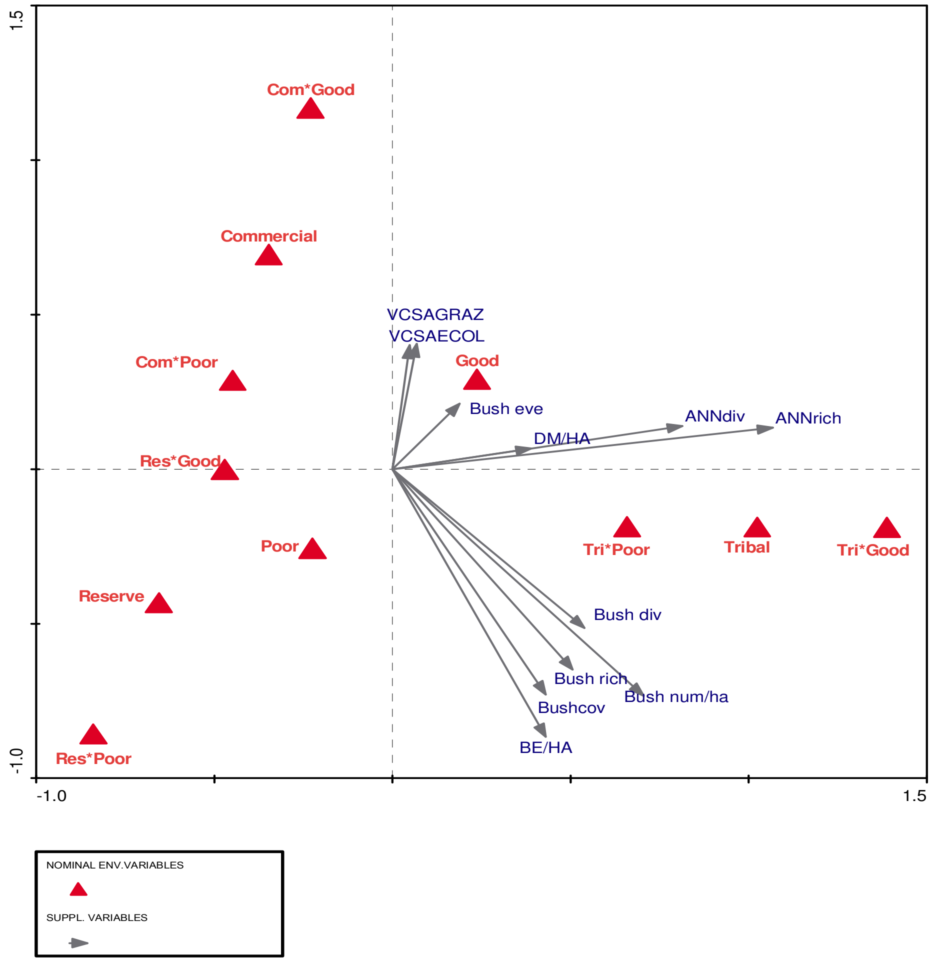


Fig. 5.9. A CCA ordination biplot displaying the environmental and passive variables associated with the first two canonical axes.

Table 5.6. A CCA weighted correlation matrix showing the correlation coefficients (r-values) between the passive variables.

BE/HA	1										
Bushcov	0.8165	1									
Bush num/ha	0.8473	0.6039	1								
VCSAGRAZ	-0.365	-0.3587	-0.2995	1							
DM/HA	0.044	-0.0665	0.1104	0.4342	1						
VCSAECOL	-0.3361	-0.3469	-0.2584	0.9714	0.4439	1					
ANNrich	0.262	0.2248	0.4147	0.0456	0.1618	0.0595	1				
ANNdiv	0.2367	0.1709	0.3631	-0.0214	0.1528	0.0221	0.8516	1			
Bush rich	0.5357	0.5304	0.5537	-0.1598	-0.0362	-0.1395	0.3748	0.2955	1		
Bush eve	-0.3114	-0.1687	-0.2381	0.1902	0.1277	0.2147	-0.0376	-0.025	0.0085	1	
Bush div	0.2615	0.3591	0.3007	-0.0825	0.0475	-0.0511	0.2371	0.1882	0.8146	0.5048	1
	BE/HA	**Bushcov**	**Bush num/ha**	**VCSAGRAZ**	**DM/HA**	**VCSAECOL**	**ANNrich**	**ANNdiv**	**Bush rich**	**Bush eve**	**Bush div**

The passive variable that best represented the first axis, was species richness (ANNrich, r = 0.7079, first quadrant), while the total TE/ha was best associated with the second axis (r = -0.5858, fourth quadrant) (Table 5.5, Fig. 5.9). The total TE/ha, bush numbers/ha and bush area coverage/ha were highly correlated (r > 0.81) (Table 5.6). These variables showed positive, intermediate correlations with bush species richness (r > 0.53) and positive, though relatively low correlations with bush species diversity (r > 0.26) (Table 5.6). Total TE/ha, bush numbers/ha and bush area coverage/ha were negatively correlated with the rangeland condition score indices (VCSAECOL and VCSAGRAZ; r > -0.25) (Table 5.6). Bush species richness and diversity were highly correlated (r = 0.8146) and woody species diversity showed an intermediate correlation with Pielou's evenness (r = 0.5048) (Table 5.6). Herbaceous species diversity (ANNdiv) and herbaceous species richness (ANNrich) were highly correlated (r = 0.8516) (Table 5.6). Herbaceous species richness and -diversity were positively correlated with total TE/ha, bush numbers/ha and bush area coverage (Table 5.6), although the correlation coefficients varied from relatively low to intermediate (r = 0.17 - 0.41) (Table 5.6).

Total TE/ha (actual density), total bush numbers/ha (actual numbers), total bush area coverage m^2/ha (actual area), bush species richness and -diversity were associated with the fourth quadrant and the Tribal land use (Fig. 5.9). Woody evenness, herbaceous species richness and herbaceous diversity (first quadrant) were all associated more closely with the Tribal land use than with the Reserve or Commercial land uses. The woody parameters were negatively correlated with the Commercial land use (Fig. 5.9). This is consistent with the discussion given in Section 5.3.1.2 regarding the woody diversity patterns.

Woody species showing the strongest association with the first axis were *Acacia hebeclada*, *Acacia karroo, Acacia robusta*, *Acacia tortilis*, *Boscia albitrunca*, *Diochrostachys cinerea*, *Diospyros lycoides*, *Grewia flavescens*, *Gymnosporia buxifoli*a, *Lycium hirsitum*, *Mundulea sericea*, *Rhigozum brevispinosum*, *Rhus ciliata*, *Tarchonanthus camphoratus* and *Terminalia sericea* (Table 5.7, Fig. 5.10). Of these species, *Boscia albitrunca*, *Rhigozum brevispinosum* and *Lycium hirsitum* were best associated with the Reserve land use and the Commercial-Poor group, whereas the rest of the above-mentioned species were mainly associated with the Tribal land use (Fig. 5.10). The woody guild within the Reserve and Commercial-Poor groups thus included trees and shrubs, whereas the woody composition within the Tribal land uses was primarily associated with shrubs and small trees (See Section 5.3.2). Modification to the woody structure due to tenure practices associated with the different land uses, was more informative than the guild classification only, and is presented in Section 5.3.2.

Woody species that best represented the second axis (and hence primarily the Commercial and secondary the Reserve land uses; Table 5.5), were *Acacia erioloba*, *Acacia haematoxylon*, *Acacia luederitzii*, *Acacia mellifera*, *Ehretia rigida*, *Grewia flava*, *Cadaba aphylla*., *Protasparagus suleovons* and *Ziziphus mucronata* (Table 5.7). *Acacia haematoxylon* was primarily associated with the Commercial land use, whereas *Grewia flava* was indicated to be a generalist species (near centre of ordination diagram) with relative abundance being highest within the Commercial land use, followed by the Reserve land use (Appendix 5.2, Fig. 5.10). *Ehretia rigida* was also indicated as a generalist woody species common to all three land uses, while *Ziziphus mucronata* was indicated to be relatively abundant within all three land uses, although the average relative abundance was higher within the Tribal and Reserve land uses (Appendix 5.2, Fig. 5.10). *Protasparagus suleovons* and *Acacia erioloba* were indicated as generalist species being mainly associated with the relative "Good" rangeland condition variables (Fig. 5.10). According to the relative abundances of the woody species, *Acacia mellifera* (third quadrant) was best associated with the Reserve land use, followed by the Tribal land use (Appendix 5.2, Fig. 5.10). *Cadaba aphylla*. had the highest average relative abundance within the Reserve land use within the third quadrant (Appendix 5.2, Fig. 5.10).

Table 5.7. Cumulative variances and eigenvalues of woody species (relative abundances – TE/ha) for the first two canonical axes, as well as species having 10% and higher of their ranges explained by the species-environment variance. Species responsive to the respective axes are indicated in **bold**.

	Cumulative variance		**Eigenvalues**	
Species	**AX1**	**AX2**	**AX1**	**AX2**
Ac eri	0.0166	**0.0394**	0.2445	**0.371**
*Ac hae **	0.0033	**0.1174**	-0.401	**3.0567**
Ac heb	**0.0013**	0.0018	**0.1442**	0.1147
*Ac lue**	0.1373	**0.2682**	-1.1833	**-1.4949**
*Ac mel **	0.0883	**0.2047**	-0.4602	**-0.6839**
Ac kar	**0.077**	0.0812	**1.8374**	-0.5553
Ac rob	**0.0091**	0.0105	**1.1049**	-0.5525
Ac tor	**0.0792**	0.0833	**1.8858**	-0.5555
*Bos alb**	**0.1109**	0.1123	**-0.8637**	0.1241
*Dic cin**	**0.279**	0.2794	**1.6248**	-0.0761
Dio lyc	**0.0581**	0.0625	**1.7881**	-0.6338
Ehr rig	0.0014	**0.0029**	0.0823	**-0.1125**
*Gre fla **	0.1329	**0.3597**	-0.2681	**0.4531**
Gre flsc	**0.0361**	0.0371	**0.8551**	-0.1792
*Gym bux**	**0.3332**	0.3518	**1.8162**	-0.5553
Cada ba	0.0177	**0.0494**	-1.4076	**-2.4325**
Lyc hir	**0.0625**	0.0758	**-0.9228**	-0.5499
Mun ser	**0.0403**	0.0443	**1.3665**	-0.5535
Prot sul	0.0059	**0.034**	0.1297	**0.3665**
Rhi bre	**0.071**	0.0771	**-0.6143**	-0.2315
Rhu cil	**0.0726**	0.0743	**0.7081**	-0.1393
*Tar cam**	**0.1271**	0.135	**1.7191**	-0.5549
*Ter ser**	**0.2951**	0.3105	**1.8767**	-0.5555
Ziz muc	0.0064	**0.0223**	0.263	**-0.5345**

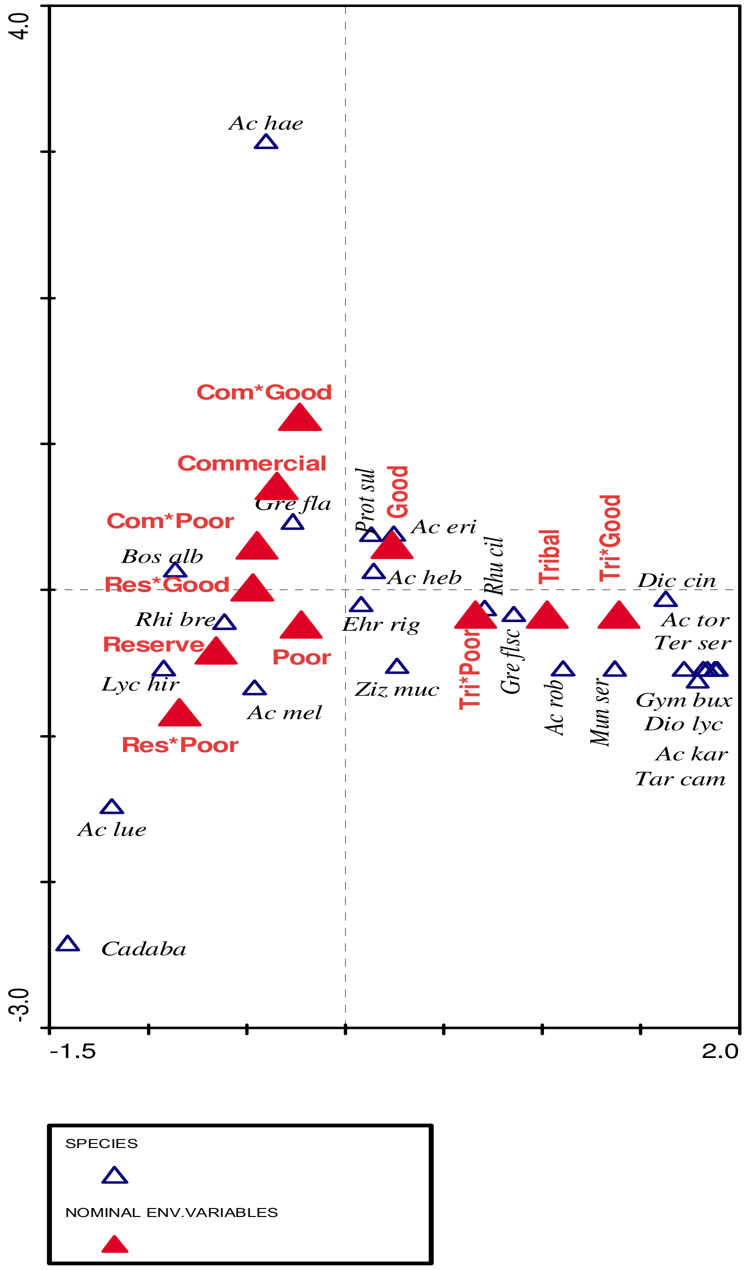


Fig. 5.10. A CCA ordination biplot displaying the woody species and environmental variables related to the first two canonical axes.

A CCA ordination LOESS attribute plot, incorporating the "Good" rangeland condition variable as predictor, indicated a pronounced gradient for the TE/ha-matrix species composition within the Commercial land use (contour levels 0 to -2), but not within Tribal land uses (same contour level) (Fig. 5.11). However, the Tribal land use was associated with the "Poor" rangeland condition spectrum with regards to the woody component (contour levels 0 – 0.2). An intermediate degradation gradient within the Reserve land use (0.2 – 0.4) pertaining to the relative "Good" and "Poor" sites existed, although the gradient within the land use differed from that of the Commercial land use (Fig. 5.11). Hence, a degradation gradient pertaining to the woody species composition (TE/ha expressed as relative abundances) were evident between the relative "Good" and "Poor" groups within the Commercial land use, with a different degradation gradient pertaining to the relative "Good" and "Poor" groups being evident within the Reserve land use. These observations will be tested by means of one-way ANOSIM tests within each land use, and in addition will be described by means of SIMPER explanatory procedures (Section 5.3.1.4). Patterns within the Commercial and Reserve land uses were more congruent, whereas the Tribal land use showed its own unique woody compositional patterns. Species compositional patterns pertaining to the direct CCA analysis were informative regarding the frequency of occurrence (relative abundances) of species within and between land uses. It thus gave a good reflection on the woody composition (frequency of occurrence) within each land use, instead of merely reflecting on the actual woody densities only (refer to Section 5.3.3).

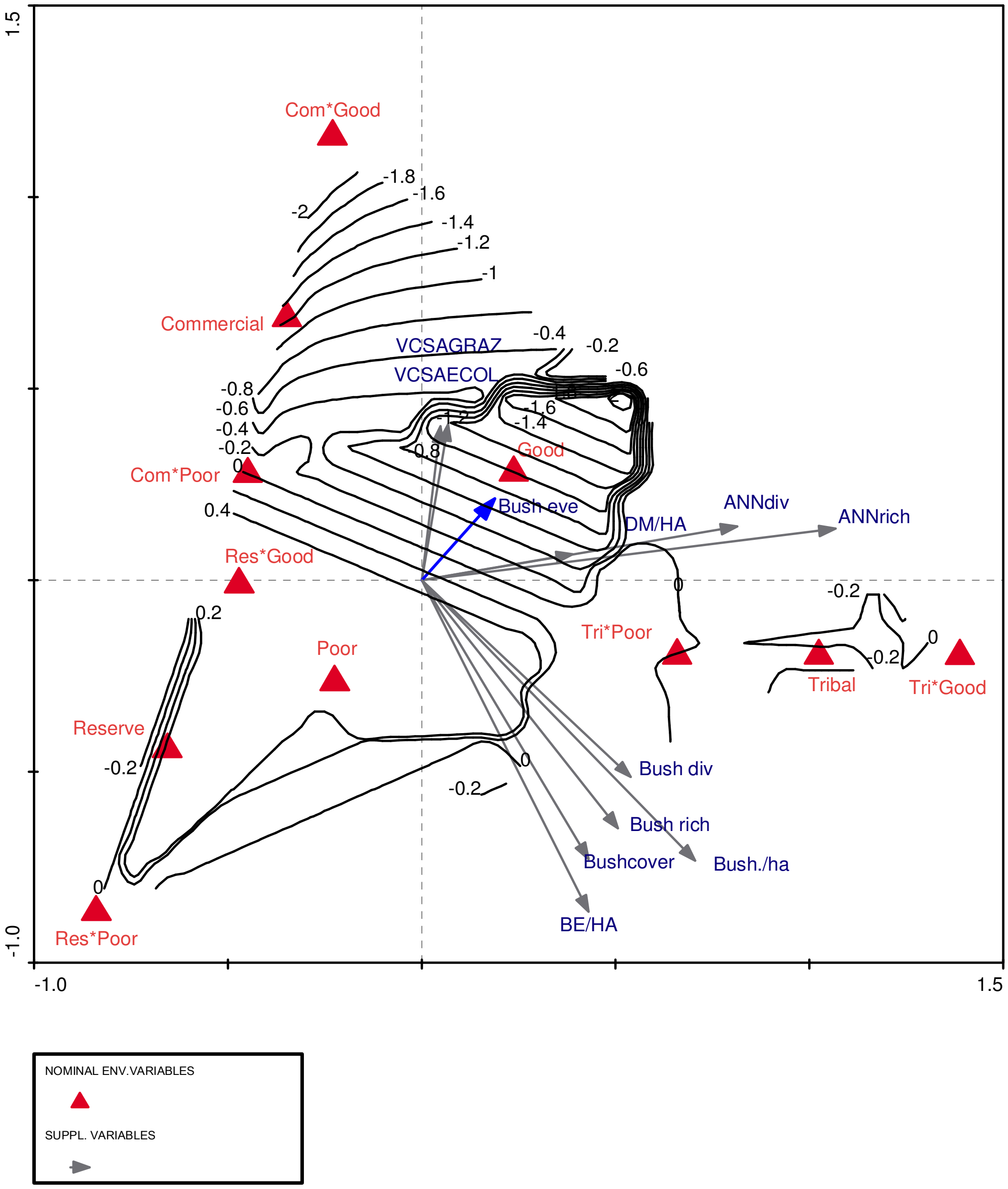


Fig. 5.11. A CCA ordination LOESS attribute plot displaying the environmental and passive variables associated with the first two canonical axes, with the relative "Good" rangeland condition variable as predictor (blue arrow).

C. Cumulative contribution towards explaining species-environment variance

Woody species having 10% and higher of their ranges being accounted for by the CCA ordination's first two axes for the TE/ha relative abundance matrix, were determined as a potential measure towards identifying key species that best represent each axis and hence the environmental variables associated best with each axis (Morris 2006, pers. comm.) (Table 5.7, Fig. 5.12). It is suggested that these key woody species can consistently act as potential indicators of the different land uses as well as indicators of the rangeland condition gradient for the larger study area (indicated in Fig. 5.11). These results are complementary to that discussed above and the results of Section 5.3.1.4. These results were incorporated into the "Key assessment matrix", and are presented in Chapter 9 (Concluding remarks).

Nine species were included by this 10% and higher inclusion rule. *Acacia haematoxylon* was most typical of the Commercial-Good sites. *Grewia flava* was the only generalist species being included, although the relative abundance was highest within the Commercial land use (Appendix 5.2; Fig. 5.12). *Boscia albitrunca* was mainly associated with both the Reserve-Good and Commercial-Poor sites, with *Acacia mellifera* primarily being associated with the Reserve land use (Fig. 5.12). Four species were associated with the Tribal land use, namely *Dichrostachys cinerea*, *Tarchonanthus camphoratus*, *Gymnosporia buxifolia* and *Terminalia sericea* (Fig. 5.12).

Cumulative variances and eigenvector scores explained for the woody species for the first two axes are presented in Table 5.7. Keys based on the eigenvector scores of the woody species, were compiled as adaptive and explanatory management measures pertaining to the environmental variables most strongly associated with the first two axes. The relative position of woody species along the first and second axes of the CCA ordination was indexed by rescaling the eigenvector scores of the woody species to a scale of 0 to 10, with 0 representing the score of that woody species located first and 10 the position of the last woody species on the gradient (see Chapter 3) (after Hurt & Hardy 1989; Lawes *et al.* 2005). These scores can be used to calculate woody component-weighted total scores for the environmental variables most strongly related to the respective axes, for comparative and monitoring purposes. These keys are presented in Chapter 9 (Concluding remarks).

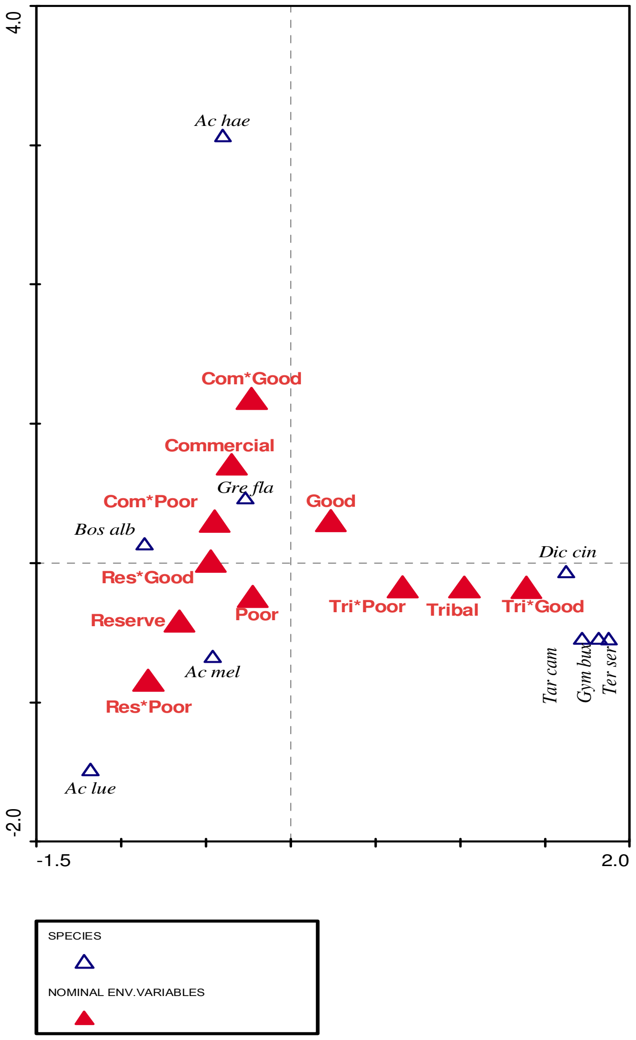


Fig. 5.12. A CCA biplot with inclusion of woody species having 10% and higher of their ranges accounted by the species-environment relation.

D. Relative abundance compositional patterns

Based on relative abundances for the TE/ha-matrix, *Grewia flava* had the highest average relative abundance (31.1%) for the total study area, with *Acacia mellifera* being the second most abundant species (average relative abundance = 12.63%) (Appendix 5.2). *Grewia flava* had the highest average relative abundance (32.27%) across the “Good” rangeland condition sites for the total study area, whereas it also had the highest average relative abundance in the study area’s relative “Poor” sites (29.92%) (Appendix 5.2). *Acacia mellifera* had the second highest average relative abundance for the “Poor” rangeland condition group (19.01%) (Appendix 5.2).

Grewia flava had the highest average relative abundance within the Commercial land use (41.05%) and the lowest within the Tribal land use (19.79%) (Appendix 5.2). *Acacia mellifera* had the highest average relative abundance within the Reserve land use (19.06%), followed by the Commercial (9.77%) and Tribal (9.07%) land uses (Appendix 5.2). However, average relative abundances pertaining to the “Good” and

"Poor" rangeland condition groups within each land use, are also presented. Analyses at this level provided to be more informative than the relative abundances that were averaged across an entire land use (Appendix 5.2). Following this approach, it can be seen that the average relative abundance of *Grewia flava* was in general equally high within the Commercial-Good (42.02%) and –Poor (41.01%) groups (Appendix 5.2). It was followed by the Reserve-Good group with an average relative abundance of 39.02%, and then the Tribal-Poor group (23.82%) (Appendix 5.2).

Acacia mellifera had the highest average relative abundance within the Reserve-Poor group (25.25%), followed by the Commercial-Poor group (17.56%) and the Tribal-Poor rangeland condition group (14.22%) (Appendix 5.2).

Woody species contributing most to the similarities within each land use, depend on the species' consistent (equitable) distribution throughout all sites, in addition to their relative abundances. Hence, the most abundant species are not necessarily always the most important typical species or species contributing to most of the similarities. These woody compositional patterns were explored by means of SIMPER analyses and are presented in the next section (Section 5.3.1.4).

The actual woody densities (TE/ha), number of woody individuals per species/ha and area coverage per species (m^2/ha), together with the woody structural form of the woody species within different land uses, are discussed in Section 5.3.2.

E. Remarks

In arid and semi-arid rangelands, vegetation change may not follow the Clementsian successional model (Clements 1916), and disturbance may push a system into a new state that is not readily reversed (Friedel 1991). The state-and-transition model is a paradigm that suggests that severe disturbances result in a transition from one state to another, with the latter being relatively stable and different in species composition from the original state (Archer 1989; Westoby *et al.* 1989; Laycock 1991).

Climatic events are acknowledged as important driving forces of vegetation change in semi-arid rangelands, with such systems being described as non-equilibrium systems (Noy-Meir 1973; Ellis & Swift 1988), which lack the density-dependence (equilibrium systems) between vegetation and herbivore populations (Behnke & Scoones 1992). Behnke & Scoomes (1992) stated that non-equilibrium systems are thought not to result in long-term degradation due to the impact of livestock densities. However, results from this chapter and the other chapters suggest that the presence of key resources within these rangelands does result in density-dependent processes (Illius & O'Connor 1999; Smet & Ward 2005) linked to the key resources.

Discussions in Chapter 4 with regard to the herbaceous species composition indicated that a dichotomy of non-equilibrium and equilibrium (density-dependent coupling to key resources) processes structure herbaceous communities within the Molopo rangelands, with disturbances potentially resulting in transitional shifts of the herbaceous species composition. Both the equilibrium and non-equilibrium processes are at the heart of the state-and-transition model (Westoby *et al.* 1989). The inherent land type (soil and geology) as well as the climate for the study area is similar (Chapter 2, Study area). Results from this chapter suggest the existence of a woody degradation gradient across the larger area, being indicative of transitional shifts in the woody species composition. It is hypothesised that both equilibrium and non-equilibrium processes are causative factors resulting in this transitional shift. As stated by Friedel (1991), such states may not be readily reversed. According to Smit (2004), there is no quick solution to bush encroachment, and that this should be seen as a long-term management practice.

Woody compositional patterns within and between land uses, were explored more in-depth in Sections 5.3.1.4 – 5.3.1.6.

5.3.1.4 SIMPER analysis for general woody species composition matrix between land uses

SIMPER analyses as explanatory procedures were used to establish which woody species contributed to similarities within land uses, and dissimilarities between land uses. This section is complementary to Sections 5.3.1.1 – 5.3.1.3, and is useful for adaptive management and monitoring purposes. Relative abundances (TE/ha; Appendix 5.2) were employed in the SIMPER analyses. The relative abundances were informative regarding the frequency of occurrence (proportional occurrence) of woody species within sites (Appendix 5.2). Explanatory SIMPER analyses results pertaining to this section are given in Appendices 5.5 and 5.6.

The Commercial land use had an average similarity of 39.81%, the Tribal land use 39.87% and the Reserve land use 46.86% (Appendix 5.5).

Grewia flava was the most abundant and highest contributing species to the similarities within the Commercial land use, followed by *Protasparagus suleovons*, *Acacia mellifera* and *Acacia erioloba*. Cumulatively these four species contributed to 91.26% of the similarities (Appendix 5.5). *Grewia flava* occurred consistently most typically throughout all the Commercial land use sites (Sim/SD = 1.65).

Seven species explained 90.22% of the Tribal land use's similarities (Appendix 5.5). *Grewia flava* was the most abundant and highly contributing species, followed by *Dichrostachys cinerea*, *Gymnosporia buxifolia* and *Acacia erioloba*. *Grewia flava* was also consistently most typical within this land use (Sim/SD = 2.47) (Appendix 5.5). However, average relative abundance of *Grewia flava* within the Tribal land use (19.79%) was considerably lower than that of the Commercial land use (41.53%) (Appendices 5.2 and 5.5).

Five species contributed to 90.52% of the Reserve land use's similarities (Appendix 5.5). *Grewia flava* was the most relative abundant and highly contributing species within this land use, followed by *Acacia* *mellifera* and *Rhigozum brevispinosum*. *Grewia flava* was found to be consistently most typical of this land use (Sim/SD = 2.2), followed by *Acacia mellifera* (Sim/SD = 1.02) (Appendix 5.5). Average relative abundance of *Grewia flava* (31.97%) was lower than that of the Commercial land use.

From the results presented above, *Grewia flava* was indicated as the highest contributing species within each land use, also consistently being the most typical species within each land use. These results indicate that *Grewia flava* is a generalist species, which is consistent with the DCA and CCA ordination results presented in Section 5.3.1.3. However, the average relative abundances of this species differed considerably between the land uses, being highest within the Commercial land use, followed by the Reserve land use.

The Commercial-Tribal land uses had an average dissimilarity of 72.02%. This dissimilarity (90% and higher of the land use) was indicated by 13 species, contributing to 92.54% of the dissimilarity (Appendix 5.5*). Grewia flava* and *Dichrostachys cinerea* were the two species contributing to most of the dissimilarities. However, the average relative abundance of *Grewia flava* was higher within the Commercial land use, whereas the average relative abundance of *Dichrostachys cinerea* was higher within the Tribal land use (Appendix 5.5). *Grewia flava* was indicated consistently as the most important discriminating species (Diss/SD = 1.45). Although *Grewia flava* is a generalist species typical of each land use, its relative abundance was considerably higher within the Commercial land use. This serves as distinguishing measure between these two land uses, in addition to the other species contributing to the dissimilarity (Appendix 5.5).

The Commercial-Reserve land use had an average dissimilarity of 60.8% (Appendix 5.5). *Grewia flava*, *Acacia mellifera* and *Rhigozum brevispinosum* were the three species that contributed most to the dissimilarities, with a total of 10 species contributing to 90.98% of the dissimilarity (Appendix 5.5). *Grewia flava* (Diss/SD = 1.36), followed by *Acacia mellifera* (Diss/SD = 1.23), were indicated as the most important discriminating species, with the former species having the highest average relative abundance in the Commercial land use and *Acacia mellifera* the highest average relative abundance in the Reserve land use (Appendix 5.5).

The average dissimilarity between the Tribal-Reserve land uses was 70.32%, with *Acacia mellifera*, followed by *Grewia flava* being the two most important species contributing to the dissimilarities (Appendix 5.5). *Acacia mellifera* was the second most important discriminating species since it did not occur consistently throughout all the sites (Diss/SD = 1.18), with *Grewia flava* being the most important discriminating species (Diss/SD = 1.36). *Acacia mellifera* and *Grewia flava* had higher average relative abundances within the Reserve land use than within the Tribal land use (Appendix 5.5).

The relative “Poor” group, averaged across all land uses, had an average similarity of 38.6%, with 92.05% of the similarity being indicated by 6 species (Appendix 5.6). *Grewia flava* was most typical (Sim/SD = 1.78) and abundant of this group, indicative of its generalist status across the total study area.

Acacia mellifera was the second most important species contributing to the dissimilarities, although it did not occur as consistently throughout all the sites (Sim/SD < 1.0) (Appendix 5.6). Most land owners view *Acacia mellifera* as a serious threat due to its invasive habits and its ability, at high densities, to suppress the herbaceous layer almost completely (Donaldson & Kelk 1970; Richter *et al.* 2001). According to Richter *et al.* (2001), herbaceous phytomass production was reduced with 82% at tree densities of 2500 TE/ha, with clearing or thinning of *Acacia mellifera* trees resulting in significant increases in the grass phytomass production. However, it is believed that enrichment of soil by *Acacia mellifera* in the Kalahari Thornveld occurs, with total eradication of this species resulting in a loss of soil nutrients from an already nutrient-poor ecosystem (Hagos & Smit 2005).

The relative “Good” group had an average similarity of 34.35%, with 7 species contributing to 94.15% of the similarity (Appendix 5.6). *Grewia flava* was the most abundant and typical species (Sim/SD = 1.62) of this group, with *Acacia erioloba* being the second most abundant contributing species to the similarity (Appendix 5.6).

The average dissimilarity between the relative “Good” and “Poor” groups was 65.46%, with *Grewia flava* contributing to most of the dissimilarities and being the most important discriminating species (Diss/SD =1.27). This species’ average relative abundance was only slightly higher within the relative “Good” group, suggesting its generalist status. *Acacia mellifera* was the second most important discriminating species (Diss/SD = 1.12), showing a considerably higher abundance within the relative “Poor” group (Appendix 5.6).

Since no unique typical species representative of the different land uses, or discriminating species between the land uses were indicated, ANOSIM and SIMPER analyses within each land use between the relative rangeland condition groups (“Good” vs. “Poor), may provide to be more informative. Two-way crossed ANOSIM tests conducted in Section 5.3.1.1 indicated the existence of a rangeland condition gradient (degradation gradient). Hence, further analyses at a more in-depth level were conducted to establish whether the degradation gradient was reflected within each land use, and whether observed patterns were congruent. Results from these analyses are presented in Section 5.3.1.5.

5.3.1.5 ANOSIM and SIMPER for relative condition groups *within* each land use

SIMPER analyses for this section, based on relative abundances (TE/ha; Appendix 5.2) are summarised in Appendix 5.7.

A. Commercial land use

The one-way ANOSIM indicated small though significant differences between the relative "Good" and "Poor" groups within the Commercial land use (r = 0.103, P < 0.05). This suggests that the TE/ha matrix reflected the rangeland condition (degradation) gradient, though not as strong as that discussed for the herbaceous species composition in Chapter 4.

The Commercial "Poor" group had an average similarity of 47.2%, with *Grewia flava* having the highest relative abundance and consistently being the most typical species (Sim/SD = 1.77) (Appendix 5.7). *Acacia mellifera*, followed by *Protasparagus suleovons* and *Boscia albitrunca*, contributed to 93.35% of this group's similarity (Appendix 5.7).

The Commercial "Good" rangeland condition group had an average similarity of 36.45%, with *Grewia flava* having the highest relative abundance and being the most important typical species (Sim/SD = 1.51), followed by *Protasparagus suleovons* (Appendix 5.7).

The average dissimilarity between the relative "Good" and "Poor" groups were 62.04%, with *Grewia flava*, *Protasparagus suleovons* and *Acacia mellifera* being the three most important species contributing the dissimilarities (Appendix 5.7). *Grewia flava* was indicated as the most important discriminating species (Diss/SD = 1.4), followed by *Acacia mellifera* (Diss/SD = 1.13). The average relative abundance of *Grewia flava* was very similar between the two groups, whereas *Acacia mellifera* was most abundant within the relative "Poor" group (Appendix 5.6).

The generalist status of *Grewia flava* was confirmed with this analysis, suggesting that in addition the other species, *Acacia mellifera* especially is more informative as discriminating species between the "Good" and "Poor" groups within this land use.

B. Tribal land use

There was no significant difference between the relative "Good" and "Poor" rangeland condition groups based on the relative abundances for the TE/ha matrix (Appendix 5.2) for the Tribal land use (r = 0.013, P > 0.1). This is consistent within the results discussed in Section 5.3.1.3, and illustrated in the CCA ordination LOESS attribute plot with relative "Good" as predictor (Fig. 5.11).

Although differences were not significant between the relative rangeland condition groups, SIMPER analyses are presented as additive data and comparative data between the other two land uses (Appendix 5.7). The "Poor" group had an average similarity of 36.27%, with *Grewia flava* being most abundant and typical (Sim/SD = 2.76), followed by *Acacia mellifera* as the second most important species contributing to the dissimilarity.

The Tribal “Good” group had an average similarity of 44.15%, with the generalist woody species *Grewia flava*, being the highest contributing species to this group’s similarity and being typical (Sim/SD = 2.51) of the Tribal-Good rangeland condition group. However, *Dichrostachys cinerea* had the highest average relative abundance, but was only the second most important species contributing to 18.75% of the similarity (Appendix 5.7). Abundant *Dichrostachys* seedling growth occurred in some of the Eska/Newnhem (Southey area) sites that burned two years prior to the surveys (Isaac Mokhwana 2004, pers. comm. - local extension officer)

The average dissimilarity between the Tribal “Poor” and “Good” relative condition groups was 60.44%, with *Dichrostachys cinerea* contributing to most of the dissimilarity, although it was not consistently the most important discriminating woody species (Appendix 5.7). *Protasparagus suleovons* (Diss/SD = 1.4) was indicated as the most important discriminating species, although it was listed only 8th in terms of contributing to the dissimilarity (Appendix 5.7). It was more abundant within the relative “Good” rangeland condition sites. *Gymnosporia buxifolia* was the second most important discriminating species (Diss/SD = 1.11), and was most abundant within the relative “Poor” sites (Appendix 5.7).

C. Reserve land use

Based on the relative abundances (TE/ha), the one-way ANOSIM test showed a low, but significant gradient between Reserve relative “Good” and “Poor” rangeland condition groups ($r = 0.208$, $P < 0.001$).

The relative “Poor” group had an average similarity of 48.53%, with *Grewia flava* having the second highest relative abundance, but being the most important contributing (to similarity) and typical species of this group (Sim/SD = 196) (Appendix 5.7). *Acacia mellifera* had the highest average relative abundance, but was the second most important species contributing to the similarity. It was also the second most important typical species (Sim/SD = 1.75).

The relative “Good” group had an average similarity of 50.32%, with *Grewia flava* having the highest average relative abundance, and being the most important species contributing to the similarities. It was also the most typical species (Sim/SD = 3.47) of this group (Appendix 5.7). *Acacia mellifera* was, as in the case of the relative “Poor” group, the second most important species contributing to the similarity.

The average dissimilarity between the relative “Good” and “Poor” groups was 55.48%. *Acacia mellifera* was indicated as the most important discriminating species (Diss/SD = 1.4), being the species contributing most to the dissimilarity as well. The average relative abundance of this species was considerably higher within the relative “Poor” sites (Appendix 5.7). *Grewia flava* was the second most important species in contributing to the dissimilarities, with the average relative abundance being higher in the relative “Good” sites (Appendix 5.7).

The SIMPER procedures were informative in terms of the following:

- SIMPER are complementary explanatory analyses in addition to that of the MDS, DCA and CCA ordinations;
- Listing of species contributing to 90% or higher of the similarities within each land use according to each interpretation method, rendering comparisons possible for adaptive management purposes easier between land uses and between analysis techniques;
- Explanatory regarding the generalist status of woody species across all the land uses;
- Reflect on the average relative abundance (frequency of occurrence) of woody species within each land use, which is useful as comparative measure for woody composition between the land uses;
- Indication of consistent typical species within each land use according to both interpretation methods;
- Indication of discriminating species between land uses;
- Indication of consistent distribution (equitability) of species within and between land uses;
- Results are useful for implementation in the “Key assessment matrix”, presented in Chapter 9.

D. Remarks

The results of Sections 5.3.1.4 and 5.3.1.5 indicated that *Grewia flava* was a generalist species being associated with all three land uses. It was associated with both the “Good” and “Poor” rangeland condition groups across the larger study area as well as within each land use, although it had a higher relative abundance within the Commercial land use. The relative abundance of *Grewia flava*, as well as other woody species discussed above, significantly reflected the existence of a degradation gradient within the Reserve and Commercial land uses, but not within the Tribal land use. This is consistent with the results of the herbaceous species composition (Chapter 4, Section 4.3.1.7) that reflected a degradation gradient within the Commercial and Reserve land uses, but not within the Tribal land use. The ANOSIM tests indicated significant differences between the three land uses, with the Commercial woody component (expressed as relative abundances) showing patterns intermediate between that of the Reserve and Tribal land uses. With regard to woody compositional patterns, the Reserve land use was more closely associated to the Commercial land use than the Tribal land use (Section 5.3.1.1 and Section 5.3.1.3), whereas for the diversity indices, the Reserve land use was more closely associated with the Tribal land use (Section 5.3.1.2).

The woody degradation gradients within the Commercial and Reserve land uses differed from each other (Fig. 5.11), suggesting that spatial variability patterns at patch and paddock scale, should caution land owners/managers and scientists against the extrapolation of management and monitoring procedures across the larger study area. Hence, monitoring and management strategies should take cognisance of patch, paddock and landscape level dynamics. The degradation gradient within the Reserve and Commercial land use can be ascribed to density-dependent-coupling processes, for the same reasons as described in Chapter 4, Section 4.3.1.7. Hence, within these two land uses, transitional shifts in woody species composition took place as a result of secondary causative factors (e.g. herbivory), as described by Teague and Smit (1992) in Section 1 of this Chapter. Such transitional shifts are described by the state-and-transition model by Westoby *et al.* (1989).

The woody composition of the Tribal land use differed significantly from the other two land uses and did not reflect any rangeland degradation gradient. This is consistent with the herbaceous species compositional results, and the same arguments stated in Chapter 4, Section 4.3.1.7, apply here. The woody composition of the Tribal land use thus showed a transitional shift towards a unique woody compositional state (Fig. 5.11). This can be ascribed to the density-dependent coupling of livestock to key resources such as settlements, water points, “kraals” etc. This is fully described in Chapter 4, Section 4.3.1.7. Although the Tribal land use did not reflect a rangeland condition gradient, the entire land use was characterised by high woody densities (see Section 5.3.3 of this chapter), indicative of bush encroachment. Thus, the land use tenure practices (intensive continuous herbivory linked to the natural resources, especially in the proximity of water points, “kraals” and settlements) associated with this land use resulted in degradation and a transitional shift in the woody composition in generally all the survey sites, irrespective of its rangeland condition status (hence “Poor” vs. “Good). Whereas the Commercial land use was primarily characterised by beef-cattle enterprises only, both the Reserve and Tribal land use were utilised by both grazers and browser. However, conservative stocking numbers within the Reserve land use, as reflected by the number of Increaser I herbaceous species (refer to Chapter 4), are applied. Within the Tribal land use, intensive continuous farming practices, especially within the proximity of the key resources, are generally applied. This result in the modification of not only the herbaceous component, but also the woody component (refer to Section 5.3.3 for discussion regarding the woody structure and density).

Evidence from literature and surveys suggests that bush encroachment in Botswana takes place as a result of the exclusive use of moisture by woody encroachers, high soil nutrient concentrations imported through dung and urine by livestock especially near foci points (Moleele 1998), low fire frequencies and high cattle selectivity (Moleele *et al.* 2002) based around foci points. This is indicative of density-dependent of livestock to key resources, suggesting that equilibrium events are important determinants of woody structure and composition. In further support of the discussions for the Molopo study presented above, Moleele *et al.* (2002) stated that selectivity by cattle may result in changes in the structure and composition of vegetation, especially near foci sites (e.g. the “sacrificial” and “bush encroachment” zones). Moleele (1998) and Scholte (1992) found that cattle rely heavily on browse even though grass is abundant, whereas Squires (1992) classified cattle as selective browsers. Palatable woody plants with high nutrient levels often are not able to survive heavy browsing within zones near foci sites, unless they have thorns (Moleele *et al.* 2002), whereas leaves of palatable thorny woody species are not easily browsed by cattle (Moleele 1998; Moleele *et al.* 2002). Hence, such species are avoided by cattle, resulting in those species becoming very abundant at high cattle densities. The Tribal land use (both the “Poor” and “Good” rangeland condition groups) was characterised by high densities of several woody species being declared as bush encroachers (see Appendix 1 for list of bush encroachers). These woody compositional patterns are consistent with the results presented by Moleele *et al.* (2002).

Woody species indicative of the "Poor" rangeland condition group for the total study area, notably within the Commercial and Reserve land use, were indicative of density-dependent processes operating within these rangelands, whereas the total Tribal land use, as discussed above, showed only one rangeland condition status (no significant differences between the "Good" and "Poor" rangeland condition groups). Such a degradation gradient (with different patterns at patch and paddock level related to the different land uses, as discussed above) is reflective of the competitive interactions between the woody and herbaceous components of savannas, primarily for soil moisture, as has been reported by several authors (Donaldson & Kelk 1970; Dye & Spear 1982; Walker *et al*. 1986; Archer *et al.* 1988; Scholes 1987; Belsky *et al.* 1989; Smit 1994; Smit & Swart 1994; Smit & Rethman 1999, 2000; Richter *et al*. 2001). Several studies showed that woody encroachment resulted in a decrease of herbaceous production and undesirable shifts in herbaceous composition (Botswana: Molelee *et al.* 2002; America: Archer 1989).

The reduction of the grass layer under high tree densities may leave areas of bare ground, often resulting in crust formations that may reduce infiltration and losses due to rainfall runoff. Studies by Moore *et al.* (1985) reported that herbaceous production declined within increasing tree abundance in the Molopo area, South Africa. However, rainfall distribution is a primary determinant of how the herbaceous component will react after woody clearing (Smit 2004). In Mopane savanna, grass yields were much higher in thinned plots compared to densely-wooded plots during years of below average rainfall, while there was little difference in grass yields for high density plots between varying rainfall events (Smit 1994). Similar tendencies found within the Molopo study area will be discussed in the next paragraph.

Acacia mellifera was indicated as an important indicator of rangeland in a "Poor" condition, with the relative abundance being highest within the Reserve-Poor sites. Research conducted by Coetzee (unpublished report 2005) investigated the impact of *Acacia mellifera* bush density on the herbaceous component within plots cleared (bush eradicated) to different densities (TE/ha) within the Bray area of the Molopo rangelands. Relationships between bush density and herbaceous species composition and phytomass production of the grass component as well as its species composition (for one trial) were investigated. Results from this study indicated that bush encroachment by *Acacia mellifera* suppresses herbaceous production and is negatively correlated with rangeland in good condition (as reflected by rangeland condition scores of the herbaceous species component). *Acacia mellifera* stands were positively correlated with relatively poor rangeland condition sites and can in dry years result in a decline of grazing capacity with a yield of only 3kg/ha (more than 2000 TE).

According to Coetzee (unpublished report 2005), the effect of different densities of *Acacia mellifera* bush encroached plots showed that grazing capacity (ha/LSU), varied between 6.99 ha/LSU for a totally cleared plot up to 7.65 ha/LSU (600 TE) for 1989 (annual rainfall of 518mm). This converts to 1.68kg/ha/mm rainfall for the cleared plot and 1.53kg/ha/mm rainfall for the 600 TE/ha plots. In 1995 (with annual rainfall of 175 mm only), the totally cleared plot had the highest yield of 402.25 kg/ha, highest rangeland condition score of 624.92, whereas the 1000 TE treatment had the lowest rangeland condition score of only 65 (with the 2000 TE = rangeland condition score of 84). In terms of DM yield, the 2000 TE plot had the lowest yield of 3.88 kg/ha only. The DM yield decreased with increasing bush density. This implies that in a year with this annual rainfall (175mm) (below the long term mean), the cleared plot had a DM yield of 3.67kg/ha/mm rainfall, and the 2000 TE plot 0.022 kg/ha/mm rainfall. In 2000, with annual rainfall of 517mm, the cleared plot had a DM yield of 1259.74kg/ha and the 2000 TE plot 251.74 kg/ha. Hence, the cleared plot produced 2.44kg/ha/mm rainfall compared to the 0.49kg/ha/mm rainfall of the 2000 TE plot. The cleared plot had a grazing capacity of 15.12ha/LSU, whereas it was 1566 ha/LSU for the 2000 TE plot. Hence, the more bush encroached a plot, the lower the DM yield/ha/mm rainfall, with this tendency being more pronounced at lower rainfall figures. The more bush encroached a plot, the more pronounced the effect on species composition (shifts in species composition, lower range condition scores) and on the herbaceous production (lower DM yield).

Results from this study suggest that although *Acacia mellifera* might not be the most abundant woody species, in denser stands it might have pronounced detrimental effects on the herbaceous species composition and production. This can be ascribed to its extensive root system and ability to compete more effectively for the available soil moisture than does the herbaceous layer (Richter 2002, pers. comm.). The detrimental suppression of the herbaceous production, and changes in herbaceous species composition by dense *Acacia mellifera* stands, may result in elevated temperatures in the soil, especially of the bare soil, creating unfavourable germination conditions for herbaceous seedlings (Richter 2002, pers.comm). These tendencies are more pronounced in drier years, and may not only result in poor livestock production, but also result in a detrimental transitional shift of the herbaceous composition, as was described in Chapter 4 (Section 3.1.7) by the state-and-transition model (Westoby *et al*. 1989). However, few large *Acacia mellifera* trees may suppress *Acacia mellifera* seedling growth, and woody eradication and management actions should thus be ecologically and economically responsible (Smit 2004).

5.3.1.6 Cumulative k-dominance plots – relative abundance TE/ha-matrix

Woody species accumulation curves reached their respective asymptotes for all three the land uses, indicating that the spatial variability for the woody species component has been accounted for in all three land uses (Fig. 5.13). The Tribal land use reached its asymptote last, thus reflecting the species diversity associated with this land use, as was discussed in Section 5.3.1.2.

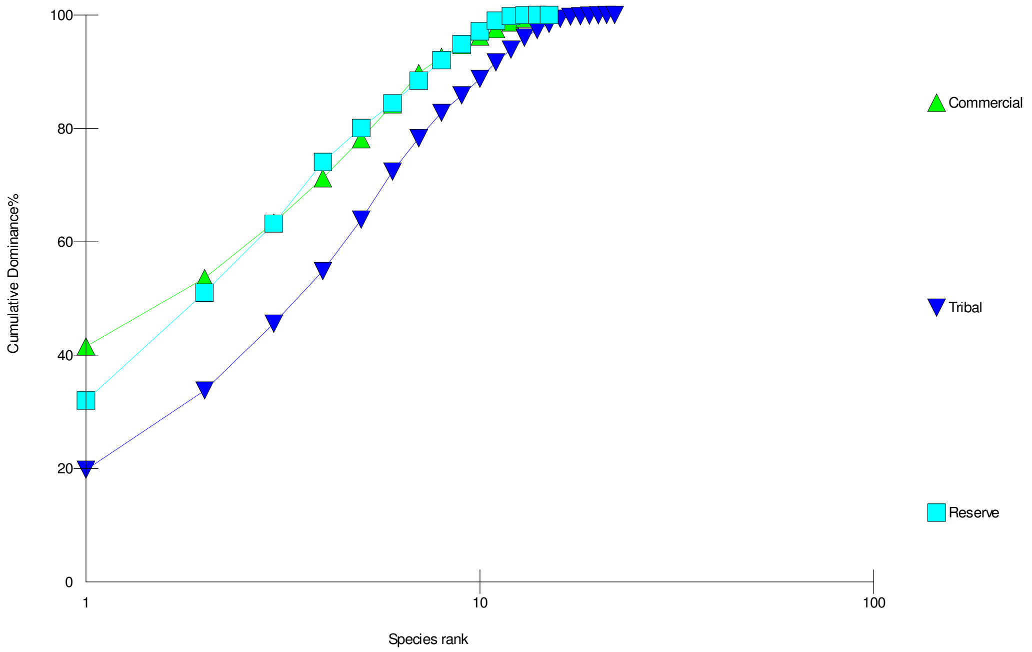


Fig. 5.13. A Cumulative k-dominance plot for the woody component (TE/ha matrix) illustrating that the three land uses attained their respective asymptotes (100% cumulative dominance).

Rank-abundance curves for woody species relative abundance (TE/ha) for all the land uses are illustrated in Fig. 5.14. Woody species dominance was most pronounced within the Commercial land use, and was lowest within the Tribal land use (Fig. 5.14). Within the Commercial land use, *Grewia flava* had the highest average relative abundance (41.53%), being considerably more dominant than other woody species (Appendix 5.2). It was also the most dominant species within the Tribal land use, although its average relative abundance (frequency of occurrence) was considerably lower (19.79%) than that of the Commercial land use, with *Dichrostachys cinerea* being the second most abundant species (13.99%) within this land use (Appendix 5.2). Hence, their dominance by one woody species was less pronounced within the Tribal land use. The Reserve land use was primarily dominated by *Grewia flava*, (31.97%), although its relative abundance and hence dominance was intermediate between that of the Tribal and Commercial land uses (Appendix 5.2).

Several authors state that increasing complexity may result in high diversity, reduced dominance (hence abundance) and thus lower productivity (Room 1975; Majer 1985; MacKay *et al.* 1991; Perfecto & Snelling 1995). This was found to be true for ant community patterns. Following this hypothesis, the woody component reflected disturbance/environmental change due to habitat modification caused by the different land use practices. The Commercial land use thus reflected a relatively productive, highly dominant environment. The Tribal land use reflected a complex, heterogeneous but low productive system environment. These patterns are congruent with those discussed for the herbaceous species component (Chapter 4, Section 4.3.1.6) and for the ants (Chapter 8, Section 8.2.4.4). However, herbaceous species dominance and ant dominance was highest within the Reserve land use, with dominance being intermediate in the Commercial land use and lowest within the Tribal land use. For the woody component, dominance was intermediate in the Reserve land use.

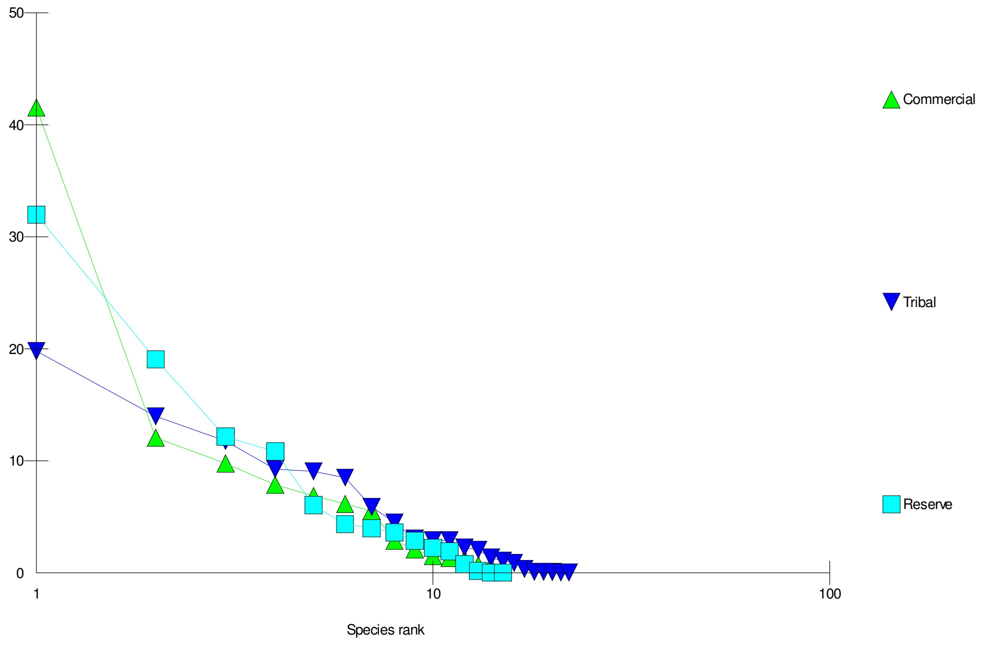


Fig. 5.14. Species-rank dominance curves for the three land uses for the woody component (TE/ha matrix), showing the highest woody species dominance by the Commercial land use, followed by the Reserve and then Tribal land uses.

5.3.2 Woody structural form, density (actual TE/ha), numbers/ha and woody area coverage (m^2 /ha)

A. Woody structural form

The average height (m) and canopy diameter (m) of each woody species within each land use are summarised in Appendix 5.8, and illustrated in Fig. 5.15 (compiled by R du Plessis 2006, AllyCAD 2003).

In general, average woody species height and diameter of species occurring in all three land uses, were highest within the Commercial land use (Appendix 5.8, Fig. 5.15). Tree species were medium sized within the Commercial land use, while the structure of the same woody species was more shrub-like within the Tribal land use (Appendix 5.8, Fig. 5.15). The woody structures of species within the Reserve were mainly of intermediate proportions between that of the Commercial and Tribal land uses (Appendix 5.8, Fig. 5.15).

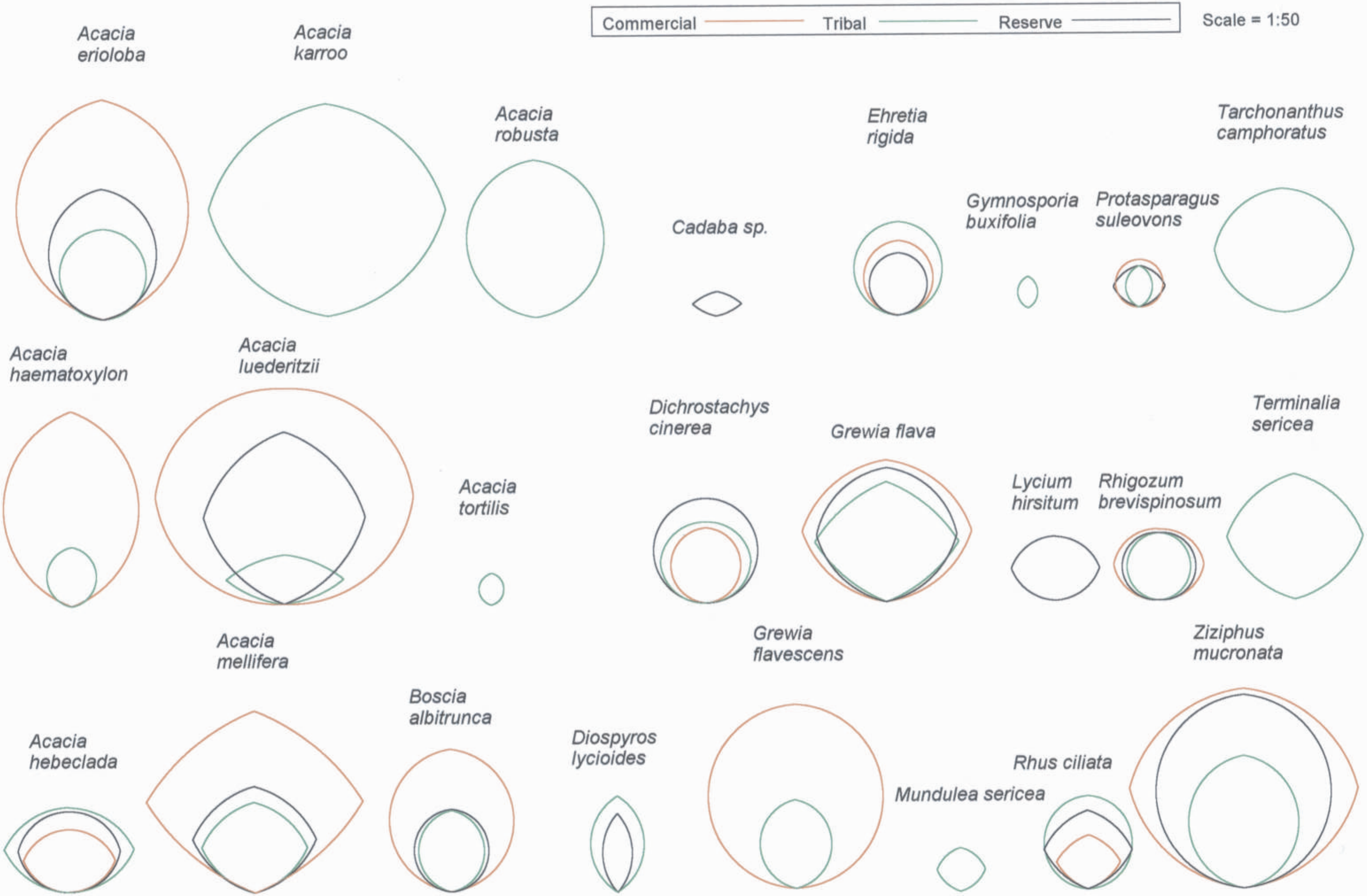


Fig. 15. A visual on - scale illustration of the height (m) and canopy diameter (m) differences between the land uses for the woody component (compiled by R. du Plessis 2006, AllyCAD).

For example, *Acacia erioloba* had an average height of 2.24 m and average canopy diameter of 1.76 m within the Commercial land use (ratio of height:canopy = 1.27), opposed to a height of 0.92m and canopy diameter of 0.88 m within the Tribal land use (ratio = 1.05) (Appendix 5.8). Within the Reserve land use, *Acacia erioloba* had a height of 1.3 m and canopy diameter of 1.1 m (ratio = 1.21). This tendency for species occurring in **all** the land uses, also applied for *Acacia luederitzii*, *Acacia mellifera*, *Boscia albitrunca*, *Grewia flava*, *Protasparagus suleovons*, *Rhigozum brevispinosum* and *Ziziphus mucronata* (Appendix 5.8).

Woody species occurring in all three land uses, and which had the largest average height and average canopy diameter within the Tribal land use, were *Acacia hebeclada*, *Diospyros lycoides*, *Ehretia rigida*, and *Rhus ciliata* (Appendix 5.8). *Dichrostachys cinerea* was the only woody species occurring within all three land uses, and had the largest average height and canopy diameter within the Reserve land use (Appendix 5.8).

The growth and size of woody individuals is a function of the resources to which it has access (Teague & Smit 1992). Hence, available moisture and nutrient levels and the proximity of other individuals influence the growth size of an individual woody plant (Teague & Smit 1992), with larger trees depleting larger areas of resources and hence exerting more competition on the neighbours (Smith & Goodman 1986). Some woody species can co-exist with little competition if they differ in terms of root distribution (Cole & Brown 1976; Van Vegten 1983; Tolsma *et al.* 1987a) and life strategy traits (Teague 1989a). According to Teague & Smit (1992), tree-tree competition is more likely to benefit grass production on sandy, well-drained soils where there is a clear separation in roots of the herbaceous and woody component, and where rainfall events result in deeper moisture penetration. The more pronounced height and canopy diameter of most of the woody species within the Commercial land use can be ascribed to tree-tree competition within this land use. Hence, fewer individuals compete for the same resources opposed to a larger number of individuals per hectare competing for the same resources in the Tribal and to an intermediate extent in the Reserve land uses. This matter will be pursued further in Section 5.3.2 A. In addition, several authors have indicated that stem basal area and tree height increased in thinned plots where trees' neighbours had been removed (Smith & Goodman 1986; Coe 1991). Smit (2004) stated that the competitive ability of the remaining trees would gradually increase and reduce the impact of the initial thinning.

Different tenure practices associated with each land use resulted in the different woody structural patterns. Within the Tribal land use, both the herbaceous and woody components are continuously utilised by domestic livestock (refer to Section 5.3.1.5 D). Hence, regrowth by palatable woody species (shoot regrowth) are utilised by either browsers and/or selective browsing by cattle, resulting in smaller but more individuals for some woody species competing for the same resources. Palatable as well as less palatable woody species encroach in areas where the competitive ability of the herbaceous component has been hampered due to intensive grazing practices, but with more intensive utilisation of the palatable woody species resulting in a smaller growth form of these species. Within the Commercial land use, control measures/eradication of the woody component, especially encroacher species, result in fewer individuals and lower tree-tree competition for the available resources. This issue is pursued in the next section (Section 5.3.2 B). The woody structural form of the Reserve differed from that of the Tribal land use, which can be ascribed to the different browsing strategies of game opposed to domestic livestock, the larger mobility of game (hence less continuous herbivory impacts on the same resources) and the more conservative stocking rate applied within the Reserve land use.

In support of the above-mentioned arguments, research by Aucamp *et al.* (1984) indicated that Boer goats at high intensities in the sweetveld areas of the Eastern Cape detrimentally affected the vegetation, having significant effects on the woody component as well, in that heavy browsing resulted in the virtual elimination of woody vegetation up to the height of 1.5 m. Thus it resulted in a decrease in the number of (available) browsing units per ha. In contrast, browsing of canopies of African *Acacia* trees can stimulate shoot production (Milton 1983; Teague & Walker 1988). Browsing thus has been found to affect the growth and production of woody species differently (Willard & McKell 1973), resulting in a complex community response (Kelly 1977). Smit (2004) proposed that bush encroachment may be detrimental not only to grazers, but to browsers as well. Low-density stands often display a better distribution of browse, having leaves in relatively younger phenological states over a longer period (Smit 2001).

B. Density – actual TE/ha, numbers/ha and area coverage/ha

Average woody densities (TE/ha) for each species are summarised in Appendix 5.9, while the average number of individuals per species/ha are presented in Appendix 5.10. Area coverage (m^2/ha) for each species pertaining to these rangeland condition groups within each land use, is summarised in Appendix 5.11.

The Tribal land use had the highest average TE/ha (1690.49), followed by the Reserve land use (1219.51 TE/ha). The Commercial land use had the lowest average TE/ha (541.81) (Appendix 5.9). The highest average number of individuals occurred in the Tribal land use (3411 individuals/ha), followed by the Reserve land use (1777 individuals/ha) and then only the Commercial land use (685 individuals/ha) (Appendix 5.10). This converts to an average woody coverage of 4075.89 m^2/ha for the Tribal land use, 2827.73 m^2/ha for the Reserve land use and 1502.85 m^2/ha for the Commercial land use (Appendix 5.11). Hence, it was evident that the Tribal land use not only had the highest average density of woody species, but also the highest number of woody individuals and woody area coverage, followed by the Reserve land use. Average woody density, area coverage and the numbers/ha were considerably lower in the Commercial land use compared to the other two land uses.

Grewia flava had the highest average density across the total study area (272.43 TE/ha), followed by *Acacia mellifera* (174.91 TE/ha) (Appendix 5.9). The average density of *Grewia flava* was highest within the Tribal land use (305.42 TE/ha), followed by the Reserve land use (303.19 TE/ha) and the Commercial land use (208.68 TE/ha) (Appendix 5.9). *Acacia mellifera's* average density was highest within the

Reserve-Good rangeland condition group (467.36 TE/ha) (Appendix 5.9). However, the relative abundance (frequency of occurrence in site) of *Grewia flava* was highest within the Commercial land use, as was discussed in Section 5.3.1.3 D (Appendix 5.2).

According to Van Vegten (1983), overgrazing of grasses was the primary cause of woody encroachment in savanna areas of Botswana. Skarpe (1990) found that shrub densities in Botswana showed no consistent changes with light or moderate grazing, whereas heavy grazing resulted in the increase of shrub densities in Botswana's rangelands. *Acacia mellifera* and *Grewia flava* were the two woody species accounting for most of the encroachment, with the shallow rooted systems being favoured by water availability following overgrazing of the grass layer (Skarpe 1990).

The average density (TE/ha) of the woody component for the total study area was 1150.6 TE/ha, with the density being 942.82 TE/ha for the relative "Good" rangeland condition group when averaged across all land uses, and 1358.38 TE/ha for the relative "Poor" rangeland condition group (Appendix 5.9). The average number of woody individuals per hectare for the total study area was 1958 individuals (Appendix 5.10). The "Good" rangeland condition group for the total study area had an average of 1667 individuals/ha and the "Poor" rangeland condition groups, 2249 individuals/ha (Appendix 5.10). Hence, the "Good" rangeland condition group consisted of 0.57 TE/individual (numbers ha^{-1}/TE ha^{-1}) and the "Poor" rangeland condition group of 0.60 TE/individual.

The Commercial-Good rangeland condition group had an average density of 429.58 TE/ha (Appendix 5.9), and consisted of 506 woody individuals (Appendix 5.10). This converts to 0.85 TE/individual. The Commercial-Poor land use had an average density of 654.03 TE/ha (Appendix 5.9), consisting of 865 woody individuals, or 0.76 TE/individual.

The average density of the Tribal-Good rangeland condition group was 1755.42 TE/ha (Appendix 5.9), and 3577 woody individuals (Appendix 5.10). This is equal to 0.49 TE/individual. The Tribal-Poor group had an average density of 1625.56 TE/ha (Appendix 5.9), as was contributed by 3246 woody individuals (Appendix 5.10), resulting in 0.5 TE/individual.

The Reserve-Good rangeland condition group had an average density of 643.47 TE/ha (Appendix 9), contributed by 917 woody individuals (Appendix 5.10), converting to 0.7 TE/individual. The average density of the Reserve-Poor land use was 1795.56 TE/ha (Appendix 5.9), consisting of 2638 individuals (Appendix 5.10). This is equal to 0.68 TE/ha.

From the results presented above, it was evident that the Tribal land use had the highest average woody density (TE/ha), number of individuals/ha as well as area coverage (m^2/ha). However, when the TE/woody individual is calculated, it was evident from the lower TE/individual ratio that the woody structure of the Tribal land use was smaller (lower ratio values), as opposed to larger individuals representative of the Commercial land use and intermediate sized individuals indicative of the Reserve land use. This is consistent with the results summarised in Appendix 5.8 and discussed in Section 5.3.2 A.

Thus, land use impact/tenure type resulted in more woody individuals (Appendix 5.10) and denser woody stands (Appendix 5.9) within the Tribal land use, generally comprised out of smaller shrublike individuals (Appendix 5.8). In contrast, the Commercial land use had fewer woody individuals of medium tree size (Appendix 5.8), being less-densely distributed (Appendix 5.9). Patterns related to the Reserve land use were intermediate between that of the Tribal and Commercial land use. An increase in woody density is primarily caused by vegetative growth, and secondly by an increase in tree density, mainly through seedling establishment (Smit 2004). It is generally accepted that woody species are able to make more efficient use of deep water than can the grasses (Walker & Noy-Meir 1979; Stuart-Hill 1985). Thus, some factors that may determine tree growth, are soil water availability and water stress (Teague 1983; Moore 1989; Smit 1994), soil nutrient availability (Bell 1982; Scholes 1991), tree age (Milton 1987), competition (Smit 1994), defoliation and shoot pruning (Milton 1988; Stuart-Hill & Tainton 1988; Teague 1989b) and soil and climatic conditions (Patten & Ellis 1995). Woody seedling establishment is often determined by competition from other woody or herbaceous plants (Smith & Walker 1983; Smith & Goodman 1986, Smith & Shackleton 1988, O'Connor 1995a). This can be ascribed to species-specific tree-on-tree competition, or be related to shade tolerance of the seedlings (Smith & Goodman 1986; Smith & Shackleton 1988; O'Connor 1995a). Seedling establishment may either be limited by canopy environments, or not be affected by it (Smith & Goodman 1986). It is hypothesised that the fewer, larger trees resulted in the competitive suppression of seedling regrowth within the Commercial land use, whereas continuous grazing and browsing practices resulted in smaller but more woody individuals within the Tribal land use.

For comparative purposes between land uses, the average relative abundances were more informative regarding the (proportional) woody compositional patterns within and across land uses. A degradation gradient across the larger study area was significant, with significant but different rangeland condition (degradation) gradients existing within the Commercial and Reserve land uses. The Tribal land use showed no significant rangeland condition patterns pertaining to the relative abundances, woody density, area coverage (m^2/ha) or number of individuals/ha. This topic was discussed in Section 5.3.1.5.

A CCA ordination LOESS attribute plot, with total TE/ha as predictor, is presented in Fig. 5.16. Total TE/ha was highest within the Tribal land use (above the 1600 TE/ha contour level), irrespective of the rangeland condition group ("Good" vs. "Poor), and second highest within the Reserve-Poor land use. A small gradient within the Reserve land use existed, with the total TE/ha being highest in the Reserve-Poor land uses (above 1200 TE/ha contour level) and lowest in the Reserve-Good areas (Fig. 5.16). There was a small gradient visible within the Commercial land use (with TE/ha varying between 400 – 600 TE/ha) (Fig. 5.16). There was no TE/ha gradient visible within the Tribal land use, with the relative "Good" and "Poor" sites all having relatively high woody densities (1400 – 1800 TE/ha contour levels) (Fig. 5.16). These results thus indicate that, based on total TE/ha, woody density was lowest within the

Commercial land use, and highest within the Tribal land use. Woody density was intermediate within the Reserve land use, showing a woody density gradient increasing from the Reserve-Good sites to the Reserve-Poor sites. There was thus not only a single woody density gradient for the total study area, but different gradients within the Reserve and Commercial land uses (Fig. 5.16), with no gradients within the Tribal land use. This holds important implications for monitoring and management purposes, suggesting that extrapolation of results across land uses and hence management procedures pertaining to the woody component should take into account the woody spatial variability.

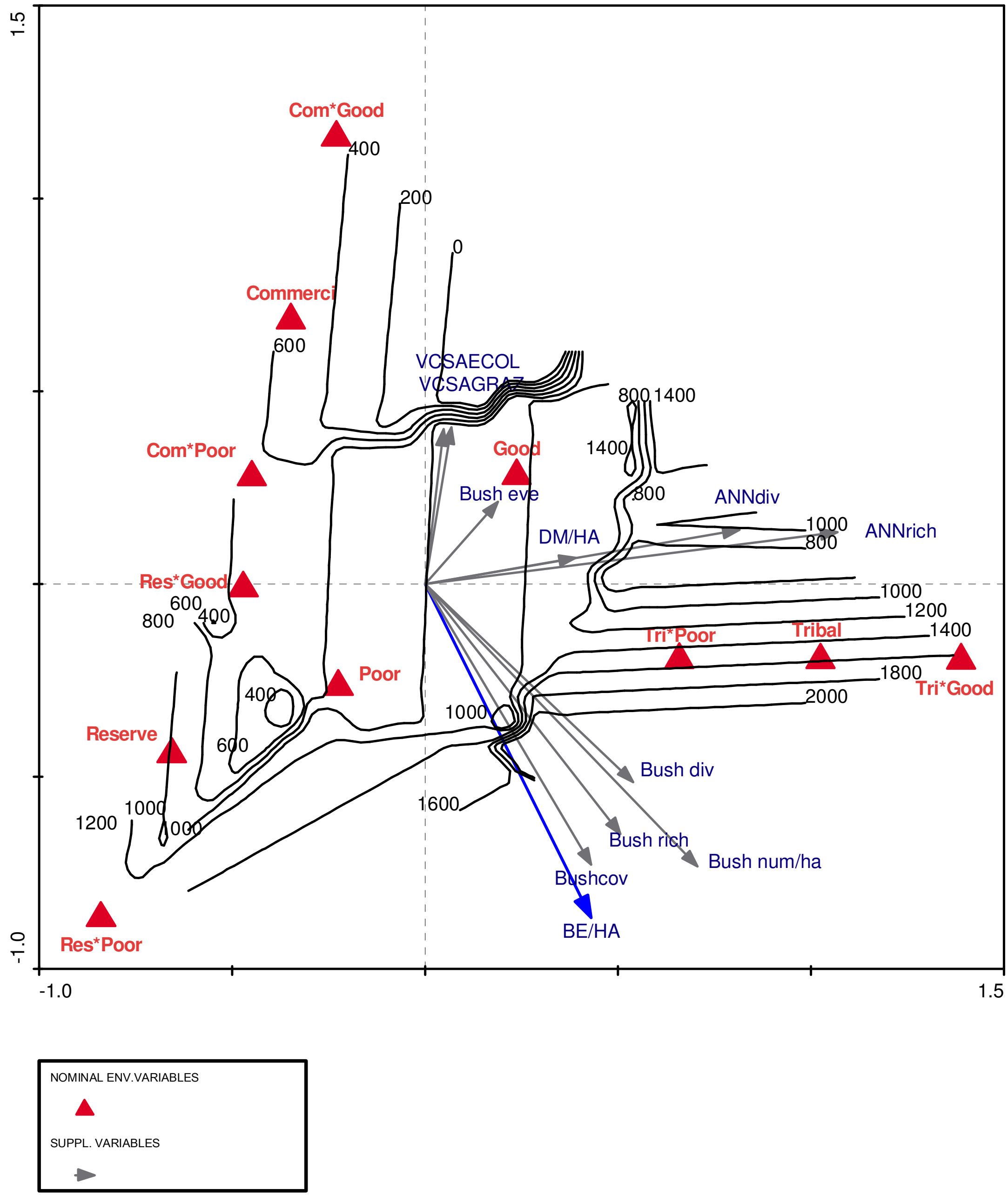


Fig. 5.16. A CCA ordination LOESS attribute plot showing the environmental and passive variables associated with the first two axes, with total TE/ha (BE/ha) as predictor (blue arrow).

5.3.3 Integration of woody species composition with other environmental and biotic variables

The integration of the woody component with other biotic and abiotic variables in order to determine which variables contribute to the main compositional patterns between the multivariate data sets, are discussed in Chapter 7. This was done to identify matching biotic and biotic/abiotic/environmental patterns, and to establish/confirm that land use was the primary determinant of species-environment relations.

5.4. CONCLUSION

The purpose of this chapter was to explore woody compositional patterns with regard to the different land uses within the Molopo study area. A knowledge regarding the functional role of the woody component within a savanna ecosystem is essential.

Smit *et al.* (1996) proposed the following aspects regarding savanna ecosystems: (i) woody plants are a natural component of savanna ecosystems and the different floristic components have evolved over many years; (ii) uncontrolled increases in woody plants as result of direct or indirect human disturbance will suppress the herbaceous component; and (iii) woody plants are essential to savanna ecosystems in terms of soil enrichment, browse, shade, fuel, providing sub-habitats, for medicinal value and aesthetic reasons. The presence of woody plants in savanna is associated with both positive and negative aspects, and is closely correlated to tree density and abundance (Smit 2004). Savanna woody plants contribute to areas of enhanced soil fertility, and soil fertility will be lost over time by complete removal of all woody plants, since soil enrichment under trees is a slow process (Smit 2004).

Smit (2004) suggested that restoration of encroached areas should focus on tree thinning instead of total clearing of all woody plants. Hence, a balance between the woody and herbaceous component needs to be established, taking into account the sizes of trees to be removed as well as the woody species that need to be thinned (Smit 2004). According to Hagos and Smit (2005), a more stable environment can be created by either maintaining or restoring savanna structure, with large trees being able to suppress the establishment of new seedlings while maintaining the benefits of soil enrichment and the provisioning of food to browsers (Smit 2004). In addition, herbaceous production has not always been found to be greatest where woody plants are absent (Kelly 1977). Kelly (1977) stated that woody plants in savanna vegetation are a source of good quality animal feed, with low woody densities favouring the productivity of the vegetation and improving botanical composition. Several authors have further stated that bird droppings and dung of large animals resting under trees, may also contribute to soil enrichment (Belsky *et al.* 1989; Teague & Smit 1992).

Thus, the indiscriminate clearing of woody vegetation may result in environmental deterioration (Kelly 1977). Fulbright (1996) suggested that woody plant control should be applied to increase diversity, by creating a mosaic of intermediately disturbed patches treated at varying intervals of time spatially distributed within a matrix of shrubland. Teague and Smit (1992) hypothesised that in encroached areas, a low number of larger trees, in conjunction with the managed presence of browsers and moderate grazing, as well as periodic fires, sustainable productivity yields will be highest. They stated that this would result in the lowest recurring management costs and a high level of vegetation and faunal diversity. Complex inter-relationships existed between plants, soil and soil moisture of the Mopani veld in the Limpopo Province, South Africa, with the absence of herbaceous plants at high tree densities reflecting the low soil water status existing under such conditions (Smit & Rethman 2000). Hence, these authors found tree thinning to be essential in ensuring conditions favourable to the establishment of herbaceous plants.

The alternative of adapting the animal factor to the vegetation has been receiving increasing interest from ranchers and scientists (Trollope 1980). This means the introduction of a browser into a normal cattle ranching system (Trollope 1980). Aucamp (1979) furthermore suggested that a combination of herbaceous plus woody vegetation could produce more forage per hectare than either of the vegetation types alone. Research by Aucamp *et al.* (1983) indicated that while grass production decreased within increasing tree densities, the increases were not linear. As a result, grass production was barely affected at low tree densities while simultaneously obtaining maximum forage production per unit area for both the herbaceous and woody components. These authors concluded that red meat production in woody communities could be increased by introducing goats into an animal production system. This is consistent with research by Kelly (1977) that suggested that mixed populations of cattle and browsers might be a means of increasing meat production. Kelly (1977) and (Donaldson 1979) found that cattle may also utilise a significant portion of browse during the dry season even though abundant grass is available.

With regard to the density-dependent coupling of livestock to key resources, the unnecessary shifting of key resources (boreholes, kraals etc.) within grazing rangelands has been found detrimental to livestock grazers, resulting in entire pastures being dominated by bush encroachers in several areas of Botswana (Moleele *et al.* 2002). These authors suggested management strategies, which might vary from enforced reduction of grazing intensity in bush encroached areas to the selective management of communal grazing in better quality, predominantly grassland areas.

Smit (2004) suggests that there is no single optimum value for tree density within a vegetation type, but that the optimum density falls within a range. Of importance is that there is no quick solution to bush encroachment, and that this should be seen as a long-term management practice. This can be achieved by minimising the direct and indirect causes of bush encroachment, for instance by maintaining sound grazing practices especially during the wet seasons in order to ensure a vigorous and competitive herbaceous layer (Smit 2004).

In view of all these discussions, the following comments regarding the woody component of the Molopo semi-arid rangelands are proposed. The state-and-transition model (Westoby *et al.* 1989) is at the heart of the dichotomous relationship between non-equilibrium (climatic) and equilibrium (density-dependent coupling to key resources) events within this study area. This applies to both the woody and the herbaceous components. Hence, woody compositional patterns are the result of both climatic as well direct and indirect human-induced impacts. The woody component is natural and essential to the functioning of the Molopo semi-arid rangelands from an ecological, economical and social point of view. The value of the woody component is closely related to the woody:herbaceous ratio, with bush encroachment detrimentally impacting on the herbaceous production and species composition. This can potentially result in a loss of resilience of the ecosystem, as was indicated by the transitional shift of woody species to a next stable state (state-and-transition model). Causative factors of bush encroachment within the study area were primarily related to proximity of the key resources (historical and current) and unsustainable practices pertaining to these key resources. Such unsustainable practices pertaining to the ecological resource include (i) continuous, intensive browsing and grazing practices without incorporating sufficient rest of the resources; (ii) incorrect browser:grazer ratios; and incorrect woody control and post-thinning measures; (iii) insufficient knowledge regarding the dichotomous relationship between the equilibrium and non-equilibrium models (and hence resilience capability of the rangelands), and as underpinned by the state-and-transitional model; (iv) inappropriate distribution of key resources, and (v) extrapolation of monitoring and management procedures without acknowledging spatial complexity and variability at patch, paddock as well as landscape level.

Results from this study further suggest that woody control can be advantageous and should be applied in selected areas for increased herbaceous production and species composition improvement, but it should be cautioned that this is a long-term process. The degree to which the rangeland condition improves depends on which transitional state the ecosystem is in, as well as the impact of non-equilibrium events on the transitional state. Hence, different transitional states may respond differently to the same non-equilibrium event.

Utilisation of the woody component by herbivores from an economical perspective can increase net profit/ha, on condition that the practices are ecologically responsible. Hence, the animal component can be “adapted” to the woody component. However, such practices should be based on ecologically sound principles. Hence, the animal factor should be managed in such a respect that maximum potential (up to browse height of 1.5 m) and not necessarily absolute browse (total height of woody species even above browse height of 1.5 m) is being utilised. However, this should be managed according to ecologically sound principles, overutilisation of the woody component may enhance in bush encroachment and actually reduce the potential browse. For instance, the presence of numerous small shrubs due to the absence of tree-tree competition by larger woody individuals may have less browseable material due to the low height and canopy diameter and hence a low TE value per woody individual. Excessively large trees may increase the TE/individual, but this does not necessarily mean than it is equal to the potential browseable TE/individual. Hence, there is a complex balance between these optima, and management strategies should take these ecological and economical factors into consideration.

Shifting of key resources, or the introduction of more key resources (water points) without proper management or monitoring strategies, may result in density-dependent degradation related to these key resources. Thus, a transitional shift to another woody and herbaceous compositional and ecosystem state, less resilient than the previous state, may take place. The complex inter-relationships between the woody, herbaceous and soil components can not be ignored, and the multivariate integration of these components is presented in Chapter 7.

With regard to the key questions stated for this chapter, the following comments are presented. Tenure practices pertaining to the different land uses resulted in significant differences in the woody composition, density, number of woody individuals and woody structure within each land use. These patterns reflect historical and current land use tenure practices. The direct CCA ordination indicated that land uses and the relative "Good" and "Poor" rangeland condition groups significantly accounted for most of the woody compositional patterns.

Species richness patterns differed between the three land uses, with patterns being more congruent between the Tribal and Reserve land use in this regard. This can be ascribed to the more complex, heterogeneous woody stratum pertaining to these two land use as discussed in the results, as opposed to the mainly controlled woody component within the Commercial and especially the Commercial-Good land use. The woody diversity indices can be considered as indicators of environmental changes (e.g. habitat modification), rather than indicators of biodiversity. Woody diversity and richness patterns did not act as an indicator of rangeland condition/degradation across the larger study area, but it did reflect productivity and environmental complexity patterns related to the different land uses. However, a small degradation gradient pertaining to the diversity indices was visible within the Commercial land use, being suggestive of the complex nature of the woody component. From the results it was evident that different patterns at patch and paddock vs. landscape level exist. This study suggests that monitoring and management strategies should acknowledge woody dynamics at patch, paddock and landscape levels. Monitoring and management practices should thus recognise the spatial variability of these semi-arid rangelands before widely extrapolating woody control strategies across different land uses.

Woody compositional patterns, density and number of woody individuals reflected a degradation gradient for the larger study area, although these gradients were reflected only within the Commercial and Reserve land use. Degradation gradients pertaining to these two land uses differed, whereas no gradient existed within the Tribal land use. The Tribal land use however was associated with "Poor" rangeland condition sites with regards to the woody component. This is ascribed to the dichotomous equilibrium and non-equilibrium relationship, discussed under the results. Differences were intermediate, though significant between land uses. This is indicative of the relatively resilient nature of these semi-arid rangelands. Hence the woody patterns are best described by both equilibrium and non-equilibrium events, with the state-and-transitional model being at the heart of both events. It is further suggested that although significant differences might be low to intermediate, it may have pronounced ecological and economical implications within these semi-arid rangelands.

Recommendations regarding the most appropriate monitoring and management procedures pertaining to the woody component, in the form of a “Key assessment matrix”, are presented in Chapter 9.

In conclusion, this chapter concurs with Smit (2004) that the woody component needs to be managed within a framework of economic viability and ecological responsibility.

5.5. RECOMMENDATIONS FOR CHAPTER 5

Soil and soil moisture studies may prove to be informative regarding the woody-herbaceous relationships. Seed bank studies regarding the herbaceous species seedbed under the tree canopy (noting the type of woody species) as well as in the open herbaceous areas are currently being conducted within the greenhouse. This is done to establish the effect of the woody component of herbaceous seedling recruitment (Coetzee, *in prep. I*). This is not presented within this study, but is considered to be important and informative for monitoring these semi-arid rangelands.

CHAPTER 6
Soil component

6.1. INTRODUCTION

The quality of soil and vegetation is interdependent (Mills & Fey 2004a). Unsustainable grazing practices can result in adverse impacts on soil nutrients, vegetation structure, production and composition (Walker *et al.* 1989; Moleele & Perkins 1998; Nsinamwa *et al.* 2005). Livestock grazing in the Sahel is regarded as a major cause of vegetation and soil degradation (Lusigi & Glaser 1984; Warren & Khogali 1992). According to Beukes and Ellis (2003), soils from degraded areas in the Succulent Karoo vegetation have been altered almost permanently due to long-term grazing pressure. As a result, resting from livestock grazing may possibly not result in vegetation recovery. Mworia *et al.* (1997) found that the ability of rangeland sites in Kenya to recuperate from shifts towards degradation depended on the grazing intensity and rainfall variability. Intensive grazing followed by drought periods resulted in vegetation and soil responses similar to overgrazing. According to Perkins and Thomas (1993b), plant species composition and soil nutrient status changed as a result of cattle grazing around artificial water holes in Botswana. Grazing can furthermore alter soil conditions, leading to shifts in plant compositions (Turner 1998; Hiernaux *et al.* 1999).

Sites for this study were selected within the same landtype (Ah), it is assumed that in geological time soil fertility was relatively (inherent environmentally) similar across the total study area (refer to Chapter 2, Study area, for description of the geology and soils). Any significant differences in soil parameters, especially nutrients linked to biological processes can therefore be interpreted as the result of shorter-term impacts, such as land-use intensity (Zeidler *et al.* 2002). The purpose of Chapter 6 is not to give an in-depth account of the soil physical and chemical processes that operate within the study area. The purpose is rather to serve as additive habitat data complementary to the vegetation and ant chapters pertaining to the impact of different land uses on rangeland condition and biodiversity. Effective maintenance of soil resources requires an understanding of how land uses affect soil quality (Mills & Fey 2004a). According to Bennett and Adams (1999), spatial and temporal variability of rainfall in drylands results in a complex association between vegetation and soils. This applies especially to the soil organic matter, nutrients and microbial activity. The soil, biotic and other environmental data that were surveyed within this study, reflects historical land use tenure and environmental patterns.

Within this chapter, soil data and nominal environmental data were ordinated together in order to attempt to quantify the soil-environmental relationship. Research has suggested that nutrients and soil organic matter levels are elevated under bush canopies, being either vegetation related (Dean *et al.* 1999) and/or being transported with the deposition of enriched eroded material (Tongway & Ludwig 1994). This spatial heterogeneity may be site specific, suggesting that full analyses of the spatial associations between soil nutrients, vegetation canopies and biological crusts are essential in understanding spatial and temporal dynamics of soil fertility and degradation processes in drylands (Dougill & Thomas 2004).

Dryland soil nutrients are preferentially concentrated near the soil surface (Tongway & Ludwig 1994; Dougill *et al.* 1999; Bennett & Adams 1999), which can partially be ascribed to the occurrence of biological crusts consisting of cyanobacteria, algae, microfungi, lichens and bryophytes which exist in the top few millimetres of soil (Belnap *et al.* 2003). Such crusts may result in higher nutrient levels within plants growing in these soils compared to those growing in non-crusted soils (Belnap 2002). Perkins and Thomas (1993a) focused on nutrient concentrations from a range of depths instead of focusing only on the surface layer. Such crusts can fixate atmospheric nitrogen (Belnap *et al.* 2003) and sequester carbon (Evans & Lange 2003). The relationship between crust development and vegetation is regarded as complex (Dougill & Thomas 2004). These authors state that woody strata can either enhance crust development by giving protection against disturbance and trapping fine sediment, or woody canopies can deter crust development by blocking the light reaching the soil surface.

Thus, data analyses and ordination based on four factors and combinations thereof for the soil data were employed in this study in order to establish which factors primarily govern soil patterns. The factors employed were land use, soil stratum (topsoil vs. subsoil), openness (woody vs. open herbaceous areas) and relative rangeland condition (relative “Good” vs. “Poor” rangeland condition sites). Analyses with regard to these four factors were essential in order to identify the correct factors explaining the soil-environmental variance. Quantification of the soil-environmental relationships pertaining to the different factor group combinations, were furthermore necessary to identify in which format the soil matrix should be ordinated with the vegetation and ant data sets, in order to explain the species-environment relation.

The geology of the different survey sites for this study were described as relatively homogeneous, and is characterised by deep sandy to loamy, freely drained sands of aeolian origin, predominantly Ah landtype, underlain by calcrete (Soil classification working group 1991; Low & Rebelo 1996). With this taken into consideration, this chapter would like to address the following key questions: Are there any significant differences in soil chemical and physical properties among the three land uses possibly as a result of tenure type, or can it primarily be ascribed to initial inherent environmental differences? What factors or combinations thereof explain the largest proportion of the soil-environment variance? Which factors pertaining to the soil matrix need to be included when analysed/ordinated together with vegetation, ant and other environmental data?

6.2. RESULTS AND DISCUSSION

In order to address the above-mentioned key questions, the Results and the discussion will be presented under the same headings due to the complexity of the data, and as motivated in the brackets next to each heading. ***For further clarification as to what the purpose of each analysis technique is, refer to Chapter 3, Material and Methods.*** It can not be emphasised enough that, although these different analyses techniques might result in the **incorrect** perception of over-analysing, the different procedures were all essential and complementary to each other. It was only after the in-dept analyses, using the different procedures that it was possible to establish the different multivariate spatial patterns, heterogeneity complexity and diversity- and rangeland gradients pertaining to the soil data, which exist within and between land uses due to different land use impacts (refer to Conclusions within each chapter and final Concluding Remarks in Chapter 9).

6.2.1 **Draftsman scatter plot and Multidimensional scaling ordinations** (normalisation of variables to common measurement scale and ordination of soil data to detect outliers)
6.2.2 **Analysis of similarities (ANOSIM)** (establish differences within and between factor groups)
6.2.3 **Mean variation for factor groups explained** (explanatory complement to Section 6.2.2)
6.2.4 **Direct Canonical Correspondence Analysis (CCA) for the total soil matrix** (ordination to quantify soil-environment relation, based on different factor groups discussed in Section 6.2.2)
6.2.5 **Direct Redundancy analysis (RDA) for topsoil open matrix** (sub-treatment ordination to quantify soil-environment relation, following analysis in Section 6.2.2)
6.2.6 **RDA for subsoil open matrix**
6.2.7 **RDA for topsoil woody matrix**
6.2.8 **RDA for subsoil woody matrix**
6.2.9 **Cumulative variance and eigenvector scores for first two axes for matrices** (proposal towards a “Key assessment matrix”)

6.2.1 Draftsman scatter plot and Multidimensional scaling ordination (MDS)

Abiotic data are usually measured on mixed measurement scales (e.g. % concentration –ppm-, sediment grain size % etc.) and a Bray-Curtis dissimilarity measure, which assumes a common measurement scale, is inappropriate. Such abiotic variables need to be normalised and put on a common, dimensionless measurement scale. Euclidean distance is then used as dissimilarity/distance measure between treatments (samples) (Clarke & Gorley 2001). Normalisation is most effective when data are as near as possible to multivariate normality. A Draftsman plot, a pair-wise scatter plot of the environmental variables, should show roughly linear relationships and a symmetric and not heavily skewed distribution of points (Clarke & Gorley 2001). Examination of this plot suggested that variables needed to be transformed (log for some and square-root for other) to aid the assumptions (Table 6.1). Variables that show intermediate to high correlations with each other, are indicated as such in Table 6.1.

Table 6.1. Pearson's correlation coefficient, Draftsman scatter plot for variable pairs.

Variable	Variable	Correlation	Variable	Variable	Correlation	Variable	Variable	Correlation
pH	P Bray 1	-0.069	K	Ca	0.297	NO3-N	Zn	0.034
pH	Conductivity	0.597**	K	Mg	0.455	NO3-N	C	0.098
pH	K	0.277	K	Na	-0.178	NO3-N	Org. mat	0.086
pH	Ca	0.790**	K	NO3-N	0.183	NO3-N	Coarse sand	0.253
pH	Mg	0.468*	K	Zn	0.034	NO3-N	Med sand	0.321
pH	Na	-0.02	K	C	0.263	NO3-N	Fine sand	-0.41
pH	NO3-N	0.374	K	Org. mat	0.227	NO3-N	Silt	-0.157
pH	Zn	-0.059	K	Coarse sand	-0.078	NO3-N	Clay	-0.114
pH	C	0.028	K	Med sand	-0.2	Zn	C	0.014
pH	Org. mat	-0.003	K	Fine sand	0.211	Zn	Org. mat	0.005
pH	Coarse sand	-0.315	K	Silt	0.41	Zn	Coarse sand	-0.015
pH	Med sand	0.294	K	Clay	-0.018	Zn	Med sand	0.043
pH	Fine sand	-0.082	Ca	Mg	0.515*	Zn	Fine sand	0.012
pH	Silt	0.034	Ca	Na	0.001	Zn	Silt	-0.096
pH	Clay	-0.144	Ca	NO3-N	0.339	Zn	Clay	-0.053
P Bray 1	Conductivity	0.171	Ca	Zn	0.035	C	Org. mat	0.962***
P Bray 1	K	-0.122	Ca	C	0.184	C	Coarse sand	-0.024
P Bray 1	Ca	-0.05	Ca	Org. mat	0.151	C	Med sand	-0.224
P Bray 1	Mg	-0.282	Ca	Coarse sand	-0.387	C	Fine sand	0.24
P Bray 1	Na	-0.035	Ca	Med sand	0.165	C	Silt	0.292
P Bray 1	NO3-N	0.308	Ca	Fine sand	0.088	C	Clay	-0.096
P Bray 1	Zn	0.09	Ca	Silt	0.051	Org.mat	Coarse sand	-0.005
P Bray 1	C	0.268	Ca	Clay	-0.047	Org.mat	Med sand	-0.242
P Bray 1	Org. mat	0.248	Mg	Na	-0.202	Org.mat	Fine sand	0.242
P Bray 1	Coarse sand	0.286	Mg	NO3-N	0.075	Org.mat	Silt	0.261
P Bray 1	Med sand	0.214	Mg	Zn	-0.034	Org.mat	Clay	-0.06
P Bray 1	Fine sand	-0.29	Mg	C	0.083	Coarse sand	Med sand	-0.121
P Bray 1	Silt	-0.18	Mg	Org.mat	0.057	Coarse sand	Fine sand	-0.533
P Bray 1	Clay	-0.155	Mg	Coarse sand	-0.318	Coarse sand	Silt	-0.091
Conductivity	K	0.349	Mg	Med sand	-0.04	Coarse sand	Clay	0.209
Conductivity	Ca	0.506*	Mg	Fine sand	0.217	Med sand	Fine sand	-0.666
Conductivity	Mg	0.265	Mg	Silt	0.444*	Med sand	Silt	-0.236
Conductivity	Na	0.007	Mg	Clay	-0.107	Med sand	Clay	-0.533
Conductivity	NO3-N	0.715**	Na	NO3-N	0.029	Fine sand	Silt	0.174
Conductivity	Zn	-0.04	Na	Zn	0.027	Fine sand	Clay	0.231
Conductivity	C	0.277	Na	C	-0.153			-0.404
Conductivity	Org.mat	0.254	Na	Org. mat	-0.148			
Conductivity	Coarse sand	0.053	Na	Coarse sand	-0.002			
Conductivity	Med sand	0.131	Na	Med sand	-0.093			
Conductivity	Fine sand	-0.143	Na	Fine sand	0.017			
Conductivity	Silt	0.044	Na	Silt	-0.429			
Conductivity	Clay	-0.061	Na	Clay	0.444*			

* Intermediate correlation

** Highly correlated

*** Very highly correlated

A non-metric MDS algorithm, an iterative procedure based on normalised Euclidean distances, was employed to satisfy as closely as possible the dissimilarity relations between samples. The MDS ordination plot, based on the transformed soil matrix, indicated no outlier samples (Fig. 6.1), suggesting in general a consistency in soil variables among the samples. However, it was evident for the MDS ordination plot that the three land uses showed a slight separation, as will be discussed by means of the different factor groups in the remainder of this chapter.

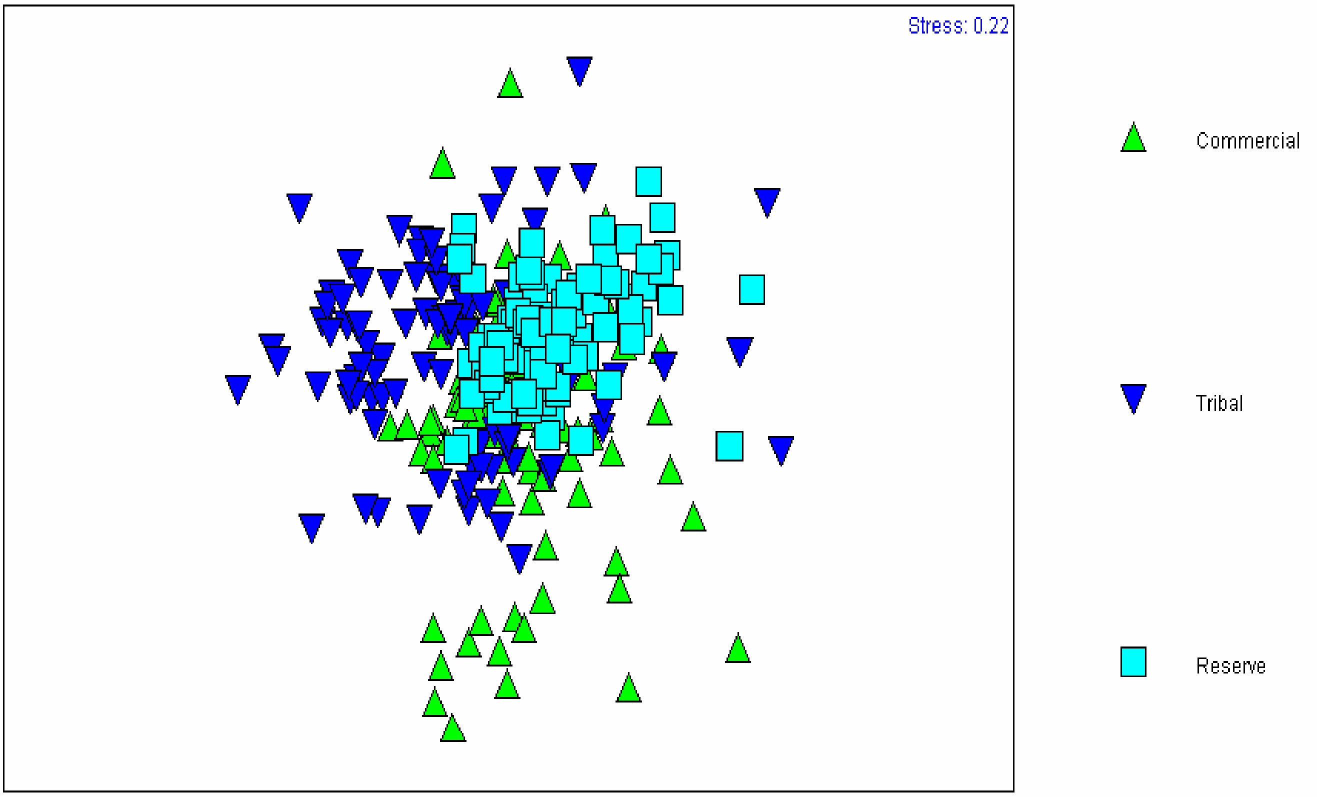


Fig. 6.1. A MDS plot for the transformed soil matrix, including land use, soil depth, openness/woodiness and rangeland condition as factor groups.

6.2.2 Analysis of similarities (ANOSIM)

A. One way ANOSIM tests for total soil matrix

One-way ANOSIM tests (1-way layout), based on normalised Euclidean distances, were conducted to establish assemblage differences between factor groups of samples that were specified *a priori* (Table 6.2). There were significant differences between the Commercial-Tribal land uses ($r = 0.175$, $P < 0.001$), the Commercial-Reserve groups ($r = 0.134$, $P < 0.001$) and the Reserve-Tribal land uses ($r = 0.293$, $P < 0.001$). These results suggest that the Commercial and Reserve groups were more similar with regard to the soil characteristics than were the Commercial-Tribal and Reserve-Tribal groups (Table 6.2).

The ANOSIM test for differences between the soil stratum groups (topsoil vs. subsoil) was significant (r = 0.123, P < 001), suggesting a gradient between the two soil stratums. There were significant, though only small differences between the relative rangeland condition groups (r = 0.017, P < 0.001) (Table 6.2). This suggests that soil characteristics, at this broad level of interpretation (across all factors), do no strongly act as indicator of rangeland condition. There was a significant, though a small difference between the open and woody groups (r = 0.089, P < 0.001) (Table 6.2). Studies conducted on Kalahari soils found no significant differences in soil chemical characteristics between intensively grazed bush-encroached sites vs. less intensively grazed herbaceous sites (de Queiroz 1993; Perkins & Thomas 1993a; Dougill *et al.* 1999). However, Dougill & Thomas (2004) suggested that these results could possibly be the consequence of using mean nutrient concentrations where spatial variability is high and nutrient concentrations are low. This study differentiated between the top- and subsoil, as well as the woody and herbaceous component in order to account as much as possible for the spatial variability. Results indicated significant differences between the herbaceous and woody component. However, results were consistent with the authors mentioned above, in that no gradient (rangeland condition/degradation gradient) pertaining to grazing intensity was found (between relative “Good” and “Poor” rangeland condition sites).

Table 6.2. Correlation coefficients (r -values) for one-way Anosim tests for differences between soil factor groups selected *a priori.*

Factor groups	**Commercial-Tribal**	**Commercial-Reserve**	**Reserve-Tribal**	**Soil stratum**	**Relative condition**	**Openness**
Land use	0.175***	0.134***	0.293***	NA	NA	NA
Soil stratum	NA	NA	NA	0.123*	NA	NA
Rangeland condition	NA	NA	NA	NA	0.017**	NA
Openness	NA	NA	NA	NA	NA	0.089*

*** = P < 0.001
** = P < 0.005
* = P < 0.05
NS = Non significant

Results from this study suggest that tests for 2-way layouts by means of two-way crossed ANOSIM tests are more informative than the one-way ANOSIM tests (Section 2.2 B below). A two-way crossed ANOSIM test for differences between treatments, based on a combination of two-factors at a time, allows for the fact that there may be site differences (Clarke & Gorley 2001). These results, incorporating two factor groups at a time, one as predictor, averaged across the other factor group, are presented below. This is done to establish differences at a more in-depth level, for future monitoring purposes and for incorporation in biotic-abiotic multivariate analyses.

B. Two-way crossed ANOSIM for total soil matrix

Table 6.3. Correlation coefficients (r -values) for two-way crossed Anosim tests for the different soil factor combination groups

	Factor groups - two-way crossed Anosim	**Commercial-Tribal**	**Commercial-Reserve**	**Reserve-Tribal**	**Rangeland condition**	**Soil stratum**	**Openness**
Total soil matrix	Land use and soil stratum	0.185***	0.14***	0.32***	NA	0.15***	NA
	Land use and rangeland condition	0.194***	0.164***	0.296***	0.046***	NA	NA
	Land use and openness	0.171***	0.136***	0.308***	NA	NA	0.1***
	Soil stratum and rangeland condition	NA	NA	NA	0.012**	0.116***	NA
	Soil stratum and openness	NA	NA	NA	NA	0.13***	0.096***
	Rangeland condition and openness	NA	NA	NA	0.16***	NA	0.087***
Zn	Land use and soil stratum	0.039**	0.029*	NS	NA	NS	NA
	Land use and rangeland condition	0.047**	0.045***	NS	0.021**	NA	NA
	Land use and openness	0.033**	0.027*	NS	NA	NA	NS
	Soil stratum and rangeland condition	NA	NA	NA	0.018*	0.02*	NA
	Soil stratum and openness	NA	NA	NA	NA	NS	NS
	Rangeland condition and openness	NA	NA	NA	NS		NS
Silt	Land use and soil stratum	NS	0.265***	0.185***	NA	NS	NA
	Land use and rangeland condition	NS	0.272***	0.206***	0.033**	NA	NA
	Land use and openness	NS	0.26***	0.185***	NA	NA	NS
	Soil stratum and rangeland condition	NA	NA	NA	0.014*	NS	NA
	Soil stratum and openness	NA	NA	NA	NA	NS	NS
	Rangeland condition and openness	NA	NA	NA	NS		NS
pH	Land use and soil stratum	0.067***	0.068***	0.167***	NA	0.042**	NA
	Land use and rangeland condition	0.037**	0.072***	0.118***	NS	NA	NA
	Land use and openness	0.046***	0.083***	0.146***	NA	NA	0.093***
	Soil stratum and rangeland condition	NA	NA	NA	NS	NS	NA
	Soil stratum and openness	NA	NA	NA	NA	0.014*	0.076***
	Rangeland condition and openness	NA	NA	NA	NS		0.077***
P	Land use and soil stratum	0.097***	0.016*	0.082***	NA	0.247***	NA
	Land use and rangeland condition	0.075***	NS	0.025*	0.032**	NA	NA
	Land use and openness	0.051***	NS	NS	NA	NA	NS
	Soil stratum and rangeland condition	NA	NA	NA	0.028***	0.215***	NA
	Soil stratum and openness	NA	NA	NA	NA	0.209***	NS
	Rangeland condition and openness	NA	NA	NA	0.018**		NS
Organic	Land use and soil stratum	0.061***	NS	0.027*	NA	0.271***	NA
	Land use and rangeland condition	0.032*	NS	NS	NS	NA	NA
	Land use and openness	0.032*	NS	NS	NA	NA	0.029**
	Soil stratum and rangeland condition	NA	NA	NA	NS	0.245***	NA
	Soil stratum and openness	NA	NA	NA	NA	0.289***	0.077***
	Rangeland condition and openness	NA	NA	NA	NS		0.031**

TABLE 6.3 (continue . . .)

	Factor groups - two-way crossed Anosim	**Commercial-Tribal**	**Commercial-Reserve**	**Reserve-Tribal**	**Rangeland condition**	**Soil stratum**	**Openness**
NO3	Land use and soil stratum	0.166***	NS	0.196***	NA	NS	NA
	Land use and rangeland condition	0.175***	NS	0.207***	0.023*	NA	NA
	Land use and openness	0.172***	0.025*	0.25***	NA	NA	0.113***
	Soil stratum and rangeland condition	NA	NA	NA	0.022*	0.016*	NA
	Soil stratum and openness	NA	NA	NA	NA	0.014*	0.085***
	Rangeland condition and openness	NA	NA	NA	0.019*		0.084***
Na	Land use and soil stratum	NS	0.072***	0.18***	NA	NS	NA
	Land use and rangeland condition	NS	0.076***	0.193***	NS	NA	NA
	Land use and openness	NS	0.074**	0.181***	NA	NA	NS
	Soil stratum and rangeland condition	NA	NA	NA	NS	NS	NA
	Soil stratum and openness	NA	NA	NA	NA	NS	NS
	Rangeland condition and openness	NA	NA	NA	NS		NS
Mg	Land use and soil stratum	0.021*	0.101***	0.175***	NA	0.097***	NA
	Land use and rangeland condition	NS	0.096***	0.113***	0.03**	NA	NA
	Land use and openness	NS	0.82***	0.126***	NA	NA	NS
	Soil stratum and rangeland condition	NA	NA	NA	0.021**	0.056***	NA
	Soil stratum and openness	NA	NA	NA	NA	0.062***	NS
	Rangeland condition and openness	NA	NA	NA	0.023**		NS
Medium sand	Land use and soil stratum	0.361***	0.071***	0.322***	NA	NS	NA
	Land use and rangeland condition	0.357***	0.083***	0.326***	NS	NA	NA
	Land use and openness	0.358***	0.078***	0.321***	NA	NA	NS
	Soil stratum and rangeland condition	NA	NA	NA	NS	NS	NA
	Soil stratum and openness	NA	NA	NA	NA	NS	NS
	Rangeland condition and openness	NA	NA	NA	NS		NS
K	Land use and soil stratum	NS	0.083***	0.099***	NA	NS	NA
	Land use and rangeland condition	NS	0.083***	0.105***	NS	NA	NA
	Land use and openness	NS	0.091***	0.13***	NA	NA	0.106***
	Soil stratum and rangeland condition	NA	NA	NA	NS	NS	NA
	Soil stratum and openness	NA	NA	NA	NA	NS	0.102***
	Rangeland condition and openness	NA	NA	NA	0.024**		0.102***
Fine sand	Land use and soil stratum	0.276***	0.082***	0.21***	NA	NS	NA
	Land use and rangeland condition	0.310***	0.117***	0.221***	0.027**	NA	NA
	Land use and openness	0.275***	0.078***	0.205***	NA	NA	NS
	Soil stratum and rangeland condition	NA	NA	NA	NS	NS	NA
	Soil stratum and openness	NA	NA	NA	NA	NS	NS
	Rangeland condition and openness	NA	NA	NA	NS		NS

TABLE 6.3 (continue . . .)

	Factor groups - two-way crossed Anosim	**Commercial-Tribal**	**Commercial-Reserve**	**Reserve-Tribal**	**Rangeland condition**	**Soil stratum**	**Openness**
Conductivity	Land use and soil stratum	0.055**	0.018*	0.098***	NA	NS	NA
	Land use and rangeland condition	0.032**	NS	0.09***	NS	NA	NA
	Land use and openness	0.046**	NS	0.127***	NA	NA	0.251***
	Soil stratum and rangeland condition	NA	NA	NA	NS	NS	NA
	Soil stratum and openness	NA	NA	NA	NA	NS	0.23***
	Rangeland condition and openness	NA	NA	NA	NS		0.229***
Coarse sand	Land use and soil stratum	NS	0.154***	0.184***	NA	NS	NA
	Land use and rangeland condition	0.055***	0.175***	0.197***	0.032**	NA	NA
	Land use and openness	NS	0.158***	0.184***	NA	NA	NS
	Soil stratum and rangeland condition	NA	NA	NA	NS	NS	NA
	Soil stratum and openness	NA	NA	NA	NA	NS	NS
	Rangeland condition and openness	NA	NA	NA	NS		NS
Clay	Land use and soil stratum	0.131***	0.042*	0.19***	NA	0.021*	NA
	Land use and rangeland condition	0.132***	0.107***	0.201***	0.072***	NA	NA
	Land use and openness	0.126***	0.037**	0.18***	NA	NA	NS
	Soil stratum and rangeland condition	NA	NA	NA	0.035**	0.015*	NA
	Soil stratum and openness	NA	NA	NA	NA	0.013*	NS
	Rangeland condition and openness	NA	NA	NA	0.033***		NS
Ca	Land use and soil stratum	NS	0.122***	0.194***	NA	NS	NA
	Land use and rangeland condition	NS	0.155***	0.209***	0.021*	NA	NA
	Land use and openness	NS	0.138***	0.206***	NA	NA	0.051***
	Soil stratum and rangeland condition	NA	NA	NA	NS	NS	NA
	Soil stratum and openness	NA	NA	NA	NA	NS	0.037**
	Rangeland condition and openness	NA	NA	NA	NS		0.041***
C	Land use and soil stratum	0.059***	NS	0.023*	NA	0.277***	NA
	Land use and rangeland condition	0.029*	NS	NS	NS	NA	NA
	Land use and openness	0.031*	NS	NS	NA	NA	0.032**
	Soil stratum and rangeland condition	NA	NA	NA	NS	0.25***	NA
	Soil stratum and openness	NA	NA	NA	NA	0.297***	0.081***
	Rangeland condition and openness	NA	NA	NA	NS		0.033**

Two-way crossed ANOSIM tests using normalised Euclidean distances for the total transformed data matrix, incorporating six two-way crossed factor groups (refer to Chapter 3), were conducted to establish differences within and between factor-group patterns (Table 6.3). Significant differences between the Commercial-Tribal, Commercial-Reserve and Reserve-Tribal land uses were indicated when averaged firstly across all relative rangeland condition groups (relative "Good" and "Poor" groups), secondly with regard to soil stratum (averaged across top- and subsoil samples) and thirdly with regard to openness (averaged across woody vs. open/herbaceous samples) (Table 6.3).

When implementing land use and soil stratum as a two-way factor group, differences (averaged across all soil stratum groups) between land uses (as predictor), for the Commercial-Tribal ($r = 0.185$, $P < 0.001$), Commercial-Reserve ($r = 0.14$, $P < 0.001$) and the Reserve Tribal ($r = 0.32$, $P < 0.001$) were highly significant. The difference between the Reserve-Tribal land uses was most pronounced, followed by the Commercial-Tribal land uses. Hence, the results suggest that in general, the Commercial and Reserve land uses were slightly more similar than the Tribal-Commercial or Tribal-Reserve land uses were (see Section 6.2.4, Fig. 6.2 CCA) for this two-way crossed factor group. Differences between the soil stratum groups, thus for the subsoil vs. topsoil, averaged across all land uses, were highly significant ($r = 0.15$, $P < 0.001$). Hence, a gradient between the topsoil and subsoil existed. These results were a slight improvement of that of the one-way ANOSIM tests (Table 6.2), showing small site differences within a treatment based on this two-way crossed ANOSIM.

Testing the land use and relative rangeland condition as two-way crossed factor group, with land use as predictor averaged across all relative rangeland condition groups, indicated highly significant differences between the three land uses (Table 6.3). The differences between the Reserve-Tribal groups were most pronounced ($r = 0.296$, $P < 0.001$), followed by the Commercial-Tribal land uses ($r = 0.194$, $P < 0.001$) and then the Commercial-Reserve groups ($r = 0.164$, $P < 0.001$) (Table 6.3). With regard to land use and rangeland condition, the Commercial and Reserve land uses were also more similar than were the Commercial-Tribal or Reserve-Tribal groups. Relative rangeland condition groups ("Good" vs. "Poor"), averaged across all land uses, showed only a small significant difference ($r = 0.046$, $P < 0.001$) (Table 6.3). There was an improvement in the correlation coefficient statistics (r-value) from the one-way ANOSIM test (Table 6.2) to the two-way ANOSIM (Table 6.3). This suggests that there were small site differences. However, the correlation coefficients for this two-way crossed factor group were not as strong as that for the land use-soil stratum two-way crossed group, indicating that the soil stratum gradient was more pronounced and resulted in more differences between land uses than did relative rangeland condition. These results further suggest that the soil variables (in general) did not pronouncedly reflect/indicate the rangeland condition/degradation gradient.

For the Land use and openness two-way crossed factor group, the land uses (averaged across all openness groups), differed significantly. Differences between the Reserve-Tribal groups were most pronounced ($r = 0.308$, $P < 0.001$), followed by differences between the Commercial-Tribal land uses ($r = 0.171$, $P < 0.001$) and the Commercial-Reserve groups ($r = 0.136$, $P < 0.001$) (Table 6.3). The

Commercial and Reserve groups were more similar than were the Reserve-Tribal or Commercial-Tribal land uses (Table 6.3) with regard to this two-way crossed factor group. Differences between the openness groups (averaged across land uses), were significant (r = 0.1, P < 0.001) (Table 6.3). These results suggest that soil properties show a gradient between openness and woodiness. These results were very similar to that of the one-way ANOSIM tests (Table 6.2) for the separate factors, indicating that based on this two-way crossed factor group, differences within treatments were similar.

The soil stratum-rangeland condition two-way crossed factor group, showed significant differences between the soil stratums (averaged across rangeland condition groups) (r = 0.116), with only neglectably small significant differences between the relative rangeland condition groups (averaged across soil stratums) (r = 0.012, P < 0.001) (Table 6.3). Hence, a soil stratum gradient was evident based on these two factor groups, whereas a rangeland condition gradient was not very evident. However, these results showed lower r-values than in the one-way crossed ANOSIM tests (Table 6.2) and the two-way crossed combination with land use (Table 6.3). This suggests that the “interaction” of the rangeland condition and soil stratum factors within the two-way crossed factor group is less informative of the observed soil-environment (land use) patterns than the land use two-way factor groups discussed above.

The two-way crossed ANOSIM for the soil stratum-openness factor group indicated significant differences based on the soil stratum group (averaged across openness groups) (r = 0.13, P < 0.001) (Table 6.3). There was a significant, though less pronounced difference between the openness groups, when averaged across all soil stratum groups (r = 0.096, P < 0.001) (Table 6.3). Results improved slightly from that of the one-way ANOSIM test (Table 6.2), indicating within-treatment differences when based on these two factors, suggesting the existence of soil stratum and rangeland condition gradients. These differences though were slightly less pronounced than in the land use-openness interaction.

The rangeland condition-openness two-way crossed ANOSIM tests were significant for the rangeland condition group (averaged across openness groups) (r = 0.16, P < 0.001) and the openness group (r = 0.87, P < 0.001) (Table 6.3). These results suggest that the soil variables (in general) showed a much more pronounced gradient with regard to the rangeland condition for the rangeland condition-openness two-way crossed factor group, than for rangeland condition alone or when in two-way crossed combination with the soil stratum or land use. Thus, openness (woodiness) resulted in the soil properties to reflect the rangeland condition gradient. Openness, averaged across relative rangeland condition groups (r = 0.086, P < 0.001), remained very similar to that of the one-way ANOSIM test (Table 6.2). However, the r-value for the rangeland condition-openness interaction (openness as predictor) was lower than that of the land use-openness and soil stratum-openness groups, suggesting that rangeland condition did not explain as much of the openness statistics as the other interactions did.

C. Two-way crossed ANOSIM tests for soil variables

Based on the significant differences discussed above (Table 6.2 and Table 6.3), two-way crossed ANOSIM tests, for the factor groups discussed in Section 6.2.2 C, were done for each transformed, normalised (Euclidean distance) soil variable (Table 6.3), to determine whether patterns related to separate soil variables prove to be informative. In support of this, Hagos and Smit (2005) stated that various soil elements act as determinants of the composition, structure and productivity of vegetation.

Significant differences for each variable and two-way crossed factor group are presented in Table 6.3. However, only the most pronounced significant differences pertaining to the factor groups will be discussed in this section.

Based on the silt content, the land uses differed significantly from each other ($P < 0.001$), irrespective of the soil stratum, openness and relative rangeland condition (Table 6.3). Differences between the Commercial-Reserve land uses were most pronounced, followed by differences between the Reserve-Tribal land uses. There were no significant differences between the Commercial-Tribal land uses, suggesting that the Reserve land use differed with regard to this environmental variable from the other two land uses. Silt content was indicated as the highest within the Reserve land use (Table 6.4).

For pH, differences between the Reserve-Tribal land uses were significant ($P < 0.001$) (Table 6.3). Differences were significant, but less pronounced between the Commercial-Reserve land uses and significant but very small between the Commercial-Tribal land uses. These results suggest that the Reserve land use differed from the other two groups with regard to pH. The pH for the Reserve was higher (more alkaline) than that of the other two land uses (Table 6.4). Openness/woodiness resulted in a small but significant gradient pertaining to pH, with pH being highest (more alkaline) in the Reserve woody stratum (Table 6.6). This is consistent with research conducted by Bosch and Van Wyk (1970) for rangelands in the North West Province. Hagos and Smit (2005) however found for studies conducted in the Pomfret area, North West Province, that pH was the lowest (moderately acid) near the stems of *Acacia mellifera* trees, and increased with distance from the stems. According to Johnston *et al.* (1971), the combined effect of dung and urine depositions with cattle grazing may also alter soil acidity. Studies by Yong-Zhong (2005) indicated that soil pH was higher in continuously grazed soils compared to livestock exclusion soils. Nsinamwa *et al.* (2005) found that acidity (pH) decreased with distance from water points which are subjected to higher densities of cattle compared to grazing points a distance away. However, the more alkaline pH in the Reserve can possibly not only be ascribed to the possible herbivore density and/or different water utilsisation patterns by game. Acidity (pH) was found to be highly correlated with Ca and intermediately with Mg concentrations, with mean concentrations being highest within the Reserve land use, also primarily being related to the woody stratum (Table 6.6). Research by Mapfumo *et al.* (2002) showed that soil depth seemed to have more influence on pH than either plant species or grazing level.

Table 6.4. Descriptive statistics for mean soil concentrations and particle sizes, with the highest content pertaining to each variable across all land use, underlined.

	pH	P Bray 1	Conductivity	K	Ca	Mg	Na	NO3-N	Zn	C	Org. mat	Coarse sand	Med sand	Fine sand	Total sand	Silt	Clay
Commercial land use																	
Mean	**5.27**	**3.55**	**11.08**	**66.69**	**257.13**	**73.25**	**17.06**	**4.92**	**0.49**	**0.15**	**0.26**	**5.29**	**38.86**	**51.44**	**95.58**	**0.94**	**3.48**
Standard Error	0.07	0.46	0.72	2.78	19.44	3.14	0.25	0.48	0.05	0.01	0.01	0.54	0.36	0.69	0.20	0.23	0.11
Minimum	4.30	0.00	3.00	15.00	72.00	6.00	12.00	0.60	0.13	0.07	0.12	1.00	30.20	32.60	78.20	0.00	2.00
Maximum	8.00	24.00	43.00	153.00	1840.00	173.00	28.00	25.50	4.83	0.39	0.67	23.20	46.70	62.20	97.80	19.80	6.00
Tribal land use																	
Mean	**5.20**	**1.61**	**8.57**	**66.95**	**320.25**	**70.40**	**17.77**	**1.84**	**0.42**	**0.17**	**0.30**	**3.67**	**29.96**	**59.86**	**93.03**	**1.44**	**5.48**
Standard Error	0.10	0.20	0.43	3.98	52.08	3.11	0.21	0.10	0.01	0.01	0.02	0.28	0.84	0.49	0.34	0.26	0.26
Minimum	4.10	0.00	3.00	15.00	100.00	27.00	14.00	0.10	0.21	0.04	0.07	0.40	17.20	40.00	70.40	0.00	2.00
Maximum	8.30	17.00	26.00	298.00	3442.00	173.00	23.00	5.10	1.20	0.40	0.99	9.40	63.60	66.80	97.20	19.60	11.00
Reserve land use																	
Mean	**5.79**	**2.00**	**13.26**	**93.21**	**371.56**	**113.74**	**15.44**	**3.83**	**0.51**	**0.16**	**0.27**	**2.61**	**36.48**	**55.94**	**95.03**	**1.82**	**3.15**
Standard Error	0.09	0.17	0.84	3.99	26.54	6.61	0.17	0.24	0.04	0.01	0.01	0.07	0.31	0.32	0.11	0.12	0.12
Minimum	4.60	0.00	3.00	35.00	136.00	41.00	12.00	0.57	0.17	0.06	0.11	1.00	30.00	48.60	91.40	0.00	2.00
Maximum	8.20	7.00	42.00	265.00	2566.00	453.00	21.00	12.94	3.93	0.36	0.62	5.80	42.80	64.20	96.60	4.80	6.00

Results from this study suggest that the woody stratum had a more pronounced effect on soil pH than did soil stratum (Table 6.3).

There were highly significant differences between soil stratum groups for P, when averaged across land uses (r = 0.247, P < 0.001), rangeland condition groups (r = 0.215, P < 0.001) and openness (r = 0.209, P < 0.001). Hence, a significant gradient for soil stratum, relatively irrespective of the other factors, was evident for the P concentration. The average P concentration was highest in the topsoil, notably in the Commercial-topsoil (Table 6.5; see Section 6.2.4, Fig. 6.2). The higher concentration in the topsoil was expected, since P is very immobile in soil. According to Belsky *et al.* (1989), the P concentration was higher under *Acacia tortilis* canopies for Kenya rangelands, than outside it. Studies by Dougill and Thomas (2004) found that sub-canopy bush sites in the Molopo had enhanced ammonium and phosphate concentrations, as well as organic matter, while Bosch and Van Wyk (1970) and Hagos and Smit (2005) also found elevated P levels under canopies of trees in the North West Province. According to Dougill and Thomas (2002), elevated nutrient concentrations beneath woody species in the Molopo basin were not the result of wind transported sediments, but rather due to autogenic processes. For this study, there were no significant differences in P concentration between the woody and herbaceous components (Table 6.3). Hilder (1966) found that available P levels increased in areas where larger herbivores concentrated. According to this study's results, the relative "Good" vs. "Poor" rangeland condition groups showed no pronounced differences pertaining to P concentration (Table 6.3). The reason for this might be due to the low inherent soil P levels and therefore low circulation of P by grazing animals.

Carbon is highly correlated with organic material (r = 0.962, Table 6.1), and thus displayed congruent patterns (Table 6.3). Thus, soil carbon and soil organic matter are discussed collectively in the chapter. Soil organic matter is a key component of any ecosystem (Du Preez & Snyman 1993), and soil quality has been typically equated with soil organic matter (Mills & Fey 2004a). Variation in its abundance may impact on soil processes (Du Preez & Snyman 1993). According to these authors, once organic matter is lost, soil degradation takes place and recuperation and restoration to the previous rangeland state is a slow process. Loss of soil organic matter has a large effect on soil infiltration and nutrient supply (Mills & Fey 2004a). Allison (1973) stated that organic matter in soil is a major source of inorganic nutrients and microbial activity; it acts as ion exchange material and holds water and nutrients in available form; it promotes soil aggregation and root development; it enhances water infiltration and water-use efficiency.

There were highly significant differences between soil stratum groups for carbon (and hence organic material), when averaged across land uses (r = 0.277, P < 0.001), rangeland condition groups (r = 0.25, P < 0.001) and openness strata (r = 0.297, P < 0.001) (Table 6.3). Hence, a significant gradient for soil stratum based on carbon (and thus organic material), relatively irrespective of the other factors, was evident (Table 6.3). Mean carbon concentration (and organic material %) was highest in the topsoil, notably within the Tribal land use (Table 6.5). According to Bauer *et al.* (1987), grazing may change soil organic matter. Organic enrichment of soils through bio-circulation occurs in the topsoil.

Table 6.5. Descriptive statistics for mean topsoil and subsoil concentrations and particle sizes

TOPSOIL	pH	P Bray 1	Conductivity	K	Ca	Mg	Na	NO3-N	Zn	C	Org.mat	Coarse sand	Med sand	Fine sand	Total sand	Silt	Clay
Total: Topsoil																	
Mean	5.27	3.53	10.81	73.38	301.94	73.40	16.60	3.77	0.52	0.19	0.33	3.85	35.20	56.25	95.03	1.21	3.76
Standard Error	0.07	0.32	0.56	2.88	20.43	3.38	0.20	0.31	0.04	0.00	0.01	0.31	0.56	0.53	0.14	0.11	0.15
Minimum	4.10	0.00	4.00	15.00	72.00	6.00	12.00	0.10	0.17	0.07	0.11	0.60	19.80	32.60	89.80	0.00	2.00
Maximum	8.10	24.00	43.00	298.00	2186.00	388.00	28.00	25.50	4.83	0.40	0.99	23.20	63.60	66.80	97.80	5.80	9.20
Commercial: Topsoil																	
Mean	5.12	5.35	11.21	66.35	266.58	64.40	17.04	5.19	0.57	0.18	0.30	5.37	38.64	51.94	95.95	0.74	3.31
Standard Error	0.08	0.79	1.22	3.85	35.13	3.67	0.40	0.79	0.10	0.01	0.01	0.81	0.53	1.06	0.10	0.15	0.15
Minimum	4.30	0.00	4.00	15.00	72.00	6.00	12.00	0.79	0.23	0.12	0.21	1.00	31.40	32.60	94.20	0.00	2.00
Maximum	7.50	24.00	43.00	126.00	1840.00	173.00	28.00	25.50	4.83	0.31	0.53	23.20	45.80	62.20	97.80	3.00	5.20
Tribal: Topsoil																	
Mean	5.16	2.10	9.21	68.06	301.08	61.94	17.52	2.08	0.44	0.21	0.38	3.60	30.62	60.27	93.66	1.22	5.12
Standard Error	0.15	0.35	0.68	6.07	47.20	4.10	0.31	0.17	0.02	0.01	0.02	0.39	1.29	0.66	0.32	0.24	0.33
Minimum	4.10	1.00	4.00	20.00	100.00	27.00	14.00	0.10	0.22	0.07	0.11	0.60	19.80	48.20	89.80	0.00	2.00
Maximum	8.10	17.00	26.00	298.00	2186.00	144.00	23.00	5.10	1.20	0.40	0.99	9.20	63.60	66.80	97.20	5.80	9.20
Reserve: Topsoil																	
Mean	5.52	3.13	12.00	85.73	338.17	93.88	15.25	4.05	0.55	0.19	0.32	2.59	36.34	56.54	95.47	1.69	2.85
Standard Error	0.10	0.24	0.93	4.37	17.14	7.77	0.22	0.35	0.08	0.01	0.01	0.09	0.47	0.49	0.11	0.16	0.14
Minimum	4.60	1.00	4.00	35.00	182.00	41.00	12.00	0.74	0.17	0.10	0.17	1.00	30.00	49.80	93.00	0.00	2.00
Maximum	7.50	7.00	32.00	154.00	664.00	388.00	18.00	12.94	3.93	0.36	0.62	3.80	42.80	64.20	96.60	3.40	4.00

SUBSOIL	pH	P Bray 1	Conductivity	K	Ca	Mg	Na	NO3-N	Zn	C	Org.mat	Coarse sand	Med sand	Fine sand	Total sand	Silt	Clay
Total: subsoil																	
Mean	5.57	1.26	11.09	77.70	329.74	98.07	16.90	3.26	0.43	0.13	0.22	3.84	35.04	55.24	94.09	1.57	4.31
Standard Error	0.08	0.11	0.60	3.34	35.69	4.43	0.18	0.24	0.02	0.00	0.01	0.29	0.54	0.49	0.26	0.22	0.18
Minimum	4.30	0.00	3.00	15.00	108.00	25.00	14.00	0.13	0.13	0.04	0.07	0.40	17.20	34.80	70.40	0.00	2.00
Maximum	8.30	8.00	42.00	265.00	3442.00	453.00	21.00	15.61	1.38	0.39	0.67	19.80	46.70	66.20	97.00	19.80	11.00
Commercial: subsoil																	
Mean	5.41	1.76	10.82	66.82	246.57	82.08	17.06	4.57	0.41	0.13	0.22	5.12	39.12	51.00	95.23	1.11	3.65
Standard Error	0.11	0.26	0.78	3.96	16.72	4.70	0.31	0.55	0.03	0.01	0.01	0.72	0.49	0.86	0.37	0.42	0.15
Minimum	4.30	0.00	3.00	31.00	112.00	25.00	14.00	0.60	0.13	0.07	0.12	1.00	30.20	34.80	78.20	0.00	2.00
Maximum	8.00	8.00	30.00	153.00	658.00	165.00	21.00	15.61	1.02	0.39	0.67	19.80	46.70	60.20	96.80	19.80	6.00
Tribal: subsoil																	
Mean	5.24	1.10	8.04	65.90	338.80	80.14	17.94	1.64	0.41	0.12	0.21	3.70	29.52	59.36	92.49	1.70	5.72
Standard Error	0.13	0.16	0.51	5.00	89.61	4.32	0.29	0.11	0.02	0.01	0.01	0.39	1.05	0.71	0.56	0.44	0.40
Minimum	4.30	0.00	3.00	15.00	108.00	31.00	16.00	0.13	0.21	0.04	0.07	0.40	17.20	40.00	70.40	0.00	2.00
Maximum	8.30	6.00	19.00	173.00	3442.00	173.00	21.00	4.08	0.91	0.20	0.34	9.40	43.40	66.20	97.00	19.60	11.00
Reserve: subsoil																	
Mean	6.10	0.89	14.70	102.13	408.48	134.59	15.61	3.63	0.46	0.14	0.23	2.62	36.72	55.27	94.60	1.93	3.47
Standard Error	0.13	0.06	1.45	6.74	52.19	10.37	0.27	0.35	0.03	0.00	0.01	0.11	0.41	0.42	0.18	0.18	0.18
Minimum	4.80	0.00	3.00	45.00	136.00	44.00	14.00	0.57	0.17	0.06	0.11	1.20	31.40	48.60	91.40	0.00	2.00
Maximum	8.20	2.00	42.00	265.00	2566.00	453.00	21.00	9.34	1.38	0.26	0.44	5.80	41.20	61.20	96.60	4.80	6.00

Organic material is also strongly bound to soil particles and does not show downward movement. This is consistent with research by Yong-Zhong (2005) who found that C levels were highest in the top 0 – 15 cm of soil. Dougill and Thomas (2004) found only a small increase in organic matter under bushes in the Molopo basin. This is consistent with this study's results, showing only small differences between the woody and herbaceous vegetation components (Table 6.3). Mills and Fey (2004b) stated, however, that total carbon significantly and pronouncedly decreased with changes from thicket to savanna for rangelands in the Eastern Cape, South Africa, and in addition Mills *et al.* (2005) found increased carbon levels within increased woodiness for semi-arid rangelands. Du Preez and Snyman (1993) found that soil organic matter decreased from rangeland in good condition to rangeland in poor condition, while Yong-Zhong (2005) found that exclusion of livestock on degraded sandy grassland resulted in a significant increase in the amount of total organic material. In contrast, Zeidler *et al.* (2002) found that total carbon levels were significantly higher at high-intensity grazing sites compared to low-intensity grazing sites in communal areas of north-western Namibia. According to Zeidler *et al.* (2002), dung and litter were not separated from the collection procedure, making it difficult to establish which of the two parameters contributed most to the high biomass inputs recorded. Nsinamwa *et al* (2005) found that concentration of C was higher around boreholes than further away along a grazing gradient. Within this study, dung and visible litter were removed from the samples. This study found no significant differences in soil organic carbon between rangeland in relative "Good" vs. "Poor" rangeland condition groups (Table 6.3). However, the purpose of this study was not to test grazing gradients pertaining to piosphere effects (see Chapter 3).

Major reasons for the loss of soil organic matter, can be ascribed to a reduced phytomass production as well as to erosion (Du Preez & Snyman 1993). Based on these assumptions, the Tribal land use thus reflected soils with relatively high phytomass cover, with the root phytomass of grasses being considered as a more important contributor to soil organic matter than above-ground phytomass (Troughton 1957). Dry-matter yield (DM yield) by herbaceous species were positively associated with the Reserve-/Commercial-Good land survey areas (refer to Chapter 4), while total bush density and diversity were highest within the Tribal land use. Significant though relatively minor differences pertaining to soil organic matter between the woody vs. herbaceous component, were found for this study (Table 6.3). It is suggested that the higher organic matter concentration within the Tribal land use can possibly be ascribed primarily to the higher woody density among other factors within this land use, since herbaceous DM yield (kg/ha) was not correlated with the Tribal land use (refer to Chapter 4 and Chapter 7). This is consistent with research by Belsky *et al.* (1989) who also found that soil organic matter and soil water content were greater under the woody canopy than outside it. In the north-western communal areas of Namibia, lower tree biomass in low-intensity grazing sites resulted in lower total soil carbon (%) than in high-intensity grazing areas with slightly higher woody biomass (Zeidler *et al.* 2002), thus being consistent with results from this study. Although organic matter content may not correlate with clay dispersion or crusting, research has indicated that the rate of infiltration and aggregate stability decrease with the loss of soil organic matter (Haynes *et al*. 1991; Blair & Crocker 2000).

Based on NO_3-N, there were significant differences between the Commercial-Tribal and Reserve-Tribal land uses, irrespective of soil stratum and rangeland condition. For the land use-openness two-way crossed ANOSIM test, openness, averaged across all land uses, was significant ($r = 0.113$, $P < 0.001$) (Table 6.3). This is an improvement from the one-way ANOSIM openness test ($r = 0.089$, $P < 0.001$), indicating small *within* treatment differences. NO_3-N concentration was highest in the Commercial land use (Table 6.4). With regard to openness, the average NO_3-N concentration was highest for the woody component notably that of the Commercial land use. The average NO_3-N concentration was the lowest in the Tribal land use (Tables 6.4 and 6.6). Nitrate move freely in soil, thus not pronouncedly reflecting a soil stratum gradient. According to Mapfumo *et al.* (2002), NO_3-N levels were greater for heavy compared to medium or light grazing areas. Higher NO_3-N concentration in the woody component might be due to mineralisation/nitrification from legume roots or mineralisation from animal excretions resting under the trees.

There were significant differences ($P < 0.001$) between the Reserve-Tribal land uses for Na, irrespective of openness, relative rangeland condition or soil stratum (Table 6.3). Differences between the Commercial-Reserve land uses were significant but less pronounced, with no significant differences between the Commercial-Tribal land uses. Hence, the Na concentration was not significantly influenced by soil stratum, relative rangeland condition or openness/woodiness. These results suggest that the Reserve differed from the other two land uses with respect to Na concentration. The average Na concentration was the lowest within the Reserve land use, while the mean concentration was very similar between the Commercial and Tribal land uses, being highest in the Tribal land use (Table 6.4). Sodium concentration and clay content (%) were intermediately correlated ($r = 0.444$, Table 6.1), with Na and clay being lowest in the Reserve land use. Average clay content (percentage) was highest within the Tribal and then the Commercial land uses, possibly contributing to the higher Na concentration within these land uses (Table 6.4). High levels of Na were found to be evident in soil continuously being overgrazed in the Succulent Karoo, contributing towards the tendency to form crusts (Beukes & Ellis 2003). Crusting reduces water infiltration, and restoration of such areas should consider infiltration as a priority (Beukes & Ellis 2003). According to Greene and Tongway (1989), relatively high sodium levels, low total salt content and poor plant protection against splash erosion contribute to the break down of the soil structure (and dispersion of clay particles) and sealing of the surface layer. The higher Na levels associated with the Tribal and Commercial land uses, can hence partially be ascribed to environmental factors, but also hold important consequences for the management strategy. Direct ordinations based on the total soil data set and subsets (based on the different factor groups, as described in Section 6.2.2. A, and further confirmed by Sections 6.2.2 B and C) are presented in Section 6.2.4.

For Mg, differences between the Reserve-Tribal groups were significant ($P < 0.001$), as well as between the Reserve-Commercial groups, though less pronounced for the latter two land uses. The Commercial-Tribal land uses were very similar with regard to Mg concentration (Table 6.3). Differences for the land use-soil stratum two-way crossed factor group were the most pronounced, followed by the land use-openness and then the land use-rangeland condition two-way crossed groups (Table 6.3). The average

Mg concentration was the highest in the Reserve land use (Table 6.4), notably in the subsoil (Table 6.5) of the Reserve open herbaceous sites (Table 6). According to Mills and Fey (2004b), Mg content was higher in thicket than savanna areas in the Eastern Cape, South Africa, whereas Bosch and Van Wyk (1970) and Hagos and Smit (2005) found elevated Mg levels under the canopies of trees in the North West Province. Results from this study showed that Mg contents were better (significantly) associated with soil depth than with woody or open stratums (non-significantly) (Table 6.3). Mg and Ca as well as Mg and silt showed intermediate correlations (Table 1), explaining the congruent patterns for differences especially between the Reserve-Tribal and Commercial-Reserve land uses (Table 6.3). Mg concentration and silt content (percentage) were highest within the Reserve land use, explaining the congruent patterns. According to Nsinamwa *et al.* (2005), Mg and Ca concentrations were found to be higher in areas associated within high herbivore intensities such as near water points, compared to grazing points a distance away. However, for this study results indicated only neglectably small differences between relative “Good” vs. relative “Poor” rangeland conditions sites. However, the purpose of this study was not to measure grazing impacts related to piosphere effects.

Results from this study, based on K concentration, showed small though significant differences between the Commercial-Reserve and Reserve-Tribal land uses averaged across rangeland condition (relative “Good” vs. “Poor”), soil stratum and openness factor groups (Table 6.3). Potassium concentration did not differ significantly between the Commercial-Tribal land uses (Table 6.3). Potassium concentration was highest within the Reserve land use, and comparable within the other two land uses (Table 6.4). Potassium did not reflect a gradient pertaining to soil stratum or rangeland condition, but it did reflect a small though significant gradient pertaining to openness (open vs. woody) (Table 6.3). The Reserve woody stratum had the highest K concentration (Table 6.6). These results are consistent with research by other authors who found K contents to be elevated under canopies of trees (Bosch & Van Wyk 1970; Belsky *et al.* 1989; Hagos & Smit 2005). According to Nsinamwa *et al* (2005), K concentration was higher near water points owing to dung and urine excretions by herbivores, compared to grazing sites further away. The higher concentration of K under the Reserve woody stratum can possibly partially be ascribed to the browsing and grazing behaviour of game within this land use, with only small numbers of free-roaming game (e.g. steenbok and duiker) occurring in the other two land uses. However, K and Mg were found to be intermediately correlated ($r = 0.455$), being the highest within the Reserve land use and explaining congruent patterns. Research by Mapfumo *et al.* (2000) indicated the K concentration differed between the topsoil and deeper soil (30 – 45 cm), ascribing it to soil macroporosity and rooting patterns. This study found no significant differences in K concentration between the top- and subsoil (Table 6.3).

Differences in medium sand particle size, irrespective of openness, rangeland condition or soil stratum, were most pronounced between the Commercial-Tribal and Reserve-Tribal groups, suggesting that the Tribal land use differed significantly from the other two land uses (Table 6.3). Medium sand (% based on particle size) was significantly lower in the Tribal land use opposed to the other two land uses ($P < 0.001$) (Table 6.3 and Table 6.4).

Table 6.6. Descriptive statistics for mean open herbaceous and woody soil concentrations and particle sizes

OPEN	pH	P Bray 1	Conductivity	K	Ca	Mg	Na	NO3-N	Zn	C	Org.mat	Coarse sand	Med sand	Fine sand	Total sand	Silt	Clay
Total: Open																	
Mean	5.16	2.26	8.05	65.25	247.24	84.22	16.60	2.64	0.45	0.14	0.25	3.81	35.37	55.68	94.55	1.40	4.02
Standard Error	0.06	0.27	0.46	2.90	9.54	4.66	0.17	0.23	0.02	0.00	0.01	0.30	0.57	0.50	0.19	0.17	0.17
Minimum	4.10	0.00	3.00	15.00	72.00	6.00	12.00	0.10	0.13	0.04	0.07	0.40	19.40	34.40	78.20	0.00	2.00
Maximum	8.00	24.00	43.00	298.00	706.00	453.00	23.00	25.50	1.90	0.39	0.99	19.80	63.60	66.80	97.20	19.80	11.00
Commercial: Open																	
Mean	5.08	3.54	8.08	58.71	217.75	69.71	16.83	3.83	0.45	0.14	0.24	5.14	39.06	51.18	95.38	1.12	3.49
Standard Error	0.10	0.72	0.88	3.25	13.37	4.18	0.28	0.60	0.04	0.01	0.01	0.75	0.51	0.93	0.38	0.42	0.15
Minimum	4.30	0.00	3.00	31.00	72.00	6.00	14.00	0.60	0.13	0.07	0.12	1.00	30.20	34.40	78.20	0.00	2.00
Maximum	8.00	24.00	43.00	126.00	640.00	140.00	21.00	25.50	1.90	0.39	0.67	19.80	46.20	60.20	97.00	19.80	6.00
Tribal: open																	
Mean	4.92	1.38	6.90	58.02	206.96	65.44	17.56	1.47	0.43	0.14	0.26	3.69	30.45	60.04	93.25	1.21	5.45
Standard Error	0.11	0.14	0.52	6.41	12.50	4.37	0.31	0.10	0.02	0.01	0.02	0.41	1.30	0.62	0.34	0.24	0.37
Minimum	4.10	0.00	3.00	15.00	100.00	27.00	14.00	0.10	0.21	0.04	0.07	0.40	19.40	48.20	87.40	0.00	2.00
Maximum	7.40	5.00	26.00	298.00	518.00	173.00	23.00	3.48	1.20	0.32	0.99	9.40	63.60	66.80	97.20	4.80	11.00
Reserve: Open																	
Mean	5.48	1.85	9.17	79.02	317.00	117.52	15.42	2.63	0.47	0.15	0.25	2.60	36.60	55.81	95.01	1.86	3.13
Standard Error	0.10	0.23	0.89	4.36	18.42	11.23	0.21	0.23	0.03	0.01	0.01	0.11	0.41	0.42	0.17	0.16	0.17
Minimum	4.60	0.00	3.00	35.00	136.00	41.00	12.00	0.57	0.17	0.06	0.11	1.60	31.40	48.60	91.40	0.00	2.00
Maximum	7.40	7.00	42.00	194.00	706.00	453.00	18.00	6.98	1.38	0.26	0.44	5.80	42.40	61.20	96.60	4.60	6.00
WOODY	**pH**	**P Bray 1**	**Conductivity**	**K**	**Ca**	**Mg**	**Na**	**NO3-N**	**Zn**	**C**	**Org.mat**	**Coarse sand**	**Med sand**	**Fine sand**	**Total san**	**Silt**	**Clay**
Total: woody																	
Mean	5.68	2.52	13.90	85.98	385.39	87.37	16.91	4.41	0.50	0.18	0.30	3.90	34.84	55.81	94.55	1.40	4.05
Standard Error	0.08	0.25	0.59	3.12	39.41	3.42	0.21	0.31	0.04	0.01	0.01	0.31	0.54	0.53	0.23	0.17	0.17
Minimum	4.10	0.00	4.00	15.00	108.00	27.00	12.00	0.60	0.13	0.06	0.10	0.80	17.20	32.60	70.40	0.00	2.00
Maximum	8.30	17.00	38.00	265.00	3442.00	263.00	28.00	25.10	4.83	0.40	0.69	23.20	46.70	66.40	97.80	19.60	11.00
Commercial: woody																	
Mean	5.42	3.65	13.74	75.54	289.35	74.20	17.39	5.99	0.53	0.16	0.27	5.52	38.63	51.69	95.84	0.67	3.49
Standard Error	0.09	0.59	0.98	4.34	36.98	4.40	0.44	0.76	0.10	0.01	0.01	0.83	0.55	1.07	0.11	0.15	0.15
Minimum	4.50	1.00	4.00	15.00	114.00	27.00	12.00	0.60	0.13	0.09	0.15	1.00	32.00	32.60	94.20	0.00	2.00
Maximum	7.20	17.00	33.00	153.00	1840.00	173.00	28.00	25.10	4.83	0.31	0.53	23.20	46.70	62.20	97.80	3.20	5.80
Tribal: woody																	
Mean	5.53	1.84	10.72	75.02	434.64	77.80	17.86	2.37	0.41	0.19	0.33	3.64	29.87	59.37	92.88	1.71	5.41
Standard Error	0.15	0.36	0.67	4.31	97.22	4.58	0.30	0.19	0.02	0.01	0.02	0.37	1.07	0.78	0.56	0.44	0.37
Minimum	4.10	0.00	5.00	26.00	108.00	27.00	14.00	0.94	0.24	0.06	0.10	0.80	17.20	40.00	70.40	0.00	2.00
Maximum	8.30	17.00	24.00	173.00	3442.00	168.00	21.00	6.41	0.91	0.40	0.69	9.20	43.40	66.40	97.20	19.60	11.00
Reserve: woody																	
Mean	6.11	2.15	17.35	107.40	426.13	109.96	15.46	5.03	0.55	0.18	0.30	2.61	36.37	56.07	95.06	1.77	3.18
Standard Error	0.12	0.24	1.17	6.06	48.80	7.05	0.27	0.35	0.08	0.01	0.01	0.09	0.46	0.50	0.15	0.17	0.16
Minimum	4.70	0.00	6.00	44.00	194.00	44.00	12.00	0.84	0.22	0.10	0.17	1.00	30.00	49.80	92.00	0.00	2.00
Maximum	8.20	6.00	38.00	265.00	2566.00	263.00	21.00	12.94	3.93	0.36	0.62	4.20	42.80	64.20	96.60	4.80	6.00

Fine sand displayed similar patterns as the medium sand, except that the percentage particles were highest in the Tribal land use, and lowest within the Commercial and Reserve land uses (Tables 6.3 and 6.4). Fine sand was positively correlated with soil organic C (r = 0.24), possibly contributing to the higher C levels within this land use. Differences in the medium and fine sand patterns can primarily be ascribed to inherent environmental factors characteristic of the respective land uses, since there were no significant differences between the soil stratum levels or woody/open areas, indicating that soil erosion did not result in the observed patterns. Research by Hilty *et al.* (2004) found similar soil variability patterns related to the inherent landscape structure. Studies by Zhao *et al.* (2005) found that C levels declined with the loss of fine fraction in soils, while Lobe *et al.* (2001) showed that C associated with clay and silt were three-to six-fold higher than those associated with sand fraction. Results from this study indicate that C was negatively correlated with medium and coarse sand. However, the degrees of correlation between C and silt, clay and fine sand were very similar (Table 1).

There were significant differences ($P < 0.001$) between the Commercial-Reserve and Reserve-Tribal land uses based on the percentage coarse sand, but no significant differences between the Commercial-Tribal land uses (Table 6.3). Hence, the Reserve land use differed significantly from the other two land uses, irrespective of openness, relative rangeland condition or soil stratum. The percentage of coarse sand was lowest within the Reserve land use, and more comparable between the other two land uses (Table 6.4). Such soil variability can be ascribed to inherent landscape structure (Hilty *et al.* 2004).

Conductivity (EC) differed significantly ($P < 0.001$) between the Reserve-Tribal land uses for the two-way crossed land use-openness factor group. Conductivity was highest in the woody stratum. It was highest for the Reserve land use, and lowest for the Tribal land use in this stratum (Table 6.6). Conductivity showed a significant increasing gradient from open to woody samples, irrespective of soil group, land use or rangeland condition (Table 6.3). Conductivity and pH were intermediately correlated (r = 0.597, Table 1), resulting in similar patterns between these two variables. Conductivity and NO_3-N were highly correlated (r = 0.715, Table 6.1), resulting in congruent patterns with regard to an openness/woodiness gradient (Table 6.3), both being highest in the woody stratum (Table 6.6). Conductivity is an indication of the total salt concentration in the soil solution and therefore displays a high correlation with the NO_3-N. Studies by Mapfumo *et al.* (2002) showed that EC increased under heavy compared to medium or light grazing. Results from this study did not indicate any differences between the relative “Good” and “Poor’ rangeland condition groups, with the relative “Poor” sites resembling more overgrazed areas.

Differences ($P < 0.001$) in clay percentage were most pronounced between the Commercial-Tribal and Reserve-Tribal groups, across all openness-, soil stratum and rangeland condition groups (Table 6.3). Hence, these results suggest that inherent environmental differences between land uses primarily resulted in the observed patterns. Clay content was highest in the Tribal land use (Table 6.4). Shainberg (1992) found that higher clay content resulted in increased aggregate stability and infiltration, as opposed to Bloem and Laker (1994) who found that an increase in clay content resulted in decreasing infiltration. Soil crusts form when clay at the surface disperses (e.g. by rainfall impact) and blocks soil pores

(McIntyre 1958; Agassi *et al*. 1981), resulting in crust formation (Greene & Tongway 1989). According to McIntyre (1958), soil crusts of 0.1 mm only can reduce infiltration rates by a factor of as much as 1800, potentially resulting in an overestimation of water intake by the soil. However, biological crusts can either increase or decrease rates of infiltration by affecting soil porosity (Belnap *et al*. 2001), and it is suggested that biological crusts should enjoy further attention within the Molopo rangelands. A loss of soil organic matter has been correlated with a decrease in aggregate stability (Haynes 1997; Dominy and Haynes 2002), and has been found to be important in contributing to soil stability. Hence, a reduction in soil organic matter has been found to be correlated with an increase in clay dispersion, with soil carbon maintaining soil structure (Cooke *et al.* 1992). According to the results from the Draftsman plot for this study, clay and soil organic matter was poorly correlated (Table 6.1). However, this will be investigated more in depth in the remainder of this chapter by using direct RDA ordinations for mean soil concentrations across the total study area (irrespective of spatial variability), as well as for the separate factor groups.

Calcium concentration resulted in significant differences ($P < 0.001$) between the Commercial-Reserve and Reserve-Tribal land uses, with no significant differences between the Commercial-Tribal land uses (Table 6.3). In general, the mean Ca concentration was highest in the Reserve land use, and lowest in the Commercial land use (Table 6.4). However, a gradient related to openness (woodiness) (Table 6.3) showed that the Ca concentration was highest in woody areas. Within the woody areas, the Ca concentration was highest in the Tribal land use (Table 6.6). Belsky *et al*. (1989) found that Ca levels were higher under canopies of trees for Kenya rangelands, than in the open areas, while research by Hagos and Smit (2005) showed for studies conducted near Pomfret in the North West Province, that Ca content was highest near the stem base area of *Acacia mellifera* trees. Calcium and pH are highly correlated ($r = 0.79$, Table 6.1), explaining congruent patterns between these two variables. Ca and conductivity were intermediately correlated ($r = 0.515$, Table 6.1), explaining similar tendencies between these two variables (Table 6.3).

6.2.3 Mean variation for factor groups explained

Variation of mean concentration levels of the soil variables, for land use, openness, soil stratum and rangeland condition (relative “Good” vs. “Poor”) is summarised in Tables 6.4 – 6.6.

6.2.4 Direct Canonical Correspondence Analysis (CCA) for the total soil matrix

The first two axes explained 75.1% of the soil (“species”)-environment relation and 95.8% by the fourth axis. None of the nominal environmental variables (factors) were strongly associated with either of the two axes (Table 6.7). The Woody/Openness ($r = 0.326/-0.326$) variables showed the strongest association with the first axis, followed by the Commercial-Poor ($r = 0.2952$, fourth quadrant) and Commercial ($r = 0.2524$) variables (Table 6.7, Fig. 6.2). The Reserve land use showed the strongest association with the second axis ($r = 0.3175$, second quadrant) (Table 6.7, Fig. 6.2).

Table 6.7. A CCA ordination for the total soil matrix, showing eigenvalues and soil-nominal environmental relations for the first four axes, as well as the nominal environmental variables explaining most of the soil-nominal environmental relation for the first two axes. Variables explaining most of the variance are indicated in **bold**.

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.015	0.007	0.005	0.002
Species-environment correlations	0.472	0.475	0.607	0.271
Cumulative percentage variance				
of species data	9.2	13.8	16.7	17.6
of species-environment relation	50.2	75.1	90.6	95.8
Environmental data	**SPEC AX1**	**SPEC AX2**		
Commercial	**0.2524**	-0.1069		
Tribal	-0.0786	-0.2275		
Reserve	-0.16	**0.3175**		
Poor	0.0359	-0.0735		
Good	-0.0359	0.0735		
Open	**0.326**	0.2261		
Woody	**-0.326**	-0.2261		
Subsoil	-0.0787	0.2545		
Topsoil	0.0787	-0.2545		
Com*Poor	**0.2925**	-0.1362		
Com*Good	0.0419	-0.0063		
Tri*Good	-0.089	-0.1076		
Tri*Poor	-0.0088	-0.1843		
Res*Poor	-0.1917	0.1841		
Res*Good	0.0007	0.2085		

The Monte Carlo permutation test significantly explained the species-environment variance for the first ($F = 28.477$, $P < 0.005$) and all the canonical axes ($F = 9.018$, $P < 0.005$). Nominal environmental variables that significantly explained the species-environment relation, in order of their inclusion in the Monte Carlo test (order of importance), are presented in Table 6.8. Openness (woodiness) was presented as the factor explaining the total data set, most of the species-environment relation, thus displaying the longest gradient between the woody and open components (Table 6.8, Fig. 6.2).

Table 6.8. The nominal environmental variables in order of importance, accounting for most of the total soil –nominal environment variance as indicated by the Monte Carlo permutation test.

Monte Carlo permutation test

Variable	**P**	**F**
Open	0.002	18.17
Com*Poor	0.002	14.9
Tribal	0.002	9.62
Subsoil	0.002	6.29
Commercial	0.008	3.81
Poor	0.02	3.46
Tri*Good	0.04	2.77

Soil variables showing the strongest association with the first axes, were P (eigenvector score = 1.368) and coarse sand (eigenvector score = 1.28) (Appendix 6.1). Both these variables were best associated with the Commercial land use. Environmental variables showing the strongest association with the second axis, were P (eigenvector score = -1.578), C, organic material and coarse sand, all associated with the Commercial land use (Appendix 6.1) (fourth quadrant; Fig. 6.2). Mg (eigenvector score = 0.642), associated with the second axis, was related to the Reserve land use (Appendix 6.1, Fig. 6.2). Ca was best associated with the woody component (Fig. 6.2). High Na levels were indicated to be associated primarily with the Commercial-Poor variable, but subset (factor) levels displaying its association with the land uses, will be presented in Section 6.2.5.

The association of the different soil properties with the respective land uses and associated with the different factors, was discussed above in Section 6.2.2 (Tables 6.1 – 6.6), and applies for the interpretation of this CCA ordination plot. However, gradients pertaining to the different factor groups, indicative of spatial variability, suggested that topsoil and subsoil samples for both the woody as well as the open herbaceous components, need to be analysed separately. Hence, for this study, using mean soil variable concentrations across all the factor groups is not advised.

A key based on the total soil matrix, indicating which soil variables best represent the environmental variables that showed the strongest association for the first and second axes, is given in Appendix 6.1. This key, based on the response of key environmental variables to the predictor (particular factor), is discussed in Section 6.2.6.

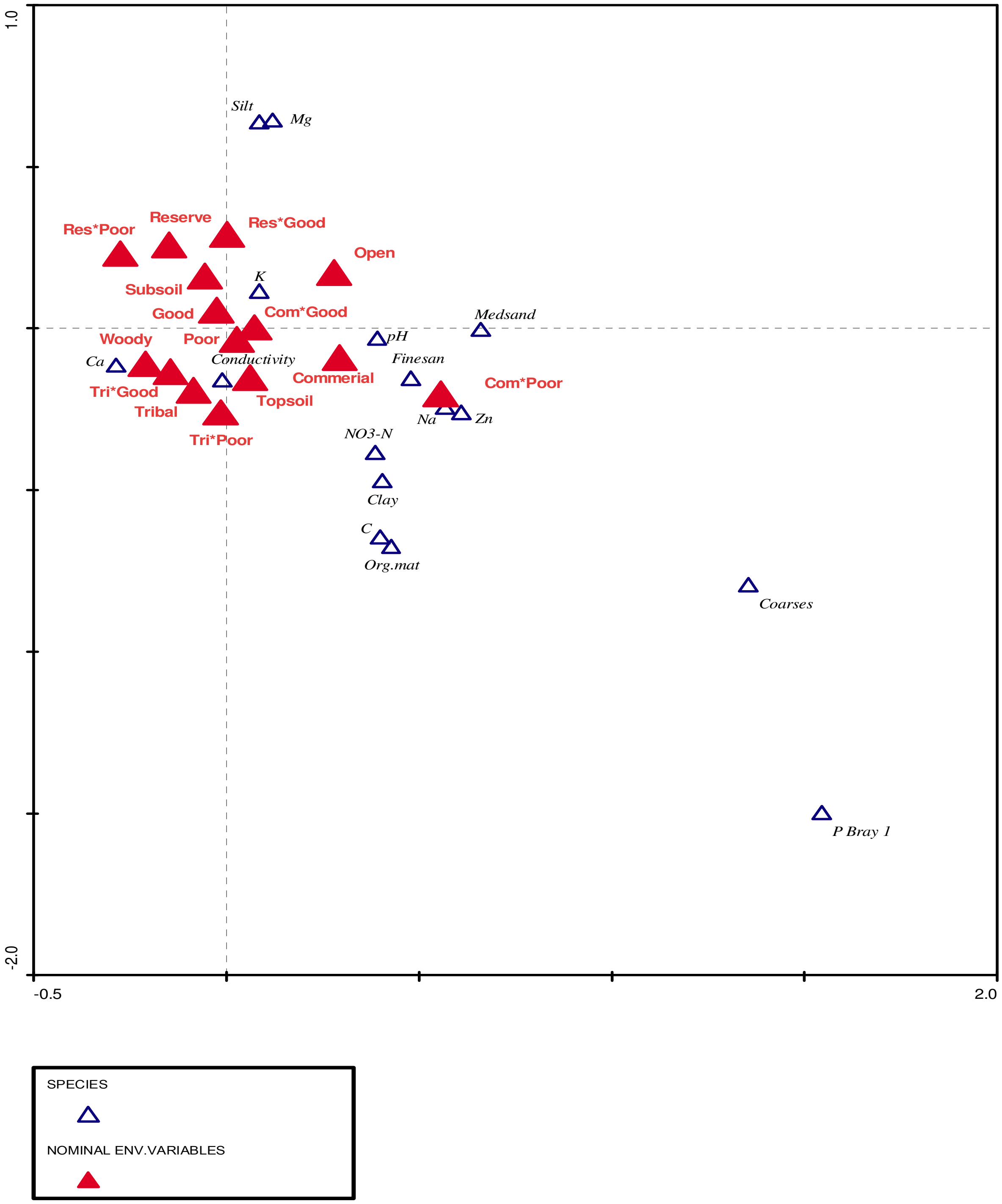


Fig. 6.2. A CCA ordination biplot displaying the soil variables and nominal environmental variables explaining the species-environment variance for the first two axes.

6.2.5 Direct Redundancy analysis (RDA) for the different soil matrices

Direct ordinations employing the three land uses and relative "Good" and "Poor' condition groups, for the topsoil open, subsoil open, topsoil woody and subsoil woody factor groups were conducted and are presented below. Since the data was linear and not unimodal, Redundancy analyses were employed to investigate the soil-environment relations. The direct RDA plots for the different soil subsets were useful in that it accounted for the spatial soil variability pertaining to these different factors. This is essential in order to correctly interpret the observed soil-environment variance explained. The RDA plots are also useful by visually displaying the soil-environment relations, as was described in Sections 6.2.2 (Tables 6.3 – 6.6). The significance of analyses for each subset (hence at a more in depth level) are indicated by means of a Monte Carlo Permutation test. Soil variables most strongly associated with the first two axes and hence the environmental variables associated with these axes, are also presented. Such information is very informative and can be used in a “Key assessment” matrix, as is discussed in Section 6.2.6.

6.2.5.1 Direct Redundancy analysis (RDA) for topsoil open matrix

A direct RDA ordination for the topsoil of the open herbaceous component, explained 80.7% of the soil-environment relation by the second axis and 95.6% of the variance by the fourth axis (Table 6.9). The Monte Carlo permutation test significantly explained the soil-environment by the first (F = 6.814, P < 0.002) and all canonical axes (F = 3.16, P < 0.002).

Environmental variables that best explained the first axis, were Tribal (r = 0.5549) and Reserve (r = -0.5753) land uses, whereas the second axis was best explained by the Commercial land use (r = 0.4975) (Table 6.9).

Table 6.9. A RDA ordination for the topsoil open matrix, showing eigenvalues and soil-nominal environmental relations for the first four axes, as well as the nominal environmental variables explaining most of the soil-nominal environmental relation for the first two axes. Variables explaining most of the variance are indicated in **bold**.

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.094	0.062	0.018	0.011
Species-environment correlations	0.705	0.556	0.408	0.496
Cumulative percentage variance				
of species data	9.4	15.6	17.4	18.5
of species-environment relation	48.4	80.7	90.1	95.6
Environmental data	**SPEC AX1**	**SPEC AX2**		
Commercial	0.0203	**0.4975**		
Tribal	**0.5549**	-0.3263		
Reserve	**-0.5753**	-0.1712		
Good	-0.1461	-0.1839		
Poor	0.1461	0.1839		
Com*Good	-0.118	0.1452		
Com*Poor	0.1437	0.484		
Tri*Poor	0.4907	-0.1476		
Tri*Good	0.2113	-0.2651		
Res*Good	-0.2893	-0.1268		
Res*Poor	-0.4384	-0.0897		

Environmental variables that explained the soil-environment relation, in order of importance as included in the Monte Carlo test, are indicated in Table 6.10. The Tribal and Commercial-Poor variables significantly explained the soil-environment variance (Table 6.10).

Table 6.10. The nominal environmental variables in order of importance, accounting for most of the topsoil open–nominal environment variance as indicated by the Monte Carlo permutation test.

Monte Carlo permutation test		
Variable	**P**	**F**
Tribal	0.002	6.09
Com*Poor	0.002	4.47
Commercial	0.088	1.76
Res*Good	0.172	1.46
Good	0.176	1.43

Soil variables that showed the strongest association with the first axis were Ca (eigenvector score = -0.9356) and Mg (eigenvector score = -0.9213), both being associated with the Reserve land use (Fig. 6.3, Appendix 6.2) and clay (eigenvector score = 0.8504), which was associated with the Tribal land use (Fig. 6.3, Appendix 6.2).

Soil variables showing the strongest association with the second axis were P (eigenvector score = 0.8843), associated with the Commercial land use, and fine textured sand (eigenvector score = -1.0607) which was associated with the Tribal land use (Appendix 6.2, Fig. 6.3).

The rangeland condition gradient (“Good” vs. “Poor) was not very pronounced (Fig. 6.3).

A key based on the topsoil openness soil matrix, indicating which soil variables best represent the environmental variables that showed the strongest association for the first and second axes, is given in Appendix 6.2. See Section 6.2.6 for further discussions.

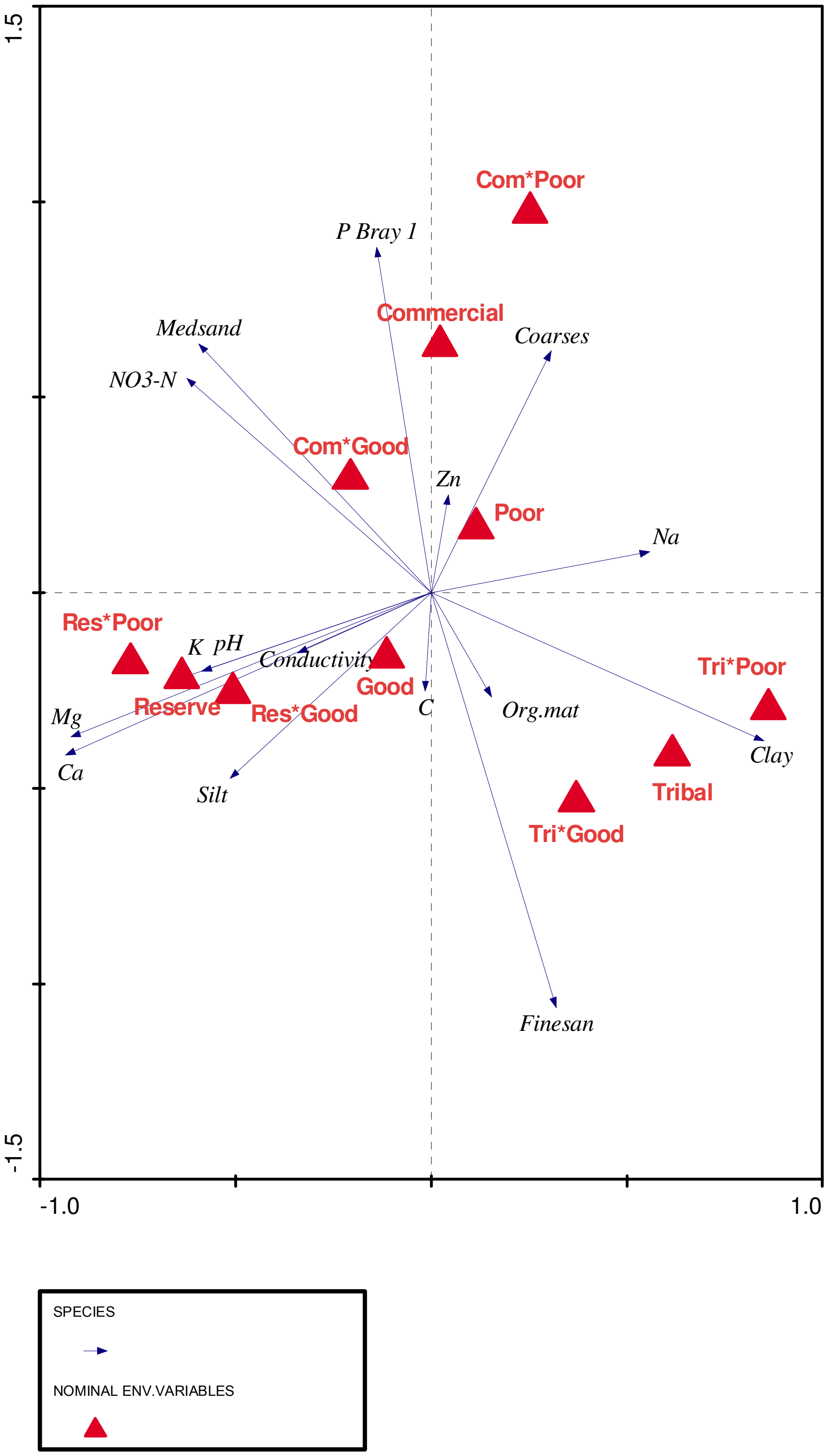


Fig. 6.3. A RDA ordination biplot displaying the soil and nominal environmental variables explaining the species-environment relation for the topsoil open matrix.

6.2.5.2 RDA for subsoil open matrix

The direct RDA ordination for the subsoil open herbaceous stratum, explained 82.6% of the soil-environment relation by the second axis and 97.5% by the fourth axis (Table 6.11). The Monte Carlo permutation test significantly explained the soil-environment relation for the first axes (F = 8.186, P < 0.005) and for all canonical axes (F = 3.531, P < 0.005).

Environmental variables that best explained the first axis was Tribal (r = 0.6876, fourth quadrant) and Reserve (r = -0.5437, third quadrant) land uses (Table 6.11, Fig. 6.4). The second axis was best explained by the Commercial land use (r = 0.5838, second quadrant) (Table 6.11, Fig. 6.4). The relative rangeland condition variables ("Good/Poor") did not show a pronounced gradient (Fig. 6.4).

Table 6.11. A RDA ordination for the subsoil open matrix, showing eigenvalues and soil-nominal environmental relations for the first four axes, as well as the nominal environmental variables explaining most of the soil-nominal environmental relation for the first two axes. Variables explaining most of the variance are indicated in **bold**

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.11	0.064	0.023	0.008
Species-environment correlations	0.744	0.636	0.429	0.388
Cumulative percentage variance				
of species data	11	17.4	19.8	20.6
of species-environment relation	52.3	82.6	93.6	97.5
Environmental data	**SPEC AX1**	**SPEC AX2**		
Commercial	-0.1439	**0.5838**		
Tribal	**0.6876**	-0.2289		
Reserve	**-0.5437**	-0.3549		
Good	-0.0488	-0.1677		
Poor	0.0488	0.1677		
Com*Good	-0.1812	0.1885		
Com*Poor	-0.0009	0.55		
Tri*Poor	0.4851	-0.0935		
Tri*Good	0.3847	-0.196		
Res*Poor	-0.4188	-0.2314		
Res*Good	-0.269	-0.2175		

Environmental that explained, in order of importance, most of the species-environment variance, is summarised in Table 6.12. The Tribal and Commercial land uses significantly explained the soil-environment relations.

Table 6.12. The nominal environmental variables in order of importance, accounting for most of the subsoil open–nominal environment variance as indicated by the Monte Carlo permutation test.

Monte Carlo permutation test		
Variable	**P**	**F**
Tribal	0.002	8.03
Commercial	0.002	4.87
Res*Poor	0.064	1.87
Com*Good	0.112	1.59
Good	0.774	0.64

Soil variables showing the strongest association with the first axis were medium texture sand (eigenvector score = -0.9721) – associated with Commercial and Reserve land uses, and Ca (eigenvector score = -0.7788), associated with the Reserve land use (Appendix 6.3, Fig. 6.4).

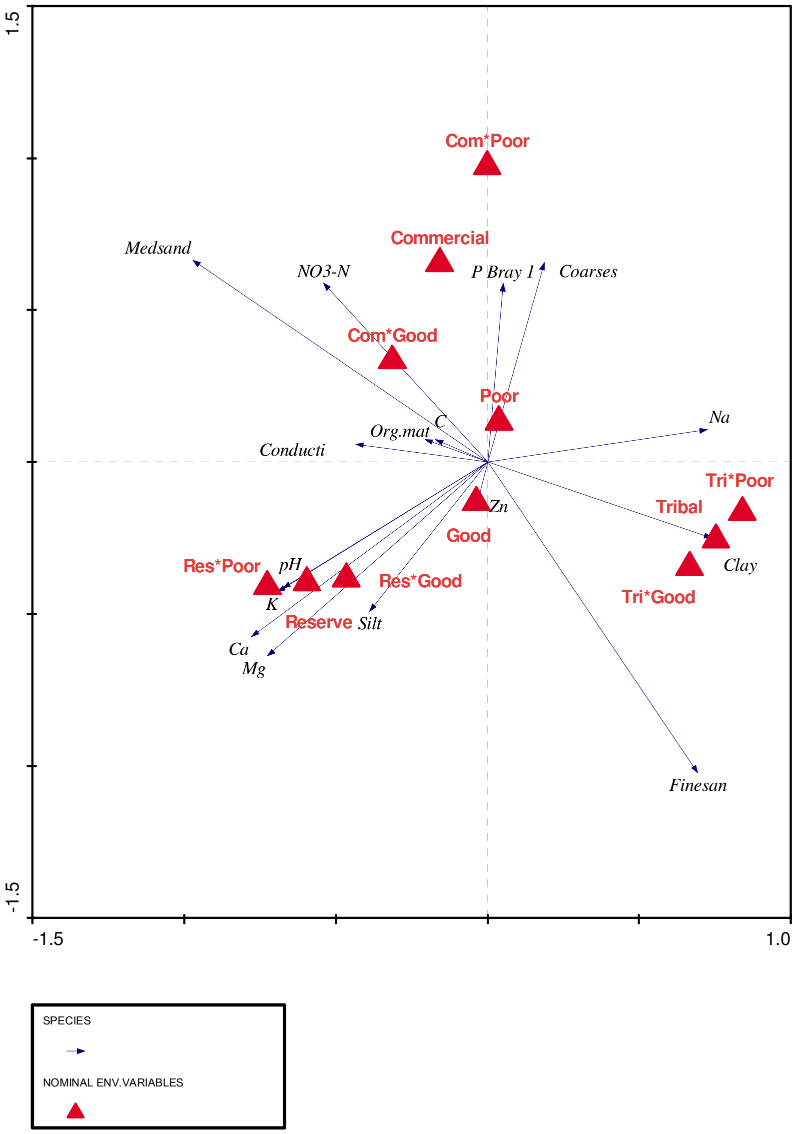


Fig. 6.4. A RDA ordination biplot displaying the soil and nominal environmental variables explaining the species-environment relation for the subsoil open matrix.

The soil variable associated most strongly with the second axis was fine textured sand (eigenvector score = -1.0227) (Appendix 6.3), which was associated with the Tribal land use (Fig. 6.4).

A key based on the subsoil openness soil matrix, indicating which soil variables best represent the environmental variables that showed the strongest association for the first and second axes, is given in Appendix 6.3. This key is addressed is Section 6.2.6.

6.2.5.3 RDA for topsoil woody matrix

The direct RDA ordination for the topsoil woody matrix, explained 85.1% of the soil-environment variance by the second axis and 98.3% by the fourth axis (Table 6.13). The Monte Carlo test showed that the first (F = 7.8, P < 0.005) and all canonical axes (F = 3.036, P < 0.005) significantly explained the soil-environment variance. The first axis was best explained by the Tribal (r = 0.7133, fourth quadrant) and Tribal-Good (r = 0.5293, first quadrant) nominal environmental variables (Table 6.13, Fig. 6.5). The second axis was best explained by the Reserve land use (r = 0.4467, second quadrant) and Reserve-Good variable (r = 0.4004, second quadrant) (Table 6.13, Fig. 6.5). The relative rangeland condition variables (“Good/Poor”) did not show a pronounced gradient (Fig. 6.5).

Table 6.13. A RDA ordination for the topsoil woody matrix, showing eigenvalues and soil-nominal environmental relations for the first four axes, as well as the nominal environmental variables explaining most of the soil-nominal environmental relation for the first two axes. Variables explaining most of the variance are indicated in **bold**

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.106	0.053	0.016	0.009
Species-environment correlations	0.728	0.525	0.402	0.481
Cumulative percentage variance				
of species data	10.6	15.9	17.5	18.4
of species-environment relation	56.5	85.1	93.6	98.3
Environmental data	**SPEC AX1**	**SPEC AX2**		
Commercial	-0.4186	-0.3677		
Tribal	**0.7133**	-0.079		
Reserve	-0.2947	**0.4467**		
Good	0.1154	0.208		
Poor	-0.1154	-0.208		
Com*Good	-0.2042	-0.1848		
Com*Poor	-0.3252	-0.2803		
Tri*Poor	0.3729	-0.1634		
Tri*Good	**0.5293**	0.0634		
Res*Poor	-0.2025	0.1646		
Res*Good	-0.1703	**0.4004**		

Nominal environmental variables that most explained the soil-environment relation, in order of importance as indicated by the Monte Carlo test, are given in Table 6.14. The Tribal and Commercial land uses significantly explained the soil-environment variance (Table 6.14).

Table 6.14. The nominal environmental variables in order of importance, accounting for most of the topsoil woody–nominal environment variance as indicated by the Monte Carlo permutation test.

Monte Carlo permutation test		
Variable	**P**	**F**
Tribal	0.002	8.01
Commercial	0.002	3.67
Good	0.168	1.48
Com*Good	0.228	1.32
Tri*Poor	0.966	0.38

Soil variables that were most strongly associated with the first axis, were medium textured sand (eigenvector score = -1.2044, third quadrant), P (eigenvector score = -0.8721, associated with Commercial land use in third quadrant) and clay (eigenvector score = 0.8124, associated with the Tribal land use in the fourth quadrant) (Appendix 6.4, Fig. 6.5). The second axis was best represented by K (eigenvector score = 0.8016, associated with Reserve land use in second quadrant) and by silt (eigenvector score = 0.7713, associated with the Reserve land use) (Appendix 6.4, Fig. 6.5). A key based on the topsoil woody soil matrix is given in Appendix 6.4, and discussed in Section 6.2.6.

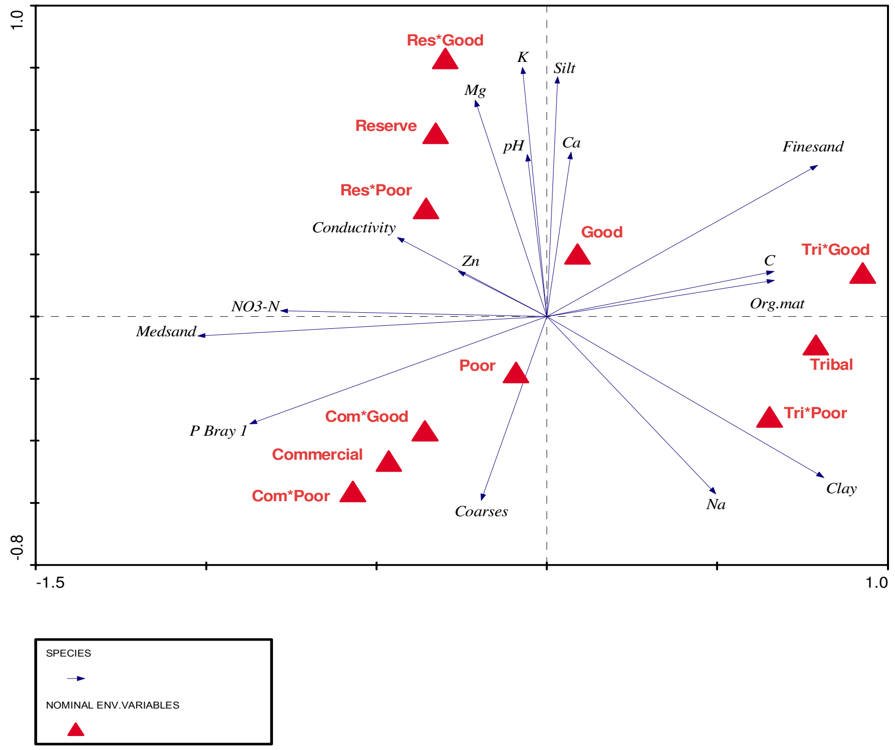


Fig. 6.5. A RDA ordination biplot displaying the soil and nominal environmental variables explaining the species-environment relation for the topsoil woody matrix.

6.2.5.4 RDA for subsoil woody

The Monte Carlo permutation test for the subsoil woody soil matrix, significantly explained the species environment variance for the first (F = 9.719, P < 0.005) and all canonical axes (F = 3.604, P < 0.005). The direct RDA ordination explained 89.5% of the soil-environment relation by the second axis and 96.8% of the soil-environment relation by the fourth axis (Table 6.15).

Nominal environmental variables showing the strongest association for the first axis, were the Tribal (r = 0.6166, fourth quadrant) and Reserve (r = -0.6155, third quadrant) land uses (Table 6.15, Fig. 6.6). The Commercial land use showed the strongest association with the second axis (r = 0.5482, second quadrant) (Table 6.15, Fig. 6.6)

Table 6.15. A RDA ordination for the subsoil woody matrix, showing eigenvalues and soil-nominal environmental relations for the first four axes, as well as the nominal environmental variables explaining most of the soil-nominal environmental relation for the first two axes. Variables explaining most of the variance are indicated in **bold**.

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.128	0.063	0.011	0.005
Species-environment correlations	0.751	0.582	0.403	0.311
Cumulative percentage variance				
of species data	12.8	19.2	20.3	20.8
of species-environment relation	59.9	89.5	94.7	96.8
Environmental data	**SPEC AX1**	**SPEC AX2**		
Commercial	-0.0462	**0.5482**		
Tribal	**0.6616**	-0.2558		
Reserve	**-0.6155**	-0.2924		
Good	-0.1151	-0.158		
Poor	0.1151	0.158		
Com*Good	-0.0352	0.205		
Com*Poor	-0.0232	**0.4885**		
Tri*Poor	0.4845	-0.1134		
Tri*Good	0.3524	-0.2102		
Res*Poor	-0.4715	-0.2068		
Res*Good	-0.307	-0.163		

Nominal environmental variables that explained most of the soil-environment variance, in order of importance, are presented in Table 6.16. The Tribal and Commercial land uses explained most of the soil-environment relation (Table 6.16).

Table 6.16. The nominal environmental variables in order of importance, accounting for most of the subsoil woody–nominal environment variance as indicated by the Monte Carlo permutation test.

Monte Carlo permutation test		
Variable	**P**	**F**
Tribal	0.002	8.84
Commercial	0.002	5.87
Com*Good	0.256	1.28
Good	0.392	1.03
Tri*Poor	0.916	0.47

Soil variables most strongly associated with the first axis were conductivity (eigenvector score = -0.9716, associated with Reserve land use) and NO_3-N (eigenvector score = -0.8936, associated with Commercial and Reserve land uses) (Appendix 6.5, Fig. 6.6). Fine textured sand (eigenvector score = -0.9269, associated with the Tribal land use) and medium textured sand (eigenvector score = 0.7161, associated with Commercial and Reserve land uses), best represented the second axis.

A key based on the subsoil woody soil matrix is given in Appendix 6.5, and is discussed in Section 6.2.6.

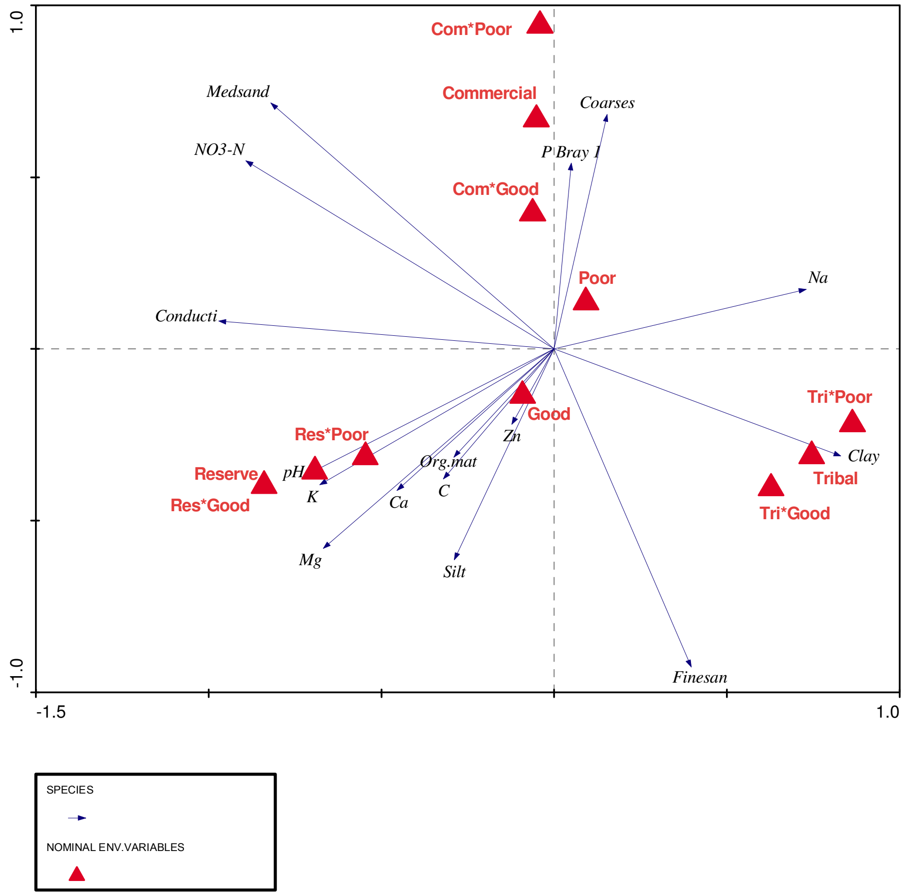


Fig. 6.6. A RDA ordination biplot displaying the soil and nominal environmental variables explaining the species-environment relation for the subsoil woody factors.

6.2.6 Cumulative variance and eigenvector scores for first two axes for matrices

Cumulative variances and eigenvector scores explained by the soil variables for the first two axes, for the matrices discussed in Sections 6.2.4 – 6.2.5, are presented in Appendices 6.1 – 6.5. Keys (incorporated into the final rangeland condition “Key assessment matrix” presented in Chapter 9) based on the eigenvector scores of the soil variables for the respective matrices, were compiled as adaptive and explanatory management measures for the environmental variables most strongly associated with the first two axes (see Appendices 6.1 – 6.5, and Chapter 9). The relative position of soil variables along the first and second axes of the CCA and RDA ordinations were indexed by rescaling the eigenvector scores of the variables to a scale of 0 to 10, with 0 representing the score of that soil variable located first and 10 the position of the last soil variable on the gradient (refer to Chapter 3) (after Hurt & Hardy 1989; Lawes *et al.* 2005). These scores can be used to calculate soil-weighted total scores for the different factor groups for comparative and monitoring purposes.

6.2.7 Summary pertaining to the factor groups

Based on the discussions above, soil variables associated with the different factors groups are summarised in Table 6.17. This summary should be applied (read) in conjunction with the “Key assessment matrices” pertaining to the different factors, as presented in Appendices 6.1 – 6.5.

Table 6.17. Summary of the soil variables associated with the different factors groups.

Soil variables	Land use (only if not explained by other factors)	Rangeland condition	Soil stratum	Openness/ Woodiness	Mostly inherent environment
Zn	■				
Silt		much lesser extent			■
pH			much lesser extent	■	
P		much lesser extent	■		
Soil organic carbon/organic material			■	lesser extent	
NO_3-N		much lesser extent	much lesser extent	■	
Na					■
Mg		much lesser extent	secondary extent		■
Medium sand					■
Fine sand					■
Coarse sand					■
K				■	
Conductivity				■	
Clay		much lesser extent	much lesser extent		■
Ca				lesser extent	■

6.3. CONCLUSION AND RECOMMENDATIONS

Soil quality is increasingly recognised as an important indicator of environmental quality and sustainable land management (Herrick 2000). The resilience and resistance of many rangelands need to consider vegetation together with soil (Herrick & Whitford 1995). Several studies have indicated that restoration is not possible with a loss of topsoil and changes in nutrient status and infiltration (Roux & Opperman 1986, Roux & Theron 1987, Tongway 1994). Such transitions are not always reversible (Westoby *et al.* 1989, Friedel 1991). According to Yong-Zhong (2005), soil restoration is a slow process although the vegetation can recover more rapidly after the removal of livestock.

This chapter attempted to establish whether differences based on soil parameters existed between land uses. This was done by employing different factors and combinations of factor groups. Significant differences existed between the land uses, being most pronounced between the Reserve-Tribal land uses (Table 6.2 and Table 6.3). Soil gradients with regard to soil stratum and openness were evident (Table 6.2, Table 6.3 and Table 6.17). Soil variables did not pronouncedly reflect a gradient based on relative rangeland condition (Table 6.2, Table 6.3 and Table 6.17). Thus, monitoring soil parameters provided to be informative in explaining the soil-environmental variance existing within the Molopo study area.

Two-way crossed ANOSIM tests, based on the combination of the four factors listed in the Introduction above (Section 6.1), were done for each soil variable in order to explain differences within land uses, between openness groups and between soil stratums (summarised in Table 6.17). These analyses made it possible to distinguish between primarily inherent environmental differences via differences induced by the land uses, as was reflected by the different factors groups and/or combinations thereof.

Soil particle size was different between the land uses with regard to the soil similarities. Coarse and medium sand percentages were highest in the Commercial/Reserve land uses, and lowest in the Tribal land use, whereas clay and fine sand percentage were highest in the Tribal land use. Silt content was highest in the Reserve land use (Table 6.4). It is suggested that these soil variables and differences pertaining to soil particle size, are primarily inherent environmental variables. Hence, differences were not the result of different land use practices. These variables did not pronouncedly reflect any soil stratum, rangeland condition or openness gradient. Sodium, silt, clay, fine, medium and coarse sand primarily displayed inherent environmental spatial variability, resulting in differences between the land uses based on these soil variables (Table 6.17).

The NO_3-N content differed significantly between the three land uses, being highest in the Commercial land use, while also being associated with the woody component. Hence, it is suggested that these differences, as reflected by the land uses and openness factor groups for NO_3-N, are possibly primarily the result of the vegetation habitat being modified by the different land uses. This can possibly be ascribed to (i) N fixation by legume trees (ii) more bio-circulation of woody plants compared to grass and

(iii) indirect bio-circulation by animals resting under the shade of the woody component. Calcium also showed a significant, though not very pronounced, association with the woody soil stratum component (Table 6.17). Conductivity, and to a lesser extent NO_3-N (these two variables were correlated), K and pH showed a gradient with regard to openness/woodiness (Table 6.3 and Table 6.4), all being highest within the woody component of each land use. Hence, it is suggested that different land use practices primarily resulted in differences between these soil variables within the three land uses.

The following soil variables significantly reflected the existence of a soil stratum gradient (topsoil vs. subsoil) across all land uses (with no major differences between the three land uses): soil organic carbon and hence organic material, P and to a lesser extent Mg (Table 6.17). This suggests that different soil stratum depths across all land uses were more informative with regard to these soil variables (especially P and C), with different land use impacts being of secondary importance.

The CCA ordination employed all four the factor groups and combinations thereof. Both the first and all canonical axes significantly explained the soil-environment variance. This suggests that these factors and factor-groups sufficiently explained the soil-environmental relations (nominal environmental variables).

The one-way and two-way crossed ANOSIM tests, as well as the Monte Carlo permutation test, indicated significant gradients with regard to soil stratum (topsoil vs. subsoil) and openness (woodiness), as well as differences caused by land use type (Table 6.8). These results suggested that it is important to account for the soil spatial variability in the Molopo rangelands, as was discussed in Section 6.2 above. Hence, it is essential to reflect on soil stratum, openness and land use when conducting surveys within these semi-arid rangelands.

Soil parameters did not act as good indicators of relative rangeland condition for these semi-arid rangelands area. However, it should be cautioned that piosphere studies might actually reflect a degradation gradient pertaining to these key resources, also called “sacrifice areas” (Perkins & Thomas 1993a, b). However, this was not the focus point of this study, and this study will not enter into a discussion regarding this aspect.

Based on the results, indicating that land use, soil stratum and openness resulted in different soil-environmental patterns, the soil matrix was subdivided into four matrices, namely topsoil open, topsoil woody, subsoil open and subsoil woody. Direct RDA ordinations significantly explained the soil-environment relations, suggesting that the correct environmental parameters (nominal) were selected to explain the observed soil-environment relations.

The significance of the RDA ordinations (as indicated by the Monte Carlo permutations) suggested the appropriateness of employing the cumulative variance and eigenvector score lengths of the first two axes for the soil variables, in “Key assessment matrices” to assist in explaining soil-environmental relations (Appendices 6.1 – 6.5). The methodology of this procedure is discussed in Chapter 3.

Although the geology of the study area is described to be relatively homogeneous, belonging to the same landtype, significant spatial differences pertaining to the soil stratum (topsoil vs. subsoil) and openness (open vs. woody) gradients, served as directive to subdivide the larger soil matrix into four smaller matrices pertaining to these factors. Inherent environmental differences between land uses related to soil particle content and sodium, occurred across these two factors. These differences were significant, though not very pronounced ($r < 0.35$), suggesting the relative uniformity of the inherent geology of the study area, while also acknowledging site specific heterogeneity.

For data analysis purposes, the most appropriate matrix to reflect the vegetation/ant-soil relations was subjectively selected. This study employed the topsoil open matrix as environmental matrix to be ordinated with the herbaceous composition (open areas) (Chapter 7) and ant matrix (Chapter 8). The subsoil woody matrix was employed for direct ordination with the woody component (Chapter 5). Past studies have also indicated that canopy-soil relations may enhance woody plant competitive dominance (Berkley *et al.* 2005). These authors have found associations between cyanobacterial soil crusts and subcanopies of shrubs in Kalahari rangelands of Botswana. Such biological soil crusts can provide additional nutrients to the plants associated with the crusts (Berkley *et al.* 2005). The rationale behind the selection of the topsoil open matrix for integration with the herbaceous layer (Chapter 7) was because of the relatively shallow root system of the herbaceous component, whereas the more extensive root system of the woody component is more associated with the subsoil, woody stratum (Chapter 7). Grasses are often more efficient than trees at extracting water from the topsoil, but in the subsoil the woody vegetation has nearly exclusive use of water that gets through (Walker *et al.* 1981). According to these authors, the effects of changes in the amounts of topsoil and subsoil water can be attributed by changes in grass or woody biomass, and hence infiltration rate. Both topsoil and subsoil open soil matrices were ordinated with the ant data, but did not result in major differences for the ant-soil relationships. Seed harvesting ants select unvegetated patches for their nests (Hölldobler & Wilson 1990). Hence, ant communities are often structured by herbaceous seed resources, which is why the topsoil open matrix was selected to be ordinated with the ant data. This study acknowledges that ants play an integral role in some soil processes, which may include the subsoil component.

This chapter did not attempt to discuss the physical, chemical and physiological processes related to the soil parameters. It rather attempted to provide criteria for selecting the most appropriate measures when incorporating the soil parameters as additive data in the multivariate analyses with the vegetation (Chapter 7), ant (Chapter 8) and nominal environmental data (this Chapter). However, the study acknowledges that further investigations of the complex interrelationships between bush canopies, soil biochemical characteristics and herbaceous vegetation structures need to be researched to better understand ecological changes and degradation processes in the Molopo rangelands. Findings with regard to the vegetation-soil properties interrelationships are presented in Chapter 7. The integration of ant and soil data is presented in Chapter 8.

“Key assessment matrices” based on different factors, were presented within this chapter for comparative and monitoring purposes.

CHAPTER 7

Integrated vegetation and soil components

7.1. INTRODUCTION

The purpose of Chapter 7 is to investigate and present multivariate integrated patterns between the woody, herbaceous, soil and nominal environmental variables (land use and rangeland condition group). Hence, this chapter will attempt to establish whether land use type and rangeland condition, as reflected by the relative "Good" and "Poor" rangeland condition extremes, are primary or secondary determinants of the integrated species-environment relations. Chapter 7 also seeks to establish whether the multivariate patterns pertaining to the woody, soil and herbaceous components, reflect a rangeland condition/degradation gradient across and within land uses as a result of the different land use practices. Thus, these analyses are complementary, explanatory and in addition to those discussed in Chapters 4, 5 and 6. Chapter 7 will not pursue hypotheses pertaining the herbaceous composition, woody and soil components already discussed, but will rather attempt to confirm and verify the results already presented.

In order to investigate these patterns, the primary soil and woody variables explaining the herbaceous species component were identified and incorporated into the integrated multivariate analysis to establish which variables primarily and which secondarily explained the species-environment variance. The same procedure was followed for the woody component, in that the key herbaceous species and soil variables significantly explaining the species-environment relation, were identified and incorporated into multivariate and partial CCA ordinations.

Chapter 7 will attempt to answer the following key questions. Is land use a primary or secondary determinant of the woody, herbaceous and soil multivariate patterns? Do the multivariate analyses reflect a rangeland condition/degradation gradient as result of different land use impacts? Are species richness and diversity associated with any of the land uses, and do these diversity indices reflect a rangeland condition/degradation gradient? Do these multivariate analyses provide key variables for rangeland monitoring purposes?

This chapter will finally propose variables that can be incorporated into a final rangeland monitoring "Key assessment matrix", presented in Chapter 9 (Concluding Remarks).

7.2. OVERVIEW OF RESULTS AND DISCUSSION

The procedures pertaining to the different analyses packages used, are discussed in Chapter 3 (Material and Methods). Results and in-depth discussions with regard to the herbaceous, woody and soil components, were presented in Chapters 4, 5 and Chapter 6 respectively, and will not be repeated.

Thus, these chapters should be consulted for explanatory purposes for the results presented in Chapter 7. The Results and the discussion will be presented under the same headings due to the complexity of the data, and as motivated in the brackets next to each heading.

7.3. RESULTS AND DISCUSSION - HERBACEOUS SPECIES COMPONENT

7.3.1 Herbaceous species composition and soil environmental variables (direct CCA ordination, Monte Carlo test and BVSTEP test)

7.3.2 Herbaceous species composition and woody environmental variables (direct CCA ordination, Monte Carlo test and BVSTEP test)

7.3.3 Integrated herbaceous species composition and environmental variables (direct CCA ordination, Monte Carlo test and BVSTEP test)

7.3.4 Partial CCA ordination (direct partial CCA ordination, Monte Carlo test)

7.4. RESULTS AND DISCUSSION - WOODY COMPONENT

7.4.1 Woody species composition and soil environmental variables (direct CCA ordination, Monte Carlo test and BVSTEP test)

7.4.2 Woody species composition and herbaceous species composition (direct CCA ordination, Monte Carlo test and BVSTEP test)

7.4.3 Integrated woody species composition and environmental variables (direct CCA ordination, Monte Carlo test and BVSTEP test)

7.4.4 Partial CCA ordination (direct partial CCA ordination, Monte Carlo test)

7.3. RESULTS AND DISCUSSION - HERBACEOUS SPECIES COMPONENT

Due to the congruent patterns between the “annual” and “perennial” interpretation methods, as was established and discussed in Chapter 4, multivariate patterns pertaining to the “annual” interpretation only, which include all herbaceous life-forms, will be presented in Section 7.3.

7.3.1 Herbaceous species composition and soil environmental variables

Key soil variables contributing to the species-environment relation were identified by means of a direct CCA ordination (significance evaluated by the Monte Carlo permutation test) for the herbaceous composition unimodal data, and by means of a BVSTEP test. A Monte Carlo test expresses how strongly the species data respond to the environmental data. The Monte Carlo permutation test is thus a test of statistical significance obtained by repeatedly permuting the samples. The test also calculates the significance level (P-value) (Ter Braak & Šmilauer 1998). The BVSTEP procedure is a stepwise search that optimises the correlation between elements of the underlying biotic-biotic/abiotic similarity matrices (Clarke & Warkwick 2001). The topsoil open component was employed in this analysis, as was motivated in Chapter 6 (Section 6.4, Conclusion).

The Monte Carlo permutation test significantly explained the species-environment variance by the first axis (F = 6.793, $P < 0.05$) and all canonical axes (F = 2.118, $P < 0.005$). The second axis of the CCA ordination explained 49.5% of the species-environment variance and the fourth axis explained 74% of the species-environment relation (Table 7.1). For the species-passive data relation, the second axis explained 39.8% of the species-environment relation and 62% by the fourth canonical axis (Table 7.1). Thus, the Monte Carlo test indicated that a significant relation existed between the herbaceous and soil components.

Table 7.1. A CCA ordination for the "annual" herbaceous composition showing the eigenvalues, cumulative species data and species-soil (environment) variance for the first four axes.

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.338	0.242	0.169	0.118
Species-environment correlations	0.821	0.827	0.646	0.686
Cumulative percentage variance				
of species data	11	18.9	24.4	28.2
of species-environment relation (environmental)	28.8	49.5	64	74
of species-environment relation (passive data)	28	39.8	54.4	62

Soil variables that significantly explained the species-environment relation, were included in order of importance in the Monte Carlo permutation test (forward selection), and are presented in Table 7.2. These soil variables were fine and coarse sand, K, Ca, clay and silt (Table 7.2). These (significant) soil variables were selected and incorporated together with other multivariate environmental data (Section 7.3.2) into the integrated matrix discussed in Section 7.3.3, in order to establish which environmental variables primarily and which variables secondary contributed to explaining the herbaceous species-environment variance. A BVSTEP test, complementary and in addition to the CCA Monte Carlo test, was done to establish which key soil variables explained the herbaceous composition-environment variance (Table 7.2). The soil variables indicated by the BVSTEP test ($\rho = 0.36$, rho > 0.95), in addition to those indicated by the Monte Carlo test, were incorporated into the multivariate integrated analyses (Section 3.3). The soil variables indicated as significantly contributing to explaining the species-environment, showed a large degree of overlap between the two methods, which is encouraging. However, variables being indicated as important by either the BVSTEP analysis or the Monte Carlo test and which did not overlap, were also included in the multivariate integrated analyses. Results are presented and discussed in Sections 7.3.3 and 7.3.4. Results from the soil analyses discussed in Chapter 6, indicated that the fine sand, coarse sand and clay variables (and to a lesser extent Ca content) were mainly inherent environmental factors, whereas differences in K and Ca content between land uses were the results of different land use practices "modifying" the soil component. However, tendencies will be pursued further in Section 7.3.3.

Table 7.2. The soil variables that explained the herbaceous species-environment relation in order of importance as indicated by the Monte Carlo permutation test, and those indicated by the BVSTEP test.

Monte Carlo permutation test			
Variable	**P**	**F**	**BVSTEP test**
Fine sand	**0.002**	**5.18**	**P Bray 1**
Coarse sand	**0.002**	**5.38**	**K**
K	**0.028**	**2.49**	**Ca**
Ca	**0.01**	**2.38**	**Na**
Clay	**0.014**	**2.12**	**Organic material**
Silt	**0.01**	**2.64**	**Coarse sand**
Mg	0.074	1.72	**Med sand**
Zn	0.124	1.52	
C	0.126	1.45	
Na	0.268	1.18	
Med sand	0.278	1.11	
Conductivity	0.324	1.02	
NO3-N	0.16	1.42	
P Bray 1	0.442	1	
Organic material	0.442	0.77	
pH	0.888	0.46	

(i) Key variables are indicated in **bold**, with $P < 0.05$ (Monte Carlo test) and Rho > 0.95 (BVSTEP test)

7.3.2 Herbaceous species composition and woody environmental variables

The Monte Carlo permutation test from the CCA ordination significantly explained the species-environment relation by the first axis ($F = 7.555$, $P < 0.002$) and all the canonical axes ($F = 1.66$, $P < 0.005$). The second axis explained 46.7% of the species-environment relation and 68% by the fourth axis (Table 7.3). For the passive data, the second axis explained 54.2% of the species-environment relation and 79.7% by the fourth axis (Table 7.3).

Table 7.3. A CCA ordination for the “annual” herbaceous composition showing the eigenvalues, cumulative species data and species-woody (environment) variance for the first four axes.

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.418	0.26	0.177	0.131
Species-environment correlations	0.903	0.758	0.72	0.698
Cumulative percentage variance				
of species data	13.6	22.1	27.8	32.1
of species-environment relation (environmental)	28.8	46.7	59	68
of species-environment relation (passive data)	28.3	54.2	65.9	70.7

The woody variables that significantly explained the species-environment relation, as included in order of importance in the forward selection by the Monte Carlo permutation test, are given in Table 7.4. The woody species that significantly contributed towards explaining the species-environment relation were: *Gymnosporia buxifolia*, *Boscia albitrunca*, *Terminalia sericea*, *Grewia flavescens*, *Acacia mellifera*, and *Mundulea sericea* (Table 7.4).

The BVSTEP test (ρ = 0.393, rho > 0.95) indicated the same woody species as above, and in addition *Diospyros lycoides*, to be included in the multivariate analysis (Section 7.3.3).

Tendencies pertaining to these woody species are discussed in the integrated multivariate analyses in Section 7.3.3.

Table 7.4. The woody variables that explained the herbaceous species-environment relation in order of importance as indicated by the Monte Carlo permutation test, and those indicated by the BVSTEP test.

Monte Carlo permutation test			
Variable	**P**	**F**	**BVSTEP test**
Gym bux	**0.002**	**5.67**	***Ac lue***
Bos alb	**0.02**	**4.54**	***Ac mel***
Ter ser	**0.01**	**4.27**	***Bos alb***
Gre flsc	**0.026**	**3.22**	***Dio lyc***
Mun ser	**0.03**	**2.68**	***Gre flsc***
Ac mel	**0.006**	**2.7**	***Gym bux***
Ac lue	**0.07**	**2.11**	***Mun ser***
Dio lyc	0.104	1.83	***Ter ser***
Ac rob	0.06	1.79	
Rhu cil	0.154	1.41	
Ac kar	0.312	1.11	
Ehr rig	0.278	1.13	
Cadaba	0.176	1.47	
Ziz muc	0.424	0.95	
Ac hae	0.376	0.93	
Prot sul	0.374	0.95	
Rhi bre	0.56	0.81	
Tar cam	0.628	0.76	
Ac heb	0.56	0.74	
Lyc hir	0.784	0.58	
Ac eri	0.774	0.67	
Dic cin	0.89	0.44	
Ac tor	0.928	0.34	

(i) Key variables are indicated in **bold**, with $P < 0.05$ (Monte Carlo test) and Rho > 0.95 (BVSTEP test)

(ii) "Marginal" variables are indicated in **bold** and underlined (Monte Carlo test)

7.3.3 Integrated herbaceous species composition and environmental variables

The key soil variables (Section 7.3.1) and woody species (Section 7.3.2) were incorporated/integrated together with the nominal land use variables and "Good" and "Poor" rangeland condition variables (Chapter 4) into the multivariate CCA ordination and the BVSTEP test. This was done in order to identify whether land use was a primary or secondary determinant of the herbaceous species-environment patterns. Cumulative variances and eigenvector scores explained by the herbaceous species for the first two axes, are presented in Appendix 7.1. A key for rangeland monitoring, presented in the "Key assessment matrix" (Chapter 9, Concluding remarks), was compiled as adaptive and explanatory management procedure for the environmental variables that were most strongly associated with the first two axes. The relative position of herbaceous species along the first and second axes of the CCA ordination was indexed by rescaling the eigenvector scores of the variables to a scale of 0 to 10, with 0 representing the score of that herbaceous species located first and 10 the position of the last herbaceous species on the gradient (refer to Chapter 3 with regard to the rescaling) (after Hurt & Hardy 1989; Lawes *et al.* 2005). These scores can be used to calculate environmental-weighted total scores for comparative and monitoring purposes.

The Monte Carlo permutation test significantly explained the species-environment relation for the first axis (F = 8.713, P < 0.005) and all the canonical axes (F = 2.917, P < 0.005). The second canonical axis explained 46% of the species-environment and 69.2% by the fourth axis (Table 7.5). For the passive data, the second axis explained 57.1% of the species-environment relation, and the fourth axis explained 70% (Table 7.5).

Table 7.5. A CCA ordination for the "annual" herbaceous composition showing the eigenvalues, cumulative species data and species-soil/woody (environment) variance for the first four axes

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.472	0.351	0.256	0.161
Species-environment correlations	0.956	0.874	0.858	0.768
Cumulative percentage variance				
of species data	15.4	26.8	35.1	40.3
of species-environment relation (environmental)	26.4	46	60.2	69.2
of species-environment relation (passive data)	28.7	57.1	64.5	70

The first canonical axis was best represented by the Tribal variable (r = 0.8542, first quadrant), followed by *Gymnosporia buxifolia* (r = 0.6208, fourth quadrant) and *Terminalia sericea* (r = 0.594, fourth quadrant) (Table 7.6, Fig. 7.1). The second canonical axis was best associated with the "Good" (r = -0.6738, third quadrant) and "Poor" (r = 0.6738, first quadrant) rangeland condition environmental variables (Table 7.6, Fig. 7.1).

Table 7.6. CCA correlation coefficients (r-values) for the environmental (soil and woody) and passive variables associated with the first two CCA axes for the "annual" herbaceous composition, with the variables showing the highest r-values indicated in **bold**.

Environmental data	SPEC AX1	SPEC AX2	Passive data	SPEC AX1	SPEC AX2
P Bray 1	-0.2032	0.3815	BE/HA	0.362	**0.4342**
K	-0.0829	-0.1897	Bushcov	0.3849	**0.4618**
Ca	-0.2612	0.0682	Bush num/ha	0.4868	0.3288
Na	0.1201	-0.0245	VCSAGRAZ	0.0918	-0.8386
Organic material	0.2621	-0.0664	VCSPGRAZ	0.0713	-0.8372
Coarse sand	0.0496	0.2343	DM/HA	0.2335	-0.4275
Med sand	-0.4949	0.1156	VCSAECOL	0.0769	-0.856
Fine sand	0.4842	-0.2687	VCSPECOL	0.0394	-0.8631
Silt	0.0861	-0.2216	ANNrich	**0.8115**	-0.0135
Clay	0.4947	-0.0187	ANNeve	0.2212	0.0018
Ac lue	-0.2612	0.2051	ANNdiv	0.6101	0.0012
Ac mel	-0.1939	0.3907	Bsh.div	0.3223	0.0619
Bos alb	-0.3025	0.3418			
Dio lyc	0.2868	-0.0247			
Gre flsc	0.0737	0.3062			
Gym bux	**0.6208**	-0.0868			
Mun ser	0.2648	0.0464			
Ter ser	**0.594**	-0.0608			
Commercial	-0.411	0.051			
Tribal	**0.8542**	0.0187			
Reserve	-0.4351	-0.0689			
Good	-0.0752	**-0.6738**			
Poor	0.0752	**0.6738**			
Com*Good	-0.3609	-0.3883			
Com*Poor	-0.1629	0.44			
Tri*Poor	0.5121	0.1485			
Tri*Good	0.572	-0.1218			
Res*Good	-0.3146	-0.3956			
Res*Poor	-0.2328	0.3098			

The environmental variables that best explained the species-environment relation, as indicated by the forward selection in the Monte Carlo permutation test, in order of importance and significance, are presented in Table 7.7. The Tribal land use, followed by the "Good/Poor" rangeland condition variables, coarse sand, *Boscia albitrunca*, fine sand, silt, the Tribal-Poor/-Good rangeland groups, *Gymnosporia buxifolia*, Ca and clay were the variables that significantly explained the species-environment variance (Table 7.7). The BVSTEP test (ρ = 0.532, rho > 0.95) showed that the following variables mainly accounted for the species-environment relation: the Tribal land use and the "Good" rangeland condition variable, coarse sand, *Grewia flavescens* and P. These results suggest that land use (especially the Tribal land use), as well as the rangeland degradation gradient (as represented by the “Good” and “Poor” rangeland condition groups), are the primary determinants of herbaceous species composition, whereas the woody composition is a secondary determinant of the herbaceous species composition, with both the herbaceous and woody components being modified by the disturbances associated with the different land use types (refer to Chapters 4 and 5 respectively). Coarse sand is mainly an inherent environmental variable, whereas P can be modified by land use type, especially with regard to the topsoil stratum (see Chapter 6, Table 6.3 and Table 6.17). Hence, from the results discussed in Chapter 6, as well as the results from the Monte Carlo permutation test, P is considered as a secondary determinant of herbaceous species composition, being modified primarily by the land use type.

Table 7.7. The soil and woody variables that explained the herbaceous species-environment relation in order of importance as indicated by the Monte Carlo permutation test, and those indicated by the BVSTEP test.

Monte Carlo permutation test			
Variable	**P**	**F**	**BVSTEP test**
Tribal	**0.002**	**10.16**	**P Bray 1**
Good /Poor	**0.002**	**6.33**	**Coarse sand**
Coarse sand	**0.002**	**5.02**	***Gre flsc***
Bos alb	**0.022**	**2.92**	**Tribal**
Fine sand	**0.002**	**2.75**	**Good**
Silt	**0.002**	**2.57**	
Tri*Poor/*Poor	**0.002**	**2.75**	
Gym bux	**0.048**	**2.28**	
Ca	**0.008**	**2.42**	
Clay	**0.026**	**2.07**	
Ac lue	0.1	1.73	
Com*Good/*Poor	0.05	1.78	
Mun ser	0.074	1.75	
Na	0.088	1.67	
Organic material	0.08	1.6	
Med sand	0.128	1.4	
Ter ser	0.172	1.38	
P Bray 1	0.254	1.23	
Dio lyc	0.234	1.12	
Gre flsc	0.26	1.14	
Commercial	0.542	0.9	
Ac mel	0.654	0.75	
K	0.776	0.67	

(i) Key variables are indicated in **bold**, with P < 0.05 (Monte Carlo test) and Rho > 0.95 (BVSTEP test)

(ii) “Marginal" variables are indicated in **bold** and underlined (BVSTEP test)

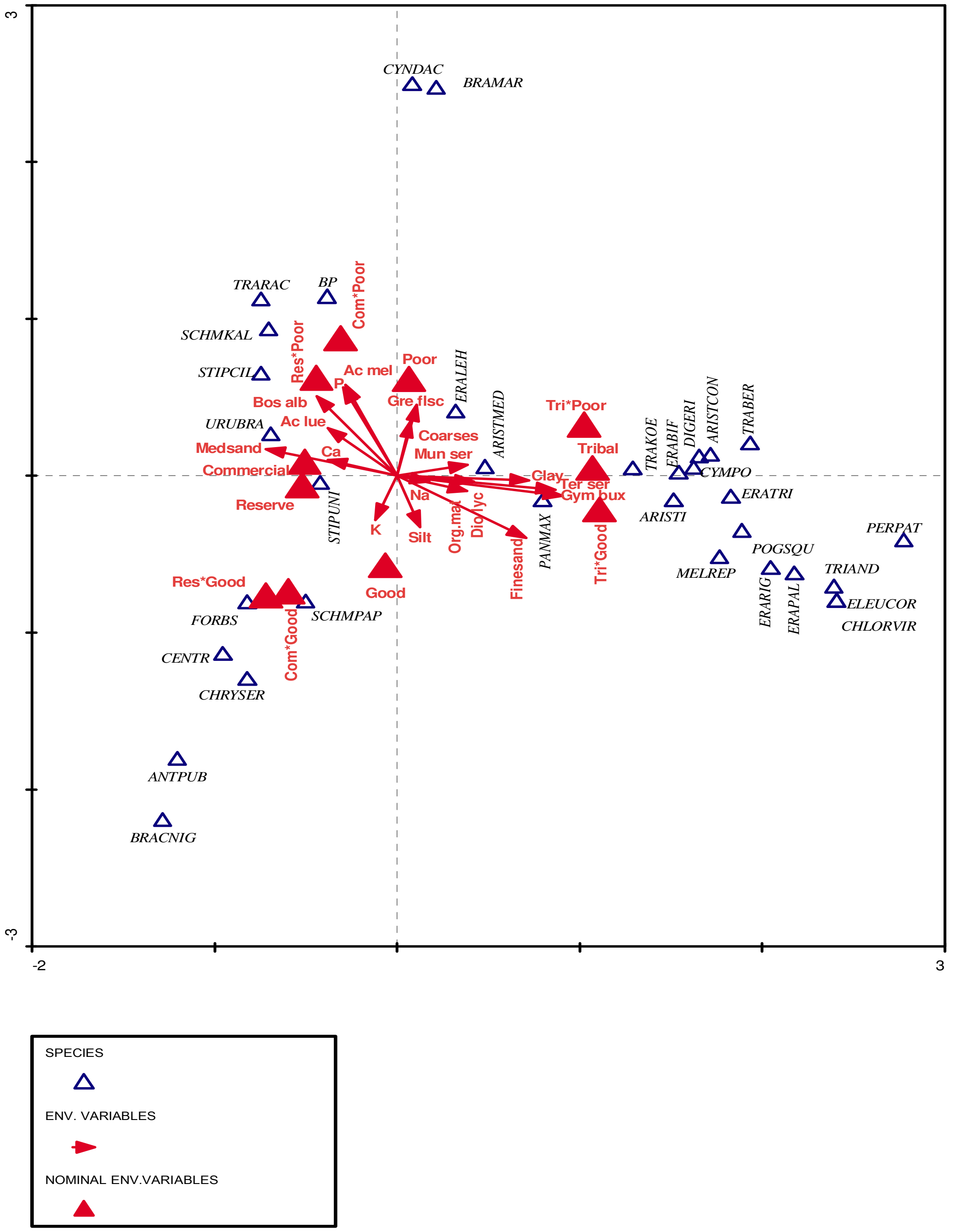


Fig. 7.1. A CCA ordination triplot, showing the herbaceous species-soil relation for the first two canonical axes, as well as the passive data associated with the woody component.

A weighted correlation matrix displaying the correlation coefficients between the environmental variables, is presented in Appendix 7.2. For each environmental variable, the one to three environmental variables with which it was associated best, are indicated in bold in Appendix 7.2. Environmental variables that were closely associated with the Tribal land use (and hence with each other), were clay (r = 0.5301, fourth quadrant), *Terminalia sericea* (r = 0.5337, fourth quadrant), *Gymnosporia buxifolia* (r = 0.5956, fourth quadrant), fine sand (r = 0.4659, fourth quadrant), *Diospyros lycoides* (r = 0.2301, fourth quadrant), *Mundulea sericea* (r = 0.2839, first quadrant) and organic material (r = 0.1568, fourth quadrant) (Appendix 7.2, Fig. 7.1). *Mundulea sericea* was closely associated with *Aristida meriodinalis* (Fig. 7.1), whereas *Panicum maximum* was closely associated with *Terminalia sericea*, *Gymnosporia buxifolia* and clay content (Fig. 7.1).

The Tribal variables (Tribal-Good and Tribal-Poor) were all closely associated (Appendix 7.2, Fig. 7.2). The Reserve-/Commercial-Good variables were closely associated with each other within the third quadrant, whereas the Reserve-/Commercial-Poor variables were closely associated with each other within the second quadrant (Fig. 7.1). Hence, the "Good" and "Poor" rangeland condition groups within the Reserve and Commercial land uses, showed pronounced differences and hence a range condition/degradation gradient. This is similar to the discussions of Chapter 4 pertaining to the rangeland condition/degradation gradient, being pronounced and significant within the Commercial and Reserve land uses, but not within the Tribal land use. This tendency will be pursued further in this section.

The environmental variable that was best associated with the Reserve-/Commercial-Good rangeland condition groups was K (Fig. 7.1), although K was in actual fact best associated with Ca (r = 0.4756) and silt (r = 0.405) (Appendix 7.2). Both Ca and silt were best associated with the Reserve land use (Appendix 7.2). These soil variables are to a large degree inherent environmental factors associated mainly with the Reserve land use. The environmental variable best associated with the Reserve-Poor group, was *Acacia mellifera*, while P was associated best with the Commercial-Poor group (Appendix 7.2, Fig. 7.1). This is consistent with results presented in Chapter 5 (Section 5.3.1.3) and Chapter 6 (Sections 6.2.4 and 6.2.5.1)

The correlation matrix (Appendix 7.2) showed the following associations: P was best associated with the Commercial-Poor land use, coarse sand and *Boscia albitrunca* (for the herbaceous-environment relations). Sodium showed the strongest associations with clay content, the Tribal-Good variable (whereas Tribal-Poor variables in Chapter 6, Sections 6.2.3 and 6.2.5.1, Fig. 6.3) and to a lesser extent with *Grewia flavescens* (Appendix 7.2). Sodium content was found to be primarily a result of the inherent environmental characteristics of the study area (Chapter 6, Tables 6.3 & 6.17). Organic material showed the strongest correlation with silt and fine sand, with content being highest within the Tribal land use (Appendix 7.2). Organic material was primarily associated with soil stratum depth (Chapter 6, Tables 6.3 and 6.17), and within this Section was found to be possibly "captured" by the type of soil particle. Coarse sand was positively associated with the Commercial-Poor group (see Chapter 6, Sections 6.2.3 and 6.2.5.1, Fig. 6.3), and was best associated with *Boscia albitrunca* and *Mundulea sericea* (Appendix 7.2). Medium sand is mainly an inherent environmental factor and was associated with the Commercial land use, whereas fine sand was associated with the Tribal land use and with silt content (Appendix 7.2). Clay content was associated with the Tribal land use and with *Mundulea sericea* (Appendix 7.2). *Acacia luederitzii* was associated with the Reserve land use, notably the Reserve-Poor rangeland condition group (Appendix 7.2). *Acacia mellifera* was best associated with the "Poor" rangeland condition group, especially the Reserve-Poor group (Appendix 7.2). *Boscia albitrunca* had the highest relative abundance within the Commercial-Poor group (Appendix 7.2). The following species were best associated with the Tribal-Poor group: *Diospyros lycoides*, *Grewia flavescens* and *Mundulea sericea* (Appendix 7.2). The following species were best associated with the Tribal-Good land use group: *Gymnosporia buxifolia* and *Terminalia sericea* (Appendix 7.2).

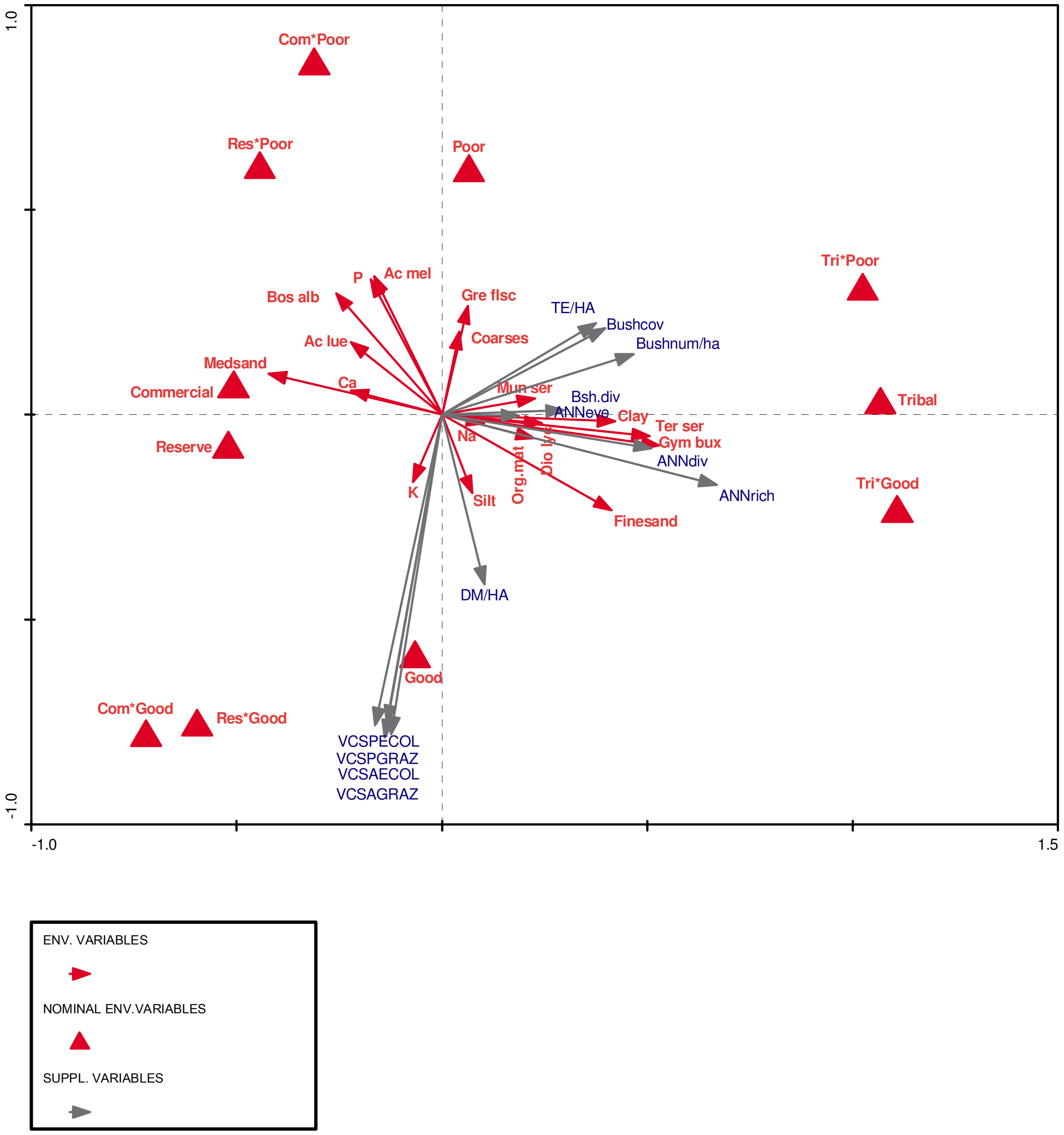


Fig. 7.2. A CCA ordination biplot displaying the environmental (soil/woody) and passive variables explaining the species-environment relation for the first two canonical axes for the "annual" herbaceous composition.

The rangeland condition score indices (indicated by VCS…, Fig. 7.2) were positively associated with the "Good" and Reserve-/Commercial-Good environmental variables in the third quadrant. The rangeland condition indices were also positively correlated with K and with dry material yield (Fig. 7.2). The woody variables (TE/ha, bush numbers/ha and bush area coverage/ha) were highly correlated with the Tribal land use, whereas herbaceous species diversity (ANNdiv, "annual" interpretation) and species richness

(ANNrich) were primarily associated with the Tribal-Good group (Fig. 7.2). The diversity indices thus displayed similar patterns as that discussed in Chapter 4 (Section 4.3.1.2), in that herbaceous species richness and diversity were highest within the Tribal land use, being positively correlated with woody diversity (Chapter 4, Fig. 4.3 and Fig. 4.4). However, as discussed in Chapter 4 (Section 4.3.1.2), herbaceous diversity and species richness did not reflect a rangeland condition gradient (Fig. 4.2 – species richness and diversity arrows perpendicular on range condition score indices, hence showing uncorrelatedness).

The response of herbaceous species with at least 10% of their variance being accounted for by the first two canonical axes, will be discussed further (Fig. 7.3). It is suggested that these species can be used as key species in explaining the species-environment relation (after Hurt & Hardy 1989; Lawes *et al.* 2005). Fifteen herbaceous species were included by this inclusion rule. Species best associated with the first two axes are presented in Appendix 7.1. These species can be indexed on a scale from 0 – 10 as explanatory measure with regard to the environmental variables best associated with each specific axis (after Hurt & Hardy 1989; Lawes *et al*. 2005). These patterns are congruent with those discussed in Chapter 4 (Section 4.3.1). The Reserve-/Commercial-Poor variables were best represented by BP and *Scmidtia kalahariensis*, with *Stipagrostis uniplumis* being associated with intermediate rangeland condition sites within the Commercial and Reserve land uses (Fig. 7.3). *Schmidtia pappophoroides* were associated with the Reserve-/Commercial-Good variables, whereas rangeland in the “best” condition for the Molopo study areas was indicated by *Antephora pubescens* and *Brachiaria nigropedata* (Fig. 7.3). Both these species occurred within the Commercial land use (Chapter 4; Appendix 4.2). The Tribal land use was best indicated by *Digitaria eriantha*, *Aristida congesta*, *Aristida stipita*, *Eragrostis tricophora*, *Pogonarthria squarrosa*, *Melinus repens*, *Eragrostis pallens* and *Triraphis androponoides* (Fig. 7.3). *Egragrosits lehmanniana* was associated with “Poor” rangeland condition sites, being a generalist herbaceous species (Fig. 7.3) (near the centre of two canonical axes, and associated with all three land uses).

A CCA LOESS attribute plot indicated the existence of a rangeland condition/degradation gradient for the larger study area. The degradation gradient was pronounced within the Commercial and Reserve land uses (Fig. 7.4). The Tribal-Good and Tribal-Poor rangeland condition groups did not differ significantly, and both groups fell within the same contour levels (Fig. 7.4). This is similar to the results discussed in Chapter 4, and will not be pursued further within Chapter 7, since the same arguments as already discussed, apply for these results (see Chapter 4, Sections 4.3.1 – Fig. 4.10 and 4.3.5 – Fig. 4.40).

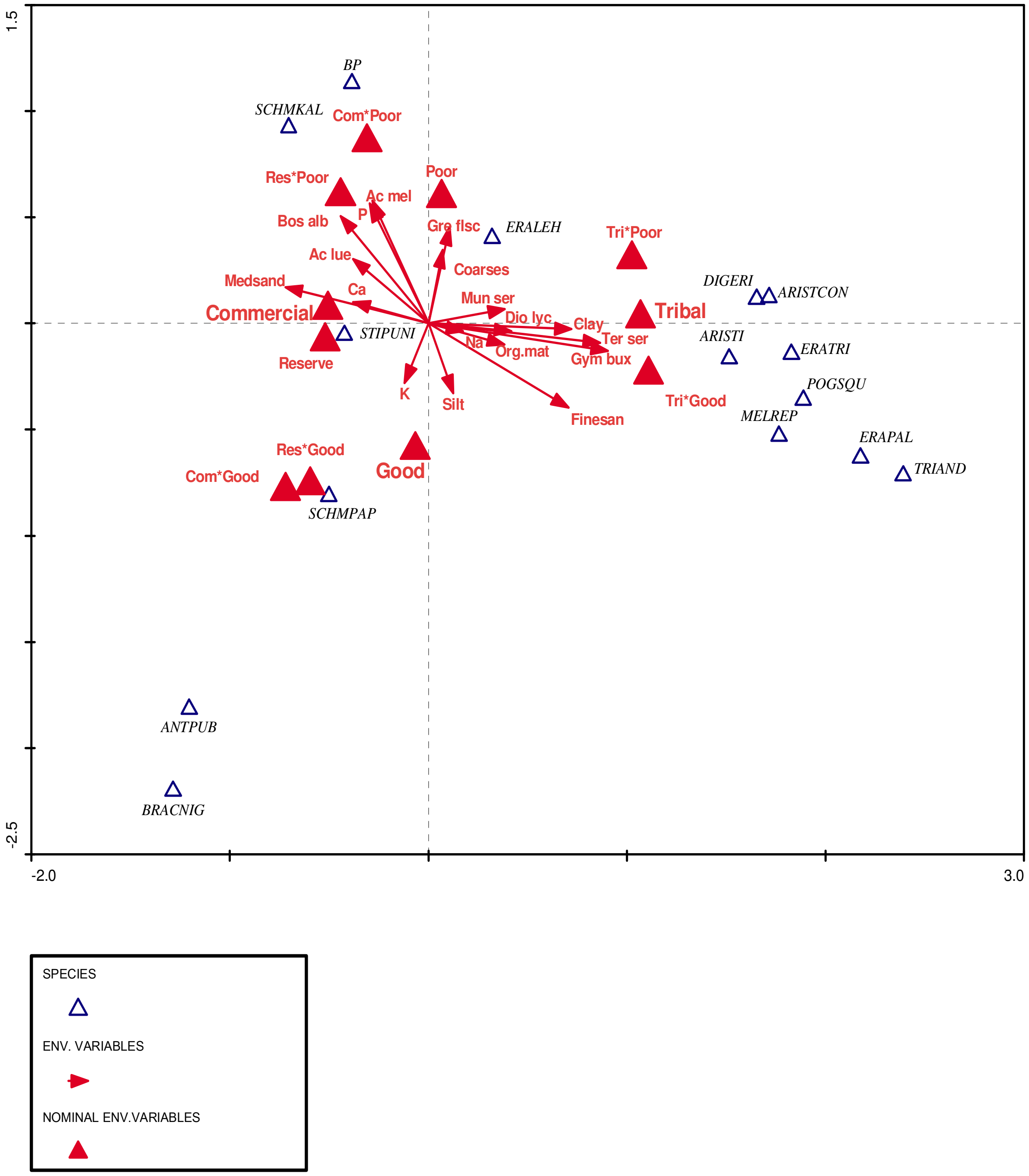


Fig. 7.3. A CCA ordination biplot showing herbaceous species having at least 10% of their ranges accounted for by the species-soil/woody environment relation.

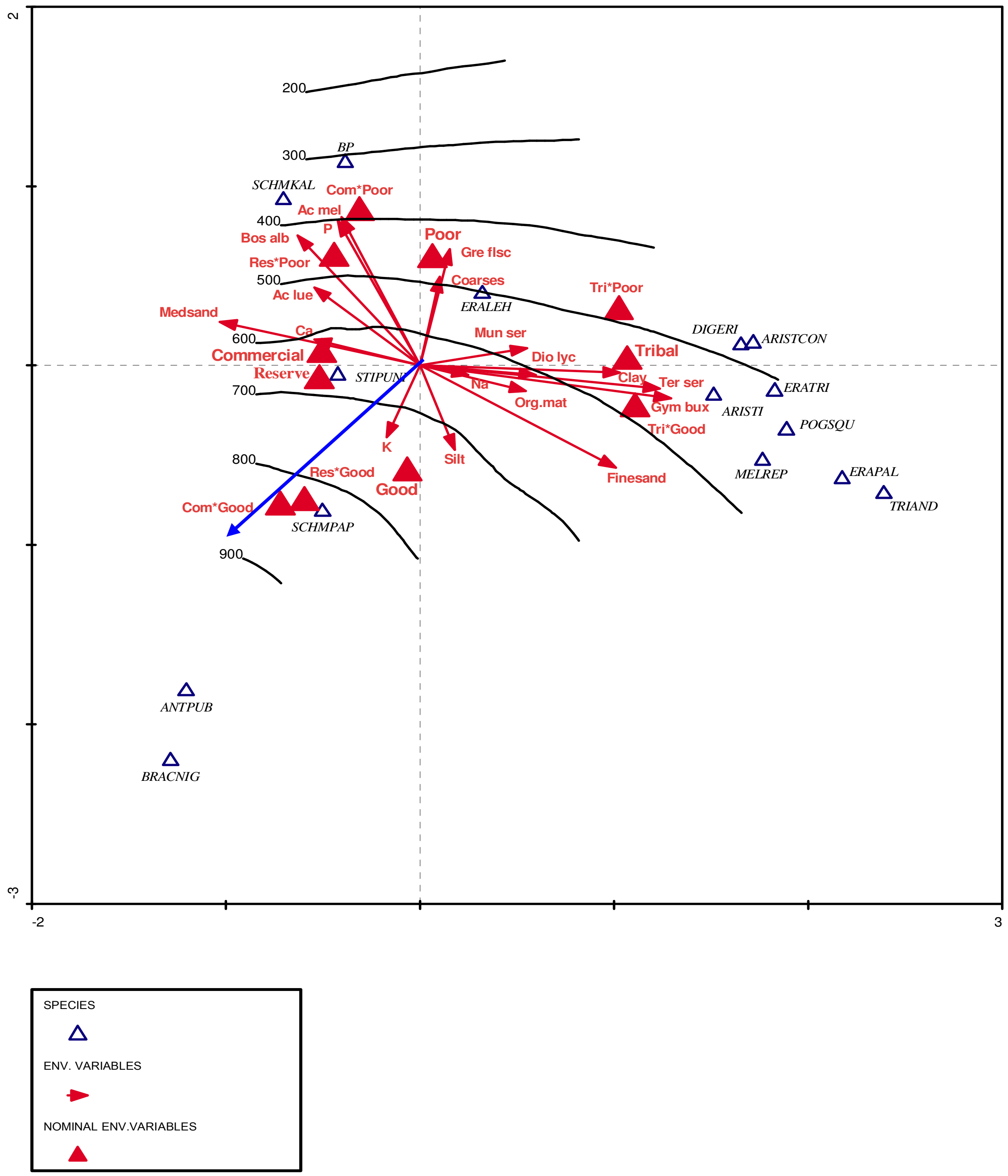


Fig. 7.4. A CCA LOESS attribute plot, indicating a rangeland condition gradient across the larger study area as indicated by the blue arrow, with the gradient being pronounced within the Commercial and Reserve land uses, but not within the Tribal land use.

7.3.4 Partial CCA ordination

One may argue that the differences in vegetation and soil among land use types are not caused by the land use type, but by differences in the (initial?) environmental characteristics of the land uses. Hence, the question is whether there are still differences in herbaceous composition among land use types after accounting for the effect of the woody and soil variables. This can be investigated with CANOCO by specifying the woody and soil characteristics as covariables (Ter Braak & Šmilauer 1998). A partial CCA test is performed, using F-ratio statistics to ensure a good level-accuracy for the test (i.e. to ensure that P-value is accurate) (Ter Braak & Šmilauer 1998). With covariables, CANOCO give an ordination of the residual variation in the species data that remains after fitting the effects of the covariables, with the ordination axes being made uncorrelated to the covariables. The environmental variables are regressed on the covariables, with the residuals of the multiple regressions taking the place of the original environmental values. The constrained ordination of the axes will thus represent the patterns that can be uniquely attributed to the environmental variables and not to the covariables (Ter Braak & Šmilauer 1998).

Table 7.8. A partial CCA ordination for the "annual" herbaceous composition showing the eigenvalues, cumulative species data and species-soil/woody (environment) variance for the first four axes and the environmental variables included in order of importance by the Monte Carlo permutation test.

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.228	0.081	0.049	0.042
Species-environment correlations	0.824	0.657	0.479	0.465
Cumulative percentage variance				
of species data	11.2	15.2	17.7	19.7
of species-environment relation (environmental)	55.5	75.2	87.2	97.4
of species-environment relation (passive data)	34.3	42.8	54.6	61

Monte Carlo permutation test

Variable	**P**	**F**
Good/Poor	0.002	5.3
Tri*Good/*Poor	0.002	4.45
Tribal	0.032	2.11
Com*Good/*Poor	0.056	1.69
Commercial	0.96	0.44

A partial CCA ordination (Table 7.8) employed the environmental variables, indicated by the Monte Carlo and BVSTEP tests in significantly explaining the species-environment relation (Table 7.7), as covariables, while only retaining the nominal land use variables and the "Good" and "Poor" rangeland condition variables as environmental variables. This procedure was followed as to confirm that land use type and the rangeland condition groups were the primary determinants of the herbaceous species compositional patterns. Significance of the species-environment relations of all the canonical axes (indicated by the Monte Carlo permutation test), and an improvement in the species-environment relation, will verify this statement. Thus, if there still remain systematic differences in herbaceous species composition after accounting for the effects of the woody and soil characteristics, land use and/or rangeland condition type can be considered as the primary determinants of the herbaceous composition-environment relation (Ter Braak & Šmilauer 1998), whereas the other environmental variables can be considered as secondary determinants of the species-environmental variance. This will mean that inherent (initial) environmental differences were not the primary determinants of the observed herbaceous species-environment relations and differences between land uses.

The second axis explained 75.2% of the species-environment variance, and the fourth axis 97.4% of the relation. For the passive data, the second axis explained 61% of the species-environment variance (Table 7.8). The Monte Carlo permutation test indicated that the first (F = 7.222, P < 0.005) and all the canonical axes (F = 2.897, P < 0.005) significantly explained the species-environment variance. Hence, these statistics suggest that the primary environmental variables explaining the species-environment variance have been correctly identified, and that land use type did primarily govern herbaceous species composition patterns. The results also indicated that a significant rangeland condition/degradation gradient existed and contributed to explaining the species-environment variance. The environmental variables (Table 7.7) employed as covariables in this section, can thus be mainly considered as secondary determinants of the herbaceous species-environment relation. These results thus indicate that land use impacts have a “snowball” effect within these rangelands, in that land use may alter the soil and woody components/composition, which may secondarily alter the herbaceous species composition and structure.

Some of these secondary herbaceous-biotic/abiotic relations can be beneficial to the herbaceous species composition, with positive associations existing between the woody and herbaceous component, while negative association between the herbaceous and woody components may exist due to competition primarily for soil moisture (refer to discussion of Chapter 5, Woody component). Vegetation may also directly or indirectly alter soil characteristics, as was discussed in Chapter 6 (Soil component). Inherent environmental factors, such as Ca content (mainly an inherent environmental variable, see Chapter 6 – Tables 6.3 and 6.17) (Table 7.7), also contributed towards explaining the species-environment. However, initial inherent environmental differences were minimal, with Ca not being indicated as a primary determinant of the herbaceous-species environment.

The following examples from the results (Fig. 7.4) are presented in support of the statements given above. *Gymnosporia buxifolia* was indicated as a secondary determinant explaining the herbaceous-environment variance (Appendix 7.2, Fig. 7.4). There were positive associations between this woody species and herbaceous species such as *Aristida stipitata* and *Eragrostis tricophora*, which were associated with the Tribal land use (Fig. 7.4). *Acacia mellifera*, P content and *Schmidtia kalahariensis* were positively associated (Appendix 7.2, Fig. 7.4). *Grewia flavescens* was associated with the “Poor” rangeland condition variables, and with *Eragrostis lehmanniana* (Fig. 7.4). *Boscia albitrunca* and *Acacia mellifera* were positively correlated with each other (Appendix 7.2), and with *Scmidtia kalahariensis* (Fig. 7.4). These woody and herbaceous species were associated with the relative “Poor” rangeland condition ranges (Fig. 7.4). Clay and calcium content were inherent environmental variables, associated with the Tribal and Reserve land use respectively (Appendix 7.2). Woody species associated with these soil variables, are presented in Appendix 7.2.

The environmental variables that explained the species-environment variance for the partial CCA, with order of inclusion in the Monte Carlo permutation test (forward selection) being according to significance and importance, are presented in Table 7.8.

7.4. RESULTS AND DISCUSSION - WOODY COMPONENT

Discussions for this section will follow the same procedures as discussed above in Section 3.

7.4.1 Woody species composition and soil environmental variables

The relationship (unimodal response) between the woody relative abundances (for the TE/ha matrix; Chapter 5, Appendix 5.2) and soil environmental variables, was investigated by means of a direct CCA ordination. The subsoil woody stratum was employed, as was motivated in Chapter 6 (Section 6.3, Conclusion and Recommendations). The second axis explained 43.9% of the species-environment relation, and the fourth axis 67.3% of the species-environment relation (Table 7.9). The passive data explained 36.7% of the species-environment variance by the second axis and 51.9% by the fourth axis (Table 7.9).

Table 7.9. A CCA ordination for the woody component (TE/ha) showing the eigenvalues, cumulative species data and species-soil (environment) variance for the first four axes.

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.274	0.129	0.121	0.094
Species-environment correlations	0.764	0.718	0.647	0.703
Cumulative percentage variance				
of species data	8.8	12.9	16.8	19.8
of species-environment relation (environmental)	29.8	43.9	57.1	67.3
of species-environment relation (passive data)	29.8	36.7	47.6	51.9

The Monte Carlo permutation test (forward selection) significantly explained the species-environment relation for the first axis ($F = 5.301$, $P < 0.005$) and all the canonical axes ($F = 1.435$, $P < 0.005$). Environmental variables that significantly explained the species-environment variance, in order of importance and significance, are given in Table 7.10. A BVSTEP test ($\rho = 0.316$, rho > 0.95) indicated that six variables should be included into the integrated, multivariate analysis (Section 4.3). Variables that were indicated by both tests in significantly explaining the species-environment relation, overlapped, with another additional two soil variables being indicated as important by the BVSTEP test (Table 7.10). Hence, these soil variables indicated by both the tests as significantly explaining the species-environment variance, were incorporated into the integrated multivariate analysis, which will be discussed in Section 7.4.3.

Table 7.10. The soil variables that explained the woody species-environment relation in order of importance as indicated by the Monte Carlo permutation test, and those indicated by the BVSTEP test.

Monte Carlo permutation test			
Variable	**P**	**F**	**BVSTEP test**
NO3-N	**0.002**	**5.12**	**Conductivity**
Conductivity	**0.002**	**2.36**	**NO3-N**
Silt	**0.012**	**2.29**	**Organic material**
Mg	0.1	1.51	**Med sand**
Med sand	0.096	1.52	**Silt**
Zn	0.158	1.33	
Fine sand	0.612	0.87	
K	0.488	0.98	
Na	0.696	0.81	
C	0.528	0.89	
Organic material	0.438	0.93	
P Bray 1	0.864	0.63	
Coarse sand	0.818	0.65	
Clay	0.284	1.16	
pH	0.878	0.62	
Ca	0.24	1.2	

(i) Key variables are indicated in **bold**, with $P < 0.05$ (Monte Carlo test) and Rho > 0.95 (BVSTEP test).

7.4.2 Woody species composition and herbaceous species composition

The woody-herbaceous relations were investigated by employing the woody component as species data, and the herbaceous component as environmental data. Both the first ($F = 6.059$, $P < 0.005$) and all the canonical axes ($F = 1.569$, $P < 0.005$) of the Monte Carlo permutation test were significant. The second axis explained 37.7% of the species-environment relation, and the fourth axis 57.7% (Table 7.11). The passive data explained 44.9% of the species-environment relation by the second axis and 60% by the fourth axis (Table 7.11).

Table 7.11. A CCA ordination for the woody component (TE/ha) showing the eigenvalues, cumulative species data and species-herbaceous composition (environment) variance for the first four axes.

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.42	0.231	0.198	0.165
Species-environment correlations	0.936	0.91	0.888	0.807
Cumulative percentage variance				
of species data	13.4	20.9	27.2	32.5
of species-environment relation (environmental)	23.9	37.1	48.3	57.7
of species-environment relation (passive data)	34.5	44.9	49.8	60

Table 7.12. The herbaceous variables that explained the woody species-environment relation in order of importance as indicated by the Monte Carlo permutation test, and those indicated by the BVSTEP test.

Monte Carlo permutation test			
Variable	**P**	**F**	**BVSTEP test**
ERA PAL	**0.002**	**5.45**	***ANT PUB***
CEN TR	**0.002**	**3.7**	***ERA RIG***
ERA TRI	**0.046**	**2.68**	***CYM POG***
ARI STI	**0.006**	**2.6**	***ERA PAL***
BP	**0.002**	**2.57**	***BRAC NIG***
SCHM KAL	**0.048**	**2.07**	***TRI AND***
STIP UNI	**0.048**	**1.76**	***CHLOR VIR***
BRA MAR	0.096	1.73	
MEL REP	0.11	1.59	
DIG ERI	0.154	1.36	
CHRY SER	0.194	1.31	
URU BRA	0.21	1.28	
FORBS	0.236	1.24	
TRI AND	0.272	1.17	
CYM PO	0.268	1.21	
CYN DAC	0.336	1.09	
PER PAT	0.352	1.05	
POG SQU	0.354	1.1	
CHLOR VIR	0.33	1.08	
ARIST CON	0.258	1.24	
ERA BIF	0.266	1.29	
ARIST MED	0.386	0.91	
ERA LEH	0.462	0.9	
ERA RIG	0.52	0.8	
ANT PUB	0.548	0.7	
BRAC NIG	0.068	2.12	
TRA RAC	0.474	0.72	
STIP CIL	0.432	0.93	
PAN MAX	0.634	0.64	
TRA KOE	0.652	0.66	
TRA BER	0.676	0.77	
SCHM PAP	0.768	0.55	

(i) Key variables are indicated in **bold**, with $P < 0.05$ (Monte Carlo test) and Rho > 0.95 (BVSTEP test)

(ii) "Marginal" variables are indicated in **bold** and underlined (BVSTEP test)

The Monte Carlo permutation test significantly explained the species-environment variance for the first ($F = 7.209$, $P < 0.005$) and all the canonical axes ($F = 2.038$, $P < 0.005$). Environmental variables that explained the woody-herbaceous variance, in order of importance and significance, are indicated in Table 7.12. In addition, herbaceous species indicated by the BVSTEP test (Spearman rank correlation) (ρ = 0.425, rho > 0.95) as best explaining the woody-herbaceous relations, are presented in Table 7.12. Species that significantly explained the woody-herbaceous variance, as indicated by these two tests (Table 7.12), were selected and included in the integrated multivariate analyses (Section 7.4.3). Hence, multivariate tendencies pertaining to the woody component will be addressed in Section 7.4.3.

7.4.3 Integrated woody species composition and environmental variables

The key soil variables (Section 7.4.1) and herbaceous species (Section 7.4.2) were incorporated together with the nominal land use type and “Good” and “Poor” rangeland condition variables (Chapter 4) into the multivariate CCA ordination and BVSTEP test of the woody component. This was done in order to identify whether land use and rangeland condition were primary or secondary determinants of the herbaceous species-environment patterns. The cumulative variances and eigenvector scores of the woody variables associated best with the first two ordination axes, are presented in Appendix 7.3.

For the integrated multivariate analysis, the Monte Carlo test significantly explained the species-environment variance for the first (F = 7.209, P < 0.005) and all the canonical axes (F = 2.038, P < 0.005).

The second axis explained 40.7% of the species-environment variance, and the fourth axis 60.4% (Table 7.13). For the passive data, the second axis explained 44.9% of the species-environment relation, and the fourth axis explained 60.6% of the species-environment relation (Table 7.13).

Table 7.13. A CCA ordination for the woody component (TE/ha) showing the eigenvalues, cumulative species data and species-soil/herbaceous (environment) variance for the first four axes.

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.415	0.233	0.163	0.15
Species-environment correlations	0.928	0.9	0.785	0.801
Cumulative percentage variance				
of species data	13.3	20.8	26	30.8
of species-environment relation (environmental)	26.1	40.7	51	60.4
of species-environment relation (passive data)	34	44.9	53.3	60.6

The environmental variables that showed the strongest association with the first axis, were the Tribal land use (r = 0.7817, fourth quadrant), followed by the Tribal-Good variable (r = 0.6857, fourth quadrant), *Eragrostis pallens* (0.6491, fourth quadrant) and *Aristida stipitata* (r = 0.5634, fourth quadrant) (Table 7.14, Fig. 7.5).

The second axis was best represented by *Centropodia glauca* (0.6233, second quadrant), the Commercial-Good rangeland condition group (r = 0.5223, second quadrant) and the Commercial land use (r = 0.4907, second quadrant) (Table 7.14, Fig. 7.5).

Table 7.14. CCA correlation coefficients (r-values) for the environmental (soil and herbaceous) and passive variables associated with the first two CCA axes for the woody component, with the variables showing the highest r-values indicated in **bold**.

Environmental data	**SPEC AX1**	**SPEC AX2**	**Passive data**	**SPEC AX1**	**SPEC AX2**
Commercial	-0.2443	**0.4907**	BE/HA	0.27	-0.4491
Tribal	**0.7817**	-0.1794	Bushcov	0.2601	-0.3622
Reserve	-0.5306	-0.3093	Bush num/ha	0.4554	-0.4368
Good	0.276	0.2734	VCSAGRAZ	0.0733	**0.2073**
Poor	-0.276	-0.2734	DM/HA	0.2781	-0.0284
Conductivity	-0.5573	-0.1202	VCSAECOL	0.0597	**0.2025**
Mg	-0.2175	-0.2896	ANNrich	**0.711**	0.026
NO3-N	-0.6018	0.1346	ANNdiv	**0.5382**	0.0512
Organic material	0.0112	-0.1307	Bush ric	0.2848	-0.4053
Med sand	-0.4992	0.1965	Bush eve	0.08	0.0661
Silt	0.0996	-0.1641	Bush div	0.2831	-0.3316
ANT PUB	-0.0079	0.3176			
BRAC NIG	-0.0064	0.0407			
ERA TRI	0.3381	-0.1962			
STIP UNI	-0.3118	0.0446			
CYM PO	0.2602	-0.1794			
CEN TR	-0.0742	**0.6233**			
ARI STI	**0.5634**	-0.1191			
ERA PAL	**0.6491**	-0.0827			
TRI AND	0.5358	-0.1082			
ERA RIG	0.3444	-0.1378			
CHLOR VIR	0.297	-0.1355			
SCHM KAL	-0.2693	0.0777			
BP	-0.3498	-0.146			
Com*Good	-0.0627	**0.5223**			
Com*Poor	-0.2447	0.1041			
Tri*Poor	0.3056	-0.1188			
Tri*Good	**0.6857**	-0.1088			
Res*Good	-0.2469	-0.0394			
Res*Poor	-0.421	-0.3493			

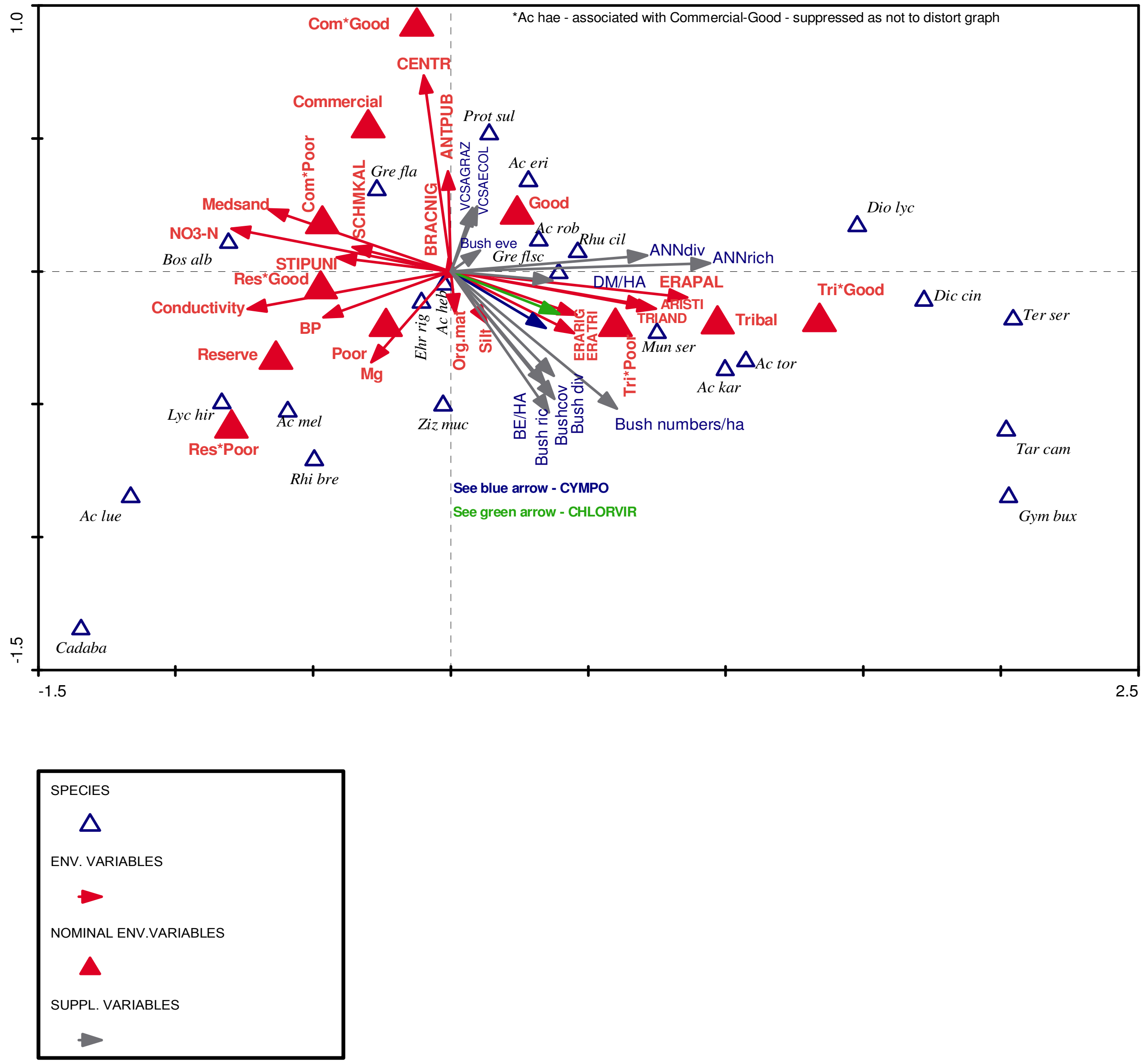


Fig. 7.5. A CCA ordination triplot, showing the woody species-soil relation for the first two canonical axes, as well as the passive data associated with the woody component.

Passive variables that were most strongly associated with the first axis, were herbaceous species richness (ANNrich) and herbaceous diversity (ANNdiv) (Table 7.14, Fig. 7.6), while the range condition score indices (VCS…) were the passive variables most strongly associated with the second axis (Table 7.14, Fig. 7.6) and with the “Good” rangeland condition group. DM yield was mainly associated with the Tribal land use, herbaceous species richness and diversity (Fig. 7.6). Woody species richness and diversity were primarily associated with the Tribal land use, and secondary with the Reserve land use (Fig. 7.6). This is similar to the results discussed in Chapter 5 (Section 5.3.1.3, Fig. 5.9). Woody diversity and species richness rather were indicators of habitat modification/environmental change, and were not good indicators of the rangeland condition/degradation gradient (Fig. 7.6). This can be deduced from the arrows representing woody diversity and species richness, being perpendicular and thus uncorrelated on those arrows indicating the rangeland condition scores (Fig. 7.6). However, woody diversity and herbaceous diversity were correlated with each other and mainly associated with the Tribal land use, as shown by the alignment of the arrows representing these variables (Fig. 7.6).

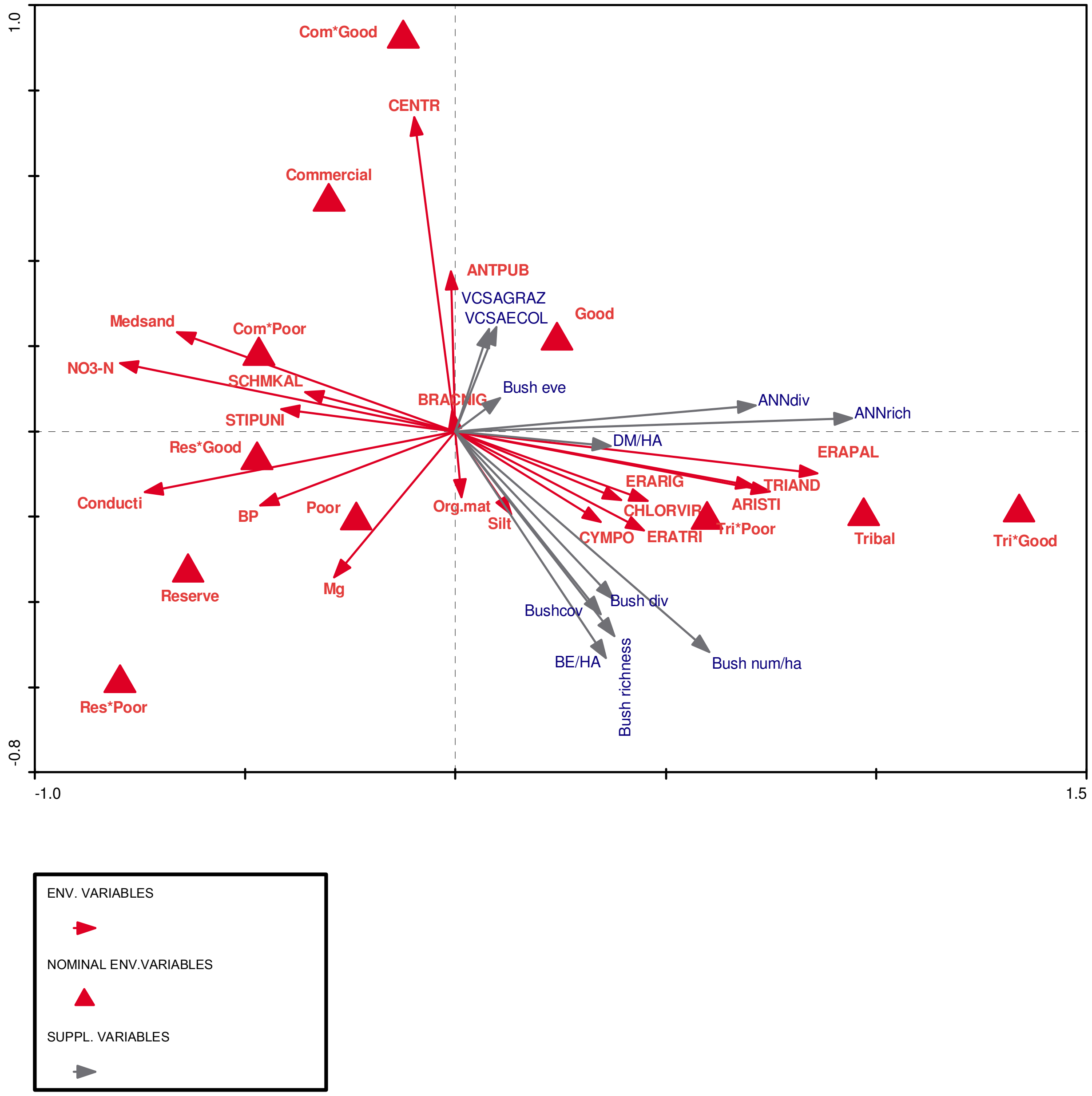


Fig. 7.6. A CCA ordination biplot displaying the environmental (soil/herbaceous) and passive variables explaining the species-environment relation for the first two canonical axes for the woody component**.**

Environmental variables that showed the strongest association with the Tribal land use (besides the Tribal-Good/-Poor rangeland condition groups), were *Eragrostis pallens* (r = 0.506, fourth quadrant) and *Aristida stipitata* (r = 0.628) (Appendix 7.4, Fig. 7.5). The Commercial land use was best represented (barring the Commercial-Good/-Poor groups) by the medium sand environmental variable (r = 0.4187, second quadrant) (Appendix 7.4, Fig. 7.5). The Reserve land use (barring the Reserve-Good/-Poor groups) was best associated with Mg (r = 0.4783, third quadrant) and conductivity (r = 0.4623, third quadrant) (Appendix 7.4, Fig. 7.5). This is similar to the results discussed in Section 3.3. Besides the

Reserve-, Tribal- and Commercial-Good groups, the “Good” rangeland condition variable was best associated with *Antephora pubescens* (r = 0.2558, first quadrant) (Chapter 4, Section 3.1, Fig. 4.10), whereas the “Poor” variables were best associated (barring the land use-Poor variables) with BP (r = 0.4682, third quadrant) (Appendix 7.4, Fig. 7.5).

Conductivity was most strongly associated with Mg and the Reserve-Good group). Mg was described as mainly an inherent environmental factor, being secondarily modified by plant-soil interactions. NO_3-N was best associated with medium sand and *Schmidtia kalahariensis* (Appendix 7.4, Fig. 7.5). Organic content was best associated with silt content and the Reserve-Good rangeland condition group (see Chapter 6, Section 6.2.5.4, Fig. 6.6) (Appendix 7.4, Fig. 7.5). According to Chapter 6 (Section 6.2.2, Tables 6.3 and 6.17), organic material was associated primarily with soil stratum and to a lesser extent with openness/woodiness. The silt content may act as “capturing” agent of the organic material, as was also found in Section 7.3.3. Medium sand was associated with the Commercial-Poor group and BP, whereas silt was best associated with the Reserve-Good group(Appendix 7.4, Fig. 7.5). *Antephora pubescens* was highly correlated with *Brachiaria nigropedata*, followed by the Commercial-Good group and then *Centropodia glauca* (Appendix 7.4, Fig. 7.5). *Brachiaria nigropedata* was also positively correlated with the Commercial-Good variable (and with *Antephora pubescens*) (Appendix 7.4, Fig. 7.5). *Stipagrostis uniplumis* was best associated with the Reserve-Poor group and with *Centropodia glauca* (Appendix 7.4, Fig. 7.5). *Centropodia glauca* was primarily associated with the Commercial-Good group, and *Schmidtia kalahariensis* was primarily associated with the Commercial-Poor group, whereas BP was primarily associated with the Commercial- and Reserve-Poor groups (Appendix 7.4, Fig. 7.5).

Eragrostis rigidior and *Chloris virgata* were positively correlated with *Eragrostis tricophora*, and were mainly associated with the Tribal-Good land use group (Appendix 7.4, Fig. 7.5). *Eragrostis pallens* was primarily associated with the Tribal-Good variable, and secondarily with *Triraphis androponoides* (Appendix 7.4, Fig. 7.5). *Cymbopogon plurinodis* showed the strongest association with *Aristida stipitata* and *Triraphis andropogonoides*, being most closely associated with the Tribal-Poor group (Appendix 7.4, Fig. 7.5).

Woody species having 10% or higher of their ranges being explained by the species-environment variance, are indicated in Fig. 7.7 (Appendix 7.3). Ten woody species were included by this inclusion rule, with patterns remaining similar to that discussed in Chapter 6, Section 6.3.1.3 C. *Acacia mellifera* and *Rhigozum brevispinosum* had the highest relative abundances within the Reserve-Poor rangeland condition group. *Boscia albitrunca* was primarily associated with the Commercial-Poor group (Fig. 7.7). The relative abundance of *Grewia flava* was highest within the Commercial land use (Fig. 7.7). The Tribal land use was represented by *Dichrostachys cinerea*, *Terminalia sericea*, *Tarchonanthus camphoratus* and *Gymnosporia buxifolia* (Fig. 7.7). It was evident that NO_3-N content was highest in soils associated with *Boscia albitrunca* (Fig. 7.7).

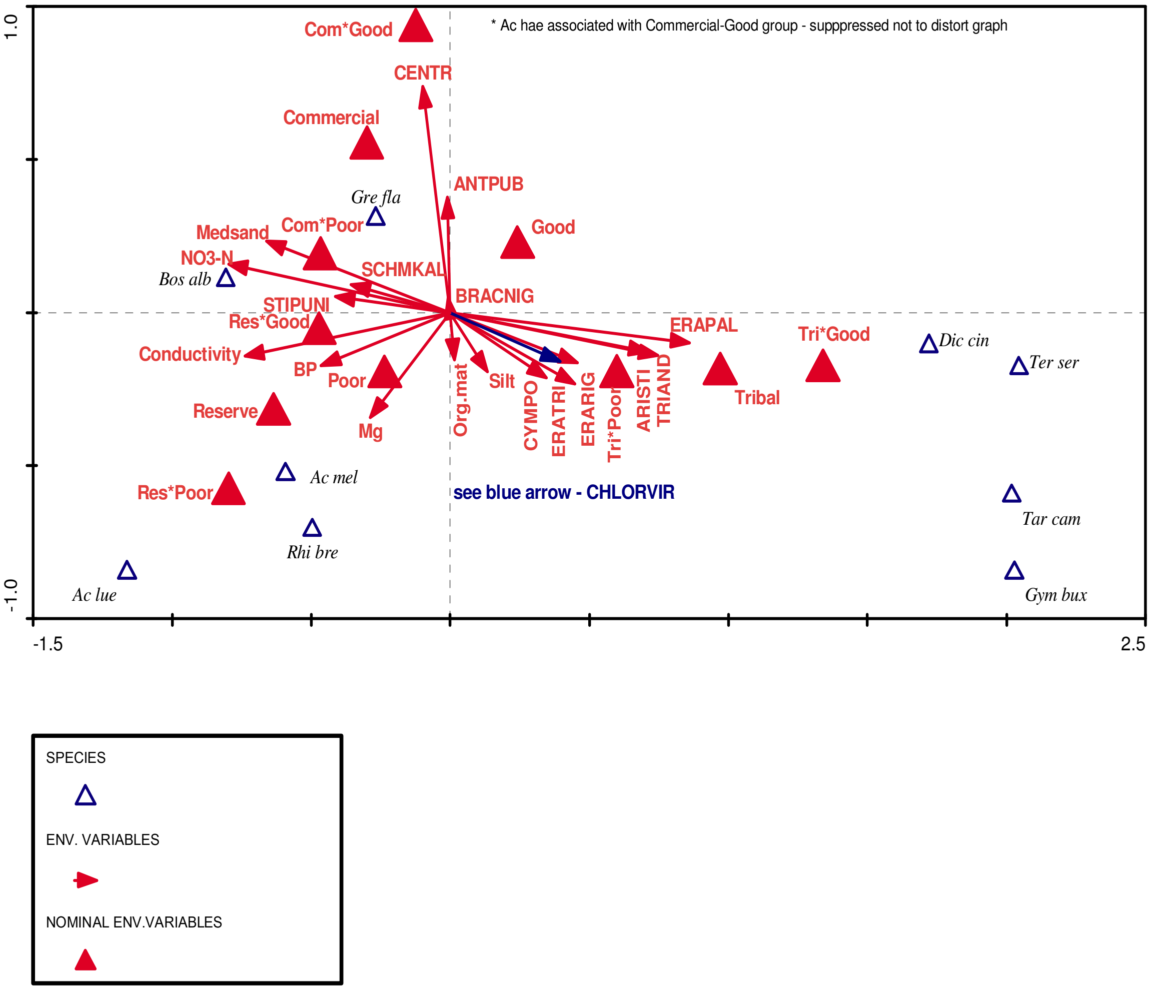


Fig. 7.7. A CCA ordination biplot showing woody species having at least 10% of their ranges accounted for by the species-soil/herbaceous environment relation.

These 10% and higher woody species can be employed as key species (indicator species) for rangeland monitoring purposes, and are presented in the rangeland monitoring “Key assessment matrix” (Chapter 9, Concluding Remarks). The woody variables associated with the respective axes (Appendix 7.3) can be indexed against the environmental variable(s) (Table 7.14) associated best with the respective axes (after Hurt & Hardy 1989; Lawes *et al.* 2005). The relative position of woody variables along the first and second axes of the CCA ordination was indexed by rescaling the eigenvector scores of the variables to a scale of 0 to 10, with 0 representing the score of that woody variable located first and 10 the position of the last woody variable on the gradient (after Hurt & Hardy 1989; Lawes *et al.* 2005) pertaining to the environmental variable best explaining the respective axes. These scores can be used to calculate environmental-weighted total scores for comparative and monitoring purposes.

A CCA LOESS attribute plot (Fig. 7.8), incorporating rangeland condition score as predictor, reflected a rangeland condition/degradation gradient across the larger study area. This is consistent with the results and discussions of Chapter 5 (Sections 5.3.1.1 A and 5.3.1.3, Fig. 5.10). However, patterns within land uses differed, in that different degradation gradients existed within the Commercial and Reserve land uses, whereas no gradient existed within the Tribal land use. This is similar to the results already discussed in Chapter 5, as mentioned above. Within the Commercial land use, a more pronounced rangeland condition/degradation gradient pertaining to the woody component existed, with range condition scores ranging from approximately 450 up to 800 (indicated by contour levels) (Fig. 7.8). The gradient within the Reserve land use was less pronounced, with range condition scores (pertaining to woody component) varying from approximately 500 to 650 (Fig. 7.8). The woody component did not reflect the rangeland condition gradient within the Tribal land use, with the Tribal-Good and Tribal-Poor rangeland condition groups being associated with the same contour levels (500 – 550) (Fig. 7.8). Hence, the Commercial land use was represented by sites associated with relatively low rangeland condition scores, as well as with high rangeland condition scores. The Reserve land use was characterised by sites (with reference to the woody component) with intermediate-low to intermediate-high rangeland condition ranges. The woody component of the Tribal land use was associated with intermediate-low rangeland condition ranges (Fig. 7.8).

Environmental variables that best explained the woody species-environment variance, in order of their importance and significance, as indicated by the Monte Carlo test (forward selection), are given in Table 7.15. The Tribal, Commercial, Reserve-Good/-Poor variables, as well as *Centropodia glauca* (associated with Commercial-Good group), silt (Reserve-Good group), *Chloris virgata* (Tribal land use), *Triraphis andropogonoides* (Tribal land use), BP (Reserve-/Commercial-Poor groups) and conductivity (Reserve land use) significantly explained the woody species-environment variance. In addition, the BVSTEP test ($\rho = 0.482$, rho > 0.95) indicated the inclusion of *Antephora pubescens*, *Eragrostis pallens*, *Eragrostis rigidior*, *Eragrostis tricophora* and *Brachiaria nigropedata*, Mg and NO_3-N.

These results suggest that land use type is the primary determinant of the woody and herbaceous compositional patterns, also altering some soil characteristics, (see Chapter 6, Section 6.2.2, Tables 6.3 and 6.17). In order to test this statement, these key environmental variables explaining the woody species-environment variance, will be incorporated as covariables in the partial canonical ordinations, retaining only the nominal land use type and rangeland condition “Good” and “Poor” variables as environmental variables. An improvement in the species-environment relation, and the significance of all the canonical axes as shown by the Monte Carlo permutation test, will indicate whether land use type and rangeland condition type (relative “Good” vs. “Poor”) are the primary or secondary determinants of the woody species-environment variance.

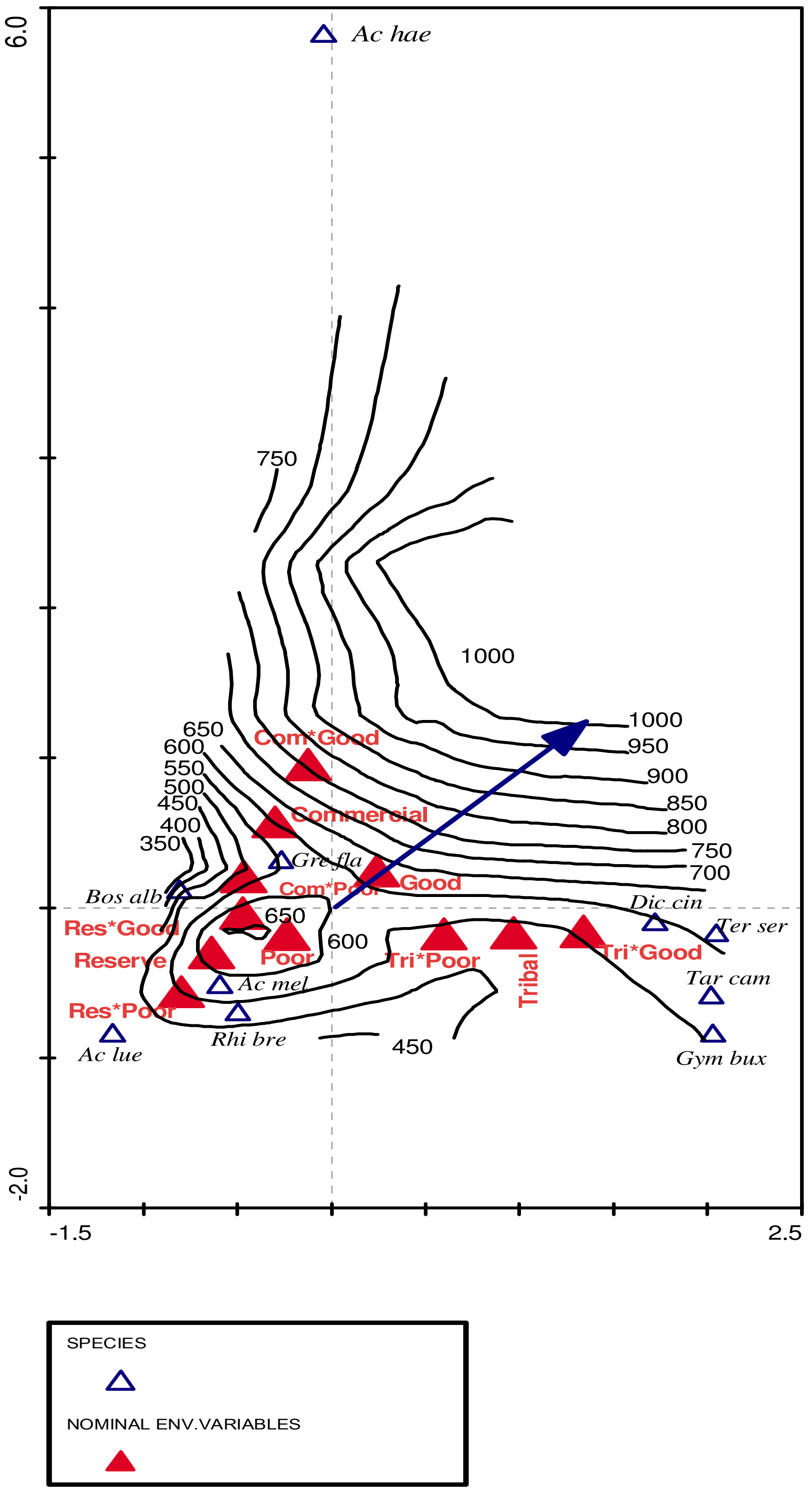


Fig. 7.8. A CCA LOESS attribute plot, with rangeland condition score as predictor as indicated by the blue arrow, showing different degradation patterns existing within the Commercial and Reserve land uses, and no gradient within the Tribal land use.

Table 7.15. The soil and herbaceous variables that explained the herbaceous species-environment relation in order of importance as indicated by the Monte Carlo permutation test, and those indicated by the BVSTEP test.

Monte Carlo permutation test			
Variable	**P**	**F**	**BVSTEP test**
Tribal	**0.002**	**7.94**	**Commercial**
CEN TR	**0.004**	**3.74**	**Tribal**
Res*Poor/*Good	**0.002**	**2.87**	**Mg**
Silt	**0.004**	**2.55**	**NO3-N**
CHLOR VIR	**0.076**	**2.33**	**Silt**
Conductivity	**0.01**	**2.26**	***ANT PUB***
BP	**0.024**	**2.08**	***BRAC NIG***
TRI AND	**0.04**	**2.04**	***ERA TRI***
SCHM KAL	0.07	2.05	**BP**
CYM PO	0.086	1.98	***ERA PAL***
Commercial	**0.048**	**1.65**	***TRI AND***
STIP UNI	0.096	1.52	***ERA RIG***
Good	0.116	1.4	***CHLOR VIR***
Mg	0.268	1.18	
Med sand	0.378	1.1	
NO3-N	0.332	1.1	
ANT PUB	0.592	0.8	
BRAC NIG	0.036	2.5	
ERA PAL	0.538	0.81	
ARI STI	0.678	0.75	
ERA RIG	0.676	0.69	
ERA TRI	0.764	0.68	
Organic Material	0.906	0.55	
Com*Good	0.93	0.51	

(i) Key variables are indicated in **bold**, with $P < 0.05$ (Monte Carlo test) and Rho > 0.95 (BVSTEP test)

(ii) "Marginal" variables are indicated in **bold** and underlined (BVSTEP test)

7.4.4 Partial CCA ordination

A partial CCA ordination employed the key environmental variables, barring the land use types and rangeland condition groups ("Good" and "Poor" rangeland condition extremes), as covariables. The land uses as well as the rangeland condition groups were employed as environmental variables.

The Monte Carlo permutation test significantly explained the species-environment relation for all the canonical axes ($F = 1.477$, $P < 0.05$). The second ordination axis explained 66.7% of the species-environment relation, and the fourth axis 96.1% of the species-environment relation (Table 7.16). Environmental variables that explained the woody species-environment relation, in order of importance and significance (as indicated by the Monte Carlo permutation test), were mainly the Tribal and Commercial land uses (Table 7.16). The improvement in the species-environment relation as well as the significance of the Monte Carlo test, suggest that land use type is mainly responsible for accounting for the species-environment variance. Land use is thus indicated as a primary determinant of the woody species compositional patterns, modifying the herbaceous, soil and woody component as a result of different disturbances associated with the different land use types. This is consistent with the results and discussions presented in Chapters 4, 5 and 6. These results further suggest that the herbaceous composition and soil variables were mainly secondary determinants of the woody-environment relations. However, as discussed in Section 7.3.4 above, land use impacts may result in transitional shifts in the woody species composition (Westoby *et al.* 1989), which may have a "snowball" effect on the herbaceous composition and soil content, and *vice versa*.

Table 7.16. A partial CCA ordination for the woody component showing the eigenvalues, cumulative species data and species-soil/herbaceous (environment) variance for the first four axes and the environmental variables included in order of importance by the Monte Carlo permutation test.

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.088	0.068	0.045	0.023
Species-environment correlations	0.67	0.613	0.551	0.401
Cumulative percentage variance				
of species data	4.3	7.7	9.9	11.1
of species-environment relation (environmental)	37.6	66.7	86	96.1
of species-environment relation (passive data)	12.8	30.4	36.6	43.1

Monte Carlo permutation test

Variable	**P**	**F**
Tribal	0.004	2.38
Commercial	0.006	2.18
Res*Good/*Poor	0.158	1.37
Tri*Poor/*Good	0.694	0.78
Good/Poor	0.988	0.35

Centropodia glauca (Table 7.15) was positively correlated with *Antephora pubescens* (Appendix 7.4, Fig. 7.8), and the Commercial-Good group. *Chloris virgata* was positively correlated with *Eragrostis rigidior*, *Eragrostis tricophora*, *Eragrostis pallens* and *Triraphis andropogonoides*, and was associated with woody species such as *Tarchonanthus camphoratus*, *Gymnosporia buxifolia* and *Terminalia sericea* in the Tribal land use (Fig. 7.8). NO3-N content was positively associated with *Boscia albitrunca*, and Mg content with *Acacia mellifera* (Fig. 7.8).

7.5. CONCLUSION

The purpose of this chapter was to verify and confirm discussions with regard to the herbaceous component (Chapter 4), the woody component (Chapter 5) and the soil component (Chapter 6). Multivariate patterns were established with regard to biotic-biotic and biotic-abiotic interactions. Hence, results of Chapter 7 are supported by the discussions presented in the abovementioned chapters (Chapters 4 – 6).

Chapter 7 attempted to identify whether land use impact was a primary or secondary determinant of the herbaceous, woody and soil compositional patterns. This was done by identifying the environmental variables that primarily accounted for the herbaceous composition-environment variance, woody-environment variance and soil-environment patterns. From the results presented above (Chapter 7), it was evident that land use impacts/disturbances from the different land uses primarily, and thus not inherent (initial) environmental differences within the study area, resulted in the observed multivariate species-environment relations. Land use type modified herbaceous species-, woody and soil compositional patterns, with these components contributing (accounting) secondarily towards explaining the species-environment relations (Sections 7.3.3 and 7.4.3).

Different land use impacts resulted in a rangeland condition/degradation gradient across the larger study area and within the Commercial and Reserve land uses. The gradient was reflected by the herbaceous species composition, woody composition (relative abundances), with a significant though very small degradation gradient being reflected by the soil variables (see Chapter 6, Section 6.2.2, Table 6.2 and Table 6.3). The rangeland condition/degradation gradient that was reflected by the herbaceous component, displayed similar tendencies within the Commercial and Reserve land uses, in that both land uses had sites being associated with very low rangeland condition scores, and sites being associated with very high rangeland condition scores. Herbaceous species typical (indicator or key species) of these extremes, were identified for incorporation into the rangeland monitoring “Key assessment matrix” presented in Chapter 9 (Concluding remarks). The Tribal land use did not reflect any rangeland condition/degradation gradient with regard to the herbaceous species composition, but rather a transitional shift towards a unique species compositional state, as described by the state-and-transition model (Westoby *et al*. 1989). These patterns were discussed in Chapter 4. Herbaceous species within the Tribal land use were associated with low to intermediate-high rangeland condition scores (Chapter 4, Section 4.3.1.3; Chapter 7, Section 7.4.3 and Fig. 7.4). The herbaceous species composition reflected different degradation patterns (gradients and/or transitional shifts) in all three the land uses, which was discussed according to the state-and-transition model that encompasses both equilibrium and non-equilibrium systems (Chapter 4). There were similar shifts for the herbaceous species composition within the Commercial and Reserve land uses, from a relative “Good” rangeland condition to another, less resilient state associated with the relative “Poor” rangeland condition sites. The Tribal land use showed, irrespective of rangeland condition group, a total transitional shift towards a state different from the other two land uses, being represented primarily with weak perennial species (Chapter 4). These species were associated with intermediate rangeland condition scores. Herbaceous species associated with the Tribal land use are perceived to be "adapted" to the continuous grazing practices.

The rangeland condition gradient reflected by the woody component was significant and most pronounced within the Commercial land use, and less pronounced but still significant within the Reserve land use. The woody composition of the Tribal land use did not reflect any rangeland condition gradient. Results for the woody component reflected sites within the Commercial land use to be associated with relatively low rangeland condition scores (Chapter 5, Section 5.3.1.3, Fig. 5.11; Chapter 7, Section 7.4.3, Fig. 7.8) as well as with relatively high rangeland condition scores. Sites within the Reserve were primarily associated with low to intermediate rangeland condition scores. Sites within the Tribal land use, irrespective of rangeland condition group ("Good" vs. "Poor"), were associated with low-intermediate rangeland condition scores (Section 7.4.3, Fig. 7.8). Key woody species associated with each rangeland condition group ("Good" vs. "Poor") within each land use, were identified and incorporated into the rangeland monitoring "Key assessment matrix" (Chapter 9, Concluding Remarks).

Soil variables did not reflect a pronounced rangeland condition gradient, but they did reflect patterns pertaining to soil stratum and openness/woodiness (Chapter 6, Section 6.4 – Conclusion). Thus, the topsoil open soil matrix was correlated with the herbaceous compositional data (Section 7.3), and the subsoil woody matrix with the woody component (Section 7.4) (refer to Chapter 6, Section 6.4). Soil patterns pertaining to the herbaceous and woody components can either be the result of inherent environmental factors (e.g. particle size), and/or it can be induced by land use type, e.g. urine and dung deposition by livestock and by plant-soil interactions. Results from Chapter 6 (Tables 6.2, 6.3 and 6.17) and from Chapter 7 (Section 7.3.3 and Section 7.4.3; Appendices 7.2 and 7.4), showed that both inherent environmental soil differences as well as plant-soil interactions contributed towards explaining the woody/herbaceous-environment relations. However, inherent environmental soil differences between the land uses were not large. Neither were these soil variables indicated by the Monte Carlo Tests (CCA ordinations and partial CCA ordinations) as the most important primary determinants of woody/herbaceous-environment relations. Thus, land use did result in different soil patterns, as was indicated by the soil-vegetation associations in Appendices 7.2 and 7.4. However, the inherent soil environmental differences also contributed to inter-set soil-soil correlations, and secondarily to soil-vegetation correlations.

The woody and herbaceous diversity indices (Margalef's species richness and Shannon's diversity), were mainly associated with the Tribal land use, but were not correlated with the range condition type and did not reflect a rangeland condition gradient. The diversity indices rather reflected habitat structural complexity and environmental modifications/disturbances, than serving as an indicator of rangeland condition (see Chapter 4, Section 4.3.1.2; Chapter 5, Section 5.3.1.2). Diversity indices are also considered to reflect environmental changes characterised by moderate disturbances (see Chapter 4, Section 4.3.1.2; Chapter 5, Section 5.3.1.2). It is suggested that the diversity indices are environmental indicators (McGeoch 1998) rather than biodiversity indicators.

The integrated multivariate analyses corresponded well with the results presented in Chapter 4 (herbaceous species composition), Chapter 5 (woody component) and Chapter 6 (soil component). Land use type was indicated as the primary determinant of species-environment relations, while secondary variables also accounting for the species-environment variances, with regard to the woody and herbaceous components), were also presented within Chapter 7. Key herbaceous and woody species associated with the first two canonical axes, and having at least 10% of their ranges being accounted for by the species-environment variance, were indexed on a scale from 0 to 10 (after Hurt & Hardy 1989; Lawes *et al.* 2005) against the environmental variables primarily being associated with the respective axes.

In conclusion, the state-and-transitional model encompasses both equilibrium and non-equilibrium systems (see discussions of Chapters 4, 5, 6). Results from this study suggest that the state-and-transition model best describes the events (climatic and density-dependent coupling to key resources) associated with the semi-arid rangelands of the Molopo, as was indicated by the different land use types (and thus different land use disturbances). The resilient nature of these rangelands, typical of non-equilibrium systems, were reflected by the low to intermediate differences between land uses with regard to the herbaceous, woody and soil components. However, density-dependent coupling of herbivores (grazing and browsing) resulted in transitional shifts and modification of the habitat composition and structure, illustrating the equilibrium dynamics pertaining to these rangelands. Even small disturbances in these rangelands may result in “snowball” interactive biotic-biotic/abiotic cascades, as discussed in Section 7.3.4 and Section 7.4.4. This may have profound economical, ecological and social implications. A “Key assessment matrix” for rangeland monitoring and management purposes, incorporating results from Chapters 4 – 8, is presented in Chapter 9 (Concluding Remarks).

CHAPTER 8
Ant component

8.1. INTRODUCTION

Knowledge regarding the spatial distribution of organisms is the cornerstone towards understanding population and community dynamics, as well as the functioning of ecosystems (Crist & Wiens 1996). The need has been recognised, as emphasised by the Desert Margins Programme (DMP – GEF; see Chapter 2), that methods should be developed for the assessment and monitoring of the environmental condition and biodiversity of arid and semi-arid rangelands (Koala 2003), also within the study area described. It implies that indicators sensitive to disturbance (e.g. livestock grazing or other human induced disturbances) should be identified that can be consistently applied over large areas. McGeoch (1998) stated that soil, vegetation and fauna are major elements in many ecological processes within rangelands, and that they reflect biodiversity.

Invertebrates such as ants are often more sensitive indicators of ecosystem health than plants (Greenslade & Greenslade 1984; Disney 1986; Rosenberg *et al.* 1986; Majer 1989), which have been shown to be a poor surrogate for invertebrate biodiversity patterns (Crisp *et al.* 1998; Jonsson & Jonsell 1999; Eyere & Luff 2002).

Ants have been extensively used as bio-indicators at species and community level, particularly with regard to minesite restoration and forestry (Majer 1983; 1985; Majer *et al.* 1987; Andersen 1993; Jackson & Fox 1996; Vanderwoude *et al.* 2000; Andersen *et al.* 2002, 2004), the monitoring of the environmental effects of rangeland pastoralism for the semi-arid and arid rangelands of Australia (Wilson 1990), soil-vegetation changes as the result of drought and overgrazing (Wisdom & Whitford 1981; James *et al.* 1999), changes after fire (Andersen & McKaige 1987; Andersen 1991c), forest clear-cutting (Jenning *et al.* 1986; Whitford & Gentry 1981) and clearing for agriculture (Lobry de Bruyn 1993).

Ants have several attributes making them useful as bio-indicators and indicators of ecological change (Andersen *et al.* 2002; Nash *et al.* 2004). It is widely recognised by several authors that ants are extremely abundant, have relatively high species richness, include many specialist species, include some species at higher trophic levels, are responsive to changing environmental conditions and are relatively easily sampled and identified (Majer 1983; Greenslade & Greenslade 1984; Andersen 1990; Brown 1997; McGeoch 1998; Nash *et al.* 2001). Their distribution throughout the world in diverse habitats renders them sensitive responders to land transformation (Rosenberg *et al.* 1986; Roth *et al.* 1994; Folgarait 1998). Ants are also described as functionally important in structuring communities in savanna systems (Folgarait 1998), while they are also relatively easily sampled and sorted to morphospecies.

In this study, the effects of herbivory (livestock grazing and game grazing and browsing) on composition and structure of ant communities were examined with the purpose of evaluating ant communities and functional groups as potential indicators of land use management and rangeland condition. Nash *et al.* (2001, 2004) state that ant communities are likely to be affected by a widespread land use practice such as livestock grazing. Livestock grazing not only affects the vegetation, but also the soil physical characteristics. In contrast, Whitford *et al.* (1999b) found no consistent differences in ant assemblages that could be attributed to vegetation changes associated with livestock grazing. Hence, this study explored the potential for ant species assemblages to be used as one of a suite of indicators of land use management and rangeland condition.

The use of bio-indicators includes individual as well as groups of species, with the choice of selection being important to environmental and ecological indication (McGeoch 1998). For biodiversity indication, "shopping baskets" of suitable taxa are used when it is difficult to identify a single taxon complying with all the criteria of a bio-indicator (Hammon 1994). This study investigated whether a few key ant species/functional groups could be identified as easy and practical monitoring assessment tools of land use as well as rangeland condition. The conceptual framework for assigning range condition was provided by Dyksterhuis (1949). In order to attain this goal, it is essential to reflect whether observed ant compositional patterns are the result of primary or secondary influences, e.g. ant species composition and abundance are affected by the type and abundance of food sources (Andersen 1990, Sanders & Gordon 2003), nest site availability, food supply and microhabitat structure (Andersen 2000). Food sources for example, are primarily derived from vegetation, which may reflect different patterns due to different disturbances caused by different land use practices. Variations in vegetation structure may either enhance or reduce ant diversity by increasing or reducing habitat heterogeneity, microclimate or the activity of the most dominant species, depending on the proportion of ant taxa being hot- or cold climate specialists (Retana & Cerdá 2000). Studies have demonstrated that diversity is positively related to heterogeneity (Retana & Cerdá 2000). It is widely recognised that spatial and temporal heterogeneity are not only important components of biotic diversity (Braithwaite 1996), but also fundamental to ecosystem functioning (Christensen 1997). Changes in microclimatic conditions, e.g. as the result of vegetation changes due to disturbance, may result in temperature stress being the principal abiotic stress governing ant community structure in Australia (Andersen 1995a). Andersen (1995a) found that the abundances of dominant ants are limited by low temperatures, hence determining community competitive dynamics. Hence, differences in spatial and temporal thermal heterogeneity may alter ant species richness in that the assemblage structuring agents have changed from temperature variation to community competition dynamics (Retana & Cerdá 2000).

Functional group abundances vary in relation to environmental stress and disturbance (Andersen 1995a), and allow for the prediction of community responses to disturbance when species-information is lacking. Hence, it provides an ecological context to interpretation of compositional change (Andersen 1990), and reduces the complexity of communities (Andersen 1997a). The categorisation of species according to functional groups enables an understanding of species' responses to environmental variation simultaneously (Bestelmeyer 2000). Australian ant communities have been categorised into functional groups whose relative abundances vary predictably in relation to environmental stress and disturbance (Greenslade 1978, Andersen 1990, 1991a, d, 1995a). However, functional groups may be insensitive in detecting changes, which might be apparent at species level (Andersen 1997b), and should be verified with other techniques.

Nash *et al.* (2004) found that livestock grazing on ant communities were reflected as changes in relative abundance of some species, genera and functional groups, with no apparent influences on the species absence/presence. Hence, this study employed ant abundance data, relative abundances, absence/presence data, functional groups, as well as species richness and diversity indices descriptive to each of these mentioned interpretation methods, to establish relations to the various environmental variables (biotic and abiotic) discussed in the previous chapters. This was done to assess the effectiveness of different analyses at species and functional level as indicators for describing ant assemblages in three different land uses (bio-indicator) and for monitoring ecosystem health (environmental indicator). Such indicators are valuable since they may act as "early warning" indicators of ecological change, enabling managers to modify practices to avoid undesirable ecological changes and a loss of biological integrity. Such indicators should not only be sensitive to disturbance, but must also be consistently applicable across large areas (Nash *et al.* 2001).

Andersen (1991a) states that ant colonies behave more like plants than animals do, resulting in a considerable ecological overlap, suggesting that ant communities might be classified according to structural attributes that paralled those in vegetation science. This study does not suggest that ants are surrogates for overall biodiversity, but that they are useful in indicating diversity patterns and loss of other species. It is further suggested that ants can act as environmental indicators that respond to environmental disturbance (McGeoch 1998) such as land use impacts (Nash *et al.* 2001, 2004).

This study specifically addresses the following key questions. Do the three different land uses govern ant assemblage patterns, and do ants reflect the vegetation and abiotic patterns associated with these land uses? Secondly, do ant species compositional and functional group patterns reflect the rangeland condition (expressed as relative "Good" vs. "Poor" extremes)? Hence, can ants be used as bio-indicators of diversity patterns of other species and as environmental indicators of ecosystem disturbances caused by different land uses? Finally, are there congruent patterns between ants and selected vegetation properties in reflecting patterns caused by different land uses?

8.2. RESULTS AND DISCUSSION

In order to address the key questions and to investigate key ant species and key environmental variables indicating and explaining most of the species-environment variance, the results will be discussed under the following headings, as motivated in brackets next to each section. Due to the complexity of the data, the Results and the discussion will be presented under the same headings. Ant functional groups and species compositional patterns were identified, and related to other environmental (biotic and abiotic) variables. ***For further clarification as to what the purpose of each analysis technique is, refer to Chapter 3, Material and Methods. Average relative abundances and absolute abundances for functional groups, species composition and genera within and between land uses are presented within the Tables and Appendices, as indicated by each relevant section. However, it should be emphasised that these GENERAL descriptive statistics, although informative, may result in major incorrect assumptions that do not reflect on spatial heterogeneity, complexity and gradients within and between land uses pertaining to rangeland degradation and biodiversity indices, neither does it reflect on the models operating within these rangelands. Neither does it reflect on key species that are consistently associated with particular land uses, rangeland conditions or other criteria. Hence, this may result in incorrect over-extrapolation of management and monitoring techniques between land uses and across different parameters, which might prove to be "development experiments" that might result in unfortunate implications for both the ecosystems and people (Ellis & Swift 1988).***

Hence, it can not be emphasised enough that, although these different analyses techniques might result in the **incorrect** perception of over-analysing, the different procedures were all essential and complementary to each other. It was only after the in-dept analyses, using the different procedures that it was possible to establish the different multivariate spatial patterns, heterogeneity complexity and diversity- and rangeland gradients pertaining to the ant compositional and functional data, which exist within and between land uses due to different land use impacts (refer to Conclusions within each chapter and final Concluding Remarks in Chapter 9).

8.2.1 **General** (a general overview)
8.2.2 **Functional groups**
8.2.3 **Multidimensional scaling** (MDS iterative procedures, based on absolute abundances vs. absence/presence data, to establish whether removal of sites from further analyses are necessary)
8.2.4 **Species dominance** (establishes ant assemblage patterns within and between land uses, based on:)
8.2.4.1 **Total ant abundance**
8.2.4.2 **ANOSIM: Absolute ant abundance, relative abundance and absence/presence data** (ANOSIM analysis of dissimilarities within and between groups based on these three matrices)
8.2.4.3 **SIMPER analysis: Absolute ant abundance, relative abundance and absence/presence data** (SIMPER % contributions to similarity within groups and dissimilarity between groups)
8.2.4.4 **K-dominance and species-rank curves** (establish whether species accumulative asymptotes in respective land uses have been reached)
8.2.5 **Species richness and diversity** (based on absolute abundance data: ANOSIM to establish patterns within and between groups based on absolute abundance data)

8.2.6 Community patterns – indirect DCA (based on absolute abundance vs. absence/presence matrices)

8.2.7 Community patterns – direct CCA and Monte Carlo test - establish species-environment relation (employing the land use, relative "Good" and relative "Poor" as environmental variables: absolute abundance data vs. absence/presence data)

8.2.8 Cumulative contribution to species variance (Cumulative variance explained by species contributing to > 10% contribution to species-environment relations)

8.2.9 Indicator species – IndVal method (single species indicators of land use for this study)

8.2.10 Multivariate integration of ant species compositional with environmental data (CCA ordinations, Monte Carlo and BVSTEP tests to establish metrics within different environmental matrices that contribute to explaining ant species-environment relations, hence for total ant compositional data sets)

8.2.11 Partial canonical ordination to distinguish between primary and secondary determinants of ant species-environment relations

8.2.12 Employing individual environmental data sets as predictors for ant species-environment associations (hence, select key ant species primarily associated with each separate environmental data matrix and finally to key environmental variables)

8.2.1 General

A total of 48 671 individuals, representing 73 morphospecies, were collected during the trapping period of 48 hours (Appendices 8.1a, b). Within Appendix 8.1a, the absolute numbers (absolute abundances) of each species within each survey area (replicate) are given. The absolute numbers of each species are also expressed as a percentage of the total within that survey site (sub-replicate or grid); as a percentage of the specific land use; as a percentage of the total survey area; and finally as a percentage, within the land use, of the total survey area (refer to Chapter 2). The mean absolute abundances of each species within each land use group are summarised in Appendix 8.1b. Twenty-one genera were sampled, and in addition one coded species (*Sp. XII*) (Table 8.1; Fig. 8.1). *Tetramorium* was the richest genera (19 species), followed by *Monomorium* and *Campontus* (7 species each), *Ocymyrmex* (6), *Anoplolepis* (4), *Pheidole* (4), *Meranoplus* (4) and *Lepisiota* (4). The number of species within the *Tetramorium* genus was highest in the Tribal land use (15), followed by the Reserve- (14) and Commercial (13) land uses. The number of species associated with the *Camponotus* genus was highest within the Commercial land use (7), followed by the Reserve and Tribal land uses (6 species each). The genus *Monomorium* was best represented by the Tribal and Reserve land use (6 species each) (5 species for the Commercial land use). The Reserve land use had the highest number of species within the genus *Ocymyrmex* (6), with the Tribal and Commercial land uses having 5 species each. The Commercial land use had the most *Anoplolepis* species (4), with the Reserve and Tribal land uses having 3 species each (Table 8.1; Appendix 8.1a). The number of species within each genus for the different land uses is summarised in Table 8.1. Patterns related to these genera, when categorised into functional groups, will be discussed next in Section 8.2.2.

The abbreviations for the ant species are summarised in Appendix 8.1, and those of the functional groups in Table 3.1, and should be consulted for the interpretation of the Tables,Figures and Appendices.

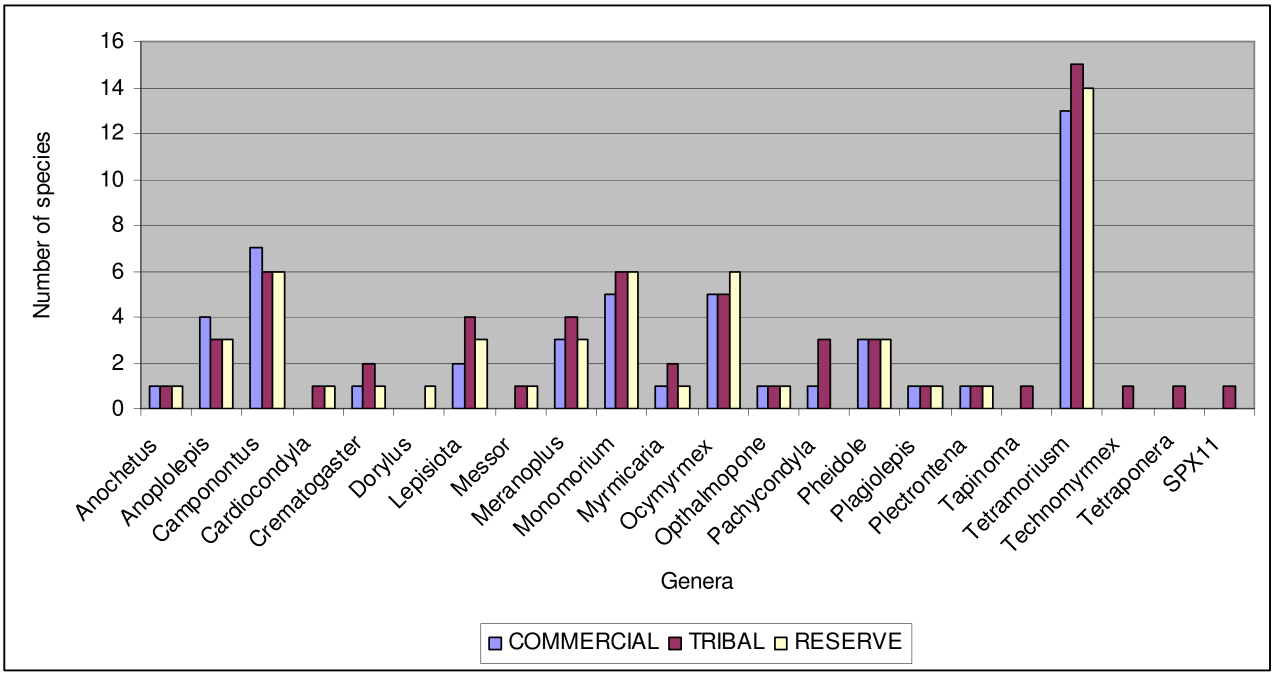


Fig. 8.1. The number of genera within each land use.

Table 8.1. The number of species within each genera as well as the total number of ants per genera within each land use

Genera	**Species/Genera Commercial**	**Species/Genera Tribal**	**Species/Genera Reserve**	**Species/Genera Total study area**	**Number of ants Commercial**	**Number of ants Tribal**	**Number of ants Reserve**	**Number of ants Total study area**
Anochetus	1	1	1	**1**	1	2	8	**11**
Anoplolepis	4	3	3	**4**	3869	337	26506	**30712**
Camponotus	7	6	6	**7**	70	165	138	**373**
Cardiocondyla	0	1	1	**1**	0	116	16	**132**
Crematogaster	1	2	1	**2**	29	327	12	**368**
Dorylus	0	0	1	**1**	0	0	1	**1**
Lepisiota	2	4	3	**4**	68	71	62	**201**
Meranoplus	3	4	3	**4**	120	101	52	**273**
Messor	0	1	1	**1**	0	7	13	**20**
Monomorium	5	6	6	**7**	1116	1321	1290	**3727**
Myrmicaria	1	2	1	**2**	32	1890	3115	**5037**
Ocymyrmex	5	5	6	**6**	1034	298	755	**2087**
Opthalmopone	1	1	1	**1**	9	17	27	**53**
Pachycondyla	1	3	0	**3**	1	9	0	**10**
Pheidole	4	4	4	**4**	1262	1103	929	**3294**
Plagiolepis	1	1	1	**1**	3	14	2	**19**
Plectrotena	1	1	1	**1**	8	28	11	**47**
Coded (Sp. XII)	0	1	0	**1**	0	7	0	**7**
Tapinoma	0	1	0	**1**	0	21	0	**21**
Technomyrnex	0	1	0	**1**	0	1	0	**1**
Tetramorium	13	15	14	**19**	778	999	499	**2276**
Tetraponera	0	0	1	**1**	0	0	1	**1**
TOTAL	**50**	**63**	**55**	**73**	**8400**	**6835**	**33437**	**48671**

8.2.2 Functional groups

Bio-indicators are most effective when supported by an understanding of the community dynamics, in ants to an extent not being matched by any other invertebrate group (Andersen 1997a). Ants were classified according to functional groups (Appendix 8.1a). Results on the functional group classification for all the land uses are presented in Table 8.2 and Fig 8.2. Functional groups are regarded as more powerful tools used to advance our understanding of ecological systems, by recognising species by their ecological behaviour rather than by their taxonomic affinity (Andersen 1990). Hence, classification of species in functional groups is especially suited to environmental evaluation systems. Functional groups respond predictively to disturbance and environmental stress, hence factors that limit productivity (e.g. moisture, nutrients, temperature, food shortage) (Andersen 1991a, 1997a). Changes in functional groups are also said to give a good indication of changes in other invertebrate groups, being sometimes a better indictor than at species level (Andersen 1997a). Many functional groups also show parallels with plant life-forms in reaction to environmental disturbance and stress (Andersen 1995a). In this context, stress and disturbance should be considered in terms of productivity of ants, not in terms of general effects on the habitat (Andersen 1995a). Hence, this study will attempt to explain whether congruent patterns among plant –and ant communities are the parallel results of the same environmental disturbance and stress (being the primary causative determinants of both plant and ant patterns), or are the patterns although related, not the result of the same causative factors. For example, are environmental stress and disturbance experienced by plants in these semi-arid rangelands also impacting and regulating ant assemblages?

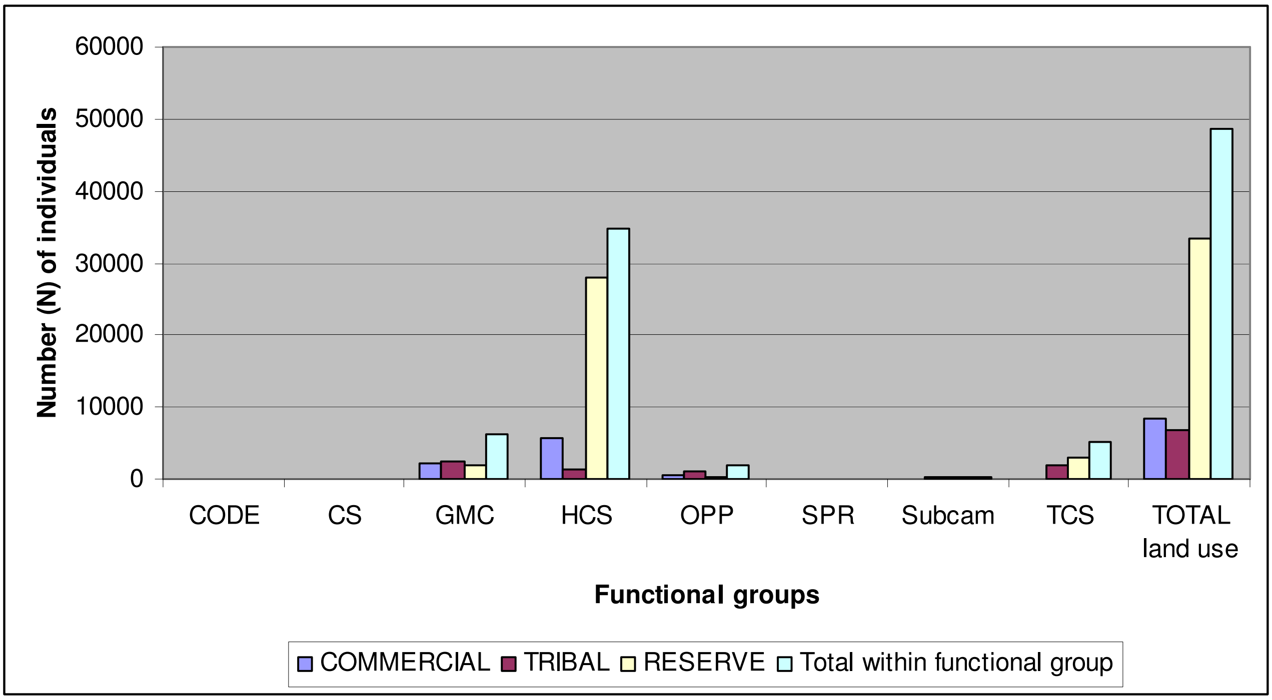


Fig. 8.2. The total number of ants within each functional group (explanation of abbreviations presented in Chapter 3, Table 3.1).

Table 8.2. Absolute ant numbers per functional group within each land use; expressed as the percentage (%) of a functional group across all land uses; as the average number of ants per functional group within each land use and as average percentages within each land use (explanation of abbreviations presented in Chapter 3, Table 3.1).

Total individuals (*N*) within land use	**CODE/*Sp XII***	**CS**	**GMC**	**HCS**	**OPP**	**SPR**	**Subcam**	**TCS**	**TOTAL land use**
Commercial	0	3	2044	5671	561	19	70	32	**8400**
Tribal	7	14	2349	1295	1058	56	165	1890	**6835**
Reserve	0	2	1894	27854	386	46	138	3117	**33437**
Total within functional group	**7**	**19**	**6287**	**34820**	**2005**	**121**	**373**	**5039**	**48671**
% of Total abundance	**0.01**	**0.04**	**12.92**	**71.54**	**4.12**	**0.25**	**0.77**	**10.35**	
% Total of functional group across all land uses	**CODE/*Sp XII***	**CS**	**GMC**	**HCS**	**OPP**	**SPR**	**Subcam**	**TCS**	
Commercial	0.00	15.73	32.51	16.29	27.98	15.66	18.76	0.64	**NA**
Tribal	100.00	73.78	37.36	3.72	52.75	46.44	44.32	37.51	**NA**
Reserve	0.00	10.49	30.13	79.99	19.27	37.90	36.92	61.85	**NA**
Average numbers within each land use	**CODE/*Sp XII***	**CS**	**GMC**	**HCS**	**OPP**	**SPR**	**Subcam**	**TCS**	
Commercial	0.00	0.17	113.56	315.06	31.17	1.06	3.89	1.78	**466.68**
Tribal	0.39	0.78	130.50	71.95	58.76	3.13	9.19	105.01	**379.72**
Reserve	0.00	0.11	105.22	1547.42	21.46	2.56	7.65	173.16	**1857.59**
Average % within each land use	**CODE/*Sp XII***	**CS**	**GMC**	**HCS**	**OPP**	**SPR**	**Subcam**	**TCS**	
Commercial	0.00	0.04	24.33	67.51	6.68	0.23	0.83	0.38	**100.00**
Tribal	0.10	0.21	34.37	18.95	15.48	0.82	2.42	27.66	**100.00**
Reserve	0.00	0.01	5.66	83.30	1.16	0.14	0.41	9.32	**100.00**

A two-way crossed ANOSIM, based on all the functional groups, indicated significant differences between the Commercial-Tribal land uses (r = 0.286, $P < 0.001$), the Commercial-Reserve land uses (r = 0.123, $P < 0.05$), but no functional differences between the Tribal-Reserve land uses (r = 0.02, $P > 0.1$). There was also no functional difference between the relative condition groups ("Good" vs. "Poor") when averaged across all land uses (r = 0.022, $P > 0.1$). Hence, based on the overall functional group classification, the Reserve and Tribal land uses were more similar to each other than the Commercial-Reserve of Commercial-Tribal land uses were. The functional group classification was not related to rangeland condition, thus reflecting no range condition gradient.

However, when differences between the relative "Poor" and "Good" groups *within* each land use for the total functional matrix were tested, it was significant for the Commercial land use (r = 0.218, $P < 0.05$) only, but not for the Tribal and Reserve land uses ($P > 0.1$). Hence, a disturbance gradient related to the range condition was evident within the Commercial land use only at this more in-depth level.

Two-way crossed pairwise ANOSIM tests to establish differences between the land uses, based on *each* independent functional group, were investigated. Differences were significant only between the following land uses for the following functional groups: Cryptic species (CS) (r = 0.11, $P < 0.05$ for the Tribal-Reserve land uses); Hot Climate Specialists (HCS) (r = 0.203, $P < 0.05$ for the Commercial-Tribal land uses); Subordinate Camponotini (Subcam) (r = 0.143, $P < 0.05$ for the Commercial-Tribal land uses); Tropical Climate Specialists (TCS) (r = 0.208, $P < 0.05$ for the Commercial-Tribal groups; r = 0.23, $P < 0.001$ for the Commercial-Reserve land uses). These differences suggest that the two land uses compared at a time, differed in terms of functional structure for that particular group.

The most abundant functional group for the entire study area (irrespective of land use) was the HCS (71.54%; N = 34 820 individuals) followed by the Generalised Myrmicinae (GMC; 12.92%; N = 6 287) (Table 8.2) (Fig. 8.2). Abundance of functional groups across the land uses indicated that the HCS was most abundant within the Reserve land use (79.99%), in the Commercial land use (16.29%), with only 3.72% occurring in the Tribal land use (Fig. 8.3). Further comparisons between functional groups across all three land uses indicated that the Tribal land use had the highest abundance within each functional group, except for the HCS and TCS which were highest in the Reserve land use (Fig. 8.3).

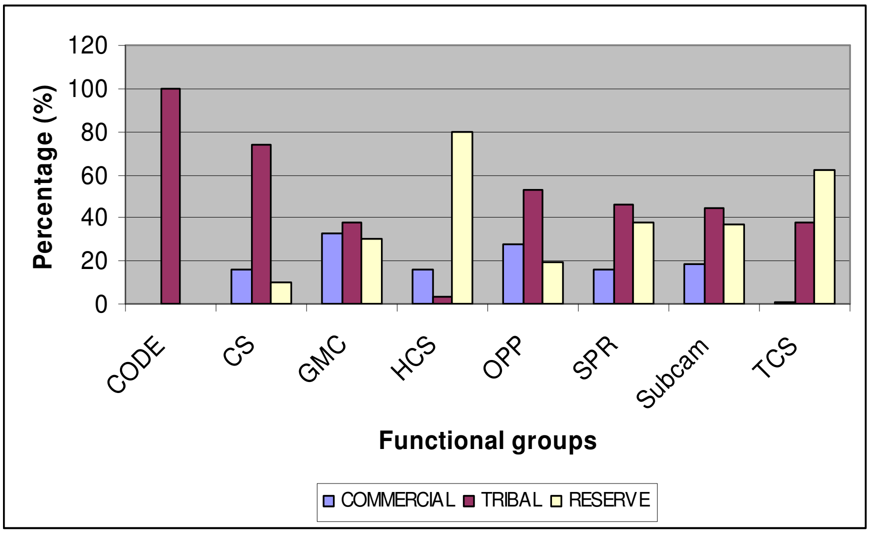


Fig. 8.3. Percentage (%) contribution by each functional group across all land uses to the total of each functional group for the larger study area group (explanation of abbreviations presented in Chapter 3, Table 3.1).

Average abundances of functional groups *within* a land use were investigated to establish whether differences existed at this level (Table 8.2; Fig. 8.4). This was done to distinguish whether investigation to this depth is necessary for rangeland assessment and monitoring purposes. The HCS was the most dominant functional group within the Reserve (84%) and Commercial land uses (68%) (Table 8.2; Fig. 8.4). Generalised Myrmicinae (GMC; 24%) was the second-most abundant group within the Commercial land use. The most dominant groups within the Tribal land uses were GMC (35%), followed by TCS (28%), HCS (19%) and Opportunists (OPP; 15%) (Table 8.2; Fig. 8.4). Several studies have described that in the absence of disturbance, the abundance of *most* functional groups were determined by stress-related factors such as climate and behavioural influences (barring Opportunists and GMC), whereas habitat disturbances often result in OPP and GMC to flourish (Andersen 1995a, 1997a, c; Majer *et al*. 2004).

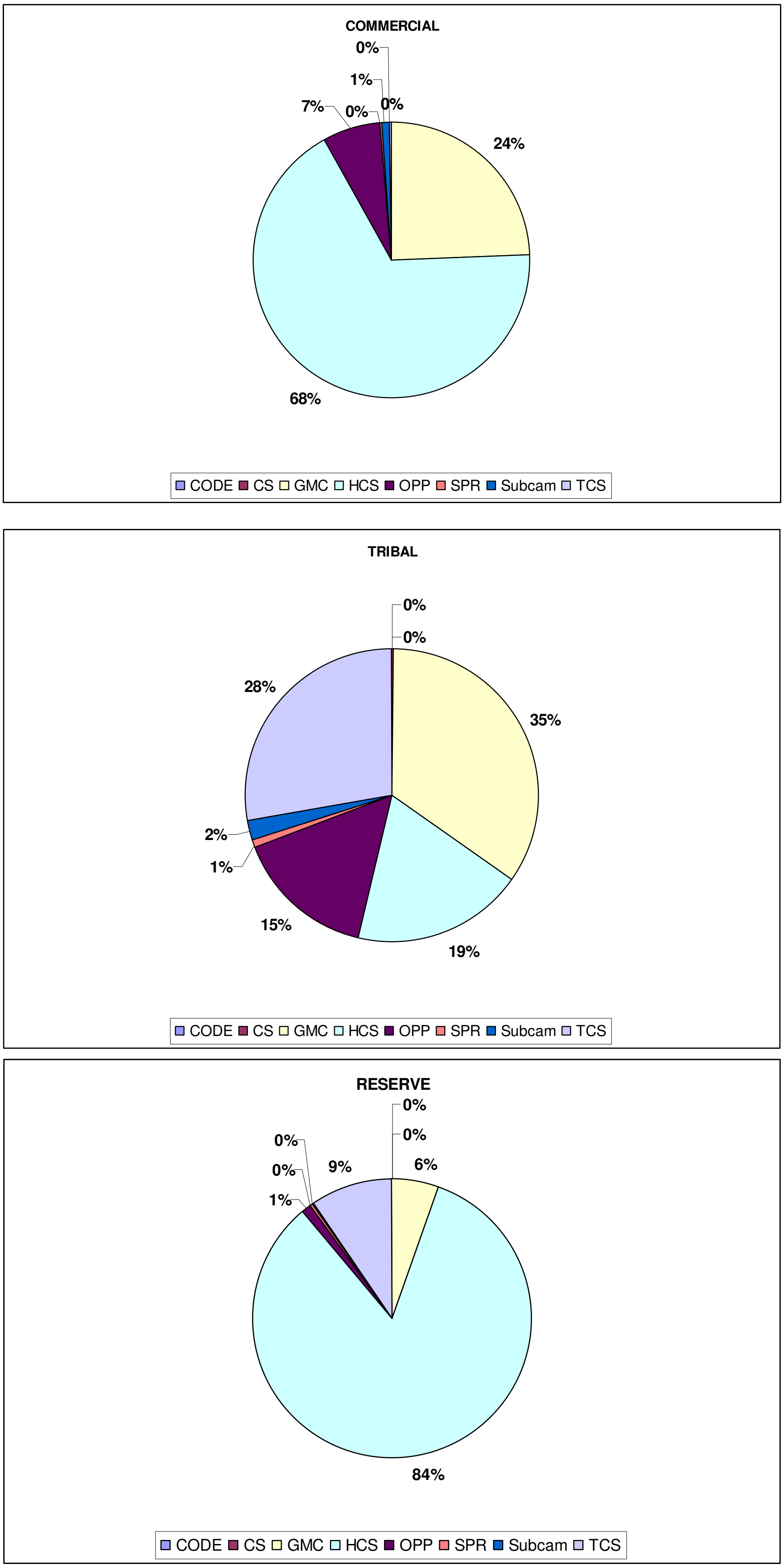


Fig. 8.4. Average abundances of functional groups *within* each land use (explanation of abbreviations presented in Chapter 3, Table 3.1).

Based on this assumption, it can be reasoned that behavioural and climate-related factors are the primary determinant of community structure within the Reserve land (as a result of the habitat created by this land use), hence being indicative of undisturbed habitats. Furthermore, according to these assumptions for the functional groups, the Commercial land use could also be considered as relatively undisturbed, but less so than the Reserve, owing to the larger component of GMC and OPP (7%) found within this land use, indicative of areas being disturbed (Andersen 1995a, 1997a, c; Majer *et al.* 2004). This can be ascribed to the larger degree of natural habitat modification and hence habitat disturbance found in the Commercial land use than within the Reserve land use (see previous chapters on vegetation). The primary functional group composition related to the Tribal land use, consisted of OPP and GMC, hence according to these authors' explanations, reflecting habitat disturbances, which negatively impact on microclimate, food supplies and changes in vegetation structure, resulting in a lower competitive pressure on these two functional groups which explains their higher abundances relative to the other functional groups within this land use. Andersen (2000) found that increased structural complexity of vegetation resulted in a reduced insolation at the soil surface, reducing the abundance of HCS and increasing the abundance of GMC. GMC tend to predominate in moderately productive environments for ants (Andersen 2003).

Although this information and classification provide to be informative in explaining ant species-environment relations, the significance should be verified with multivariate analysis to establish:

1. Whether the functional groups display the same patterns as within the single species-environment multivariate relations, and are the functional group classification although informative, still too robust and preliminary for the Molopo study area?
2. Do the structuring of ant assemblages according to the definition of "disturbance" and "productivity" for both the ant functional group and single species-environment relations correspond with these definitions when employed in vegetation analyses and definitions?

The relationship between the land uses and relative condition groups (environmental variables) and ant abundance data was directly examined by canonical correspondence analysis (CCA) (Table 8.3). The CCA extracted gradients in the functional group composition that were constrained to be a function of the explanatory/environmental variables (Ter Braak & Šmilauer 1998) and allowed functional groups that were most responsive to the explanatory variables, in this case the different land use and relative "Good" and "Poor" groups, to be identified. The effect of these environmental variables on the ant species composition was tested with a Monte Carlo permutation test (N = 499) (Manly 1997).

The first two axes of the CCA ordination explained 97.5% of the species-environment variance and 99.9% by the fourth axis. For the passive data, 97.7% of the species-environment relation was explained by the second axis. Environmental variables that showed the strongest association with the first axis, were the Reserve-Poor interaction (r = 0.25), Reserve- (r = 0.246, fourth quadrant) and Tribal (r = -0.245, third quadrant) land uses. The second axis was best associated with the Commercial-Good interaction (r = 0.282, second quadrant) and Reserve (r = -0.26) land use environmental variables (Table 8.4) (Fig. 8.5). For the passive variables, the first axis was best described by ant abundance (r = 0.93, first quadrant), which was primarily associated with the Reserve and then Commercial land uses, ant diversity, and species richness and ant evenness (all associated with the third quadrant and Tribal variables). The second axis was best represented by the woody variables (BE/ha; bush numbers/ha; bush cover) and by the number of ant species (Table 8.4) (Fig. 8.6). These passive variables were associated with the Tribal variables (third quadrant). Ant abundance was negatively correlated with ant diversity (r = -0.816), ant richness (r = -0.556), number of ant species (r = -0.406) and ant evenness (r = -0.888). Ant richness was positively correlated with ant diversity (r = 0.856), evenness (r = 0.562), herbaceous diversity (Ann div; r = 0.218) and woody diversity (Bsh.div, r = 0.26) (Table 8.5).

Table 8.3. A CCA ordination based on ant functional groups showing the eigenvalues, cumulative species data and species-environment variance for the first four axes, as well as the significance of the canonical axes as indicated by the Monte Carlo permutation test.

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.095	0.024	0.002	0.001
Species-environment correlations	0.339	0.426	0.315	0.266
Cumulative percentage variance				
of species data	9.5	11.9	12.1	12.2
of species-environment relation (environmental)	78.1	97.5	99	99.9
of species-environment relation (passive data)	92.1	97.7	99.2	99.5

<u>Monte Carlo permutation test</u>

Test of significance of first canonical axis: eigenvalue= 0.095
F-ratio = 5.05
P-value = 0.26
Test of significance of all canonical axes : Trace = 0.122
F-ratio = 1.333
P-value = 0.166

Table 8.4. CCA correlation coefficients (r-values) for the environmental and passive variables associated with the first two CCA axes for the ant functional groups, with the variables showing the highest r-values being indicated in **bold**.

Environmental data	**SPEC AX1**	**SPEC AX2**	**Passive data**	**SPEC AX1**	**SPEC AX2**
Commercial	-0.0012	**0.3972**	BE/HA	-0.1582	**-0.3611**
Tribal	**-0.2447**	-0.1388	Bushcov	-0.1063	**-0.3275**
Reserve	**0.2459**	**-0.2584**	Bush num/ha	-0.1759	-0.2782
Good	0.0184	0.0005	VCSAGRAZ	-0.0733	0.0683
Poor	-0.0184	-0.0005	DM/HA	-0.0299	0.0669
Com*Good	0.1086	**0.2827**	VCSAECOL	-0.0552	0.078
Com*Poor	-0.1101	0.2197	ANNdiv	-0.0263	0.0282
Tri*Poor	-0.1646	-0.1421	Antabun	**0.9304**	0.0744
Tri*Good	-0.1449	-0.0334	AntSpec	-0.3924	**-0.3287**
Res*Good	0.061	-0.2485	Bsh.div	-0.0859	-0.2699
Res*Poor	0.2501	-0.0783	Antrich	-0.5758	-0.2328
			Anteven	**-0.9294**	0.0065
			Antdiv	**-0.8457**	-0.1352

Table 8.5. A CCA correlation matrix between the passive variables for ant functional groups, with relatively high r-values being indicated in **bold**.

BE/HA	1												
Bushcov	0.7722	1											
Bush num/ha	0.8192	0.5235	1										
VCSAGRAZ	-0.411	-0.4041	-0.2991	1									
DM/HA	0.0154	-0.1311	0.1131	0.391	1								
VCSAECOL	-0.3766	-0.3979	-0.2501	0.9618	0.4064	1							
ANNdiv	0.3044	0.139	0.4139	-0.108	0.097	-0.0639	1						
Antabun	-0.0847	-0.0578	-0.096	-0.1347	-0.0819	-0.1451	0.0253	-0.8161	1				
AntSpec	0.4342	0.3988	0.435	0.0802	0.3805	0.1235	0.2207	0.7305	**-0.4056**	1			
Bsh.div	0.1279	0.325	0.0545	-0.096	-0.0674	-0.0645	0.0179	0.1749	-0.0304	0.2616	1		
Antrich	0.3969	0.3412	0.3925	0.0738	0.3781	0.1088	0.2176	0.857	-0.5561	0.9522	0.2618	1	
Anteven	0.1257	0.1167	0.1083	0.0228	-0.0052	0.0134	0.0278	0.8983	-0.8884	0.3651	0.0846	**0.5621**	1
Antdiv	0.2956	0.2736	0.274	0.0439	0.1749	0.0546	0.1333	1	-0.8165	**0.7301**	0.1756	0.8569	0.8985
	BE/HA	**Bushcov**	**Bush num/ha**	**VCSAGRAZ**	**DM/HA**	**VCSAECOL**	**ANNdiv**	**Antdiv**	**Antabun**	**AntSpec**	**Bsh.div**	**Antrich**	**Anteven**

However, the Monte Carlo test for the first as well as all canonical axes were not significant ($P > 0.1$), with the Reserve land use (as subset) being the most important variable explaining the species-environment variance ($P < 0.05$, $F = 3.25$). Hence, it is suggested that although these multivariate patterns related to the functional groups are informative, compositional patterns at species level and their significance should be investigated as possibly more sensitive environmental and bio-indicators in addition to the functional groups.

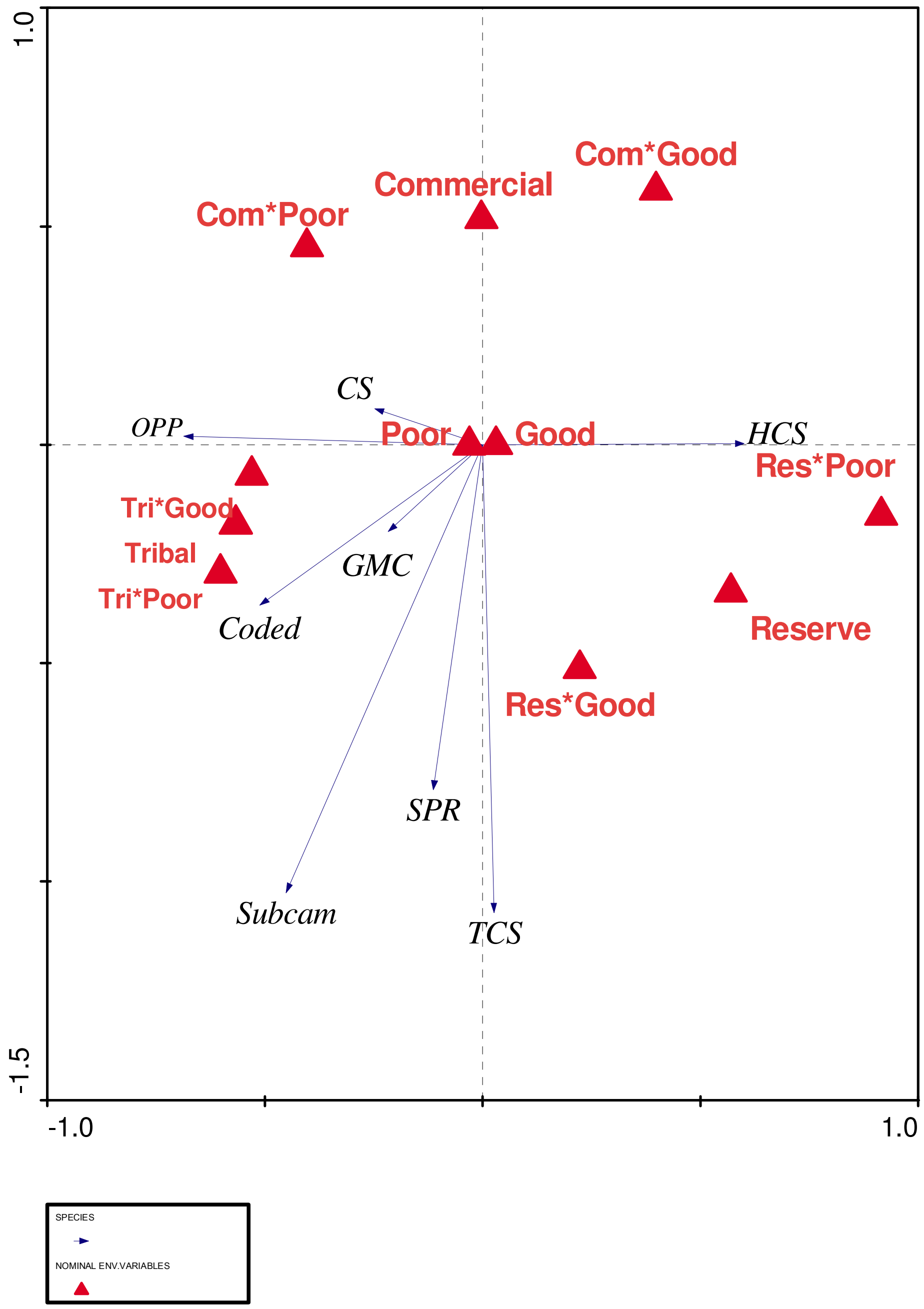


Fig 8.5. A CCA biplot displaying environmental and functional groups (explanation of abbreviations presented in Chapter 3, Table 3.1).

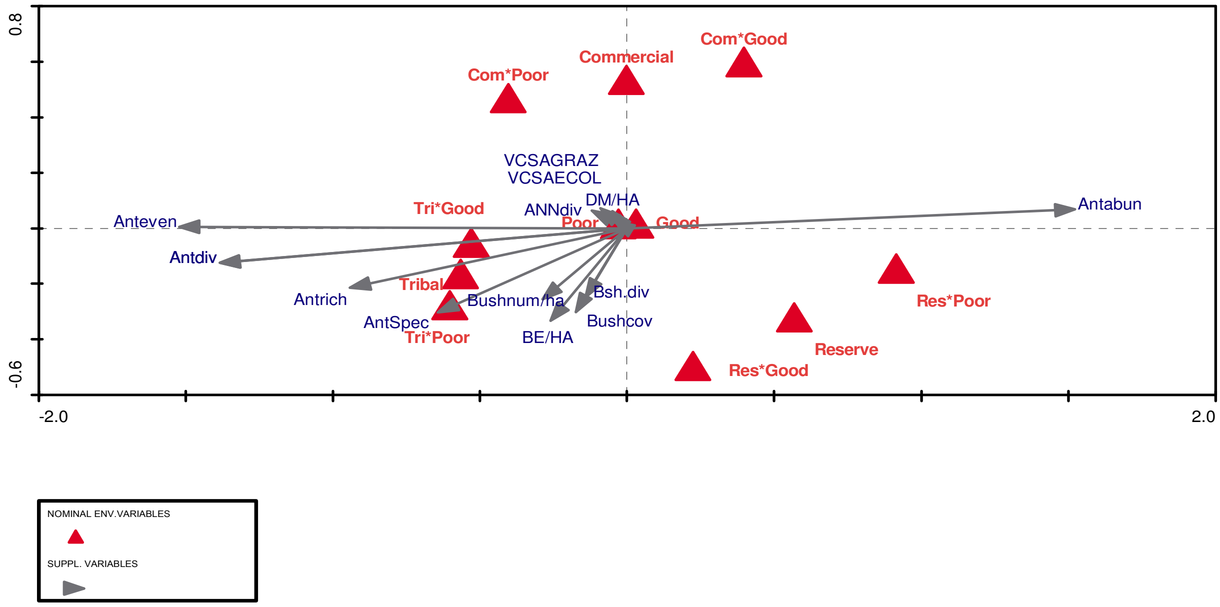


Fig 8.6. A CCA ordination biplot presenting environmental and passive variables for the functional groups.

8.2.3 Multidimensional scaling (MDS) – absolute abundances, absence-presence data

A non-metric MDS algorithm, an iterative procedure based on Bray-Curtis dissimilarities, was employed to satisfy as closely as possible the dissimilarity relations between samples. The MDS ordination, based on the square-root transformed absolute abundance matrix, indicated site mS2 as a possible outlier sample (Fig 8.7a). It was removed from the analysis and a new MDS plot indicated that the stress value, an indication of the distortion between the dissimilarity rankings and the corresponding distance rankings in the ordination plot (Clarke & Warwick 2001) increased, motivating that sample mS2 should not be removed (Fig 8.7b). Site mS2 was characterised by a high dominance (hence a high abundance) of *Anoplolepis steingroeveri*. However, this species also occurred relatively commonly in other Reserve and Commercial sites, although in lower abundances (Appendix 1a, b), suggesting the inclusion of site mS2 in the rest of the analysis. This phenomenum will be explained more in-depth in the remainder of this chapter according to ant species' functional group classification, species richness, -diversity and dominance patterns.

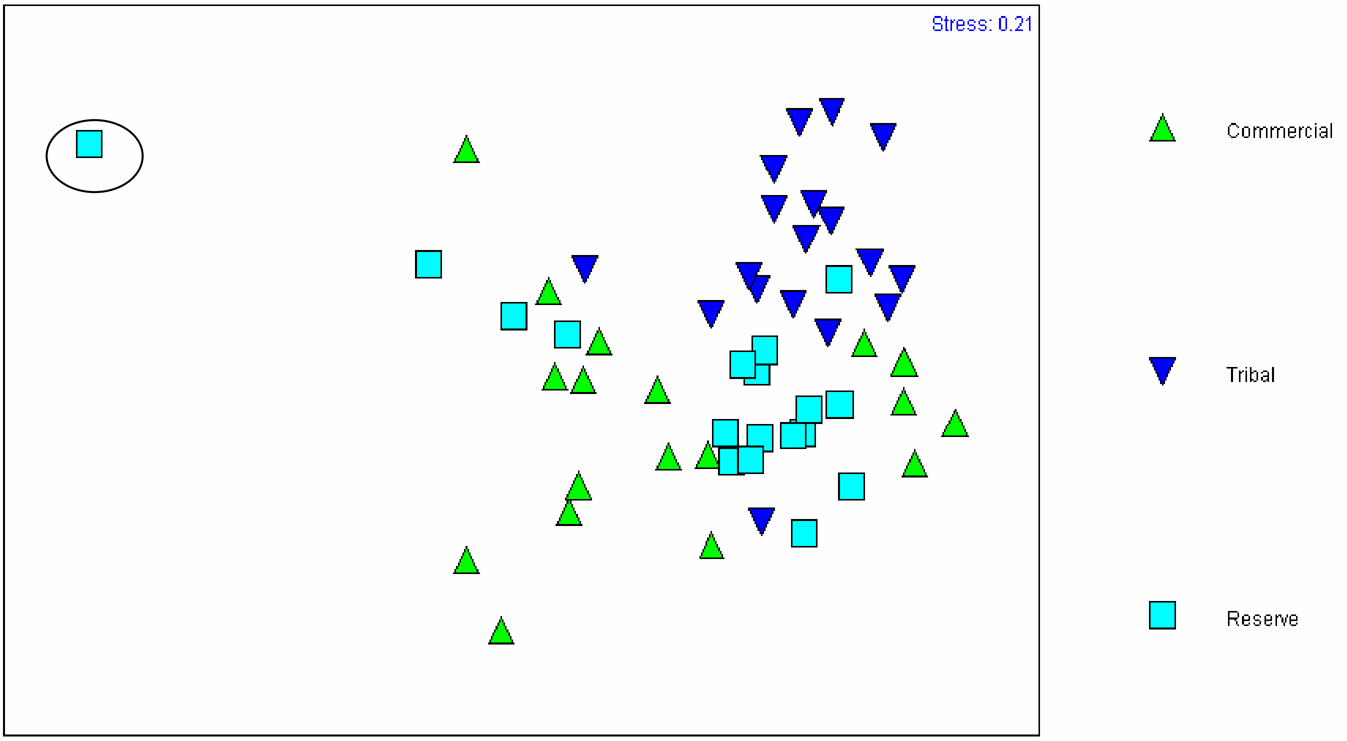


Fig 8.7a. A MDS plot for square-root transformed absolute ant abundances, with the inclusion of the “outlier” site mS2.

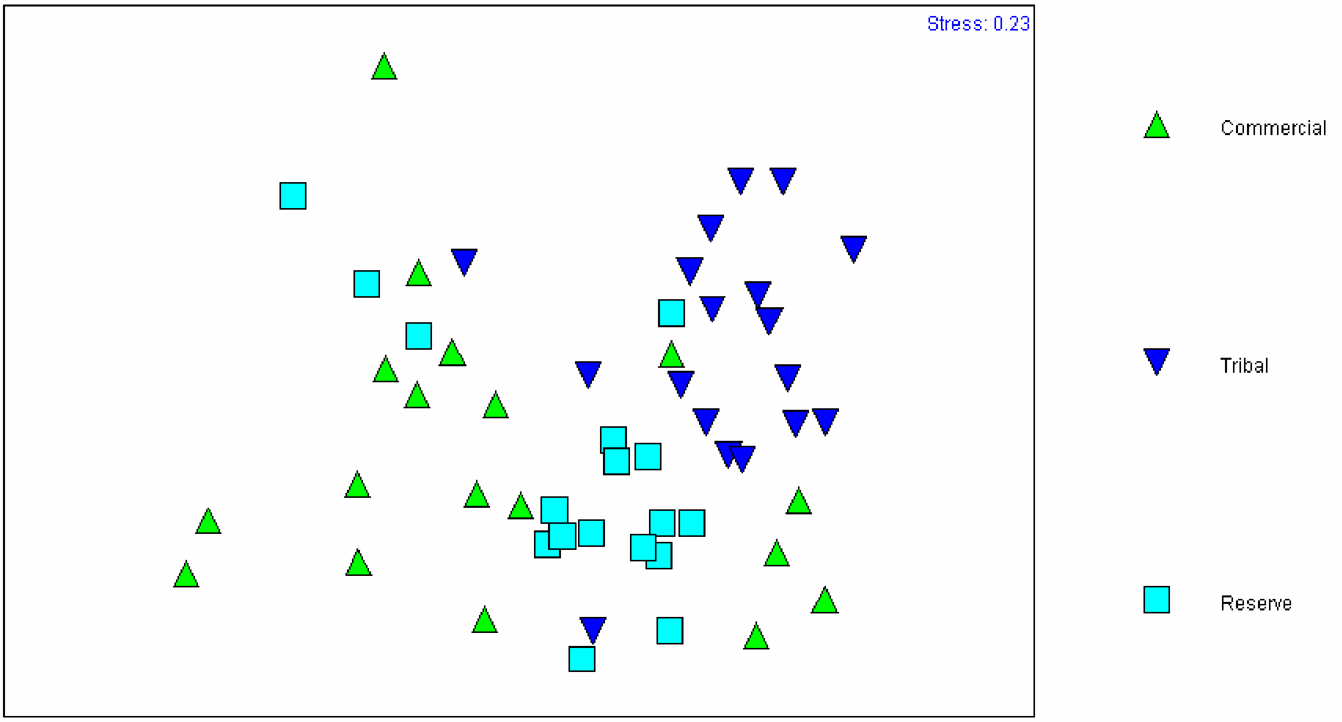


Fig. 8.7b. A MDS plot for square-root transformed absolute ant abundances, with the removal of the “outlier” site mS2.

The MDS plot incorporating absence-presence data was similar to that of the abundance data, and hence will not be presented again.

8.2.4 Species dominance

Ant numbers (N) within each site, and species occurrences expressed as a percentage of the total within a land use and a total of the larger study area, are presented in Appendix 8.1a. The number of species per genera for each land use is summarised in Table 8.1.

8.2.4.1 Total ant abundance

A two-way crossed analysis of similarities (ANOSIM), incorporating Bray-Curtis dissimilarty measures, showed no significant differences based on the square-root transformed **total (sum)** abundances between the three land uses, with $r = 0.038$ ($P > 0.1$) for the Commercial-Tribal land uses, $r = 0.001$ ($P > 0.1$) for the Commercial-Reserve groups and $r = 0.003$, ($P > 0.1$) for the Tribal-Reserve land uses. There were also no significant differences between the relative "Good" and "Poor" groups when averaged across *all* land uses ($r = 0.04$, $P > 0.1$). Hence, it is suggested that ANOSIMS, incorporating absolute and relative abundances for the entire species matrix instead of employing the total abundance for each land use only (thus, dimensionality of data is removed and presented as one figure only, should be used as a comparative measures to establish differences within and between land uses). This is discussed in the following section (Section 8.2.4.2).

Differences between the relative "Good" and "Poor" groups based on the total abundance *within* each land use, were investigated by means of one-way ANOSIM tests. There was a significant difference between these two range condition groups for the Commercial land use ($r = 0.281$, $P < 0.001$), but no significant differences between these relative condition groups for the Tribal and Reserve groups ($P > 0.1$). The Commercial land use was the only group showing an observable gradient based on the relative condition ("Good" vs. "Poor").

Hence, *total* ant abundance seems to have little potential to serve as indicators of rangeland condition when averaged across *all* land uses. However, it does seem to have potential within the Commercial land use. These findings are consistent with that of Nash *et al.* (2004) that found that ant communities showed patterns related to localised rather than in intermediate widespread conditions.

8.2.4.2 General and Analysis of similarities (ANOSIM): Absolute abundance, relative abundances and absence/presence data matrices

A. Absolute abundance

The abundance of *each* species was calculated as the sums of the abundance scores at each grid/site within a land use and also cumulatively summarised over all the land uses. Total ant abundance was highest in the Reserve land use (*N* = 33 437, 68.7%), followed by the Commercial (*N* = 8 400, 17.26%) and Tribal (*N* = 6 835, 14.04%) land uses.

Analysis of similarities based on Bray-Curtis dissimilarity measures, for the **species abundance data matrix (absolute abundances)** (two-way crossed ANOSIM, square-root transformed) indicated significant differences between all the land uses. The difference was intermediate between the Commercial-Tribal land uses (r = 0.456, $P < 0.001$), intermediate-low between the Tribal-Reserve land uses (r = 0.315, $P < 0.001$) and low between the Commercial-Reserve land uses (r = 0.163, $P < 0.05$). Based on absolute abundance, the Commercial-Reserve land uses were more similar (though still significantly different) than any other two land uses associated with each other. The removal of sample mS2 from the analyses indicated no significant improvement from the ANOSIM presented above, further motivating the inclusion of mS2 in the rest of the data analyses.

There were no significant differences between the relative "Good" and "Poor" groups, when averaged across all land use groups (r = -0.009, $P > 0.1$). One-way ANOSIMS (absolute abundance matrix) indicated that there were no significant differences between the relative "Good" and "Poor" groups *within* the Commercial- (r = 0.105, $P > 0.1$), Tribal- (r = -0.085, $P > 0.1$) or Reserve (r = -0.047, $P > 0.1$) land uses. Within the previous section (8.2.4.1), based on the total abundances (irrespective of the species absolute abundance matrix), there was a significant disturbance gradient evident within the Commercial land use, but no significant gradient between the relative condition groups for the absolute abundance matrix. Hence, ANOSIMS testing for ant assemblage patterns based on the entire absolute abundance matrix, and not only on the total abundances within each land use, indicated that ant assemblage patterns at this level of interpretation were not potentially a good indicator of rangeland condition, whereas the *total* abundance within the Commercial land use indicated a slight gradient related to range condition. Although the statistics were not significant for the Commercial land use at this more in-depth level, multivariate patterns can be informative, as is reflected in Fig 8.8. A Loess plot (CCA ordination) illustrates a gradient based on **ant abundances as predictor**, being lowest within the Tribal land use, and increasing towards the Reserve land use. It can be seen that both the Reserve's relative condition groups are clustered together at the high spectrum of the abundance gradient, whereas the Tribal's relative condition groups are clustered together at the low spectrum of the abundance gradient. The relative condition groups (Commercial-Good/-Poor) within the Commercial land use, however, were not clustered together, and were distributed in two different "contours", indicating a small difference in abundance between these condition groups. However, it is suggested that *both* interpretations should be used complementary to each other, since the observed (although not significant) patterns might also be quite informative.

Ant communities respond differently to stress, whether it is due to thermal responses, microhabitat changes, food availability or competition. Disturbances that structure plant communities, also appear to structure ant communities (Andersen 1995a), which may explain not only the differences in abundance between the land uses, but also the potential disturbance gradient within the Commercial land use. Hence, multivariate analyses of species compositional data are useful in detecting and describing such patterns, as will be addressed in more detail in the remainder of this chapter.

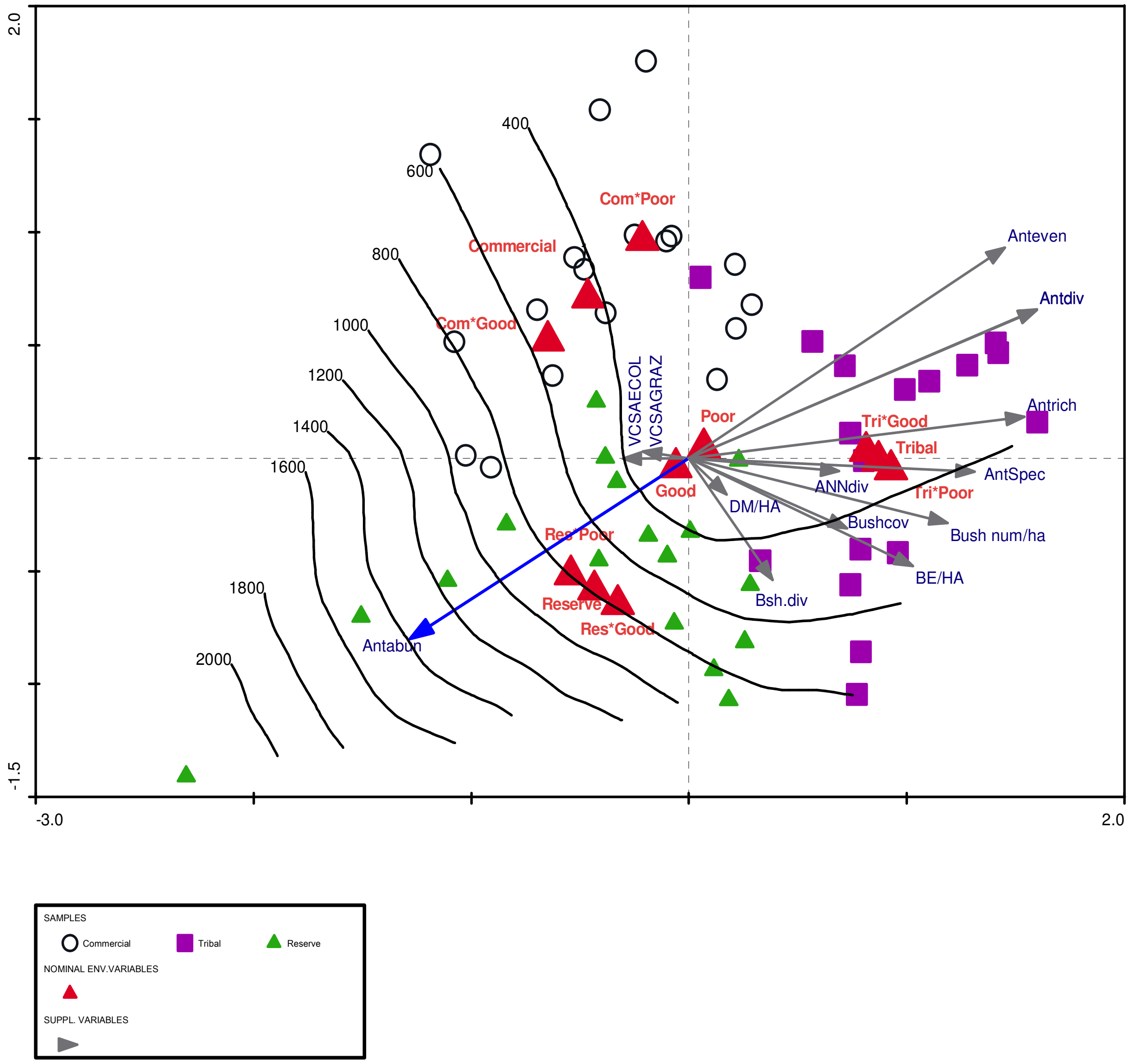


Fig. 8.8. A CCA ordination LOESS attribute plot (gradient) incorporating ant abundance (Antabun) (blue arrow) as predictor, being highest within the Reserve land use.

B. Absence/presence data

A two-way crossed ANOSIM based on **absence/presence** data indicated larger differences between the Reserve-Tribal land uses (r = 0.392, P < 0.001), but the statistics were lower for differences between the Commercial-Tribal land uses (r = 0.448, P < 0.001) and the Commercial-Reserve (r = 0.279, P < 0.001) land uses. There were, however, still no significant differences between the "Good" and "Poor" groups when averaged across all land uses (r = 0.023, P > 0.1), or within land uses (P > 0.1). Absence/presence analyses excluding the outlier site mS2 were still not significant (P > 0.1), and hence this site was included in the analysis, as in the case of the abundance data. The absence/presence data thus reflected similar patterns and statistics as the absolute abundance data (differed only slightly), and can serve as a substitute technique at this level of interpretation

C. Relative abundance data

Species abundances were also expressed as relative abundances/percentages of the total abundance within each *grid/site*, and then secondly expressed as average percentages *within* a land use as well as across all land uses, irrespective of land use. DCA and CCA ordinations automatically convert species absolute abundance data to relative abundance data (Morris 2006, pers. comm.). Hence, expression of data as relative abundance percentages is complementary and explanatory to the multivariate canonical ordination of the absolute abundance data matrix, and were informative in the sense that the percentage abundance, and not only number of individuals per species, within a grid rendered comparisons more easily.

A two-way crossed ANOSIM (square-root transformed data; Bray-Curtis dissimilarity measures) for the relative abundance matrix indicated significant (intermediate) differences between the Commercial-Tribal land uses (r = 0.436, P < 0.001), intermediate-low differences between the Tribal-Reserve land uses (r = 0.291, P < 0.001) and small significant differences between the Commercial-Reserve land uses (r = 0.144, P < 0.001). There were no differences between the relative condition groups when averaged across all land uses (r = -0.026, P > 0.1), or when tested within a land use (P > 0.1). Differences in land use species compositional patterns, as established by a two-way crossed ANOSIM incorporating *relative abundances*, showed similar significant patterns as the absolute abundance data, with the statistics (r-values) being slightly lower than with absolute abundance data.

All three expression methods investigated by means of ANOSIMS, corresponded well with each other at this level, suggesting that they can serve as substitute for each other for these types of analyses at the level discussed above. However, any possible discrepancies will be investigated by means of the SIMPER analyses and CCA ordinations.

D. Species compositional patterns

Species compositional patterns based on the absolute abundance matrix, are presented below. *Anoplolepis steingroeveri* was the most abundant ant species (*N* = 30 191, total study area; *N* = 3 547, Commercial land use; *N* = 245, Tribal land use; *N* = 26 399, Reserve land use), comprising 42.23% of the Commercial land use, 3.58% of the Tribal land use and 78.95% of the Reserve land use. The second-most abundant species was *Myrmicaria sp A* (*N* = 5 036, 10.35%), with *Pheidole sp C* being the third-most abundant species (*N* = 1 553, 3.19% for total survey area), comprising 8.82% (*N* = 741) of the total number of individuals in the Commercial land use, 2.57% (N = 176) for the Tribal- and 1.9% (*N* = 636) for the Reserve land uses (Appendix 8.1a).

Within the Reserve and Commercial land uses, *Anoplolepis steingroeveri* had the highest abundance, whereas for the Tribal land use, *Myrmicaria sp A* (*N* = 1 889, 27.64% of this land use) had the highest abundance. However, the overall abundance of *Myrmicaria sp A* was highest in the Reserve land use (*N* = 3 115, 9.32% of this land use), with only 32 individuals being present in the Commercial land use (0.38% of this land use's abundance). Species abundance contributions within each land use were not only expressed as the number of individuals (*N*), but also as percentages of the total *within* a land use. In addition it was also expressed as the *N*/percentages proportion of the *total* survey area, as summarised in Appendix 8.1a. Although certain species e.g. *Myrmicaria sp A* (for the Tribal land use) were the most abundant species *within* a land use, they were not necessarily most abundant for that land use relative to the other two land uses.

Anoplolepis steingroeveri is functionally classified as an HCS (see Section 8.2.1). Climate specialists are considered to be physiologically, morphologically and behaviourally specialised related to their foraging ecology, implicating a reduction in their interaction with other ants (Andersen 1995a). These specialists forage when other ants are not active. Within the Reserve, this species was primarily collected within one of the Reserve-Poor sites (mS2), which was characterised by sparse herbaceous cover (annual life-form) (Appendix 8.2; discussed in Section 8.2.12). However, it should be emphasised that the MDS, DCA and CCA analyses indicated no sample/site outliers within the ant species compositional data set, or within any of the biotic and abiotic environmental matrices they were related to (see discussions in the previous chapters). *Anoplolepis steingroeveri* was sampled relatively consistently throughout the Commercial land use, although it was less abundant than in the Reserve. It was found inconsistently in high abundances in only a few sites within the Reserve and in only one site within the Tribal land use. Hence, since no outlier sites were identified within the matrices mentioned above, the high abundance of *Anonplolepis steingroeveri* in mS2 (20 361 individuals within grid), suggested that not only the annual life-form, as indicated by multivariate analyses as governing this species compositional patterns (Appendix 8.2; see Section 8.2.12), but also other abiotic factors indirectly, e.g. behavioural specialisation/competition, contributed to this species' high abundances for selected sites within the study area. There is considerable evidence that interspecific competition contributes to patterns of distribution and abundance in ant communities (Andersen 1992; Human & Gordon 1996; Morrison 1996). These patterns, displaying high overall abundances within the Reserve, as well as the high abundance of some individual species within the Reserve, and low abundances in especially the Tribal land use, are discussed in detail in Section 8.2.5.

Myrmicaria sp A is classified as a tropical climate specialist (TCS), with TCS species being considered as unspecialised in terms of foraging ecology (Andersen 1995a). Although it was the most abundant species for the Tribal land use, it was still more abundant in the Reserve land use. However, it did not occur consistently in any of these land uses, each occurring in two of the three areas/villages in each land use. However, they were collected in each sub-replicate/grid within each of the two areas/villages (see Material and Methods) in which they occurred abundantly. Results from this study found no apparent association/parallels for this species with any environmental metric (Appendix 8.2; see Section 8.2.12). It is suggested that the distribution of this species can possibly be ascribed to factors other than biotic variables, e.g. behaviour/competition/thermal responses, and not only to vegetation structure, i.e. the presence woody components.

Pheidole species are classified as a GMC (Andersen 1995a, Majer *et al.* 2004), and are abundant in warmer regions of the world. Majer *et al*. (2004) further state that species of the *Pheidole* genus have a wider distribution in relation to environmental stress and disturbance, and tend to predominate in moderately instead of highly productive environments for ants. Within this study, *Pheidole sp C* was found consistently throughout all the sites within each land use, irrespective of the relative rangeland condition. It was also indicated as a generalist species by the DCA and CCA ordinations (Sections 8.2.6 and 8.2.7), although it had a slightly higher abundance in the Commercial land use, having the lowest abundance in the Tribal land use. Monte Carlo and BVSTEP tests (Spearman correlation) indicated that land use was the primary environmental variable governing *Pheidole sp C*'s distribution (Appendix 8.2; see Section 8.2.12). After Majer *et al.*'s (2004) description, it can be philosophised that the Reserve and Commercial land uses provided moderately productive environments for this species. However, it should be cautioned that single-species approaches may not be adequate as bio-indicators, and that groups of related taxa, hence a "shopping basket", might prove to be more informative of biodiversity, environmental and ecological changes (Hammon 1994; McGeogh 1998).

8.2.4.3 SIMPER analysis: Absolute abundance, relative abundances and absence/presence data matrices

SIMPER analyses were done as explanatory, comparitive procedures to establish which species contributed to similarities within land uses, and dissimilarities between land uses. The results between the three interpretation techniques were compared to establish whether one technique could be substituted for another one, or whether different results were obtained for the different techniques.

A. Absolute abundance

SIMPER analysis incorporating the species absolute abundance matrix, indicated that the Commercial land use had and average similarity of 27.99%, with *Pheidole sp C*, *Ocymyrmex sp B*, *Monomorium rufulum* and then *Anoplolepis steingroeveri* being the most important species contributing to 61.3% of the similarity (Appendix 8.3).

The Tribal land use had an overall similarity of 33.53%, with *Monomorium fastidium*, *Myrmicaria sp A*, *Tetramorium baufra* and *Monomorium rufulum* contributing to most of the similarities.

The average similarity of the Reserve was 28.69%, with *Pheidole sp C*, followed by *Monomorium fastidium*, *Myrmicaria sp A, Monomorium rufulum* and *Ocymyrmex sp B* being the species contributing most to the similarities. Species contributing to most of the similarities within groups and dissimilarities between groups, as well as species consistently being the best discriminators between groups, were very similar to that of the section on relative abundances.

Deduced from the results presented above, *Pheidole sp C*, *Monomorium fastidium* and *Monomorium rufulum* can be classified as GMC, and were also indicated as generalists by the DCA, CCA and IndVal analyses. In this study, *Monomorium fastidium* was found to be associated with the soil properties (Appendix 8.2; see Section 8.2.12), which were similar within all three land uses (see Chapter 4). GMC has a broad distribution in relation to environmental stress (Andersen 2003; Majer *et al.* 2004), as described in the section above (Section 8.2.4.2). *Mymicaria sp A* was described as a TCS in Section 8.2.4.2, and *Ocymyrmex sp B* can be classified as an HCS. BVSTEP analyses indicated that *Ocymyrmex sp B* showed strong associations with the soil as well as the herbaceous properties (Appendix 8.2). *Tetramorium baufra* is classified as an OPP, with species related to this functional group being characterised by unspecialised, poorly competitive ants, showing wide habitat distributions. They occur predominantly in sites where stress and disturbance limit diversity (Andersen 1995a, Majer *et al.* 2004). Key environmental variables related to this species were woody properties, herbaceous species composition and land use disturbance (Appendix 8.2; Section 8.2.12).

Species contributing to 90% or higher of a land use's similarity for the Commercial land use **primarily** consisted of species belonging to the HCS and GMC functional groups, indicative of species associated with moderate productive systems (for ants), whereas the Tribal land use was characterised primarily by species belonging to the GMC and OPP functional groups, indicative of moderate to low productive systems structured by habitat disturbance and environmental stress. The Reserve land use (species contributing to 90% and higher of the similarity) was best represented by species primarily belonging to the GMC, HCS and TCS functional groups, suggesting that this was a moderate to highly productive system for ants, in which behavioural aspects contributed in structuring the observed ant compositional patterns.

The one-way ANOSIM tests for the absolute abundance data indicated no significant differences between the “Good” and “Poor” groups (ANOSIM), hence the SIMPER analyses for similarities within and dissimilarities between these relative condition groups *within* a land use were not informative and will not be discussed further.

B. Relative abundance

Analyses of similarities for the relative abundance data were performed to establish which species were associated with each land use, and which species can be considered typical within and discriminant between the land uses (Appendix 8.4). Results incorporating relative abundances were consistent with those of the absolute abundance data, although % contributions toward similarities and dissimilarities differed slightly between these two methods. However, expression of ant data as relative abundance percentages within a land use is useful in the sense that it not only agrees with the DCA and CCA ordinations (abundance data being converted to relative species composition data; Morris 2006, pers. comm.), but also simplifies comparisons within and between sites within and between land uses.

Based on the relative abundances, the Commercial land use had an overall similarity of 30.7%, the Tribal land use 35.67% and the Reserve 33.39%. Species most abundant and highest contributing to the Commercial land use were *Pheidole sp C* (av. abund = 14.42%, contribution = 20.05%, Sim/SD), *Ocymyrmex sp B* (av.abund = 10.45%, contribution = 15.06%), *Anoplolepis steingroeveri* (highest av. abund = 19.26%) and *Monomorium rufulum* (av. abund = 6.22%). Cumulatively these species contributed to 62.51% of the similarity, with 12 species contributing to 90.38% of the similarity. *Monomorium rufulum* was indicated as consistently being most typical of all these species for this group (Sim/SD = 1.58).

Species contributing most to the Tribal land use’s similarity were *Myrmicaria sp A* (av. abund = 19.72, contribution = 16.47%), *Monomorium fastidium (*av. abund = 10.04%, contribution = 15.16%) and *Tetramorium baufra* (av. abund = 9.02%, contribution = 11.16%), with these three species cumulatively contributing to 42.79% of the similarity, with 13 species contributing to 90.52% of the similarity. *Monomorium fastidium* (Sim/SD = 1.09), followed by *Monomorium rufulum* (Sim/SD = 1.07) were indicated as the two most important consistent typical species within this group. Both these species are generalist species, as was also indicated in the CCA ordination (Section 2.6) and IndVal method (Section 8.2.9).

Ten species accounted for 91.06% of the Reserve’s similarity, with *Myrmicaria sp A* (av. abund = 20.63%, contribution = 19.09%), *Pheidole sp C* (av. abund = 11.44%, contribution = 16.28%) and *Monomorium fastidium* (av. abund = 7.64%, contribution = 12.6%) being the three primary contributors to 47.97% of the similarity. Although *Anoplolepis steingroeveri* had the second highest abundance (av. abund = 19.88%), it was listed only 5th in terms of contribution to the similarity (9.76%). *Monomorium rufulum* (Sim/SD =

1.05) and *Monomorium fastidium* (Sim/SD = 1.2), two generalist species, were also consistently typical of this land use, as well as *Monomorium notulum* (Sim/SD = 1.05)

Hence, the SIMPER analysis for the relative abundance matrix also indicated *Monomorium rufulum* and *Monomorium fastidium* to be consistently typical species of all three land uses, confirming their generalist status indicated by the SIMPER analysis (absolute abundance matrix), CCA ordination (Section 8.2.6) and the IndVal method (Section 8.2.9).

The average dissimilarity between the Commercial and Tribal land uses was 77.09%, with *Anoplolepis steingroeveri* (av. dissimilarity = 10.04%, contribution = 13.02%) and *Myrmicaria sp A* (av. dissimilarity = 9.83%, contribution = 12.75%) being the two primary species contributing to 25.77% of the dissimilarity, with 22 species contributing to 90.3% of the dissimilarity. Large (average) dissimilarities in average abundances for species contributing to the different land uses resulted in species being listed as the most important contributors to the average dissimilarity. However, species that were consistently indicated as discriminating species between these two land uses, were *Monomorium rufulum* (Diss/SD = 1.26) and *Monomorium sp B* (associated best with Tribal land use, Diss/SD = 1.15%). Hence, highly contributing species (with high average dissimilarity) were not necessarily consistently being the most important discriminating species, owing to an uneven distribution within a land use.

The average dissimilarity between the Commercial and Reserve land uses was 60.04%, with *Anoplolepis steingroeveri* (av. dissimilarity = 11.03%, contribution = 18.37%), *Myrmicaria sp A* (av. dissimilarity = 5.42%, contribution = 9.02%) and *Pheidole sp C* (av. dissimilarity = 2.68%, contribution = 4.46%) being the three most important species contributing cumulatively to 31.85% of the dissimilarity, with 31 species contributing to 90.62% of the dissimilarity. Although *Anoplolepis steingroeveri* had high average abundances in the Reserve and Commercial land uses, it was not consistently so, resulting in a low Diss/SD = 0.71. The most important discriminating species were *Pheidole sp C* (Diss/SD = 1.55, contribution = 3.26%), which had a higher average abundance in the Commercial land use, followed by *Monomorium fastidium* (Diss/SD = 1.19, higher av. abundance in Reserve land use) and *Monomorium rufulum* (Diss/SD = 1.17, higher average abundance in the Reserve land use). These three species were indicated as “generalist” species by the CCA ordination and Indval method, hence occurring in all three land uses, with the abundance differing slightly between land uses.

The Tribal- and Reserve land uses had an average dissimilarity of 71.9%, with *Myrmicaria sp A* (av. dissimilarity = 13.35%, contribution = 18.57%), *Anoplolepis steingroeveri* and *Pheidole sp C* contributing to 40.37% of the dissimilarity, and a total of 21 species cumulatively contributing to 90.08% of the dissimilarity. Most consistent discriminant species were the generalist species *Monomorium fastidium* (Diss/SD = 1.23) and *Momorium rufulum* (Diss/SD = 1.17).

There were no significant differences based on the square-root transformed relative abundance matrix between the relative “Good” and “Poor” groups (ANOSIM). Hence further discussions based on the

SIMPER results for similarities within and dissimilarities between these condition groups were not informative.

C. Absence/Presence data

SIMPER analyses for the absence/presence matrix investigated whether different patterns for this matrix opposed to that of the absolute and relative abundance matrices could be established (Appendix 8.5). Results indicated that the Commercial-Tribal land uses had an average dissimilarity of 51.45%, with *Cardiocondyla sp A* (contribution = 3.83%) being the most important discriminating species (Diss/SD = 2.15), followed by *Ocymyrmex sp C* (Diss/SD = 1.41), *Camponotus fulvipilosus* (Diss/SD = 1.33) and *Crematogaster sp A* (Diss/SD = 1.35) being the 4 most important species contributing to 90.53% of the dissimilarity.

The average dissimilarity between the Commercial and Reserve land uses, based on the absence-presence data was 47.03%, with *Tetramorium sericeiventre* (Diss/SD = 1.91) and *Myrmicaria sp A* (Diss/SD = 1.25) being the two most important contributing species and consitent discriminating species to the dissimilarity between the two land uses.

The Tribal-Reserve land uses had an average dissimilarity of 47.89%, with *Pheidole sp D* (Diss/SD = 1.69, contribution = 3.6%) and *Cardiocondyla sp A* (Diss/SD = 1.54) being the most important discriminating and highest contributing species to the total dissimilarity.

SIMPER analyses were informative in terms of the following:

- Listing of species contributing to 90% or higher of the similarities within each land use according to each interpretation method, is presented;
- Average abundance of each species within each land use (number of individuals, averaged across all survey sites within a land use) is presented (absolute abundance matrix);
- Average relative abundance of each species within each land use is expressed as an average across all survey sites within a land use;
- Presentation of species contributing to similarities/dissimilarities, based on absence/presence data without the confounded effect of the abundance of species;
- Reliable indication of consistent generalist species by all three interpretation methods;
- Indication of typical species within a land use;
- Indication of discriminating species between land uses;
- Reliable indication of consistency of species within and between land uses.

All three techniques analysed with the SIMPER analyses (Sections 8.2.4.3 A – C) displayed roughly similar patterns for the similarity groups *within* each land use, but the absence/presence matrix's discriminating species (*between* different land uses) differed from that of the abundance and relative abundance SIMPER analyses (Sections 8.2.4.3 A and B respectively). Discriminating species indicated by the absence/presence data were more informative as potential indicators related to each land use, and corresponded well with the IndVal method discussed in Section 8.2.9 and with the 10% and higher species-environment variance being explained by the first two canonical axes of a direct CCA (see Section 8.2.6). Species indicated as typical and discriminating within and between land uses for the absolute and relative abundance matrices were not as informative and included generalist species consistently associated with all three land uses. However, this was informative in the respect that the generalist status of these species was confirmed by all the SIMPER interpretation methods.

8.2.4.4 K-dominance and species-rank curves

Rank-abundance curves for species absolute abundance data for each of the land uses are illustrated in Fig 8.9a. The purpose of this analysis procedure is discussed in Chapter 3. Dominance by certain species was most pronounced in the Reserve land use (78.95% for *Anoplolepis steingroeveri*). Dominance was less marked in the Commercial- (42.23% for *Anoplolepis steingroeveri*) and Tribal land uses (27.64% for *Myrmicaria sp A*). Both the Reserve and Commercial land uses were dominated by HCS, while the Tribal land use was dominated by a TCS. HCS display specialisations suggestive of a long evolutionary association with behaviourally dominant ants (Andersen 1995b). For this study, the high dominance of *Anoplolepis steingroeveri*, in certain sites, especially within the Reserve, can possibly be attributed not only to the annual herbaceous life-form with which it showed an affinity (Appendix 8.2) (Sections 8.2.7 – 8.2.9), but also to behavioural associations with dominant ants in those sites.

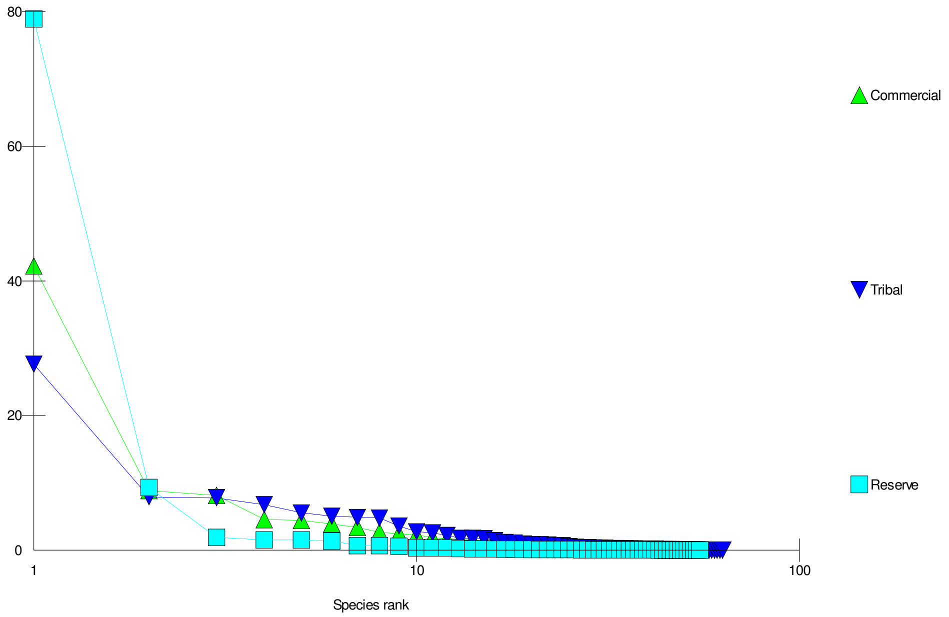


Fig 8.9a. Rank abundance curves for species abundance data indicating percentage (%) dominance within all three land uses, being highest within the Reserve.

Species accumulation curves reached their respective asymptotes for the Reserve and Commercial land uses, but possibly not completely for the Tribal land use (Fig 8.9b). This is often the case, even though invertebrate samplings might be very intensive (Gotelli & Colwell 2001). The high dominance and hence abundance of certain species (e.g. *Anoplolepis steingroeveri*) in the Reserve land use is discussed, in association with species richness and diversity, in the next section.

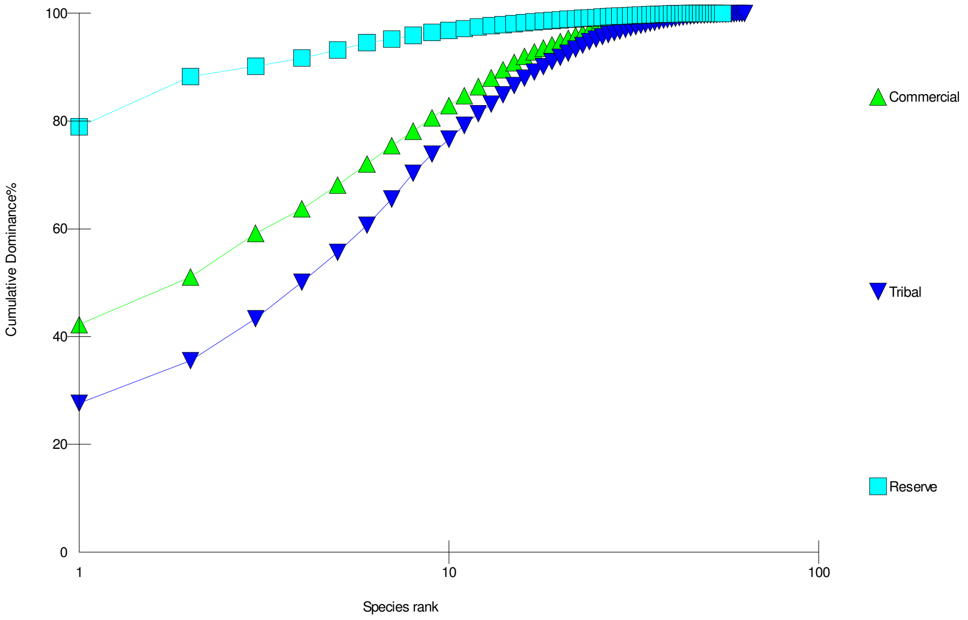


Fig. 8.9b. Species accumulation curves illustrated for all three land uses, with cumulative domincance attained first by the Reserve.

8.2.5 Species richness and diversity

Studies have indicated a positive correlation between vegetation and arthropod diversity (Janzen *et al.* 1976). This section will attempt to establish whether such congruent patterns between ant- and plant diversity and richness exist within the Molopo semi-arid rangelands, and how it is related to the different land use and range condition sites.

Species richness is often described simply as the total numbers of species (*S*) present, hence the bigger the sample, the more species there are likely to be. Or it can be expressed as some adjusted form that allows for differing numbers of individuals (Clarke & Warwick 2001) and is measured as the number of species present for a given number of individuals (*N*) (richness expressed as Margalef's index; d = (*S*-1)/log*N*). Hence, results for both Margalef's species richness and simply the total number of species are presented below. Evenness (also called equitability, e.g. Pielou's evenness) describes how evenly individuals are distributed among different species. If a species is distributed inconsistently among samples, showing high abundances in some samples and low abundances in other, it has a high dominance but a low evenness, and vice versa. Diversity indices emphasise the species richness or evenness to varying degrees, with the Shannon (or Shannon-Wiener) diversity index ($H' = -\sum_i p_i \log(p_i)$, where p_i is the proportion of the total count arising from the ith species) being most commonly used (Clarke & Warwick 2001). It is advised that *H'* should only be compared across equivalent experimental designs, which was the case in this study. Margalef's species richness, the number of species, Shannon diversity and Pielou's evenness for each site are presented in Appendix 8.6. Average diversity indices scores for each land use (averaged across 18 sites within each land use) are presented in Table 8.6, Fig. 8.10

Table 8.6. Average Shannon diversity (Antdiv), Margalef's species richness (Antrich) and Pielou's evenness (Anteven) for the three land uses, being highest in the Tribal land use.

	Antdiv	Antrich	Anteven	AntSpec
Commercial	2.622	4.300	0.898	18.778
Tribal	2.884	5.295	0.917	23.667
Reserve	2.596	4.674	0.853	20.944

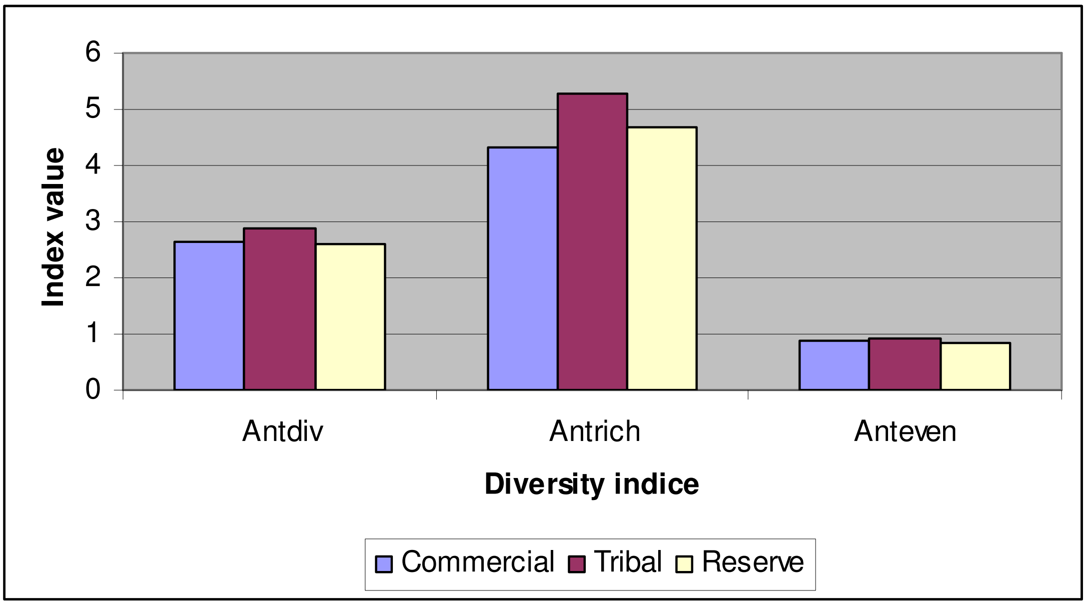


Fig. 8.10. Average Shannon diversity (Antdiv), Margalef's species richness (Antrich) and Pielou's evenness (Anteven) for the three land uses, being highest in the Tribal land use.

Although ant abundance was highest in the Reserve land use, Margalef's species richness (and thus the actual number of species) was highest in the Tribal land use (63 species), with the Reserve land use having 55 species and the Commercial land use 50 species (Table 8.1; Appendices 8.1 a, b). A two-way crossed ANOSIM based on Margalef's species richness showed significant differences between the Commercial-Tribal groups ($r = 0.37$, $P < 0.001$), significant but small differences between the Commercial-Reserve groups ($r = 0.184$, $P < 0.05$) but no significant differences between the Tribal-Reserve land uses ($r = -0.016$, $P > 0.1$). Although species richness was higher in the Tribal land use

(Fig. 8.10), it did not differ significantly from the Reserve land use, illustrating congruent patterns between these two land uses. There were also no significant differences between the “Good” and “Poor” groups when averaged across all land uses (r = -0.057, P > 0.1). One-way ANOSIM tests for differences within a land use based on relative condition for species richness were also insignificant for all three land uses (P > 0.1). This suggests that species richness is not a good potential indicator of rangeland condition.

Based on the number of ant species (*N*), there was a significant, intermediate-low difference between the Commercial and Tribal land uses (r = 0.371, P < 0.001), a small but significant difference between the Commercial-Reserve groups (r = 0.152, P < 0.05) and no difference between the Tribal and Reserve land uses (r = -0.013, P > 0.1). There was no significant difference between the relative condition groups when averaged across all land uses (r = -0.028, P > 0.1). One-way ANOSIMS showed that there were no significant differences between the “Good” and “Poor” groups for any of the land uses based on the number of species (P > 0.1). These results correspond with the results on Margalef’s species richness, although the overall statistics for Margalef’s species richness were slightly better (higher r-values).

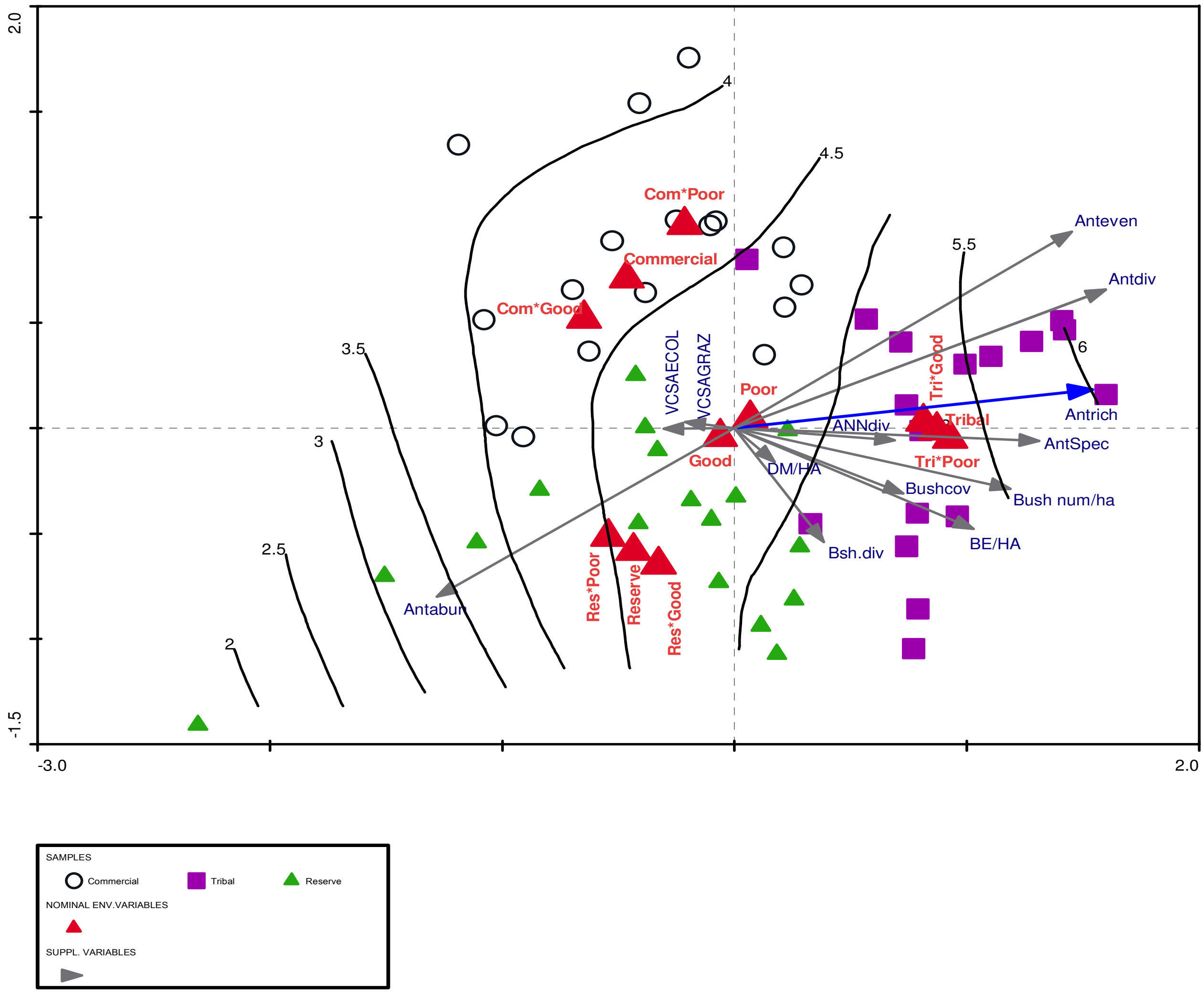


Fig. 8.11. A CCA LOESS attribute plot (gradient) incorporating Margalef’s species richness (Antrich) as predictor (blue arrow), illustrating an increase in species richness from the Commercial land use towards the Reserve and the Tribal land uses.

Habitat modification influences species richness, with the effect varying with the degree of disturbance and also with the taxon being considered (Lawton *et al.* 1998). Disturbance has been found to be important in determining the composition and structure of ant communities (Brain *et al.* 1976; Majer *et al.* 1984; Roth *et al.* 1994). Studies by Lobry de Bruyn (1999) indicated that ant species richness was almost always lower in farmlands than in natural vegetated areas, with agricultural activities resulting in a decrease of ant species richness by as much as 50%. Woinarski *et al.* (2002) also found that ant species richness and composition were affected by pastoralism, ant species richness being least in grazed sites. Species richness within the Commercial land use was 68.49% of the species richness for the total survey area, as opposed to the 84.93% for the Tribal land use and 75.34% for the Reserve land use. Hence, species richness was highest within the Tribal land use (Fig 8.10; Fig. 8.11).

Ant diversity, and to a lesser extent ant evenness, was also highest in the Tribal land use (Fig 8.10; Fig.8.12), followed by the Reserve land use. The association of evenness primarily with the Tribal land use, indicates the absence of one or more species dominating the ant compositional patterns within this land use. For ant diversity, a two-way crossed ANOSIM showed significant differences between the Commercial-Tribal land uses ($r = 0.282$, $P < 0.001$), but no significant differences between the Commercial-Reserve groups ($r = 0.068$, $P > 0.05$) or the Tribal-Reserve groups ($r = -0.017$, $P > 0.1$). Ant compositional patterns of the Reserve were a “combination” of those of the Commercial and Tribal land uses. The two-way crossed ANOSIM test also showed no significant differences between the “Good” and “Poor” groups ($r = -0.065$, $P > 0.1$) when averaged across all land uses. Hence, species diversity also did not reflect range condition. One-way ANOSIM tests within each land use also indicated no differences between the relative “Good” and “Poor” groups ($P > 0.1$). A LOESS plot from a CCA ordination incorporating ant diversity (Shannon diversity index) as predictor, indicated a significant gradient ($r^2 = 0.88$ for axis1*axis2) increasing from the Reserve and Commercial land use (both having intermediate high diversity indices) towards the Tribal land use (Fig. 8.12). It was clear that within a land use, the relative “Good” and “Poor” sites fell within the same diversity contour, although the difference between these two relative rangeland condition groups was more pronounced in the Commercial land use (Fig. 8.12). Thus, although there were no significant differences between these condition groups within each land use based on diversity, the relative condition groups (Commercial-Good and Commercial-Poor) within the Commercial land use showed a slight gradient, though still falling within the same diversity “contour” (Fig. 8.12). This can possibly be ascribed to relatively homogeneous habitat structure of the relative “Good” rangeland condition sites, as opposed to the pronounced different structure of the “Poor” sites. This tendency can be ascribed to the land use management strategies pertaining to woody eradication, as was discussed in Chapter 5, Section 5.3.1.2. Within the Reserve and Tribal areas, the woody structure is more uniform between the “Good” and “Poor” rangeland condition sites due to the absence of a woody eradication programme. The association between ants and habitat heterogeneity and hence structure/complexity, is discussed below.

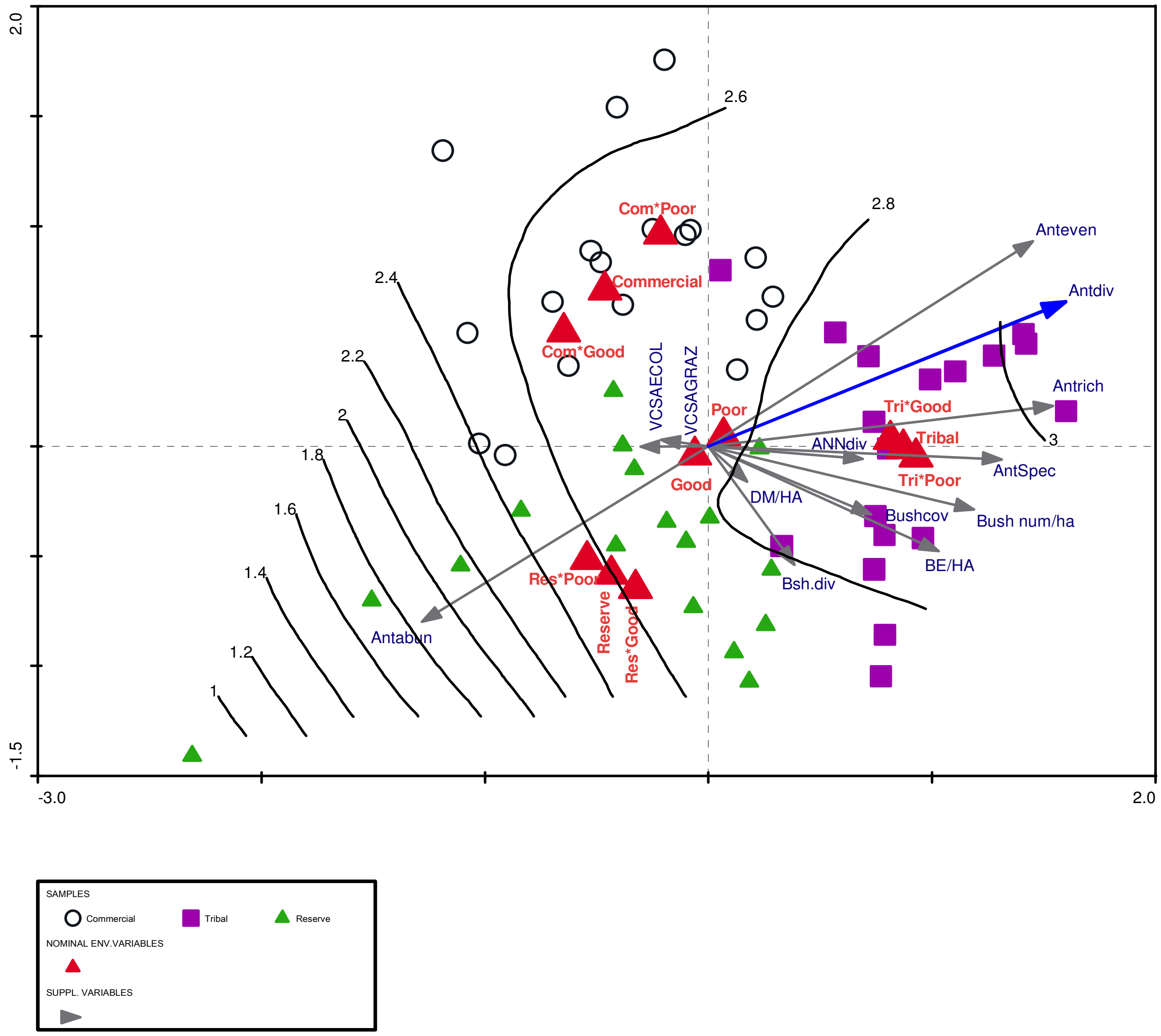


Fig. 8.12. A CCA LOESS attribute plot (gradient) incorporating Shannon's diversity (Antdiv) as predictor, showing a significant gradient (r^2 = 0.88 for axis1*axis2) based on land use increasing from the Reserve and Commercial land use towards the Tribal land use.

It has been described by several authors that increasing habitat complexity may result in high diversity and reduced dominance (hence abundance) in ants (Room 1975; Majer 1985; MacKay *et al* 1991; Perfecto & Snelling 1995). Another school of thought suggests that ant assemblages show increased diversity along the successional gradient as conditions improve until the communities become dominated (high abundance) by some dominant species, resulting in a decline in diversity (Majer 1985; Andersen 1992). This is called a humped distribution. This tendency is consitent with findings by Van Hamburg *et al.* (2004) for ant communinity development on rehabilitated ash dams in South Africa. According to Retana and Cerdá (2000), a more structured habitat may negatively affect the coexistence of groups of organisms, opposed to Putman's (1994) suggestion that species richness increases with increased structural complexity. Results obtained from the DCA and CCA ordinations (Sections 8.2.6, and 8.2.7) indicated that ant abundance was negatively correlated with species richness and diversity. This is opposed to findings by Andersen (1997c) that showed that site species richness and ant abundance were closely correlated for North American ant species. Diversity and species richness patterns related to the Tribal area (low overall abundance), and to a lesser extent the Reserve, suggest that the structural heterogeneity patterns (see previous chapters and the woody properties expressed as TE/ha, Bush numbers/ha and Bush diversity linked to these two land uses), as a function of land use (disturbance), result in higher ant diversity composition within the Tribal land use, followed by the Reserve land use. Hence within the Tribal land use, species richness seemed to increase with structural complexity, while abundance by a few dominant species declined. Although ant diversity did not differ significantly between the Reserve-Tribal land uses, species composition did (Sections 8.2.4.2 – 2.4.4; Appendices 8.1a, b).

This pattern is more evident and informative when investigated *in addition* by means of the functional group classification. According to above-mentioned arguments, it is suggested that the Commercial land use represent moderately productive systems, with a combination of climatic and behavioural as well as habitat disturbance factors governing ant compositional patterns within this land use. Ant community patterns within the Reserve can potentially be best explained by the humped distribution rationale, in which climate and bevarioural competitive structuring agents are the strongest determinants of ant community compositional patterns. However, it is suggested that heterogeneity, as the result of moderate disturbance (e.g. due to habitat modification as the result of land use disturbance) is a secondary factor governing the observed patterns within the Reserve land use. Hence, a dichotomy between these two models for the Molopo semi-arid rangelands is suggested. These statements will be tested in the next sections by employing multivariate analysis.

Although some studies indicated that ant species richness and relative abundance were positively correlated with *some* range condition sites in Idaho (Nash *et al.* 2001) and some individual species and functional groups responded to declining rangeland condition in southern Australia (Hoffmann 2000), for this study neither species richness, ant diversity nor abundance were correlated with range condition. This is consistent with studies by Whitford *et al* (1999b), Nash *et al.* (2001; 2004), finding no consistent patterns as a function of degradation due to livestock grazing.

Ant species richness and diversity showed parallel patterns with herbaceous- and woody diversity and richness, which were also not related to rangeland condition. Ant species compositional patterns further agreed with that of vegetation compositional patterns in that the three land uses clustered separately. However, vegetation species compositional patterns were correlated with rangeland condition (a rangeland degradation gradient), whereas ant assemblages (functional or species compositional classification) were not correlated with range condition. Ant functional and species composition patterns appear to be the result of habitat disturbance, environmental stress (due to land use disturbances) and abiotic responses (climatic and behavioural responses). The remainder of the chapter will attempt to answer whether the definition of productivity and disturbance that applies to ant assemblages, also applies to vegetation patterns. Primary and secondary determinants resulting in ant species compositional patterns (hence, are observed ant assemblages the result of natural environmental vs. land use habitat modified disturbances?) will also be investigated.

8.2.6 Community patterns- DCA

Analyses at species level, in addition to the functional groups, were also done within this study, for the reason that functional groups at broad scale may conceal the response of species to some disturbances (Bestelmeyer & Wiens 1996; Lavorel *et al.* 1997). The response of ant functional groups to disturbance may vary as a result of local species pools and regional biogeographic affinities at different localities (Bestelmeyer & Wiens 1996) and due to different behavioural (Greenslade 1982) responses of species occupying different competitive niches.

The patterns of variation in the ant community composition (square-root transformed, downweighted) in relation to the different land uses and relative condition groups ("Good" vs. "Poor") were examined by detrended correspondence analysis (DCA) using CANOCO 4 (Ter Braak & Šmilauer 1998). Detrending was required as an artificial "arch effect" was evident in the joint plot. The main gradients in composition (DCA axes) were related (indirect ordination) to measured environmental and vegetation variables by multiple regression to identify the main determinants of the ant species composition. The first four axes of the indirect DCA ordination accounted for 43.1% of the species variance, with the second axis representing 49.8% of the species-environment correlation (Table 8.7). The first axis was best represented by the Tribal land use (r = -0.485), followed by the Commercial-Good interaction (r = 0.360) and Commercial land use (r = 0.360). The second axis was best represented by the Reserve environmental variable (r = 0.486), followed by the Tribal land use (r = -0.459) (Table 8.8; Fig. 8.13). Hence, the different land uses were represented by different axes and were clustered separately.

Table 8.7. A DCA ordination based on absolute ant abundances showing the eigenvalues, cumulative species data and species-environment variance for the first four axes.

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.454	0.181	0.081	0.062
Lengths of gradient	2.836	1.891	1.715	1.527
Species-environment correlations	0.55	0.551	0.421	0.434
Cumulative percentage variance				
of species data	25.1	35.1	39.6	43.1
of species-environment relation (environmental)	32.7	49.8	0	0
of species-environment relation (passive data)	30.4	39	0	0

Table 8.8. DCA correlation coefficients (r-values) for the environmental and passive variables associated with the first two DCA axes for absolute ant abundances, with the variables showing the highest r-values being indicated in **bold**.

Environmental data	SPEC AX1	SPEC AX2	Passive data	SPEC AX1	SPEC AX2
Commercial	**0.3603**	-0.0339	BE/HA	-0.4197	-0.0406
Tribal	**-0.485**	**-0.4592**	Bushcov	-0.2806	0.0258
Reserve	0.1343	**0.4857**	Bush num/ha	**-0.4318**	-0.2045
Good	0.0619	-0.0035	VCSAGRAZ	0.0188	0.0098
Poor	-0.0619	0.0035	DM/HA	-0.0264	-0.2112
Com*Good	**0.3607**	-0.0544	VCSAECOL	0.0593	0.0314
Com*Poor	0.0862	0.0151	ANNdiv	-0.146	**-0.3637**
Tri*Poor	-0.353	-0.2495	Antdiv	**-0.7185**	-0.0979
Tri*Good	-0.2586	-0.3296	Antabun	**0.6239**	-0.0334
Res*Good	-0.0219	0.3718	AntSpec	-0.5426	-0.1395
Res*Poor	0.1897	0.2352	Bsh.div	-0.1965	0.1047
			Antrich	-**0.6483**	-0.1908
			Anteven	**-0.6839**	-0.041

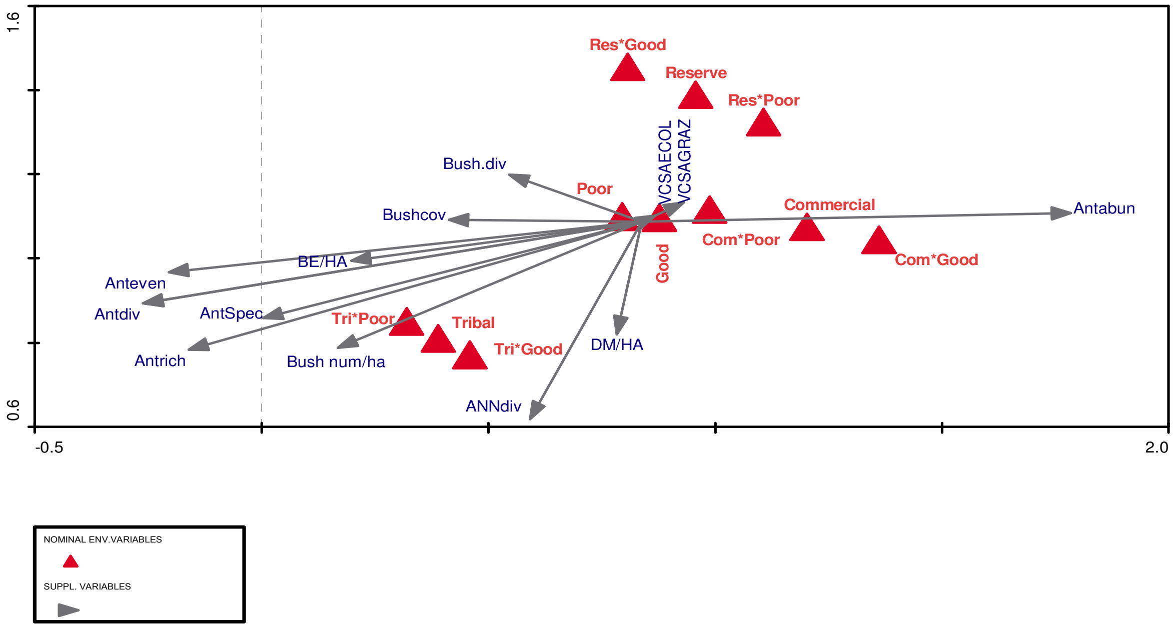


Fig 8.13. A DCA biplot for environmental and supplementary variables for absolute ant abundances.

Passive variables showing the strongest association with the first axis were ant diversity (Antdiv, r = -0.719) ant “Pielou’s evenness” (Anteven, r = -0.684), ant species richness (Antrich, r = -0.648), ant abundance (Antabun, r = 0.624) and the bush numbers/ha (r = -0.432). For the passive data, 39% of the species-environment relation was accounted for by the second axis (Table 8.8). The first two axes explained most of the species-environment correlations (r = 0.55 for axis 1, r = 0.551 for axis 2) (Table 8.8).

Total ant abundance (incorporated as passive data) was positively correlated with the Commercial variables (first quadrant), though actual abundances were higher in the Reserve. However, a DCA is a representation of the indirect species-environment relation, and the composition of the ant community as a *function* of the environmental variables should be studied by canonical correspondence analysis (CCA).

Ant species richness, the number of ant species, ant diversity and ant evenness were strongly associated with the Tribal variables of the third quadrant. These values were also associated with the woody properties expressed as TE/ha (BE/ha) and bush numbers/ha (Fig 8.13). Ant diversity and species richness also displayed a positive correlation with herbaceous species diversity. Ant abundance was negatively correlated with the ant species richness (r = -0.676). This differs from findings by Andersen (1997c) that found that ant species richness and abundance were closely correlated for ants in Arizona, North America. For this study, ant species richness was also positively correlated with ant diversity (r = 0.88) and herbaceous species diversity (r = 0.13). Ant species diversity and evenness were strongly correlated (r = 0.94). Ant species richness was negatively correlated with the Commercial and Reserve land uses.

The direct relation of the species-environmental patterns, and not only the indirect association, were investigated and discussed in the next section by means of Canonical Correspondence Analysis (CCA). Results were verified with that of the DCA to identify whether the environmental patterns explaining the largest portion of the species-environment variance, has been correctly identified.

8.2.7 Community patterns - CCA

Direct ordinations for both absolute abundance and absence/presence matrices are presented. This is done once again to establish whether the absence/presence matrix can serve as substitute for the absolute abundance matrix.

A. Absolute abundance matrix

The relationships between the land uses, relative condition groups (all employed as environmental variables) and absolute ant abundance data (square-root transformed, downweighted) were directly examined by canonical correspondence analysis (CCA). CCA extracted gradients in the ant community composition that were constrained to be a function of the environmental variables (Ter Braak & Šmilauer

1998) and allows species that are most responsive to the explanatory variables to be identified. The effect of these environmental variables on the ant species composition was then tested with a Monte Carlo permutation test (N = 499) (Manly 1997). The cumulative variances and eigenvalue scores of the ant species for the first two axes are presented in Table 8.13 (also see Section 8.2.8).

The ordination revealed significant patterns related to the environmental variables for both the first (F-ratio = 4.898, P < 0.005) and all canonical axes (F = 2.162, P < 0.005). The first two axes accounted for 75.5% of the species-environment relation with 94.6% being accounted for by all four axes. Statistics improved compared to that of the DCA analysis. These high values are extremely encouraging, indicating that the correct environmental variables explaining the largest portion of the species-environment variance has been explained. The first two axes accounted for 13.9% of the species data and for 17.4% of the species data by all four axes. For abundance data, species-data percentages are usually quite low, in particular when analysed with a CCA. This is normal since species data are often noisy, and an ordination diagram explaining only a low percentage might be very informative (Ter Braak & Šmilauer 1998). The first two axes accounted for 38.4% of the species-environment relation for the passive data, and for 54.3% of this relation by all the axes (Table 8.9). Environmental data best explaining the first axis were the Tribal land use (r = 0.737, fourth quadrant), Tribal-Poor and Tribal-Good interactions (both first quadrant) (Table 8.10, Fig. 8.14). The Commercial land use (r = 0.656, second quadrant), followed by the Reserve (third quadrant) and then Commercial-Poor group (second quadrant) best represented the second axis (Table 8.10, Fig. 8.14). The high species-environment data being explained, and the high significance of the Monte Carlo test, suggest that land use is the fundamental structuring agent of ant communities within the Molopo study area. This statement was tested and verified in the remainder of the chapter.

Table 8.9. A CCA ordination based on absolute ant abundances showing the eigenvalues, cumulative species data and species-environment variance for the first four axes.

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.167	0.083	0.04	0.023
Species-environment correlations	0.755	0.759	0.468	0.655
Cumulative percentage variance				
of species data	9.3	13.9	16.1	17.4
of species-environment relation (environmental)	50.4	75.5	87.6	94.6
of species-environment relation (passive data)	28.6	38.4	51	54.3

Table 8.10. CCA correlation coefficients (r-values) for the environmental and passive variables associated with the first two CCA axes for absolute ant abundances, with the variables showing the highest r-values being indicated in **bold**.

Environmental data	SPEC AX1	SPEC AX2	Passive data	SPEC AX1	SPEC AX2
Commercial	-0.3589	**0.6555**	BE/HA	0.4606	-0.2568
Tribal	**0.7371**	-0.0107	Bushcov	0.3254	-0.1662
Reserve	-0.3846	**-0.616**	Bush num/ha	0.5319	-0.1542
Good	-0.0763	-0.0604	VCSAGRAZ	-0.0949	0.015
Poor	0.0763	0.0604	DM/HA	0.0778	-0.0869
Com*Good	-0.3496	0.3359	VCSAECOL	-0.1365	-0.002
Com*Poor	-0.0968	**0.5202**	ANNdiv	0.309	-0.0317
Tri*Poor	0.495	-0.032	Antabun	-0.5735	-0.429
Tri*Good	0.4347	0.0185	AntSpec	0.5872	-0.0322
Res*Good	-0.1801	-0.428	Bsh.div	0.1719	-0.2893
Res*Poor	-0.3005	-0.3418	Antrich	**0.6904**	0.0981
			Anteven	**0.6499**	**0.4992**
			Antdiv	**0.7157**	0.3517

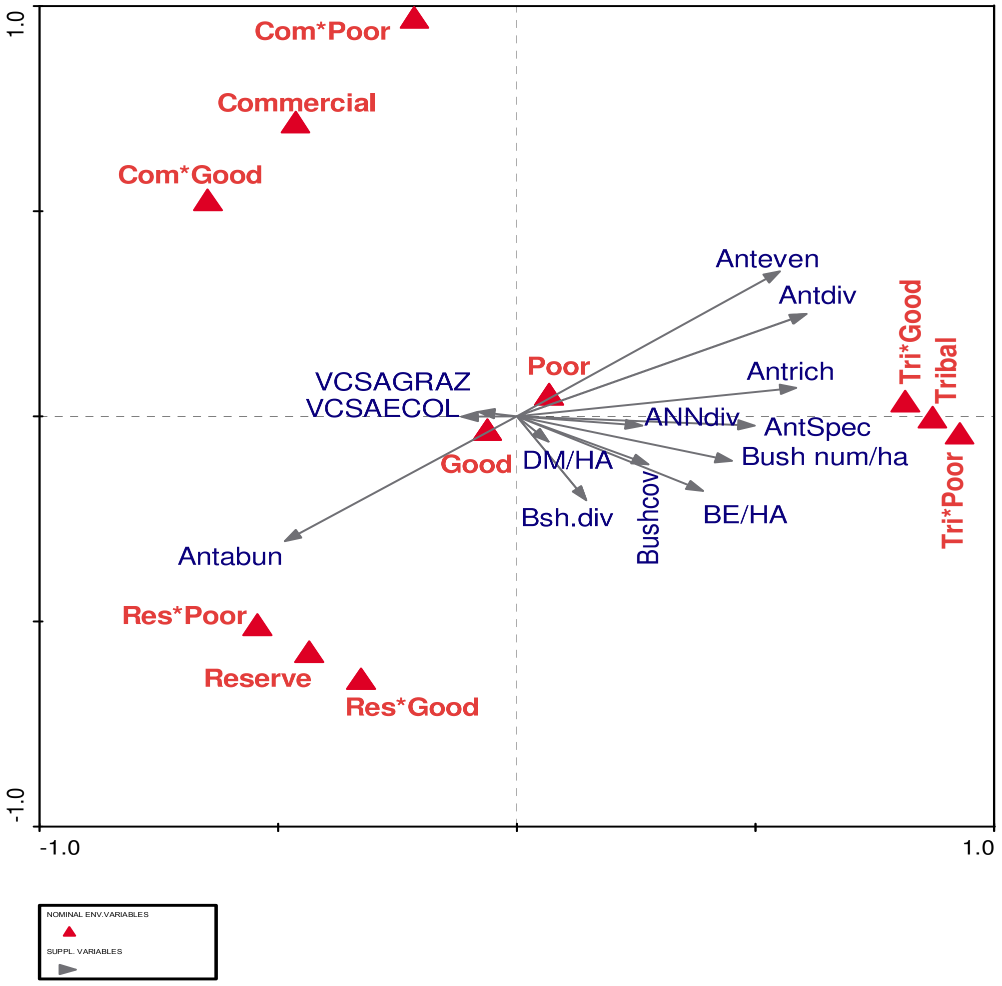


Fig. 8.14. A CCA biplot displaying environmental and passive variables for absolute ant abundances.

Supplementary variables that best explained the first axis were ant diversity (r = 0.716, first quadrant), followed by ant species richness (Antrich, first quadrant) and ant abundance (third quadrant) (Table 8.10, Fig. 8.14). Ant abundance showed the strongest correlation with the Reserve-Poor, Reserve and Reserve-Good variables (third quadrant), and not any more with the Commercial land use, as indicated in the indirect ordination (Fig. 8.14). This can be ascribed to the direct vs. the indirect DCA ordination discussed in the section above.

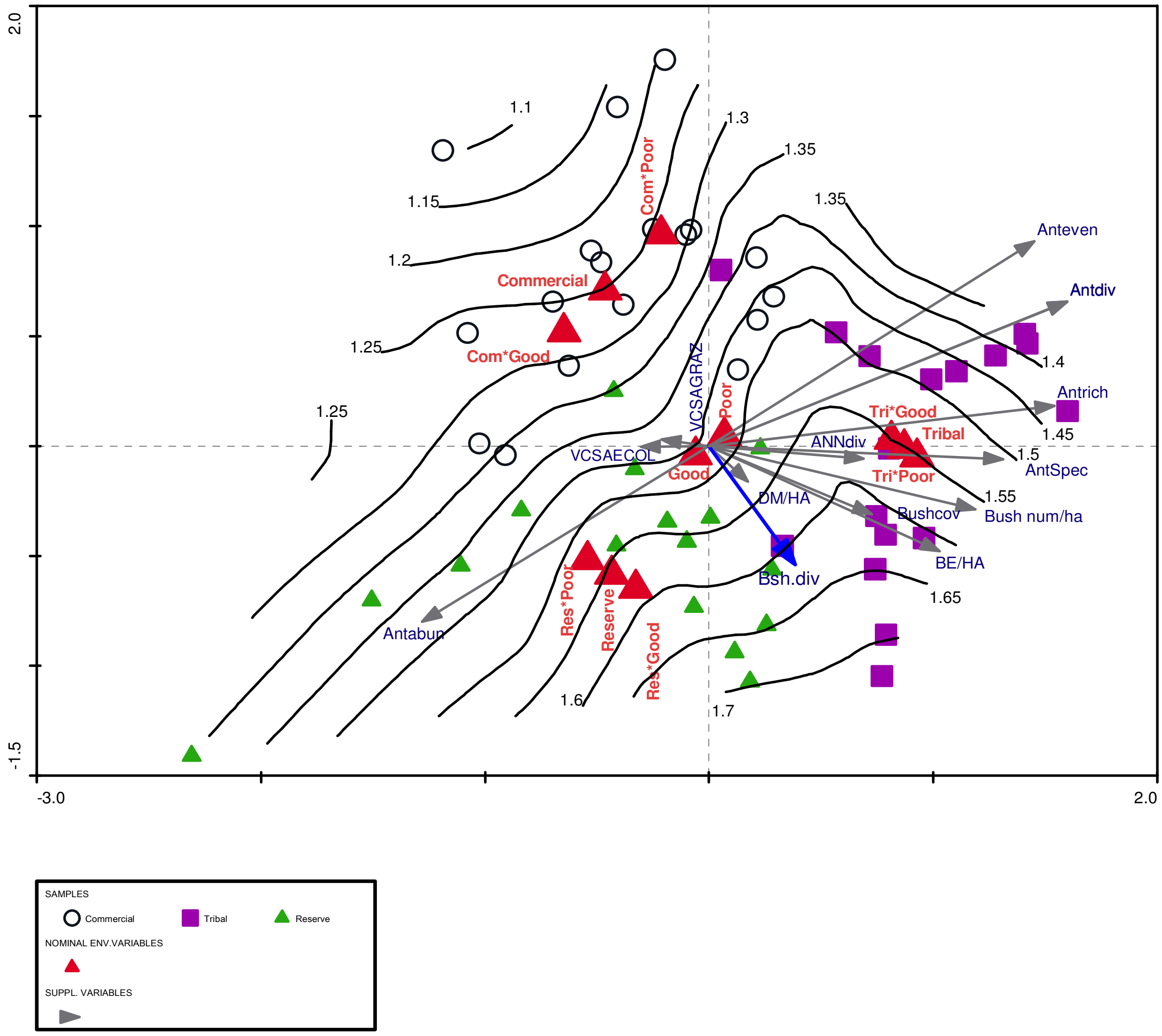


Fig. 8.15. A CCA LOESS plot incorporating woody diversity (Bsh div) as predictor (blue arrow), to establish parallel patterns between ant and woody diversity, indicating a less pronounced gradient (r^2 = 0.33) running from the Reserve, then Commercial land uses, being highest in the Tribal land use.

Ant species richness, diversity, number of ant species and ant "Pielou's evenness" were strongly associated with the Tribal variables along the first axis (first and fourth quadrants). Ant species richness showed positive correlations with the bush numbers/ha (r = 0.365), TE/ha (r = 0.38) (Fig. 8.14) and herbaceous species diversity (Anndiv, r = 0.13) (all fourth quadrant). Ant diversity and woody diversity were positively correlated, as are indicated in Fig. 8.15. A LOESS plot (CCA ordination) incorporating woody diversity as predictor, to establish parallel patterns between ant and woody diversity, also indicated a less pronounced gradient (r^2 = 0.33) running from the Reserve, then to the Commercial land use, being highest in the Tribal land use. Within *each* land use, both the relative "Poor" and "Good" environmental variables were grouped together. The TE/ha gradient was positively correlated to the diversity measures discussed above. Ant diversity was also positively associated with ant species richness (r = 0.88) and Pielou's evenness (r = 0.672). Ant abundance was negatively correlated with ant species richness (r = -0.676), ant diversity (r = -0.879), ant evenness (r = -0.918), bush numbers/ha (r = -0.137) and bush diversity (r = -0.031), with only a small positive association with herbaceous species diversity (r = 0.0317). Ant abundance also showed a slight negative correlation with range condition score (r = -0.22 for ecological index and r = -0.2 for grazing index).

Ant species richness and diversity were positively correlated with herbaceous and woody species diversity. However, it was not correlated with rangeland condition, as discussed in Section 8.2.5. In the previous chapters, herbaceous- and woody *diversity* and *richness* were uncorrelated to "Good" rangeland conditions and the rangeland condition gradient (as indicated by the rangeland condition indices). The multivariate CCA ordination indicated that ant species richness (r = 0.13 and r = 0.17 for the grazing and ecological indices respectively) and richness (r = 0.11 and 0.13 respectively) were (only slightly) positively correlated with rangeland condition and the relative "Good/Poor" environmental variables. However, a more in-depth focus revealed a rangeland condition gradient being observable in the Commercial land use relative to the other land uses. A CCA ordination LOESS plot displayed a gradient related to "Good/Poor" rangeland condition variables. The gradient, although not significant, increased from the Commercial, then Tribal and towards the Reserve land use, with a small gradient being visible within Commercial land use only (Fig. 8.16). A CCA LOESS plot, incorporating rangeland condition ("annual" ecological index) as predictor, showed the pattern, although insignificant, that rangeland condition was highest within the Reserve land use, and lowest within the Commercial-Poor land use, and of intermediate ranges in the Tribal land use. Only the Commercial land use indicated a small rangeland condition gradient (though not significant) within the land use itself, with the Commercial-Good variable having the second highest rangeland condition scores after the Reserve variables with regard to the ant abundance compositional matrix (Fig. 8.17). There was no rangeland gradient visible within the Reserve or Tribal land uses. Such patterns in relation to ant species richness, abundance and diversity need to be investigated in future studies.

Variables, included in order of importance in the Monte Carlo model significantly explaining most of the species-environment relation, were the Tribal land use (F = 5.1, P < 0.005), followed by the Commercial land use (F = 2.61, P < 0.005).

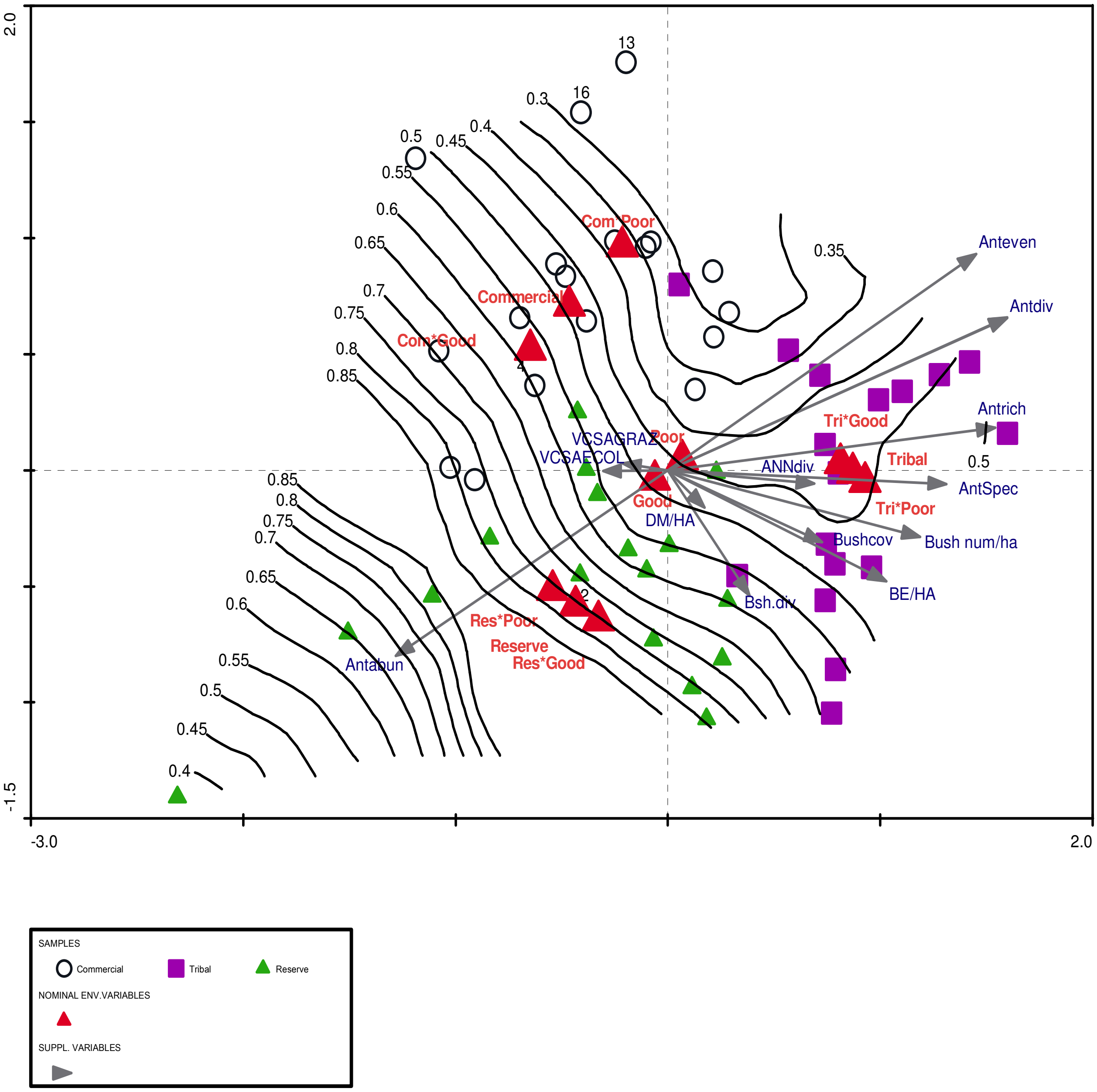


Fig. 8.16. A CCA ordination LOESS plot displaying a non-significant gradient (see contour values) related to nominal environmental “Good/Poor” (blue triangles) rangeland condition variables.

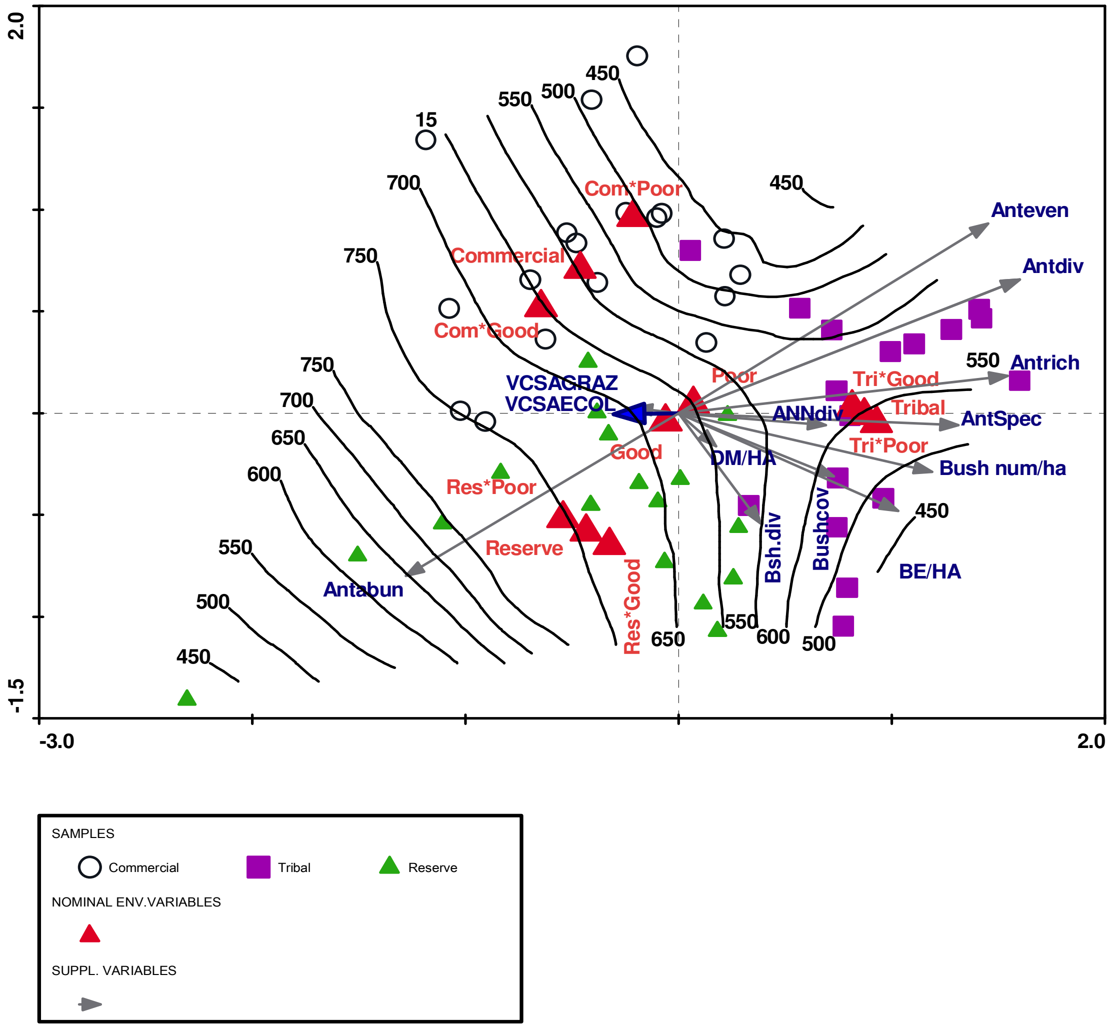


Fig. 8.17. A CCA LOESS attribute plot (gradient), incorporating rangeland condition ("annual" ecological index for the herbaceous composition) as predictor (blue arrow).

Results from this CCA ordination highlighted the parallel patterns between plant (herbaceous and woody component) diversity and richness and ant diversity and richness, and confirm the results discussed in Section 8.2.5. These diversity indices for both the plants and ants were not as much related to range condition ("Poor" and "Good" variables) as to the Tribal land use and its complex heterogeneous structure. These results agree with empirical evidence from natural communities suggesting a causal relationship between diversity and heterogeneity of a system (Rosenzweig & Abramsky 1993), with a complex system effectively creating a wider potential of niches, resulting in a richer fauna and flora (MacArthur 1972). However, there is also considerable evidence that interspecific competition is fundamental in structuring ant communities and abundance (Andersen 1992; Human & Gordon 1996; Morrison 1996). High abundance of ants, especially of only a few dominant species in the Reserve land use, and its inverse correlation to ant species richness and diversity can possibly be ascribed to competitive exclusion (Andersen 1992), and secondary to habitat disturbance/modification as a result of land use. These results support those discussed in Section 8.2.5, and suggest that different models or a combination thereof apply in the different land uses. Key species patterns are consistent with those displayed by the functional groups, and will be discussed in more depth.

Species centred at the middle of the CCA ordination are descriptive of generalist species belonging to all three land uses, owing to the distribution of the land uses in separate quadrants (Fig. 8.18). Generalist species indicated by the CCA ordination were *Monomorium rufulum, Monomorium fastidium, Lepisiota sp A, Tetramorium sp V, Camponotus sp C, Ocymyrmex sp D, Pheidole sp A, Camponotus sp D, Tetramorium setuliferum* and *Meranoplus sp B*. Abundances of these generalist species were comparable within all three land uses. These species were representative of HCS, GMC, OPP and Subcam. These species correspond well with those indicated as generalists in the SIMPER analyses. The CCA ordination confirmed the generalist characteristics of *Monomorium rufulum*, with further BVSTEP (Spearman correlation) tests (discussed in Section 8.2.12) showing that *Monomorium fastidium* was associated with the soil properties (Appendix 8.2). *Lepisiota sp A* was found to be a generalist in terms of habitat preference (both woody and herbaceous associations), *Tetramorium sp V* an opportunistic generalist, *Camponotus sp C* and *Camponotus sp D* were primarily associated with herbaceous species composition, *Pheidole sp A* was best represented by the herbaceous grazing- and ecological indices, *Tetramorium setuliferum* by woody properties and herbaceous material and *Meranoplus sp B* by soil properties, the herbaceous grazing- and ecological indices (Appendix 8.2).

Species more specific/typical of the Reserve land use included: *Monomorium notulum, Opthalmopone berthoudi, Anochetus sp A, Camponotus sp E, Campontus sp A, Anoplolepis steingroeveri* and *Tetramorium sericeiventre* (Fig. 8.18). These species are representative of HCS, SPR and subordinate Camponotini. Their specific associations with various environmental variables are discussed in Section 8.2.12, and presented in Appendix 8.2.

Species associated with the Tribal land use were: *Tetramorium baufra, Camponotus sp B, Tetramorium ? weitzeckeri, Plagiolepis sp A* and *Tetramorium n.setigerum*. These species are primarily OPP, Subcam and then also the only CS surveyed for the total study area: *Plagiolepis sp A*. Cryptic ants are most diverse and abundant within woody habitats, and forage within litter and soil (Andersen 1995a, 1997c, Majer *et al*. 2004). These cryptic species do not compete with other species (Majer *et al*. 2004). *Plagiolepis sp A* was found inconsistently and in low abundances throughout all land uses, although being most abundant in the Tribal land use (Appendices 8.1a, b). In this study, it was associated with the soil variables and herbaceous production, suggesting that it is associated with herbaceous litter (Appendix 8.2).

Species most common to the Commercial land use were: *Ocymyrmex sp A, Ocymyrmex sp B, Ocymyrmex sp C, Ocymyrmex weitzeckeri, Lepisiota sp B, Anoplolepis sp A, Anoplolepis sp B, Meranoplus spinisior, Meranoplus sp C, Tetramorium sp VIII* and *Pheidole sp D* (Fig. 8.18). These species are primarily HCS, OPP and to a lesser degree GMC (*Pheidole sp D*). Their significant associations with different environmental variables, as established for this study (Section 8.2.12), are summarised in Appendix 8.2.

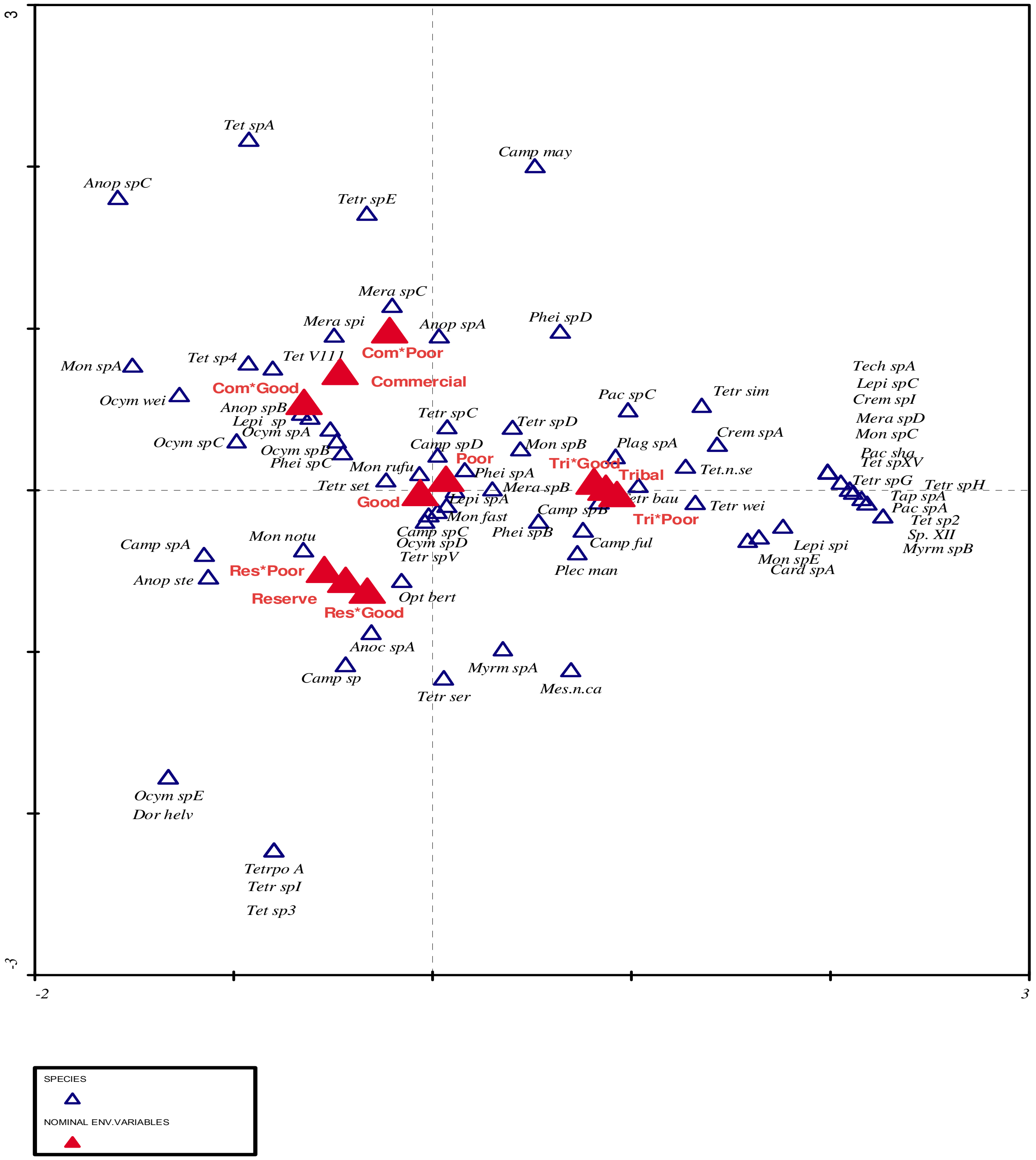


Fig. 8.18. A CCA biplot displaying species compositional patterns related to environmental variables.

B. Absence/presence matrix

A CCA ordination on the absence/presence data resulted in a slightly lower species-environment relation, with 72.2% being explained by the second axis and 93.2% by the fourth axis (Table 8.11). However, association between environmental variables and the axes were better, with the Tribal land use showing the strongest association with the first axis (r = 0.905) and the Reserve land use (r = 0.711), followed by the Commercial land use (r = -0.670) best representing the second axis (Table 8.12).

The Monte Carlo test for the first (F = 4.878, P < 0.005) as well as all the canonical axes (F = 2.3, P < 0.005) was significant. As in the case of the abundance data, ant compositional patterns were significantly best explained by the Tribal land use (F = 5.19, P < 0.005), followed by the Commercial land use (F = 2.69, P < 0.005) (Table 8.11)

Table 8.11. A CCA ordination based on absence/presence data showing the eigenvalues, cumulative species data and species-environment variance for the first four axes, as well as the environmental variables that explained the species-environment relation in order of importance as indicated by the Monte Carlo permutation test.

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.092	0.047	0.021	0.019
Species-environment correlations	0.915	0.829	0.715	0.762
Cumulative percentage variance				
of species data	9.2	14	16.1	18
of species-environment relation (environmental)	47.7	72.2	83.2	93.2
of species-environment relation (passive data)	25	29.7	35.7	39.7

Monte Carlo permutation test

Variable	**P**	**F**
Tribal	0.002	5.19
Commercial	0.002	2.69
Good	0.134	1.26
Com*Good	0.152	1.23
Tri*Poor	0.654	0.9

Table 8.12. CCA correlation coefficients (r-values) for the environmental and passive variables associated with the first two CCA axes for absence/presence data, with the variables showing the highest r-values being indicated in **bold**.

Environmental data	**SPEC AX1**	**SPEC AX2**	**Passive data**	**SPEC AX1**	**SPEC AX2**
Commercial	-0.4996	-0.6705	BE/HA	0.4816	0.1967
Tribal	**0.9053**	-0.0411	Bushcov	0.4102	0.1592
Reserve	-0.4058	**0.7116**	Bush num/ha	**0.5622**	0.1247
Good	-0.0992	0.0455	VCSAGRAZ	-0.2606	0.1042
Poor	0.0992	-0.0455	DM/HA	0.0111	0.204
Com*Good	-0.3497	-0.5399	VCSAECOL	-0.2905	0.1484
Com*Poor	-0.2822	-0.3082	ANNdiv	0.4568	-0.0322
Tri*Poor	0.659	-0.0972	Antdiv	0.3848	0.2099
Tri*Good	0.4861	0.0452	Antabun	-0.1415	-0.083
Res*Good	-0.2695	0.5558	AntSpec	0.4963	**0.296**
Res*Poor	-0.2437	0.3443			

Hence, the absence/presence data matrix, when used in the CCA ordination, was found to correspond well with the abundance data, and can serve as a reliable substitute for the abundance data in multivariate ordinations. Andersen *et al.* (2002) also employed absence/presence data as substitute for abundance data, stating that the occurrence of species across sites can be used as an abundance surrogate.

8.2.8 Cumulative contribution toward explaining species-environment variance

Species (absolute ant abundances) having 10% and higher of their ranges being accounted for by the CCA ordination's first two axes (see Section 8.2.7 A), were determined as a potential "instrument" towards identifying species that best represent each respective land use (Table 8.13). Hence, it is suggested that these species can act as potential indicators of these land uses. Results obtained from these analyses, were then compared to those of the IndVal method, Section 8.2.9.

Table 8.13. Cumulative variances and eigenvalues of ant species (absolute ant abundances) for the first two canonical axes, as well as species having 10% and higher and 20% and higher of their ranges explained by the species-environment variance. Species responsive to the respective axes are indicated in **bold**.

	Eigen values		**Cumulative variance**	
NAME	**AX1**	**AX2**	**AX1**	**AX2**
Anoc spA	-0.3073	**-0.8928**	0.0042	**0.0294**
*Anop spA**	0.0336	**0.9421**	0.0003	**0.1453**
*Anop spB**	**-0.6581**	0.4633	**0.1232**	0.1663
Anop spC	-1.5811	**1.7977**	0.0175	**0.0335**
*Anop ste**	**-1.1268**	-0.5503	**0.11**	0.1286
*Camp ful***	**0.7578**	-0.2598	**0.2028**	0.2196
*Camp spB**	**0.8385**	-0.088	**0.144**	0.1451
Camp spC	0.0243	**-0.1443**	0.0002	**0.0056**
Camp spD	0.0258	**0.2048**	0.0001	**0.0058**
Camp spA	**-1.148**	-0.4122	**0.0228**	0.0249
Camp sp	-0.4365	**-1.0921**	0.0111	**0.0603**
Camp may	0.5163	**1.9949**	0.0041	**0.0478**
*Card spA***	**1.6416**	-0.304	**0.4899**	0.5017
*Crem spA***	**1.4318**	0.2689	**0.2353**	0.2411
Crem spl	**1.9881**	0.1001	**0.0359**	0.036
Dor helv	-1.3283	**-1.7878**	0.0093	**0.0212**
*Lepi spA**	**0.1132**	-0.015	**0.0041**	0.0041
Lepi sp	**-0.6154**	0.4394	**0.018**	0.0244
Lepi spi	**1.7625**	-0.2378	**0.1791**	0.1814
Lepi spC	**1.9881**	0.1001	**0.0423**	0.0424
*Mera spi***	-0.4947	**0.9452**	0.0613	**0.2191**
Mera spB	**0.3022**	-0.0075	**0.0211**	0.0211
*Mera spC**	-0.2021	**1.1298**	0.0058	**0.1342**
Mera spD	**1.9881**	0.1001	**0.0423**	0.0424
Mes. n.ca	0.6953	**-1.1252**	0.0103	**0.0292**
Mon fast	0.0727	**-0.1083**	0.0111	**0.0284**
*Mon notu***	**-0.6484**	-0.3823	**0.2243**	0.2793
Mon rufu	-0.0647	**0.0865**	0.0098	**0.0221**

Table 8.13 (continue ...)

	Eigen values		**Cumulative variance**	
NAME	**AX1**	**AX2**	**AX1**	**AX2**
*Mon spA**	**-1.5078**	0.7579	**0.0938**	0.1106
*Mon spB**	**0.4435**	0.2406	**0.1209**	0.146
Mon spC	**1.9881**	0.1001	**0.0298**	0.0299
Mon spE	**1.5852**	-0.3237	**0.074**	0.0762
*Myrm spA**	0.3548	**-0.9956**	0.029	**0.1902**
Myrm spB	**2.2663**	-0.1731	**0.0414**	0.0415
Ocym spA	**-0.5141**	0.3633	**0.0527**	0.0712
*Ocym spB***	**-0.481**	0.2921	**0.175**	0.2206
*Ocym spC***	**-0.9847**	0.2904	**0.2511**	0.2665
Ocym spD	-0.0185	**-0.1678**	0.0001	**0.0088**
Ocym spE	-1.3283	**-1.7878**	0.0093	**0.0212**
Ocym wei	**-1.273**	0.5786	**0.0806**	0.0923
Opt bert	-0.1545	**-0.5727**	0.0056	**0.0594**
*Pac spA**	**2.1848**	-0.0931	**0.1112**	0.1114
Pac sha	**1.9881**	0.1001	**0.0328**	0.0328
Pac spC	**0.9838**	0.4838	**0.0096**	0.0112
Phei spA	**0.1633**	0.1129	**0.006**	0.008
*Phei spB**	**0.5341**	-0.206	**0.1191**	0.1316
*Phei spC**	**-0.451**	0.2179	**0.1286**	0.1498
*Phei spD***	0.6417	**0.9679**	0.12	**0.3127**
Plag spA	**0.9207**	0.1947	**0.0634**	0.0654
*Plec man**	**0.7289**	-0.4011	**0.0907**	0.1101
*Sp. XII**	**2.1582**	-0.067	0.1402	0.1403
*Tap spA**	**2.1168**	-0.0263	**0.1339**	0.1339
*Tetr bau***	**1.0346**	0.0137	**0.3333**	0.3333
Tech spA	**1.9881**	0.1001	**0.0368**	0.0369
*Tetr ser***	0.0566	**-1.1757**	0.0008	**0.257**
Tetr set	**-0.2341**	0.0496	**0.034**	0.0351
*Tet spA**	-0.9225	**2.1584**	0.0212	**0.1033**
*Tetr sim***	**1.3547**	0.5101	**0.1832**	0.2016
Tetr spC	0.0732	**0.3791**	0.0034	**0.0673**
Tetr spD	**0.4024**	0.3738	**0.0193**	0.031
*Tetr spE**	-0.3292	**1.6993**	0.0059	**0.1164**
Tetr spG	**2.0549**	0.0344	**0.0614**	0.0614
*Tetr spH**	**2.0982**	-0.008	**0.1331**	0.1331
Tet. n.se	**1.2723**	0.1347	**0.0533**	0.0537
Tetr spI	-0.7972	**-2.242**	0.0036	**0.0235**
Tetr spV	-0.0373	**-0.2058**	0	**0.0006**
Tet V111	-0.803	**0.7415**	0.0528	**0.0846**
Tetr wei	**1.3212**	-0.0903	**0.0544**	0.0546
Tet spXV	**1.9881**	0.1001	**0.0328**	0.0328
Tet sp2	**2.2663**	-0.1731	**0.037**	0.0371
Tet sp3	-0.7972	**-2.242**	0.0065	**0.0431**
Tet sp4	**-0.9264**	0.7735	**0.0097**	0.0145
Tetr po A	-0.7972	**-2.242**	0.007	**0.0459**

*Key species having 10% and higher of their ranges explained by the species-environment relation

**Key species having 20% and higher of their ranges explained by the species-environment relation

Twenty-nine species had more than 10% of their variance accounted for by CCA axes 1 and 2 (Table 8.13, Fig. 8.19). The twenty species closely associated with CCA axis 1 were chosen as possible indicator species of land use. These species' relative position along the land use gradient could be indicative of relatedness to either the Tribal land use or the Commercial/Reserve land use groups/complex. The nine species associated with the CCA axis 2 were indicative of either the Commercial or the Reserve land use. The 29 species that had more than 10% of their variance accounted by CCA axes 1 and 2 respectively are presented in Table 8.13 together with the cumulative fraction of the variance of each species accounted for by the first two axes. Eigenvector scores of these species along these axes, reflecting on association with the different land uses are also presented (Table 8.13).

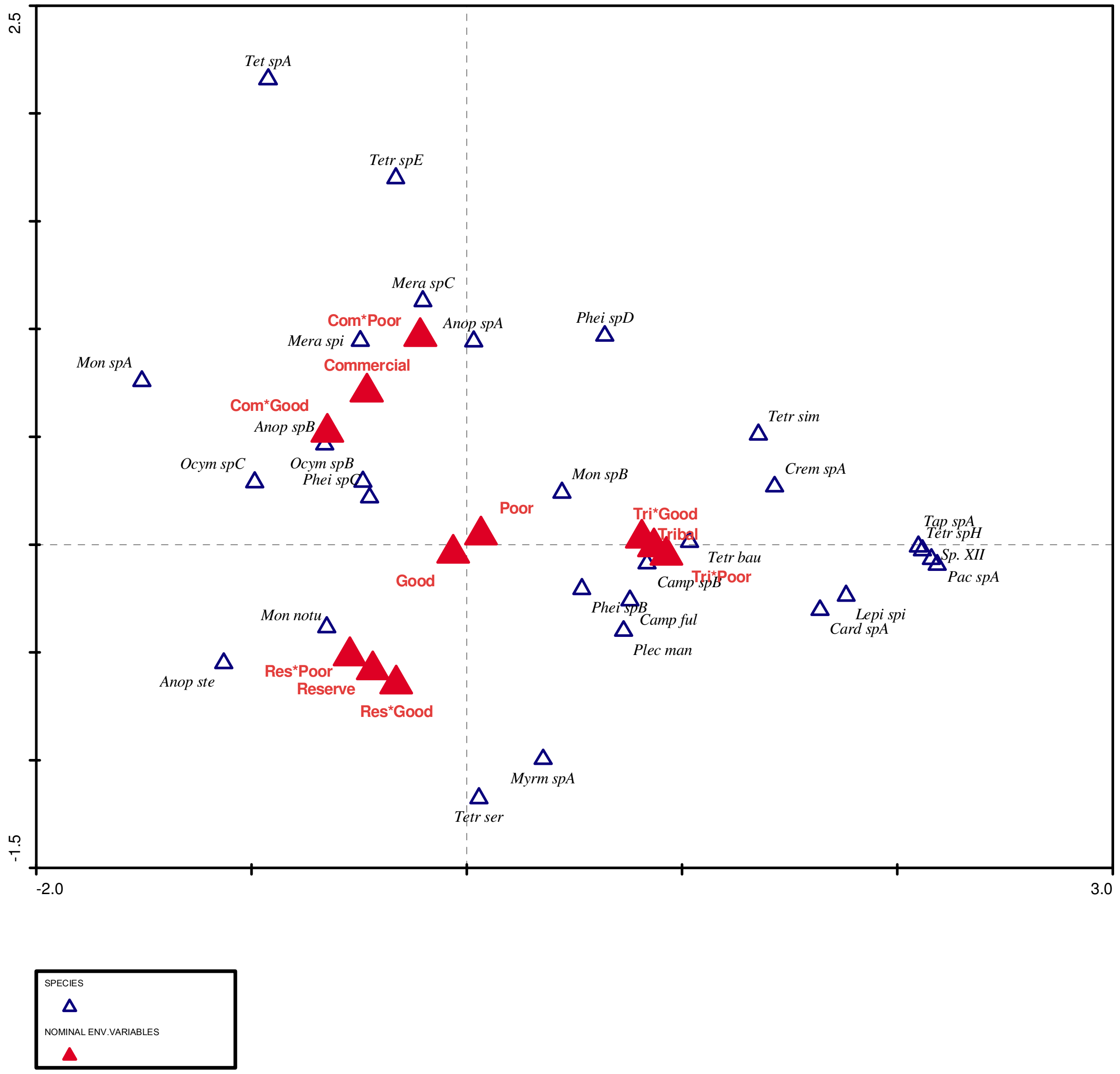


Fig. 8.19. Ant species' ranges explaining 10% or higher of the species-environment variance.

Species with ranges 20% or higher being accounted for by the first two axes are presented in Fig. 8.20. Only 11 species were included, with 3 species being associated with the Commercial land use, 6 species with the Tribal land use and 2 with the Reserve land use.

These species, included under the 10% and 20% and higher inclusion rules, are found consistently throughout the respective land uses. Hence, it is also suggested that they are reliable and specific/typical indicators of the respective land uses. This will be verified by the IndVal results.

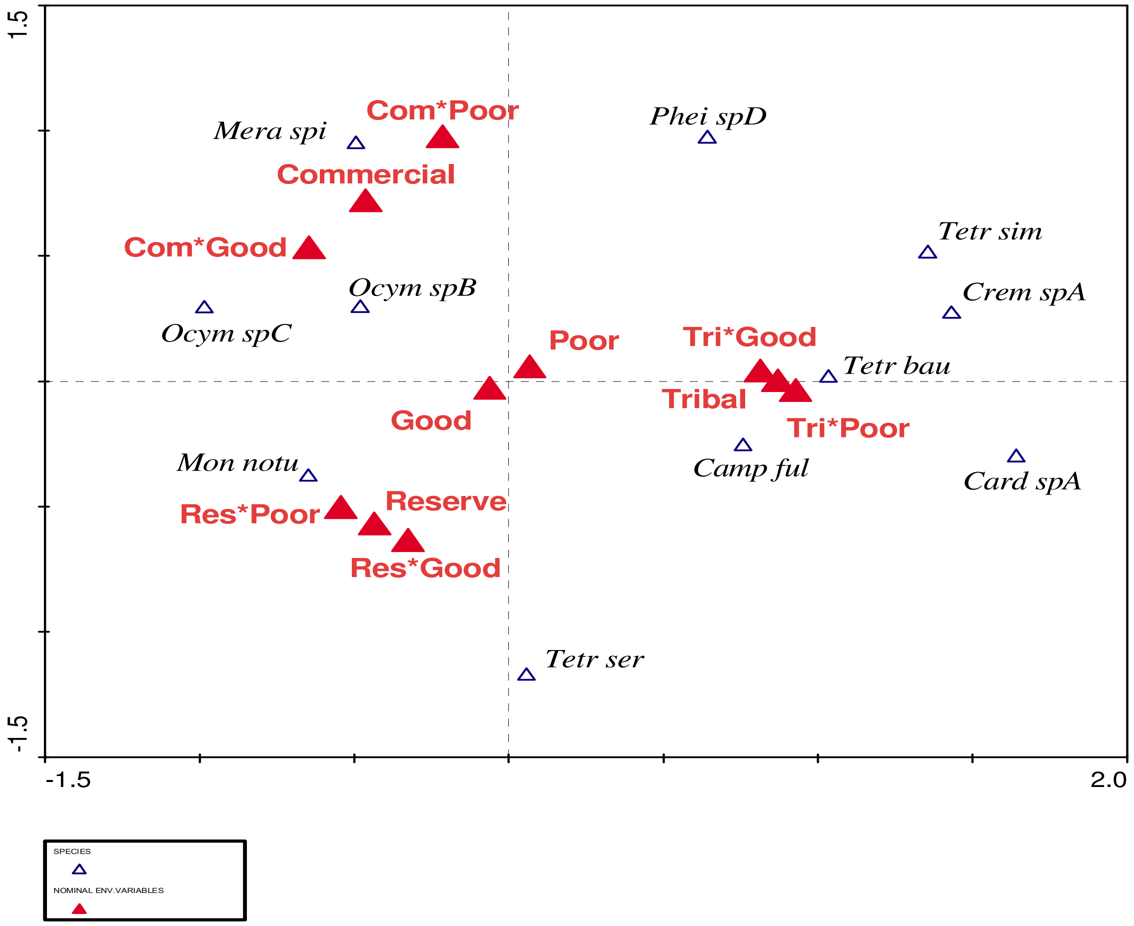


Fig. 8.20. Ant species' ranges explaining 20% or higher of species-environment variance.

8.2.9 Indicator species – IndVal method

Following the ANOSIM and ordination analyses (absolute abundance data; absence/presence matrix), it was evident that the three land uses differed significantly. Indicator species characteristic to each land use, in addition and comparative to the methods employed above were identified using the Indicator Value Method (Dufrêne & Legendre 1997). This method assesses the degree (%) to which each species is unique (specificity) and frequent within a habitat (fidelity). A high percentage IndVal (indicator value) indicates a high fidelity and specificity for a particular species, and hence a high representativeness for a particular locality/habitat/land use. Such indicator species are not only specific to a locality, but also have a high probability of being sampled in that locality (McGeogh & Chown 1998).

Comparisons were made between the land uses by using the random allocation procedure of sites among sited groups, as suggested by Dufrêne and Legendre (1997). Van Rensburg *et al*. (1999) regarded a species as an indicator of a locality when it had a significant IndVal > 70%. It was also used as benchmark for this study, as baseline departure point for this study in the absence of previous contradicted studies.

Species obtaining > 70% IndVal scores across the entire study area (typological level 1, hence irrespective of the land use), were *Monomorium fastidium* (96.3%), *Monomorium rufulum* (98.15%), *Ocymyrmex sp B* (87.04%), *Pheidole sp C* (81.48%), *Monomorium sp B*, *Tetramorium sp C (*both 75.93%) and *Tetramorium setuliferum* (70.37%) (Appendix 8.7). These species can be considered as consistent good indicators of the generalist group (level 1), which are unlikely to respond to rapidly changing environmental conditions (Van Rensburg *et al*. 1999). These generalist species indicated corresponds with results of the CCA ordination as well as the SIMPER analyses, indicating that these techniques complement each other. These generalist species can all be categorised as HCS, except *Pheidole sp C*, which is classified as a GMC and *Tetramorium sp C*, which is classified as an OPP.

Table 8.14. Indicator species (P < 0.05) for the three land uses.

Species	IndVal %	Land use
Anop spA	43.54	Commercial
Mera spi	43.48	Commercial
Ocym spB	46.78	Commercial
Ocym spC	38.52	Commercial
Mon notu	58.38	Reserve
Myrm spA	44.67	Reserve
Tetr ser	51.98	Reserve
Camp ful	49.17	Tribal
Camp spB	34.39	Tribal
Card spA	73.23	Tribal
Crem spA	69.09	Tribal
Lepi spi	30.77	Tribal
Mon spB	50	Tribal
Phei spB	49.78	Tribal
Phei spD	43.87	Tribal
Plag spA	24.56	Tribal
Plec man	33.1	Tribal
Sp. XII	22.22	Tribal
Tap spA	22.22	Tribal
Tetr bau	72.2	Tribal
Tetr sim	43.97	Tribal
Tetr spH	22.22	Tribal

Indicator species ($P < 0.05$) for each land use were identified (Table 8.14). For the Commercial land use, *Anoplolepis sp A, Meranoplus spinisior, Ocymyrmex sp B* and *Ocymerymex sp* C were the four indicator species (all classified as HCS) for this land use, although the IndVal scores were relatively low varying between 38 – 47%. The inclusion of these species corresponds to a range inclusion rule of 14% within the CCA ordination.

Eleven species were identified as indicator species specific to the Tribal land use, of which *Cardiocondyla sp A* (73.23%), *Crematogastr sp A* (69.09%) and *Monomorium sp B* (50%) (the first two species are opportunists, and *Monomoriusm sp B* is a hot climate specialist) were the most important (satisfied by 6% inclusion rule in CCA ordination). These results are also supported by those of the CCA ordination and the SIMPER analysis for absence/presence data, suggesting that the Absence/presence matrix in the SIMPER analysis provides a more reliable reflection of indicator species than the abundance data.

Monomorium notulum (58.38%; HCS), *Myrmicaria sp A* (44.67%; TCS) and *Tetramorium sericeiventre* (51.98%; OPP) were shown to be indicator species for the Reserve land use, although their IndVal scores were only of intermediate range. The inclusion of these species in the Reserve was satisfied by a 19% inclusion rule in the CCA analysis. Selection of these species corresponded well with the species identified under the 10 – 20% of variance explained by the first two axes inclusion rules of the CCA ordination.

It is suggested that the considerably higher number of indicator species within the Tribal land use, can be attributed to its higher species richness, for reasons already discussed (i.e. habitat heterogeneity due to land use type as well as, to a lesser extent, ant behavioural responses).

McGeoch (1998) further employed “detector species” derived from the IndVal method to detect habitat changes, as has been described in the study by Van Rensburg *et al*. (1999). Indicator species (Indval > 70%) are not likely to move out from the preferred habitats even under changing conditions, while generalist species are unlikely to respond to disturbance. The classification of generalist species primarily into the GMC, OPP and HCS groups for this study, suggests that climate, competitive behaviour and disturbance are prevalent within all three land uses, although disturbance was not reflected as a negative correlation or association with range condition, but rather as habitat modification. Species with intermediate IndVal percentages are most likely to move to adjacent habitats under changing conditions (Van Rensburg *et al*. 1999). If this criterion was to be applied for this study, the relatively low to intermediate values of the indicator species for the three land uses, especially for the Commercial and Reserve land uses, imply that indicator species related to these respective land uses are important detector species, being sensitive to disturbance such as habitat change. These species are presented in Table 8.14. However, inclusion rules (percentages) for detector vs. indicator species for the Molopo habitat types need to be verified by future studies, to test and adjust the sensitivity of the benchmark (after Van Rensburg *et al*. 1999 for the Maputaland Centre, southern Africa) used as baseline in this study for semi-arid rangelands.

8.2.10 Multivariate integration of ant species compositional with environmental data

BVSTEP tests (Mantel's test; Spearman rank correlation) and Monte Carlo tests (within the CCA ordinations) (refer to Chapter 3) were used to investigate multivariate correlations between ant abundance and different biotic and environmental data sets, in order to verify and confirm whether land use, as discussed in the sections above, is the primary or a secondary determinant of ant species compositional patterns (Appendix 8.8).

Hence, ant abundance data **(incorporated as predictor)** was related to the woody component, herbaceous species composition, herbaceous production, grazing and ecological indices, herbaceous life-form and soil variables (Appendix 8.8). Although the grazing and ecological indices, as well as the herbaceous life-form were derived from the herbaceous species compositional data, it might prove to be more informative (being more robust) than the in-depth species compositional data matrix. The significance of the tests were evaluated, and environmental variables within each ordination and BVSTEP test explaining most of the species-environment relation (Appendix 8.8), were then selected and compiled into a single environmental matrix (Section 8.2.10 J). Lastly, a CCA ordination, Monte Carlo and BVSTEP tests were performed to identify which of these environmental variables contributed primarily vs. secondarily towards explaining the species-environment variance.

A. Woody component – expressed as Bush numbers/species/ha

Ant species compositional data (ant abundance matrix) was related to the woody component matrix, expressed as number of individuals per woody species/ha. The second axis of a CCA described 63.5% of the species-environment relation, with 63.5% of the variance being explained by the fourth axis. The species-environment variance related to the first axis was not significant (Monte Carlo permutation, $P > 0.1$), neither was it significant for all canonical axis ($P > 0.1$). Hence, the woody component was not the primary determinant of ant compositional patterns. Woody species most strongly representing the first axis were *Acacia erioloba* and *Boscia albitrunca*, with *Dichrostachys cinerea, Acacia mellifera* and *Terminalia sericea* showing the strongest association with the second axis.

Although the Monte Carlo test for the first and all canonical axes for the total woody matrix as environmental set were not significant, primary woody species (as a subset of the total data set) contributing significantly to explaining the species-environment variance, were identified as potential secondary environmental variables that need to be included in the final environmental matrix (Section J). Woody species that were listed as significant by the forward selection in the Monte Carlo test, were *Boscia albitrunca, Acacia erioloba, Dichrostachys cinerea* and *Gymnosporia buxifolia* ($P< 0.05$ for all these species, except for *Gymnosporia buxifolia*: $P = 0.06$, which was included as marginal species). A BVSTEP test ($\rho = 0.28$, rho > 0.95) indicated that in addition to these species listed by the Monte Carlo test ($P < 0.05$), *Acacia haemotoxilyn*, *Ehridtia rigida*, *Rhigozum brevispinosum*, *Grewia flava* and *Terminalia sericea* also contributed to explaining the species-environment patterns. Hence, all these species identified by the BVSTEP and Monte Carlo tests (Appendix 8.8), were included in the final integrated CCA and BVSTEP matrix (Section 8.2.10 J).

B. Woody component – expressed as TE/ha

The same procedure as discussed above, was followed for the same woody information, except that it was expressed as species contribution to TE/ha. This was done in order to identify to which expression/interpretation method of the woody component ants were most sensitive for (if any). A CCA ordination indicated the inclusions of the same species as by the ordination of section A, although the statistics varied slightly. Hence, both methods were effective, and choice of selection will depend on the client using the information (TE/ha being scientifically described by various authors: see Material and Methods, whereas the interpretation method discussed in Section A might be useful to consultants and farmers for bush eradication procedures). The CCA species-environment relation explained 61.9% of the species-environment relation by the fourth axis and 44.2% of the relation by the second axis, which was slightly lower than with the above-mentioned interpretation method, indicating that above-mentioned method yields slightly better interpretational possibilities. None of the canonical axes showed significant patterns between the woody and ant abundance data ($P = 0.44$ for the first axis; $P = 0.3$ for all axes). *Dichrostachys cinerea, Acacia erioloba* and *Gymnosporia buxifolia* were the only species showing significant species-environment relations ($P < 0.05$). However, *Acacia mellifera* and *Acacia luderitzii* were included next in the model as best explaining the species-environment relation, and these marginal species were included in the final integrated model in Section 8.2.10 J (Appendix 8.8)

The BVSTEP test ($\rho = 0.22$, rho > 0.95) indicated the inclusion of *Boscia albitrunca, Dichrostachys cinerea* and *Grewia flava*, with marginal species ($\rho = 0.208$, rho > 0.95) *Acacia erioloba, Ehrethia rigida* and *Terminalia sericea* that should be included in the final analysis/matrix (Section 8.2.10 J).

C. Land use and relative condition

Land use and relative condition variables ("Good" and "Poor) were included in the final analysis, with the Commercial and Tribal land uses being indicated as the most important environmental variables by the Monte Carlo ($P < 0.05$) and BVSTEP tests ($\rho = 0.308$, rho > 0.95), with both tests significantly explaining the species-environment variance (Appendix 8.8). These variables explained 94.6% of the species-environment relation by the fourth axis, as was indicated in Section 8.2.6. These results suggest that land use, primarily the Tribal and Commercial groups, were the primary variables explaining most of the species-environment relation. However, these variables, in addition to other environmental variables, were included in one environmental matrix in Section 8.2.10 J to correctly identify primary and secondary environmental variables explaining the species-environment patterns.

D. Herbaceous species composition

One challenge that should be addressed and described is the association between ant community patterns and seed dispersal related to different herbaceous species. It has been found that certain ant species may disperse seeds of several plant species, whereas the seed of one plant species may also be dispersed by several ant species (Cummings & Heithaus 1992). However, the purpose of this section is to identify herbaceous species important in explaining ant species-environmental relations, hence identifying key herbaceous species that can be incorporated in the final multivariate analysis (Section 8.2.10 J). Only broad patterns related to this section are presented, and a more in-depth analysis related to the seed bank, will be addressed in other papers (Coetzee, *in prep. I*).

A CCA, incorporating herbaceous species composition data ("annual" interpretation") as environmental data, explained 35.1% of the species-environment relation by the second axis and 54.2% by the fourth axis. However, neither the first nor all canonical axes significantly explained the species-environment variance ($P > 0.1$), suggesting that these variables, although important, were not primarily responsible for observed ant species-environment relations. Forward selection (Monte Carlo test) of environmental variables indicated that *Eragrostis pallens, Schmidtia kalahariensis, Eragrostis lehmanniana* and *Aristida congesta* were the environmental variables (as subset) that significantly explained the species-enviroment variance ($P < 0.05$), while *Brachiaria nigropedata*, as marginal species ($P = 0.074$) was also included in the analysis (Appendix 8.8).

The BVSTEP test ($\rho = 0.348$, rho > 0.95) indicated that in addition to above-mentioned species (*Aristida congesta* not listed), *Antephora pubescens*, *Aristida stipitata* and *Melinis repens* (marginal: $\rho = 0.339$, rho > 0.95) should be included in the final environmental matrix of Section 8.2.10 J (Appendix 8.8).

E. Herbaceous grazing index

A BVSTEP test ($\rho = 0.207$, rho > 0.95) showed that the DE, LD and UD groups explained most of the species-environment relations, and was confirmed by the Monte Carlo test in the CCA ordination (Appendix 8.8).

Ant species richness and diversity showed the highest association with the DE and LD grazing classes (Fig. 8.21). Ant abundance was positively correlated with the UD and HD environmental variables.

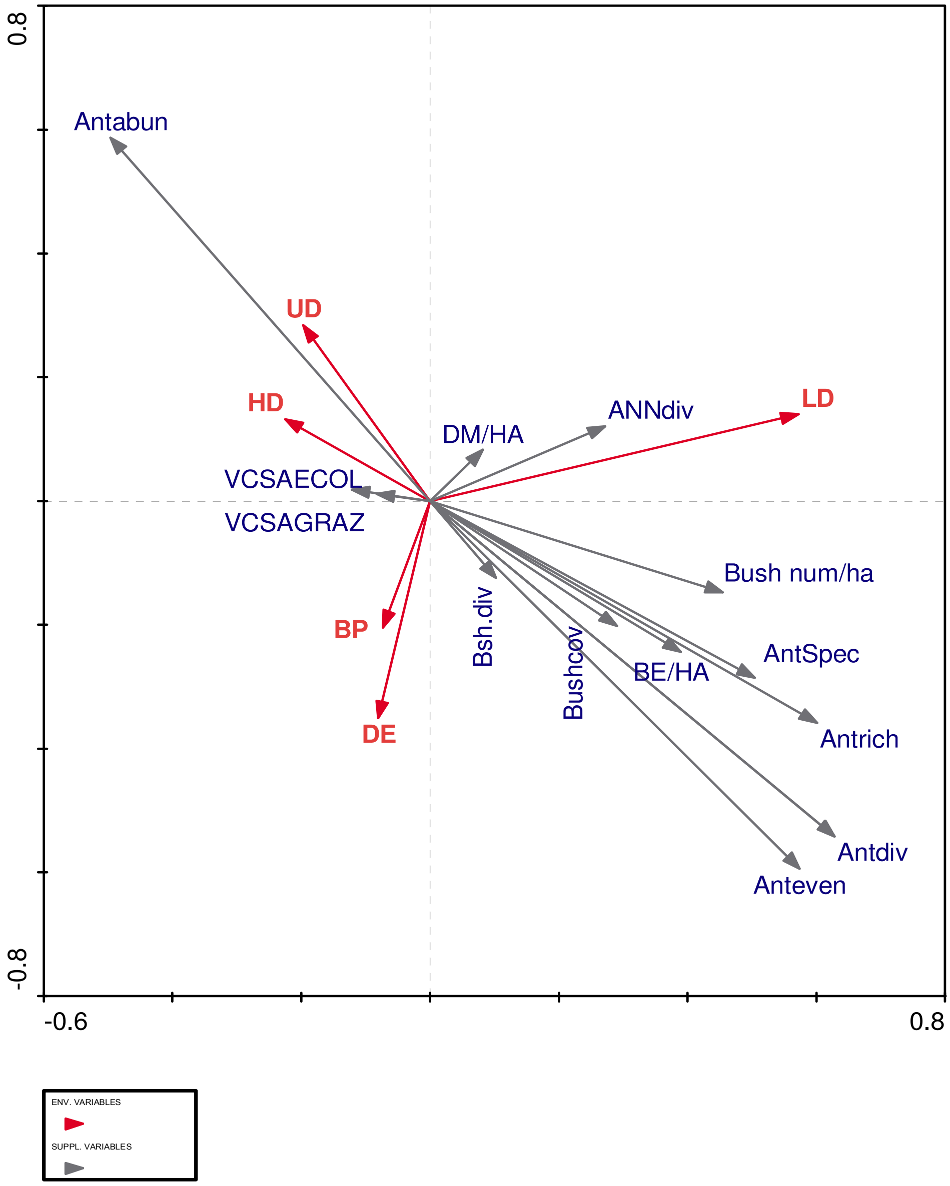


Fig. 8.21. A CCA biplot displaying herbaceous grazing index and passive variables explanatory of the ant species compositional patterns.

F. Herbaceous ecological index

Ecological herbaceous classes explaining most of the species environment variance were the Increaser I, II and III groups (BVSTEP test, ρ = 0.222, rho > 0.95). Forward selection through the Monte Carlo test confirmed that these three classes should be included in the final comprehensive matrix (Section 8.2.10 J) (Appendix 8.8).

Ant abundance was best associated with the Decreaser and Increaser III classes, and ant species richness and diversity with the Increaser II and Increaser I classes (Fig. 8.22).

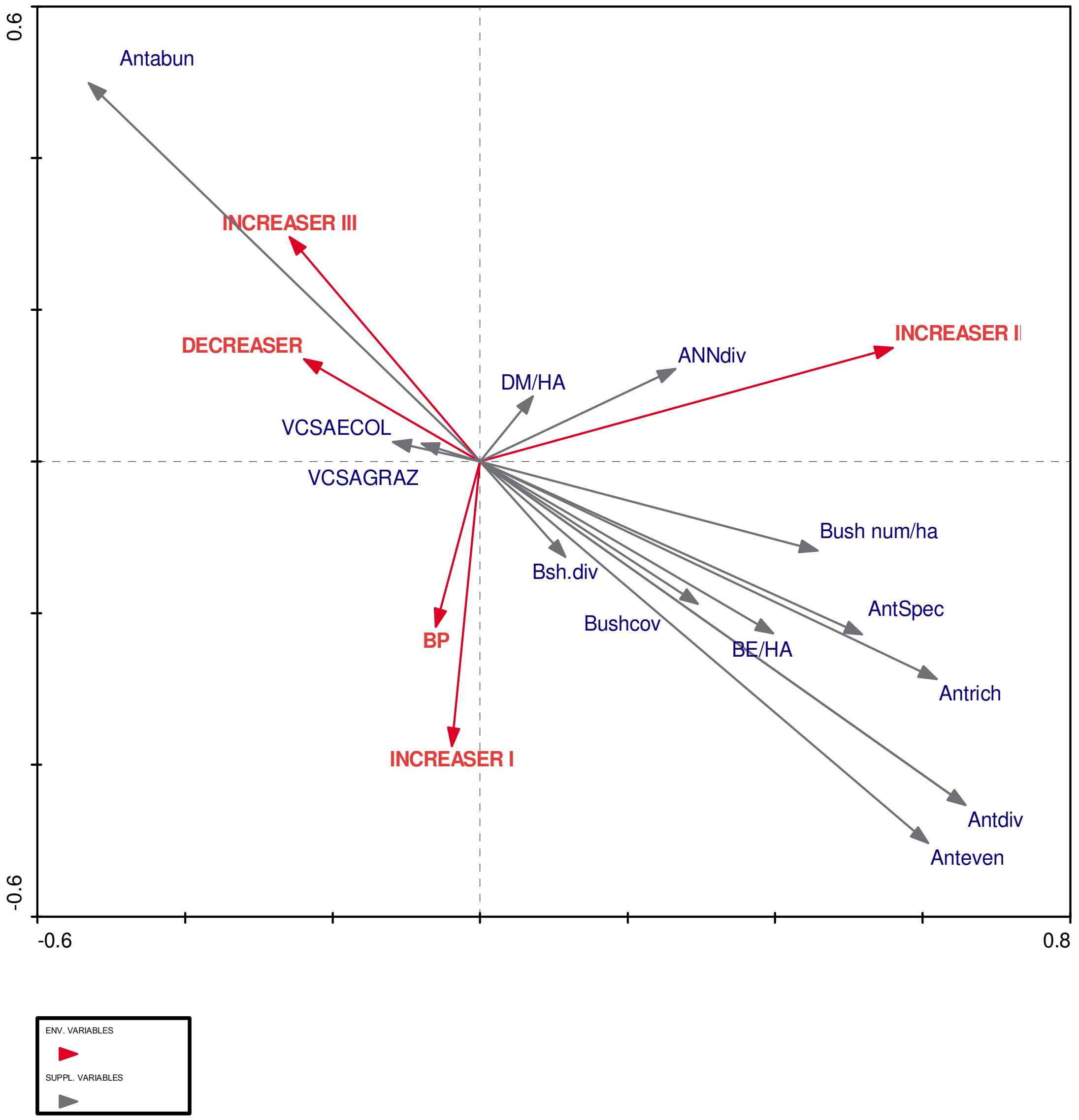


Fig. 8.22. A CCA biplot displaying herbaceous ecological index and passive variables explanatory of the ant species compositional patterns.

G. Herbaceous life-form

The BVSTEP test showed that the Weak perennial and Annual life-forms were the herbaceous life-forms that best explained the species-environment variance (ρ = 0.17, rho > 0.95) (Appendix 8.8).

Ant abundance was best associated with the annual life-form, and ant species richness and diversity with the weak perennial life-form (Fig. 8.23). Seed harvesting ants select unvegetated patches for their nests (Hölldobler & Wilson 1990). Annual grasses are not so adversely affected by heavy grazing (Nash *et al.* 1999), resulting in rangeland with a poor condition producing as much food for seed harvesting as rangeland in a good condition (Nash *et al*. 2001). This might possibly explain the affinity of ant abundances with the annual and weak perennial life-forms in this study. Nash *et al.* (2004) found that ant species richness was negatively related to annual forb cover. Within this study, the annual herbaceous life-form showed a negative relation to ant species richness and diversity.

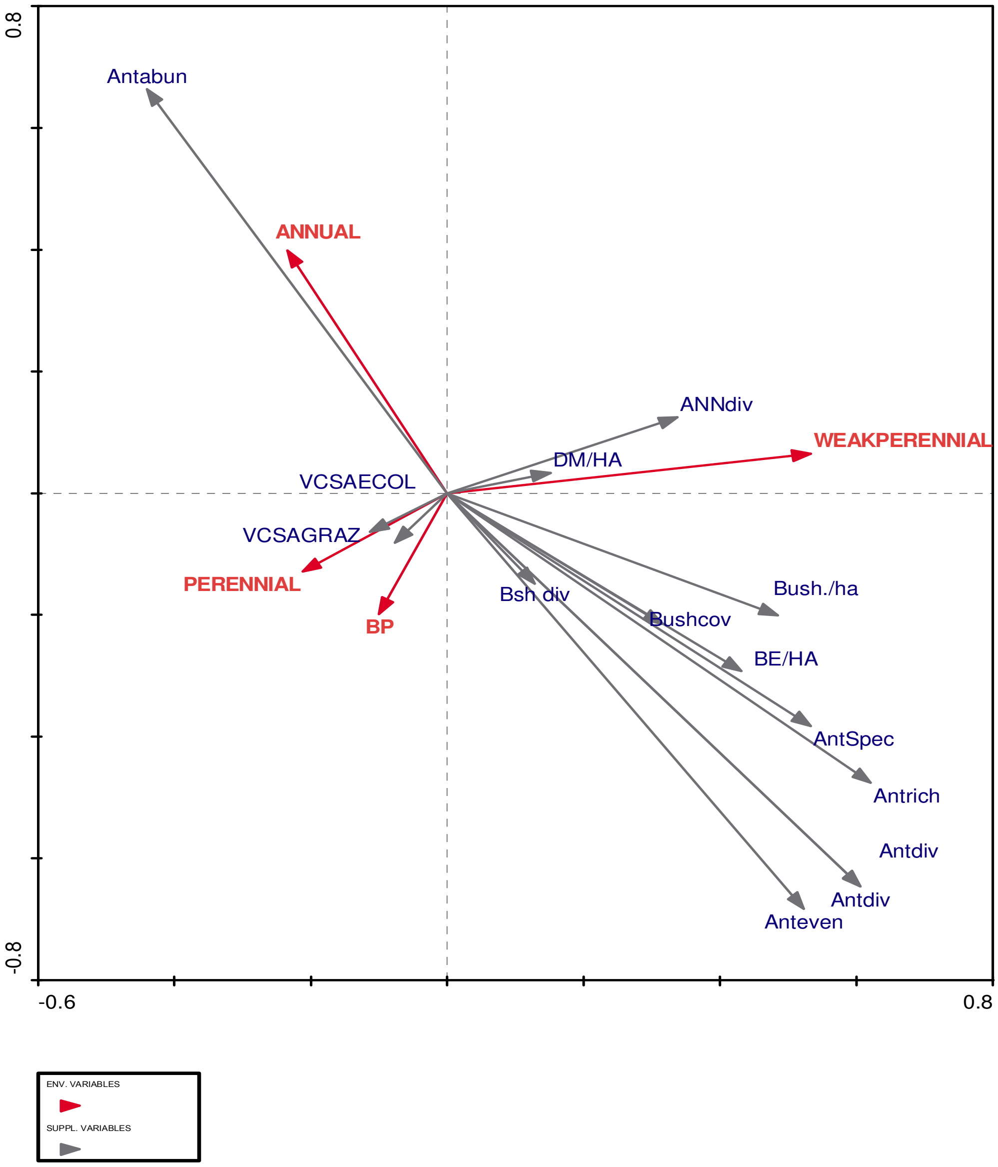


Fig. 8.23. A CCA biplot displaying herbaceous life-form and passive variables explanatory of the ant species compositional patterns.

H. Herbaceous production –kg DM yield per species/ha

Ant abundance data (square-root transformed) was also related to dry material yield per herbaceous species (kg/species/ha). This was done because some species, such as *Plagiolepis sp A* (CS), are related to litter rather than to herbaceous species composition and life-form and the seed produced by these species. The second axis explained 37.9% of the species-environment relation, with 53.4% being explained by the fourth axis. However, a Monte Carlo test indicated that neither the first axis nor any of the axes showed significant species-environment relations ($P > 0.1$), once again illustrating that these environmental variables, although important (see variables below), are not primarily responsible for the observed ant species-environment patterns. Species that significantly contributed to explaining the species-environment relation were *Eragrostis pallens* ($P < 0.05$), while *Aristida congesta* and *Stipagrostis uniplumis* were added as marginal species ($P < 0.096$) (Appendix 8.8).

The BVSTEP test ($\rho = 0.207$, rho > 0.95) indicated that *Antephora pubescens*, *Brachiaria nigropedata*, *Elionorus muticus*, *Schmidtia kalahariensis*, and the marginal species *Triraphis andropogonoides* and *Urochloa brachyura* ($\rho = 0.199$, rho > 0.95) should be included in the model presented in Section 8.2.10 J (Appendix 8.8).

I. Topsoil

Ant nests contribute to soil nutrient heterogeneity in many ecosystems (Wagner *et al.* 2004), with microsites having varying nutrient concentrations, supporting different species. Hence, soil is often an important determinant in explaining ant compositional patterns.

A CCA ordination explained 70.2% of the species-environment relation by the fourth axis, and 48.3% by the second axis. However, the summary of the Monte Carlo permutation showed that the test for the first canonical axis was not significant, whereas it was significant for all other canonical axes ($F = 1.375$, $P < 0.05$). Hence, although some soil variables were important in explaining some of the ant species-environment variance, it was not the primary, but an important secondary ant compositional structuring environmental variable. Variables indicated as significantly explaining the variance (as subset), were medium and fine sand texture ($P < 0.05$ for all), with P ($P = 0.06$), Ca and K ($P < 0.099$) being included as marginal environmental variables in the final integrated analysis of Section 8.2.10 J (Appendix 8.8).

Ant nests contribute to soil nutrient heterogeneity, with the soils near ant nests often containing higher concentrations of nitrogen and phosphorus than soils collected from the nest mounds themselves (Wagner *et al.* 2004). They found that the nests of old colonies were rich in N- and P-containing components, creating nutrient-rich microsites becoming available for plant colonisation once the ant colony had died off. This might explain the inclusion of these variables, as indicated for this study.

The BVSTEP test showed that the following variables should be included ($\rho = 0.189$, rho > 0.95): P, medium and fine texture sand, silt and coarse sand ($\rho = 0.175$, rho > 0.95) (Appendix 8.8). Bestelmeyer and Wiens (2001) found that soil strength (soil texture) was related to patterns of ant species abundance, with both grazing-induced differences and natural processes affecting soil strength and hence resulting in environmental variation affecting species composition. However, although ant behaviour likely enhances soil nutrient concentrations, the dynamics of this process still need to be fully quantified (Wagner *et al.*

2004). Ant species that were indicated to be sensitive to these key soil variables are listed in Appendix 8.2 (See Section 8.2.12).

J. Integration of key environmental variables (selected in section a-h above) in multivariate analysis

A CCA ordination was performed, incorporating all variables as indicated by the Monte Carlo permutation and BVSTEP tests in the sections above (Appendix 8.8), as environmental data. The second axis explained 37.4% of the species-environment relation, with 53.9% being explained by the fourth axis. The second axis explained 58.7% of the species-passive data relation (Table 8.15). A Monte Carlo permutation indicated that the test for the first canonical axis was not significant (F = 2.142, P = 0.306), but that the test for all canonical axes were significant (F = 1.548, P < 0.05). This suggests that some of the environmental variables included, are not primary environmental variables explaining the ant species-environment variance, and should be removed from the matrix.

Table 8.15. A CCA ordination based on the key environmental variables, showing the eigenvalues, cumulative species data and species-environment variance for the first four axes.

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.424	0.193	0.168	0.103
Species-environment correlations	0.967	0.995	0.979	0.959
Cumulative percentage variance				
of species data	23.4	34.1	43.4	49.1
of species-environment relation (environmental)	25.7	37.4	47.6	53.9
of species-environment relation (passive data)	47.6	58.7	67	71.9

The environmental variables (positive correlation of variables with land uses indicated in brackets), in order of importance that explained most of the variance in the Monte Carlo forward selecteion model, are presented in Appendix 8.9. The Tribal land use (P < 0.005), followed by *Acacia erioloba* (positive correlation with Commercial land use, r = 0.32), the Commercial land use (P < 0.005 for all three these variables) were the three most important variables explaining the species-environment variance. Fine textured sand (positive correlation with Tribal land use, r = 0.453), silt (Reserve land use, r = 0.160), *Eragrostis lehmanniana* (Tribal land use, r = 0.2), *Schmidtia kalahariensis* (Commercial, r = 0.243) (both herbaceous species composition variables), medium textured sand (Commercial land use, r = 0.334), the Commercial-Good interaction (P < 0.05 for all these variables) also significantly contributed to the species-environment relation. *Acacia hebeclada* (Commercial, r = 0.27) (woody component), the LD palatability class (Tribal, r = 0.765) (grazing index), *Elionorus muticus* (Tribal, r = 0.208) (herbaceous production) and *Antephora pubescens* (Commercial, r = 0.351) (herbaceous species composition) significantly explained some of the variance.

A BVSTEP test, in addition and complementary to the CCA ordination and Monte Carlo test discussed above, was performed to establish which environmental variables explained most of the species-environment variance for the ant abundance data. Variables that significantly contributed (rho > 0.95) towards explaining the species-environment relation (ρ = 0.44), were the Commercial and Tribal land uses, *Brachiaria nigropedata*, *Schmidtia kalahariensis*, *Eragrostis pallens* (all herbaceous species composition), *Schmidtia kalahariensis* (herbaceous production), P, fine textured sand, *Acacia erioloba*, the annual herbaceous life-form, the UD palatability class and the Increaser III ecological class (indicative of "under-"grazing). Additional variables explaining second-most of the species-environment relation (rho > 0.95), were *Antephora pubescens* (herbaceous species composition – ρ = 0.437- and production (ρ = 0.431), *Ehretia rigida*, *Grewia flava* (all woody number of individuals/ha; ρ = 0.423) and the LD herbaceous grazing class (ρ = 0.32).

Above-mentioned results suggest that **land use** type primarily (Sections 8.2.10 A – J), with vegetation properties *related* (or being the product of; secondary determinant) to these land use management practices, are the determinants structuring ant communities within the study area.

An additional BVSTEP test, based on the above-mentioned selected environmental variables (BVSTEP tests), was performed in order to established which ant species significantly showed the strongest association with the above-mentioned key environmental variables. These 19 species (ρ = 0.459, rho > 0.95) are presented in Table 8.16, with another 7 "marginal" species underlined (ρ = 0.453 – 0.456, rho > 0.95), being presented as well.

Table 8.16. Key ant species related to key environmental variables as indicated by the BVSTEP and Monte Carlo tests. "Marginal" species, indicated by the BVSTEP test, are underlined.

Species		
Anop spB	*Mon fasti*	*Sp. XII*
Camp spC	*Mon notu*	*Tetr bau*
Camp spD	*Mon spC*	*Tetr set*
Camp may	*Mon spE*	*Tet spA*
Card spA	*Ocym spB*	*Tetr spG*
Crem spA	*Pac spA*	*Tetr spH*
Lepi spi	*Pac sha*	*Tetr spV*
Lepi spC	*Pac spC*	*Tet spXVI*
Mera spD	*Phei spD*	

8.2.11 Partial canonical ordination to distinguish between primary and secondary determinants of ant species-environment relations

A partial CCA ordination was carried out retaining only the three land uses and relative “Good” and “Poor” environmental variables (as discussed in Section 8.2.6) while incorporating the rest of the key environmental variable data (discussed above in Section 8.2.10 J) as covariable data. This was done as final test to ascertain that land use as primary structuring agent, followed by vegetation variables associated (being the product of) with these land uses, was responsible for explaining the largest proportion of the species-environment variance. Hence, the effect of these variables was partialled out from the ordination. Greenslade and Greenslade (1977) suggested that vegetation impacted on ant communities through structural complexity of the habitat, its carrying capacity and its effect on the microclimate. Effects of site disturbance are often secondary and stress-related, through modifications to habitat structure and microclimate (Andersen 1988, 1990). Hence, changes in plant composition and structure may be reflected by changes in ant species and community composition (Andersen 1983). This section seeks to establish whether land use types are primary determinants of ant assemblage patterns, by governing habitat structure and composition, and by directly and indirectly impacting on the behavioural responses of ant communities. Woinarski *et al.* (2002) found that ant species composition and richness showed patterns largely due to the effects of land use in northern Australia. Parr *et al.* (2002) furthermore illustrated that a clear relationship exists between habitat structure and ant species richness (southern African savannas), with litter, bare ground and vegetation structure being responsible for overall structuring of ant assemblages (Andersen 1991c; Crist & Wiens 1994; Bestelmeyer & Wiens 1996).

The Monte Carlo permutation to test the significance of the relation between the species and environment was significant for the first ($F = 2.917$ =, $P < 0.05$) as well as all the canonical axes ($F = 1.73$, $P < 0.005$), with 67.6% of the species-environment variance being explained by the second axis and 92.3% by the fourth axis (Table 8.17). This is a considerable improvement from the statistics presented in Section 8.2.10 J, and is very similar to the statistics of Section 8.2.2.4, suggesting that the land use variables primarily accounted for the observed patterns, whereas the other key environmental variables employed as covariables in the partial canonical ordination, were secondary determinants of the ant species compositional patterns. It is also suggested that the key environmental variables (vegetation properties) were the result (product) of the land use management types, and hence secondary environmental variables in explaining the ant species-environment relation.

Table 8.17. A partial CCA ordination based on absolute abundance data for the integrated environmental data, showing the eigenvalues, cumulative species data and species-environment variance for the first four axes, as well as the environmental variables that explained the species-environment variance, in order of importance as indicated by the Monte Carlo permutation test.

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.08	0.06	0.026	0.025
Species-environment correlations	0.807	0.683	0.784	0.75
Cumulative percentage variance				
of species data	7.1	12.5	14.9	17.1
of species-environment relation (environmental)	38.5	67.6	80.2	92.3
of species-environment relation (passive data)	11.8	31.2	34	37.6

Monte Carlo permutation test

Variable	**P**	**F**
Commercial	0.002	2.87
Tribal	0.008	2.09
Com*Good	0.046	1.69
Good	0.302	1.13
Tri*Poor	0.794	0.73

Environmental variables strongly associated with the first axis were the Commercial land use (r = 0.7074), followed by the Tribal land use (r = -0.5919). The Commercial-Poor (r = 0.452) and Reserve (r = -0.4485) variables were most strongly associated with the second axis (Table 8.18). The passive variables best related to the first axis were the TE/ha (BE/ha) and bush numbers/ha, which were then also associated with the Tribal and Tribal-Good variables. The second axis was best represented by the following passive variables: ant evenness, ant abundance and ant diversity variables, with ant abundance being associated with the Reserve-Poor variable, and ant evenness, -diversity and –richness with the Tribal-Poor variable (and to a lesser extent the Commercial-Poor variable) (Table 8.18).

Variables significantly explaining the species-environment variance, as indicated by forward selection in the Monte Carlo permutation, were the Commercial land use, Tribal land use and Commercial-Good interaction (P < 0.05) (Table 8.17). Hence, this study confirmed that vegetation changes, due to different land use disturbances, were a primary determinant of ant species compositional patterns.

Table 8.18. Partial CCA correlation coefficients (r-values) for the environmental and passive variables associated with the first two CCA axes for the partial CCA, with the variables showing the highest r-values being indicated in **bold**.

Environmental data	SPEC AX1	SPEC AX2	Passive data	SPEC AX1	SPEC AX2
Commercial	**0.7074**	0.2435	BE/HA	**-0.4437**	0.051
Tribal	**-0.5919**	0.3189	Bushcov	-0.2274	-0.0814
Reserve	-0.3456	**-0.4485**	Bush num/ha	**-0.484**	0.0381
Good	-0.0507	-0.2927	VCSAGRAZ	0.1572	-0.2033
Poor	0.0507	0.2927	DM/HA	-0.1487	-0.1223
Com*Good	0.4608	-0.1269	VCSAECOL	0.1584	-0.2242
Com*Poor	0.4683	**0.452**	ANNdiv	-0.0883	-0.1653
Tri*Poor	-0.2798	0.2861	Antdiv	-0.088	**0.6487**
Tri*Good	-0.1619	-0.0611	Antabun	0.05	-0.677
Res*Good	-0.322	-0.2175	AntSpec	-0.3299	0.1558
Res*Poor	-0.0601	-0.2747	Bsh.div	-0.2783	0.016
			Antrich	-0.2687	**0.3652**
			Anteven	0.0688	**0.7737**

8.2.12 Employing individual environmental data matrices as predictors for ant species-environment associations

In the Sections above (8.2.10 and 8.2.11), ant species data (abundance) were used as predictor to identify which key environmental factors of the separate matrices explained most of the species-environment relation (Appendix 8.8).

This section has two primary focus areas. Firstly, a matrix is provided to establish, by incorporating the different environmental matrices individually as predictors (and not by incorporating the ant abundance matrix as predictor), which (selected subsets) key ant species are best related to the respective matrices (Appendix 8.2). It is suggested that these key ant species associated with the different biotic/abiotic environmental variables, can be used for management and monitoring purposes, in addition to the “Key assessment matrix” provided in Chapter 9 (Concluding remarks). This approach differs from the assessments and discussions of the two sections above (Sections 8.2.10 and 8.2.11), in that in the above-mentioned sections, ant species composition was employed as predictor to identify the key environmental variables (subsets) within each environmental matrix that was associated with ant species composition (Appendix 8.8).

BVSTEP tests were performed (refer to Chapter 3), and ant species significantly associated with each separate biotic/abiotic matrix (rho > 0.95), were identified (Appendix 8.2). The r-value describes how good the key ant species (indicated by highlighted blocks) were related to each separate environmental matrix (Appendix 8.2). These analyses served as departure point for compiling a basic matrix in which species were not only categorised in terms of preference based on the different environmental data sets, but finally into three broad categories: Specialist/Generalist/Land use/Association type) (Appendix 8.2). For example, *Anoplolepis sp A* was mainly associated with the soil component ($\rho = 0.6$, rho > 0.95), showing a "specialist" association with the soil component. *Camponotus sp D* was associated with both the herbaceous and soil components, whereas *Monomorium notulum* was associated with the herbaceous production and land use type (hence, other inherent factors associated with land use, e.g. behavioural or climatic factors) (Appendix 8.2). Generalist species showed an association with most of the biotic/abiotic environmental matrices whereas specialists were associated with only one or two of the environmental matrices (Appendix 8.2). It is suggested that this matrix should be used complementary to the "Key assessment matrix" (Chapter 9, Concluding remarks) for monitoring and management purposes.

Secondly, these selected key ant species associated with each biotic/abiotic environmental matrix (Appendix 8.2, indicated by highlighted blocks), were then related (as predictors) to each independent environmental matrix (by means of BVSTEP tests). This was done in order to identify whether the key ant species (associated with that particular environmental matrix, as indicated in Appendix 8.2 by highlighted blocks) can be associated with a small proportion of key environmental variables within each matrix, for future monitoring purposes (Appendix 8.10). This procedure also attempted to establish whether similar or different environmental variables within each biotic/abiotic matrix were indicated as opposed to when the total ant compositional matrix was employed in the analyses to compile the matrix presented in Appendix 8.8. Thus, key ant species might not necessarily be sensitive to the same environmental variables (Appendix 8.10) as was indicated by the complete ant compositional matrix (Appendix 8.8). This holds important implications for rangeland and conservation monitoring, management and planning strategies. Research and management questions should thus be clearly defined in order to ensure that the correct scientific approach is used to reflect on the diversity, land use impacts, heterogeneity issues and biotic-biotic/abiotic associations. For example, *Anoplolepis sp A*, *Camponotus sp D*, *Lepisiota sp A*, *Lepisiota spinisior*, *Meranoplus sp B*, *Monomorium fastidium*, *Ocymyrmex sp B*, *Ocymyrmex sp C*, *Opthalmopone berthoudi*, *Pachycondyla sp C*, *Pheidole sp A*, *Plagiolepis sp A*, *Tetramorium sp A* and *Tetramorium ? weitzeckeri* were key species that showed an association with the soil component (Appendix 8.2).

Only these key ant species were then related to the total soil matrix, and from this matrix only the key soil variables indicated by the BVSTEP test (rho > 0.95), were listed (Appendix 8.10). The most important observation was that the r-values declined in all cases when only the key ant species were related to the environment variables of the respective matrices (although still significant, with rho > 0.95), except in the case of the "land use" and "kg herbaceous production per species/ha", which improved from the matrix presented in Appendix 8.2. These results suggest that these last two mentioned environmental matrices are relatively sensitive as monitoring tools at this in-depth level of analysis. The r-values pertaining to the other environmental matrices in Appendix 8.10, were lower than that of Appendix 8.8, suggesting that analyses at this level of interpretation, although still significant (rho > 0.95), were less informative. However, an important observation was that the key ant species were related to other environmental variables within each environmental matrix (Appendix 8.10), in addition to those listed in Appendix 8.8.

This emphasises and supports the statement given above that, depending on the research question and thus the level of monitoring, the correct parameters need to be quantified when describing ant species-biotic/abiotic relations. However, such finding should be verified by future studies for these semi-arid rangelands.

8.3. CONCLUSION

Invertebrates have been extensively used as ecological, environmental and biodiversity indicator species (Brown 1997; McGeoch 1998). The use of faunal indicators can be justified only if their performance is superior to that of plants, or if they provide information other than plants do, owing to fauna being more difficult to census than plants (Andersen & Sparling 1997). The purpose of environmental and biodiversity indicators is to provide cost- and time-effective means to answer conservation and management questions.

Ants are diverse, abundant, and an ecologically dominant group in Australia (Andersen 1995a), and have been widely used as bio-indicators in Australia and have the potential to integrate many aspects of ecological change, rendering them good indicators in environmental monitoring (Greenslade & Greenslade 1984; Andersen 1990). Ants have also been found to show a considerable ecological overlap with plants, suggesting that congruent patterns between vegetation and ant communities exist (Andersen 1991a).

This is the first study that has been conducted to examine the effects of different land use practices on vegetation and ant communities in the Molopo semi-arid rangelands, with reference to degradation management and sustainable biodiversity practices. Plant and ant communities may respond differently to disturbance and stress, hence this study investigated potential parallel patterns between vegetation and ants as a result of land use practices and rangeland condition. Compositional patterns, species richness, diversity and abundance variables (metrics) were used as comparative measures between vegetation and ants. In order to attain this, key environmental variables explaining most of the ant-species environment variance were identified. Functional groups, absolute and relative abundances, absence/presence data and indicator species derived from the IndVal, CCA ordination and to a lesser extent from the SIMPER analyses, were jointly used to address these questions.

The functional grouping provided a good framework indicating and explaining broad community composition and behavioural dominance within and between the three land use groups within these semi-arid Molopo rangelands. However, the significance of this approach was indicated as too robust to fully explain the species-environmental variance. Thus, ant species composition, (single species approach) expressed in terms of different matrices, were used in addition to explain ant community structures. Both approaches indicated the structuring of ant assemblages (at community and functional level) in response to habitat and environmental disturbances, as well as the result of climatic and behavioural responses.

Indicator species derived from the various programmes were complementary to each other, and should be used jointly, since each programme provided additional information specific to that package. Indicator species for this study proved to be useful in distinguishing between the different land uses, and it is suggested that these species are important in detecting habitat changes, and could possibly be employed as detector species of environmental disturbance. Subjective IndVal benchmarks for indicator vs. detector species for these semi-arid rangelands should be verified in future studies with that used by Van Rensburg *et al.* (1999).

Ant compositional patterns were indicated, by means of multivariate ordinations, to be primarily the result of different land use practices that resulted in habitat modification and hence also resulting in climatic and behavioural responses among ant assemblages. This was congruent with the vegetation patterns that differed in composition between the land uses, owing to the different management practices (also see previous chapters on different vegetation properties). Habitat heterogeneity was highest in the Tribal land use, resulting in the highest vegetation (woody and herbaceous) richness and diversity associated with this land use. Ant species richness and diversity was also highest within the Tribal land use, hence displaying parallel patterns. The complex heterogeneity, as a result of land use, can possibly explain the functional and species compositional structures related to the Tribal land use, as has been supported by several studies discussed in the results. The lower ant diversity and richness associated with the Reserve and especially with the Commercial land use, are also congruent to the vegetation patterns, which indicated that the Molopo semi-arid rangelands are probably governed by a dichotomy between non-equilibrium and equilibrium (density-dependent) models. The high overall abundance of ants within the Reserve land use, as well as the high abundance of certain key species, followed by the Commercial land use, are also consistent with the herbaceous species compositional patterns. High dominance and low diversity/richness by ants have been suggested to be indicative of highly productive systems (high ant biomass) in the humped distributional model (Majer 1985; Andersen 1992). For this study, ant functional and species compositional assemblage patterns support this statement, indicating that the humped distribution is potentially prevalent within the Reserve land use and to a lesser extent in the Commercial land use. Hence, climatic and behavioural responses are important determinants governing community structures within the Reserve, and secondly in the Commercial land uses (with the habitat structure and composition being primarily a result of land use), whereas environmental disturbance due to habitat changes resulting in a complex heterogeneous system in the Tribal land use resulted in high diversity/richness and low ant dominance. However, it is suggested that a dichotomy of these two models operate within the Molopo semi-arid rangelands, being most apparent in the Reserve land use that shows an intermediate heterogeneous system (vegetation and ant diversity and richness), but also being classified as highly productive.

Higher plant productivity has also been related to less overall vegetation diversity, since more competitive species tend to dominate in a given area, resulting in lower vegetation species number (Huston 1993). In terms of vegetation compositional patterns, the Reserve and Commercial land uses had similar (significant) herbaceous communities as a primary result of land use management, whereas the Tribal land use seemed to have a transitional shift in herbaceous species composition, as described by the state-and-transition model (Westoby et *al.* 1989) following a triggering (disturbance) event. Therefore it seems as though ant compositional patterns, expressed in terms of productivity and heterogeneity, are parallel to that of vegetation patterns within the Molopo semi-arid rangelands. Both ant and vegetation patterns were found to be related to land use practices, and agree with studies by Woinarski *et al.* (2002) that found that ant species composition and richness showed patterns largely due to the effects of land use in northern Australia.

However, the debate regarding the sustainability and productivity of communal rangelands, in comparison to commercial ranching, is still under discussion. It is a common perception that overgrazing and poor management strategies are far greater in communal farming areas than in commercial farming areas (Archer *et al* 1989), resulting in unproductive and degraded rangelands (Dahlberg 2000). Ant functional groups and community assemblages did not show any correlations with rangeland condition in this study (community patterns, abundance, diversity, species richness). Read and Andersen (2000) also found that ants did not respond significantly to grazing, and Whiford *et al.* (1999) stated that ant communities may be poor indicators of rangeland condition. However, Hoffmann (2000) found that individual species and functional group patterns reflected changes in declining rangeland condition, hence potentially serving as indicators of pasture and rangeland conditions. A degradation gradient based on total abundance was visible within the Commercial land use (significant when total abundances were used, but not significant for absolute or relative abundances or for the diversity indices), suggesting that localised patterns should also be monitored in future studies. Vegetation surveys indicated the existence of a degradation gradient for the larger Molopo study area, including **all** land uses. These surveys indicated a more pronounced degradation gradient ranging from very low to very high range condition scores within the Commercial and Reserve land uses compared to the Tribal land use showing a neglectable gradient, occupying as total low to midrange condition ranges. Hence, it is suggested that the ant patterns were congruent to the vegetation patterns owing to the vegetation community structures associated with each land use. It is proposed that ants are indicative/sensitive to the habitat modification/change related to the entire land use (and hence the transitional shift of the Tribal land use), but not significantly to an overall range condition gradient. However, some inconsistent patterns on a finer scale indicated that the Commercial land use had an observable gradient associated with range condition, though it was not significant. However, this requires future investigations. Major effects of habitat disturbance on ants are found to be more typically indirect and stress-related through habitat structure, microhabitat and food supply modifications (Andersen 1995a; Hoffmann & Andersen 2003; Majer *et al.* 2004). This was consistent with this study's results.

The study did not attempt to identify which components of land use (e.g. grazing, browsing, and management regime) specifically resulted in changes in ant assemblages. It is suggested that such discrimination at this point does not serve any purpose, as there were clearly interrelationships between the various vegetation properties as a result of land use type.

In this study, the use of ants as environmental and possibly bio-indicators has been found to be applicable in the monitoring of different land use disturbances, reflecting parallel patterns with vegetation properties, although not with overall range condition. Potential key ant species related to the various environmental parameters were identified as practical monitoring and habitat assessment tools within the Molopo semi-arid rangelands (Appendices 8.2, 8.9, and 8.10). It is suggested that ants within this study rather reflected diversity and environmental disturbances than biodiversity.

For the Molopo study area, the Reserve land use includes structural heterogeneity as well as relative undisturbed and productive systems, satisfying best the habitat preference of most ant species compared to the other two land uses.

8.4. RECOMMENDATIONS FOR CHAPTER 8

Evaluation of ants as bio-indicators in these semi-arid rangelands opposed to parallel studies of other taxa in relation to different land uses should be undertaken. This will require seasonal surveys for the ants as well as other taxa. Another challenge that should be addressed and described is the association between ant community patterns and seed bank studies (Coetzee, *in prep. I*). Once invertebrate bio-indicators become more common in land-management monitoring, one can consider what might be the "best" indicator taxon (Andersen *et al.* 2002).

CHAPTER 9

Concluding Remarks

The aim of this study was to determine to what extent can vegetation in combination with ant communities be used as indicators of ecosystem changes/modifications due to anthropogenic human induced land-use patterns and how can this information be used in land degradation management and the conservation of biodiversity in the semi-arid western rangelands of Southern Africa. In order to address the aim and objectives stated in Chapter 1 (Introduction), the study attempted to establish whether the observed patterns as reflected by the herbaceous, woody, soil and ant parameters, were mainly the result of different land use impacts and/or due to initial inherent environmental differences between land uses types. In addition, congruent patterns between the listed parameters with regard to compositional, diversity and land degradation were established. Environmental variables that are responsible for the greatest proportion of the species-environment relation pertaining to the different parameters were investigated.

This chapter will address three core focus areas: (Section 9.1) summarise the patterns pertaining to the different parameters that were employed to establish whether any diversity and rangeland condition/degradation patterns were primarily the result of land use type, or the result of initial inherent environmental differences; (Section 9.2) provide suggestions for best land-use practices towards sustainable biodiversity and land degradation management; and (Section 9.3) present a “Key assessment matrix” that can be employed for rangeland monitoring and adaptive management purposes.

More detailed conclusions pertaining to each parameter (component) are presented in each respective chapter, and should be consulted for detailed comments (Chapters 4 – 8). Section 9.1 is thus a summarised version (repetition) regarding the main points discussed in the Conclusions of Chapters 4 – 8, and is given for explanatory purposes.

9.1 Diversity and land degradation patterns

9.1.1 Herbaceous species component (Chapter 4)

Land-use type (especially the Tribal land use) was indicated as the primary determinant in explaining the herbaceous compositional-environmental variance within the Molopo semi-arid rangelands. A significant rangeland condition/degradation gradient existed across the larger study area as well as within the Reserve and Commercial land uses. The Tribal land use did not show a significant gradient within the land use, but was characterised by a transitional shift in species composition different to that of the other two land uses, and was associated with low to intermediate-high rangeland condition scores. Hardin’s (1968) “tragedy of the commons” states that multiple managers are one of the primary reasons for tribal rangeland degradation. In response to this, the study found the following:

1. The existence of a degradation gradient across the larger Molopo study area, including all land uses.

2. A more pronounced degradation gradient with very low to very high rangeland condition scores within the Commercial and Reserve land uses opposed to the Tribal land use showing no rangeland condition gradient, but with the entire land use being associated with low to intermediate-high rangeland condition scores.

3. A relatively "unique" transitional shift in species composition for the entire Tribal land use towards another state.

Herbaceous composition thus reflected a significant degradation gradient, and a simplified visualisation is presented in Fig. 9.1. Differences were most pronounced between the Reserve and Tribal land uses, followed by the Commercial-Tribal land uses. Differences were the least pronounced between the Commercial-Reserve land uses. Within the Commercial and Reserve land uses, species composition associated with "Poor" rangeland condition scores also showed a transitional shift towards another state. The thresholds for establishing whether these transitional shifts within the three land uses to a new domain have been crossed, need to be studied over a longer temporal scale. Such changes may often be irreversible in the medium and even the long term.

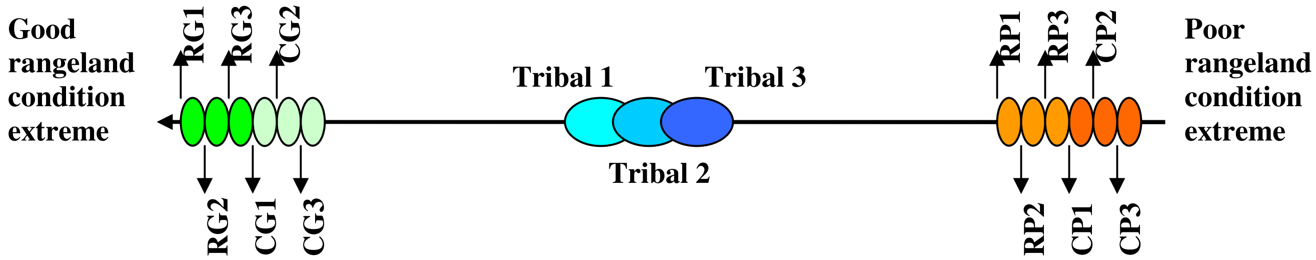


Fig. 9.1. The rangeland condition gradient pertaining to the herbaceous species composition. RG1 – 3 = Reserve "Good" sites; RP 1 - 3 = Reserve "Poor" sites; CG1 - 3 = Commercial "Good" sites; CP1 - 3 = Commercial "Poor" sites.

Species richness and diversity were mainly associated with the Tribal land use, suggesting that these diversity indices are indicators of complex heterogeneous systems and diversity. Results from this study suggest that the diversity indices are indicators of environmental change and disturbance, rather than indicators of biodiversity. Biodiversity indicates the sustenance of diversity typical of the particular landscape at genetic, functional and structural level (refer to Chapter 1 for definitions regarding biodiversity).

This dichotomy between the non-equilibrium processes and density-dependent (equilibrium) factors renders these semi-arid systems relatively resilient, possibly explaining the intermediate differences between relative “Good” and “Poor” rangeland sites within the Reserve and Commercial land uses, and the intermediate differences between the Tribal-Reserve and Tribal-Commercial land uses. However, the transitional shifts in species composition displayed by the Tribal land use, as well by the Reserve-Poor and Commercial-Poor rangeland condition groups, suggest that both the equilibrium (effect of continuous livestock grazing or unsustainable livestock management strategies) and non-equilibrium systems (resilience following favourable climatic events) operate within these rangelands. If a shift towards a new domain has been reached, non-equilibrium events will not easily result in a transitional shift (flexibility) back towards the previous domain and range condition state. For this study, it is suggested that climatic events (non-equilibrium events) might mask density-dependent coupling effects within the new domain up to a certain point, whereafter the system may reflect the longer-term degradation events due to losing its flexibility (resilience). State-and-transition models may be the most useful way to describe vegetation dynamics of the semi-arid rangelands of the study area, and should include the respective equilibrium and non-equilibrium ecological paradigms.

9.1.2 Woody component (Chapter 5)

Tenure practices pertaining to the different land uses resulted in significant differences in the woody composition, density, number of woody individuals and woody structure between the land uses. These patterns reflect historical and current land use tenure practices. Woody compositional patterns, density (TE/ha) and number of woody individuals/ha reflected a degradation gradient across the larger study area. These gradients were reflected within the Commercial and Reserve land uses only. Degradation gradients pertaining to these two land uses differed, whereas no gradient existed within the Tribal land use. However, the Tribal land use was associated with “Poor” rangeland condition sites with regard to the woody component (Fig. 9.2). Differences were intermediate, though significant between land uses. This is indicative of the relatively resilient nature of these semi-arid rangelands. It is further suggested that although significant differences might be intermediate, they may have pronounced ecological and economical implications within these semi-arid rangelands. The state-and-transition model (Westoby *et al*. 1989) is at the heart of the dichotomous relationship between non-equilibrium (climatic) and equilibrium (density-dependent coupling to key resources – see Chapter 3 for explanation of “Key resources”) events within this study area. This applies to both the woody and the herbaceous components.

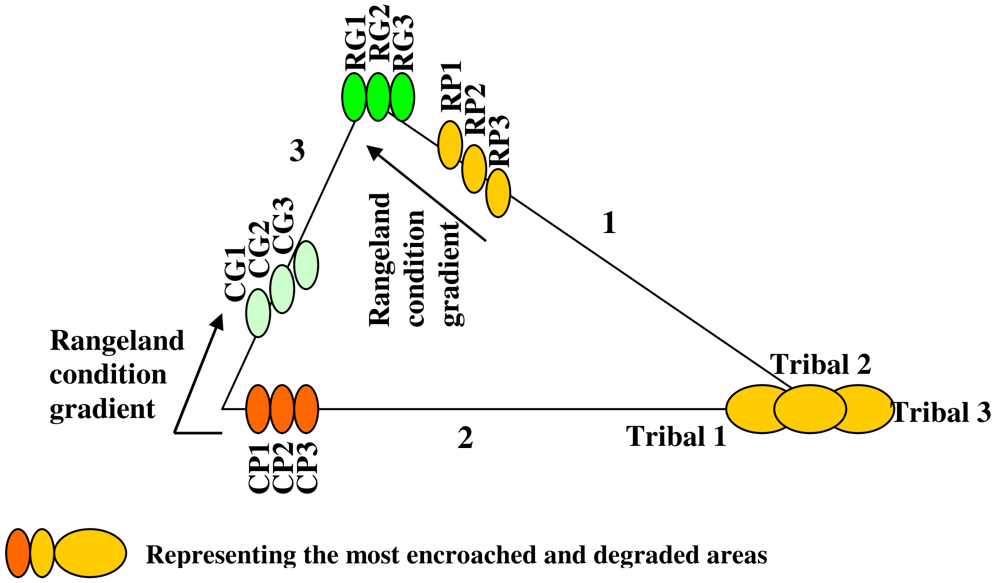


Fig. 9.2. A simplified illustration of the patterns pertaining to the woody component with regard to a rangeland condition gradient. RG1 – 3 = Reserve "Good" sites; RP 1 - 3 = Reserve "Poor" sites; CG1 - 3 = Commercial "Good" sites; CP1 - 3 = Commercial "Poor" sites. The number 1 represents the largest differences between land uses, 2 the second largest and 3 the smallest differences between land uses.

Causative factors of bush encroachment within the study area were primarily related to proximity of the key resources (historical and current) and unsustainable practices pertaining to these key resources. These unsustainable practices were listed in the Conclusions of Chapter 5.

Woody control can be advantageous and should be applied in selected areas for increased herbaceous production and species composition improvement, but it should be cautioned that this is a long-term process, with the degree to which the rangeland condition improves depending on the transitional state in which the ecosystem occurs. Recommendations regarding the adaptation of the "animal component" to the woody resources are presented in the Conclusions of Chapter 5.

Species richness patterns differed between the three land uses, with patterns being more congruent between the Tribal and Reserve land uses in this regard. This can be ascribed to the more complex, heterogeneous woody stratum pertaining to these two land uses (Chapter 5, Section 5.3.1.2), as opposed to the mainly controlled/eradicated woody component within the Commercial and notably within the Commercial-Good land use types. The woody diversity indices can be considered as indicators of environmental changes (e.g. habitat modification), rather than indicators of biodiversity. Woody diversity and richness patterns did not act as indicators of rangeland condition/degradation across the larger study area, but they did reflect productivity and environmental complexity patterns related to the different land uses. However, a small degradation gradient pertaining to the diversity indices was visible within the Commercial land use, being suggestive of the complex nature of the woody component. From the results it was evident that different patterns at patch and paddock vs. landscape level exist. Monitoring and management practices should thus recognise the spatial variability of these semi-arid rangelands before widely extrapolating woody control strategies across different land uses.

9.1.3 Ant component

Ant compositional and functional patterns were indicated to be primarily the result of different land use practices that resulted in habitat modification and hence also resulting in different climatic and behavioural responses among ant assemblages. This was congruent with the vegetation patterns that differed in composition between the land uses, due to the different management impacts. Habitat heterogeneity was highest within the Tribal land use, resulting in the highest vegetation (woody and herbaceous) richness and diversity associated with this land use. Ant species richness and diversity were also highest within the Tribal land use, hence displaying parallel patterns. The lower ant diversity and richness associated with the Reserve and especially with the Commercial land use, is also congruent to that of the vegetation patterns. The high overall abundance of ants within the Reserve land use, as well as the high abundance and hence dominance of certain key species, followed by the Commercial land use, is also consistent with the herbaceous species compositional and woody patterns. High dominance and low diversity/richness by ants have been suggested to be indicative of highly productive systems (high ant biomass) by the humped distributional model (Majer 1985; Andersen 1992). For this study, ant functional and species compositional assemblage patterns support this statement, indicating that the humped distribution is potentially prevalent within the Reserve land use and to a lesser extent in the Commercial land use. Climatic and behavioural responses are important determinants governing ant community structures within the Reserve, and secondly within the Commercial land uses (with the habitat structure and composition primarily being structured by the land use management strategies), whereas environmental disturbance due to habitat changes resulting in a complex heterogeneous system within the Tribal land use, resulted in high diversity/richness and low ant dominance. However, it is suggested that a dichotomy of these two models (humped productivity vs. diversity model, and heterogeneous complex model) operates within the Molopo semi-arid rangelands. This dichotomy is most apparent in the Reserve land use that shows an intermediate heterogeneous system (vegetation and ant diversity and richness – heterogeneous complexity model), but which is also being classified as highly productive (humped shaped model).

Ant communities did not show any correlations with regard to rangeland condition across the larger study area (community patterns, absolute and relative abundances, diversity, species richness) (Fig. 9.3). However, a degradation gradient based on total abundance as well as ant functional groups were visible within the Commercial land use only (not significant for absolute or relative abundances or for the diversity indices), suggesting that localised patterns should also be monitored in future studies (Fig. 9.3). Major effects of habitat disturbance on ants are found to be stress-related through modification of the habitat structure, microhabitat and food supply modifications, as were also described by several other studies (Andersen 1995a; Hoffmann & Andersen 2003; Majer *et al.* 2004).

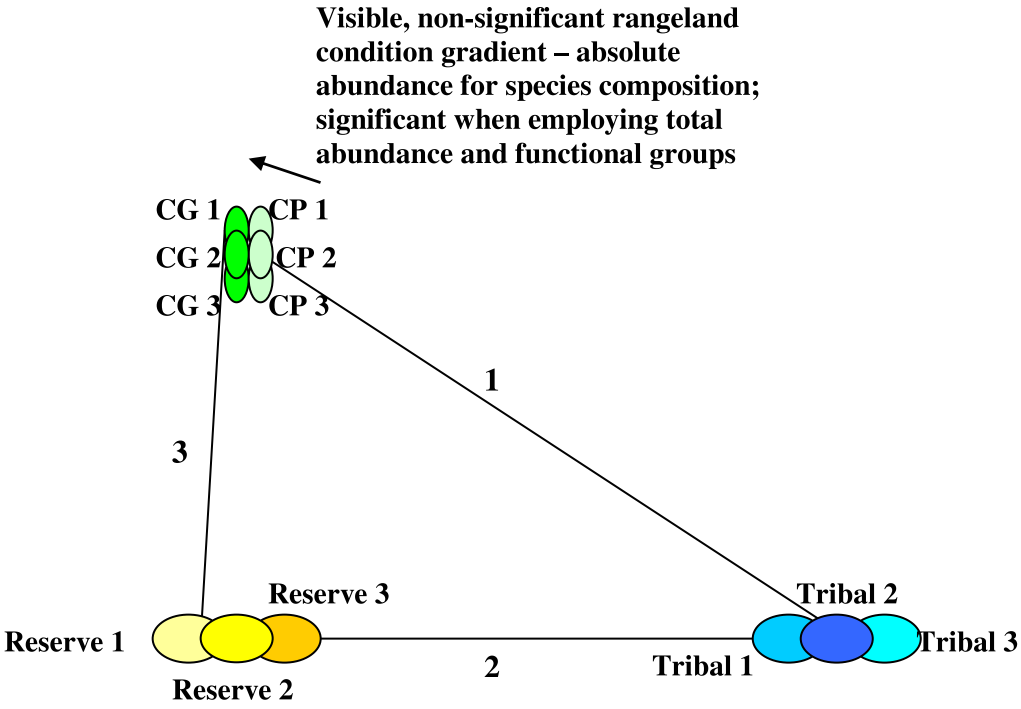


Fig. 9.3. Ant community patterns with the semi-arid rangelands of the Molopo, showing a small non-significant gradient reflecting rangeland condition only within the Commercial land use. RG1 – 3 = Reserve "Good" sites; RP 1 - 3 = Reserve "Poor" sites; CG1 - 3 = Commercial "Good" sites; CP1 - 3 = Commercial "Poor" sites. The number 1 represents the largest differences between land uses, 2 the second largest and 3 the smallest differences between land uses.

The use of ants as environmental indicators has been found to be applicable in the monitoring of different land use disturbances, reflecting parallel patterns with vegetation properties, although it did not reflect overall rangeland condition/degradation. Ants were found to be good surrogates of diversity indicators/environmental indicators with respect to the woody and herbaceous components.

9.1.4 Soil component

This study (Chapter 6, Soil component) established that there were significant differences in some soil chemical properties among the three land uses as a result of different tenure impacts, while small inherent environmental differences pertaining to soil particle size existed between the three land uses. This study described which factor groups (e.g. soil stratum depth, woodiness/openness, rangeland conditions) or combinations thereof explain the largest proportion of the soil-environment variance, and hence which factors or combinations thereof pertaining to the soil matrix need to be included when analysed/ordinated together with vegetation, ant and other environmental data (refer to the Conclusions of Chapter 6, Table 6.3 and Table 6.17).

Although the geology of the study area is described to be relatively homogeneous and belonging to the same land type, significant differences pertaining to the soil stratum (topsoil vs. subsoil) and openness (open vs. woody) gradients, served as directive to subdivide the larger soil matrix into four smaller matrices pertaining to these factors. Thus, the soil matrix was subdivided into the following matrices: topsoil open, topsoil woody, subsoil open and subsoil woody. Direct RDA ordinations significantly explained the soil-environment relations, suggesting that the correct environmental parameters (nominal) were selected to explain the observed soil-environment relations. These analyses served as departure points to select the most appropriate matrices to reflect on the integrated vegetation, ant and soil relations (see Conclusions, Chapter 5; see Chapter 7, Section 7.3.2 and 7.4.2).

Significant differences existed between the land uses, being most pronounced between the Reserve-Tribal land uses (Chapter 6, Table 6.2 and Table 6.3). Gradients with regard to soil stratum and openness were evident (Chapter 6, Table 6.2, Table 6.3 and Table 6.17). Soil variables did not reflect a pronounced gradient based on relative rangeland condition (Chapter 6, Table 6.2, Table 6.3 and Table 6.17) (Fig. 9.4). However, it should be cautioned that piosphere studies might actually reflect a degradation gradient pertaining to these key resources, also called "sacrifice areas" (Perkins & Thomas 1993a, b). However, openness/woodiness did reflect a significant, though small rangeland condition/degradation gradient (Chapter 6, Table 6.3). This suggests that bush encroachment is reflective of degraded areas, but spatial variability within and between different land uses, as indicated in Fig. 9.4, and described in Section 9.1.2 above, cautions managers against widely extrapolating woody control strategies across different land uses.

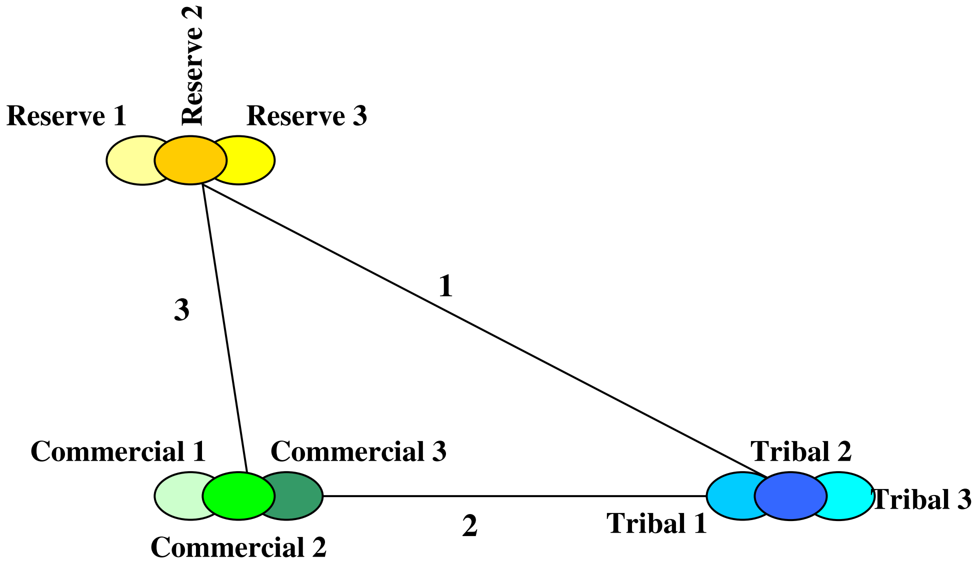


Fig. 9.4. Soil patterns as function of the different land uses with regard to rangeland condition. The number 1 represents the largest differences between land uses, 2 the second largest and 3 the smallest differences between land uses.

9.1.5 Multivariate integration of the vegetation, ant and soil components

The primary focus of the multivariate analyses by means of BVSTEP and Monte Carlo tests was to establish whether different land use impacts are primary or secondary determinants of the herbaceous, woody, ant and soil patterns. Secondly, this study investigated whether the multivariate analyses reflected a rangeland condition/degradation gradient as result of the different land use impacts. Thirdly, the multivariate analyses attempted to establish if species richness and diversity are associated with any of the land uses particularly, and whether these diversity indices reflect a rangeland condition/degradation gradient. Thus, the applicability of adopting these multivariate analyses into the final "Key assessment matrix" (Section 9.3), was evaluated.

It was evident from the results that different land use impacts/disturbances primarily, and thus not inherent (initial) environmental differences within the study area, resulted in the observed multivariate species-environment relations. The herbaceous, woody, soil and ant components displayed congruent patterns in terms of the separate clustering of the different land uses (refer to Section 9.1) due to different land use impacts on the environment, with the Commercial and Reserve land uses generally being more similar to each other than they were to the Tribal land use (barring the ant community patterns, where the Reserve and Tribal land uses were more similar, see Chapter 8). Different land use impacts were the primary agency modifying herbaceous species-, woody, soil and ant compositional structures; with inter- and intra- biotic-biotic and biotic-abiotic relations within and between these parameters contributing (accounting) secondarily towards explaining the species-environment relations (Chapter 7 - Sections 7.3.3 and 7.4.3; Chapter 8, Sections 8.2.10 – 8.2.12). Refer to the Conclusions of Chapters 7 and 8, and to Section 9.1.1 – 9.1.5 above for more in-depth discussions.

A. Rangeland condition/degradation gradient

- Both the herbaceous and woody components can be employed as indicators of rangeland condition/degradation within the Molopo semi-arid rangelands.
- The rangeland degradation gradients between these two parameters did not display congruent gradients between the different land uses.
- Thus, spatial heterogeneous patterns within and between land uses pertaining to these two components suggest that rangeland monitoring strategies should not be injudiciously extrapolated across all land uses and between different rangeland parameters, without acknowledging the complex dynamics pertaining to these rangelands.
- Soil parameters did not act as a good indicator of relative rangeland condition for these semi-arid rangelands area. However, it should be cautioned that piosphere studies might actually reflect a degradation gradient pertaining to these key resources, also being described as "sacrifice areas" (Perkins & Thomas 1993a, b) (see Chapter 10, Recommendations).
- Absolute and relative abundances for ant species composition did not significantly reflect a rangeland condition across the larger study area, or within any of the land uses, although a slight

non-significant gradient was observable between the Commercial-Good and Commercial-Poor rangeland condition groups. However, total abundance and ant functional groups did reflect a significant though less pronounced gradient between the "Good" and "Poor" rangeland condition extremes within the Commercial land use. Hence, in general, ant functional and community patterns primarily reflected habitat modifications/disturbances pertaining to the different land uses, but were less indicative of rangeland condition/degradation than were the woody and herbaceous components. In this study, ants did not display congruent rangeland condition/degradation patterns with the woody and herbaceous composition components, thus having limited potential as indicators of a degradation gradient. However, based on the ant functional groups and total abundances, the significant degradation gradient within the Commercial land use only can be ascribed to pronounced differences in habitat complexity and heterogeneity between the Commercial-Good and Commercial-Poor extremes (refer to Chapter 8, Section 2.5). The most appropriate classification of ants, whether according to functional groups or at species level as indicators of rangeland condition, needs to be verified by future studies. It is suggested that the impacts of habitat disturbance/modification through different land use impact on ants are found to be more typically stress-related through the modification of habitat structure, microhabitat and food supply modifications.

B. Diversity, heterogeneity and productivity patterns

- Diversity patterns between the woody, herbaceous and ant components were congruent, thus indicating that ants can act as a surrogate taxon (indicator) of the diversity patterns within the Molopo semi-arid rangelands. The diversity indices (species richness and diversity) of the vegetation and ant parameters were primarily associated with the Tribal land use. Important though is that the vegetation parameters, especially the herbaceous species component, also proved to be a sensitive and appropriate indicator of diversity patterns within these rangelands.
- The vegetation and ant components thus acted as environmental indicators of habitat change/disturbance due to different land-use impacts, rather than as indicators of biodiversity. More recommendations regarding bio-indication are given in Chapter 10 (Recommendations).
- Higher plant productivity has been related to less overall vegetation diversity, since more competitive species tend to dominate in a given area, resulting in lower vegetation species numbers (Huston 1993). In terms of vegetation compositional patterns, the Reserve and Commercial land uses had relatively similar herbaceous compositions. The Tribal land use was more dissimilar with regard to these two land uses, and was characterised by a transitional shift in the vegetation composition (herbaceous and woody) to a state different to that of the other two land uses. This phenomenon is best described by the state-and-transition model (Westoby *et al.* 1989), and follows after a triggering (disturbance) event. Ant compositional patterns, expressed in terms of productivity (dominance) and heterogeneity, are parallel to that of the vegetation patterns within the Molopo semi-arid rangelands. Hence, both ant and vegetation patterns were found to be related to land use practices, and agree with studies by Woinarski *et al.* (2002) that

found that ant species composition and richness showed patterns largely due to the effects of land use impacts in northern Australia. Recommendations with regard to the soil biodiversity, are presented in Chapter 10 (Recommendations).

9.2 Some suggestions towards best land-use practices

9.2.1 Spatial heterogeneity

A large number of factors influences grazing, thus acting and interacting over a range of scales from individual plants to patch, landscape and regional scale (Weber *et al.* 1998). Model predictions scaling up vegetation response to the landscape levels based on mean values for grazing pressure, may deviate from models taking account of heterogeneity (*Weber et al.* 1998). Noy-Meir (1981) stated that spatial heterogeneity is crucial for models of arid ecosystems. Landscape heterogeneity increases as grazing unit increases, resulting in heavier impact on preferred areas and thus leading to rangeland degradation (Teague & Dowhower 2003). This may result in a long-term impact on the environment and primary and secondary production (Teague & Dowhower 2003). Grazing impacts at such patches are not easily reversed (Fuls & Bosch 1991), with large paddocks that are continuously being grazed deteriorating due to patch-selective grazing (Kellner & Bosch 1992). Patch-selective grazing induces a pattern of heavily grazed areas and lightly or ungrazed areas (Fuls 1992), with heavily grazed areas being overgrazed even when the stocking rate for the grazing unit is within the carrying capacity for a while (Kellner & Bosch 1992). This results in a degradation spiral (Teague & Dowhower 2003).

Much of the diversity in a landscape may exist at scales larger than the farm. Resultantly, the diversity dynamics depend to which degree different farms remain similar or become more different, with the homogenisation of farms with similar intensified demands for inputs, services and outputs for markets, often causing the reduction of inter-farm diversity (Swift *et al.* 2004). These authors hypothesise that the presence of a relative small number of different land use types can optimise diversity and satisfy the functional needs of the majority of ecosystem services. Swift *et al.* (2004) suggest that monotypic landscapes are likely to be the most vulnerable to dangers/catastrophes to ecosystem services as the farm or plot scale. Land-use decisions can be optimised by providing different scenarios that illustrate how different land-use combinations may result in different levels of diversity and in the efficiency of different ecosystem services, and the associated biodiversity values (Swift *et al.* 2004).

With regard to above-mentioned comments, results from this study indicated spatial heterogeneous patterns within and between different land uses (see Section 9.1 above), with the different parameters displaying in some cases similar, but in other cases unique patterns pertaining to rangeland condition, diversity patterns, species compositional patterns and habitat structure (see Section 9.1). These results suggest that monitoring at patch, paddock and landscape level should be conducted, and that monitoring and management strategies should not be extrapolated across spatial scales and tenure types, without acknowledging and at least partially understanding the complex, heterogeneous dynamics of the Molopo semi-arid rangelands. However, monotypic landscapes, especially because of the total eradication of the woody component and as are relatively commonly found within the Commercial land use ("conservation farmer"), may result in an impaired resilience (to catastrophes such as drought, nutrient cycling processes, carbon sequestration etc.) and biodiversity services and functioning (refer to Chapter 1, Introduction) within this land use in the long term.

9.2.2 Land degradation

According to Hoffman *et al.* (1999), land tenure system appears to be the most important causative effect related to land degradation in South Africa. Thus, land use history and disturbance, rather than environmental or primary factors, appear to be the most important determinants of the rate and extent of bush encroachment (Hoffman *et al.* 1999). Milton *et al.* (1994) suggest that for every step descended in rangeland degradation, restoration becomes more costly in terms of the loss of secondary productivity and expenditure of energy required (e.g. machinery, labour, materials). Many desertified arid rangelands show little recovery in perennial grass cover during the first two decades following the removal of livestock grazing, but more additional work needs to be conducted to evaluate the reversibility of vegetation change in desertified systems (Valone & Sauter 2005).

Tribal rangelands have a long history of environmental and political neglect, with these areas being subjected to overutilisation due to the high human populations that were involuntarily resettled and confined to these relatively small areas (Ross 1999; Fox & Rowntree 2001). Today, communal areas are generally characterised by high human populations, overgrazing, soil erosion, an increase in unpalatable plant species, and excessive wood harvesting (Hoffman & Todd 2000). Severe degradation in the tribal areas of the former Bophuthatswana of the NW Province resulted in socio-economic imbalances, which contributed to heavier degradation and biodiversity loss in these areas (Hoffman *et al.* 1999). However, in the commercial sector too, it has been recognised that farmers can be environmentally irresponsible, with in many cases, changed herbaceous species composition, alien plant invasions and woody encroachment being more of a problem in commercial than tribal areas (Hoffman *et al*. 1999). Studies of land degradation in South Africa should focus on both commercial and tribal areas, with the dynamic interaction between commercial and tribal areas becoming increasingly important (Hoffman *et al*. 1999). Hoffman *et al.* (1999) state that with our poorly developed understanding of tribal farming and land use systems, commercial models of land use should not be unthinkingly impositioned onto communal areas (see Chapter 10).

This study found that land-use type primarily resulted in different patterns pertaining to the different parameters. The differences were significant, though moderate, indicative of the relatively resilient nature of these rangelands, and thus reflective of its non-equilibrium nature. However, transitional shifts in species composition within all three land uses, due to unsustainable practices associated primarily with the historic and current proximity of key resources, are indicative of the density-dependent (non-equilibrium) nature of these rangelands. Thus, even small disturbances in these rangelands may result in detrimental “snowball” interactive biotic-biotic/abiotic cascades (refer to Chapter 7, Sections 7.3.3 and 7.4.3). The state-and-transition model (Westoby *et al.* 1989) best describes events pertaining to land degradation within these Molopo semi-arid rangelands. Thus, degradation is not only limited to the Tribal land use, but also occurs within the Reserve and Commercial land uses. Monitoring procedures should take into consideration spatial variability, as was discussed in Section 9.2.1, and should be applied across different temporal scales.

9.2.3 Climate

The detrimental effects of low rainfall are more pronounced in overexploited rangelands (Hudak 1999). Drought and unreliable rainfall are often blamed for agricultural declines and failures, instead of ascribing it to societal factors (Hudak 1999). Environmental threats such as desertification do not feature high on the priority list of developing countries, with basic needs such as food, water and housing enjoying a higher priority in rural communities than environmental issues such as biodiversity and desertification (Van Rooyen 1998). Schwinning *et al.* (2005) found that changes in summer precipitation, especially if associated with an increase in the frequency of summer droughts in desert ecosystems, could result in irreversible ecological changes. Since primary productivity is often masked by climatic fluctuations, changes in ecosystem functioning are often not detected, together with the slow nature of rangeland degradation making the observation of changes difficult without prior monitoring (Van Rooyen 1998).

Climatic induced events (non-equilibrium events) may mask degradation effects, displaying the inherent resilience of the Molopo semi-arid rangelands, up to the point where density-dependent events such as a lack of rest and recovery may result in an irreversible shift towards another domain. These transitional shifts were discussed in Section 9.1. Bush encroachment is considered as a major indicator/result of rangeland degradation within the North West Province (Hoffman *et al.* 1999), and is a major factor contributing towards the low occurrence or even absence of herbaceous cover (Smit *et al.* 1999). An increase in woody plant density beyond a critical density causes the suppression of herbaceous plants, mainly through severe competition for available soil moisture, resulting in lower herbaceous yields and thus lowering the grazing capacity, as was described in Chapter 5 (Woody component). Such effects may be more pronounced in degraded areas, especially during droughts. Ant community patterns as structured by behavioural patterns, as indicated by the high dominance of the HCS functional group within the Reserve and to a lesser extent within the Commercial land uses, may potentially reflect the indirect impact of climatic (and micro-climatic) events on these two land uses due to habitat modification.

Land users should take ownership and responsibility in the management of their resources, and should be capacitated to understand and acknowledge that sustainable rangeland practices are a primary livelihood (also see Chapter 10, Recommendations).

9.2.4 Equilibrium and non-equilibrium models

The multivariate analyses from this study suggest that the state-and-transition model best describes the events (climatic and density-dependent coupling to key resources) associated with the semi-arid rangelands of the Molopo. The resilient nature of these rangelands, typical of non-equilibrium systems, was reflected by the low to intermediate differences between land uses with regard to the herbaceous, woody, ant and soil components. However, density-dependent coupling of herbivores (grazing and browsing) resulted in transitional shifts and modification of the habitat structure and composition, illustrating the equilibrium dynamics pertaining to the key resources within these rangelands. This may have profound economical, ecological and social implications.

9.2.5 Key resources – water provisioning

The availability of permanent water sources expose grasses to continuous grazing pressure, and permanent drinking stations in rangelands to improve rangelands may actually increase deteriorations of the resources bases (Glantz 1976; Picardi & Siefert 1976; Hudak 1999), if not managed sustainably.

Artificial water sources have been developed to maintain populations of herbivores in arid areas for increased commercial production of domestic stock, resulting in the water resources to fundamentally changing the landscape character (James *et al.* 1999). As a result, native wild animal species that rely on water are able to persist in areas previously not habitable for long periods, while high levels of grazing pressures are also maintained over large areas (James *et al.* 1999). Several researchers and managers raised their concern regarding the provisioning of artificial water sources which have multiple effects (Belsky 1995; Noy-Meir 1996; Owen-Smith 1996; Landsberg *et al.* 1997), resulting in a diversity of responses from different plant and animal species over different spatial scales (James *et al.* 1999). Increased water provisioning in drylands may potentially threaten many species, e.g. through grazing and trampling of resources; create unnatural key sources or foci for non-domestic and domestic water dependent animals; create wetland habitats from overflowing water resources influencing the distribution of water-dependent species; and are focus areas for hunting and scavenging by predators (James *et al.* 1999).

With regard to the density-dependent coupling of livestock to key resources, the unnecessary shifting of key resources (boreholes, kraals etc.) within grazing rangelands has been found detrimental to livestock grazers, resulting in entire pastures being dominated by bush encroachers in several areas of Botswana (Moleele *et al.* 2002). These authors suggested management strategies, which might vary from enforced reduction of grazing intensity in bush encroached areas to the selective management of communal grazing in better quality, predominantly grassland areas.

The implications for management as indicated by this study, are the options that will include the appropriate distribution of water sources and management pertaining to other key sources (e.g. kraals, settlements etc.), together with a co-ordinated grazing and resting management system that is adaptable and flexible. The addition of more water resources (hence key resources resulting in density-dependent coupling by livestock/wildlife) in these rangelands may result in an intensification of grazing and browsing, and if not regulated correctly, may result in increased "sacrifice" or "high impact" zones (Leggett *et al.* 2003a). Examples of such "sacrifice" areas within the study area, with the resulting degradation being indicated by bush encroachment and bare patches, are indicated in Fig. 10.1 of Chapter 10, (Chapter 10 will provide some recommendations towards using remote sensing in monitoring land uses practices. The remote sensing was done by A van Rooyen, in cooperation with M. Coetzee, who performed the groundtruthing of the images (signatures). Thus, inappropriate historical and current land-use practices associated with the key resources (especially water sources) within the Molopo study area, resulted in degradation within all three land uses. However, sound land-use practices based on knowledge of the ecological processes of these semi-arid rangelands, and ownership and thus responsibility taken by the land user towards managing and regularly monitoring these resources, may enhance the rangeland condition (see Chapter 10, Fig. 10.1b). Thus, a baseline "Key assessment matrix" towards rangeland evaluation and monitoring is provided in Section 9.3.

9.2.6 Infrastructure – fencing

Constraining livestock movements forces livestock to graze the same pasture continuously, thus reducing the ecosystem resilience or ability to respond to varying climatic conditions (Niamir-Fuller 1998). In order to prevent the deterioration of heavily grazed and browsed patches, adequate lengths of time between successive defoliations must be provided. The successful promotion of fencing as a means to facilitate better management will largely depend on farmers' needs and perceptions, as well as the governing socio-economic factors (Sebina & Dűvel 1999). Thus, the fencing of communal grazing areas can potentially curb degradation of natural rangelands, providing the adoption of fencing and good management practices (Sebina & Dűvel 1999). Constraints that need to be overcome is a tendency to perceive fencing of grazing areas as a means to basic stock management rather than improved rangeland management, suggesting that the erection of fences to enable the implementation of a ranching system is no solution without improved management of both stock and techniques (Sebina & Dűvel 1999).

The most sustainable grazing management strategy is to manage stock numbers to reflect changing vegetation condition (Westoby *et al.* 1989; Behnke & Scoones 1992; Hudak 1999). Both economic and ecological sustainability should be used to evaluate livestock farming success, with grazing/browsing management proving sustainable only once existing knowledge is applied (Hudak 1999).

Thus, infrastructure provisioning within the Molopo semi-arid rangelands, especially within the Tribal areas, should be considered only as a secondary means (in terms of importance) towards sustainable and improved livestock production. Land users should firstly understand and acknowledge land degradation management as a primary livelihood option, and take responsibility for their resources by employing good rangeland management practices. Accordingly, sound grazing strategies should be adaptable to the changing vegetation condition (e.g. as a result of climatic or other events). Thus, increased livestock production can only be achieved if the interdependency between the ecological and socio-economical factors are understood, evaluated, adapted, incorporated and applied within regular monitoring of these rangelands. This aspect will be addressed in more detail in Section 9.3.

9.2.7 Monitoring

Landsberg and Crowley (2004) suggested that plants can act as early warning indicators of potentially catastrophic changes, but concluded that a set of plant-related indicators should be an important component of any biodiversity monitoring framework for rangelands. Krogh *et al.* (2002) stated that by linking the minimum requirements of a keystone (faunal) species with vegetation parameters that can be easily measured an indicator of the threshold for irreversible degradation could be provided. Vegetation, soil and ant parameters displayed similar patterns with regard to land uses, while both the woody and herbaceous components acted as good indicators of rangeland degradation. However, rangeland condition/degradation patterns between the woody and herbaceous components were not completely congruent (see Section 9.1). This is indicative of the complexity of these rangelands, and emphasises that monitoring of the different parameters at different spatial and temporal scales with regard to rangeland condition/degradation and diversity within the Molopo semi-arid rangelands, needs to be conducted responsibly and correctly. With regard to the diversity patterns, the woody, herbaceous and ant components displayed congruent diversity patterns, being primarily associated with the Tribal land use (see discussions pertaining to “Species richness and diversity” within each relevant chapter for the different parameters – barring the soil component). It is suggested that these diversity measures are indicators of environmental change/disturbance, rather than indicators of biodiversity. It is suggested that the diversity measures of both the vegetation and the ant components, are indicative of habitat heterogeneity/complexity, being associated with moderate to moderately-high environmental disturbances. Within the Molopo semi-arid rangelands, it appears as though diversity is negatively correlated with ecosystem productivity. However, this observation should be verified across different spatial and temporal scales, employing other taxons as well (see Chapter 10, Recommendations). In addition, both biophysical and socio-economical systems should be interrelated in quantifying “productivity” within these semi-arid rangelands.

With regard to ecological “best land use practices” within the Molopo study area, the Reserve land use includes structural heterogeneity as well as relatively undisturbed and highly productive systems, satisfying best the habitat preference of grazers, browsers and ant species, relatively compared to the other two land uses. The relatively high productivity of the Reserve can further be ascribed to the relative norm for stocking rates applied for game species, diversification of the different resources niches that are being utilised by the game (different vegetation strata and – parts selected by different game browser and grazer species) and the fact that the game can move freely, providing the opportunity to the resources to “rest”. However, the historical and current impacts of key resources on the rangeland condition if unsustainably managed, are evident within all three land uses, as was also indicated by the BP and Increaser II and Increaser III species. Incorrect grazer:browser and/or grazer:grazer ratios may further exacerbate degradation associated with the key resources. The impact of the animal factor and its behaviour on these semi-rangelands needs to be understood and acknowledged, in order to ensure optimal sustainable ecological and economical productivity (refer to Chapter 10, Recommendations). Sustainable, appropriate and frequent monitoring strategies pertaining to the diversification of the animal component (using the vegetation component), can thus enhance the ecological, economical and sociological viability of the Molopo semi-arid rangelands. Homogenisation of the rangelands for improved herbaceous production for domesticated livestock, as is commonly the result of woody eradication procedures by commercial farmers, may in the longer term prove to be unsustainable, resulting in a reduced rangeland resilience due to the impairment of the natural ecosystem processes (e.g. nutrient cycling, carbon sequestration, the loss of biodiversity services etc). Smit (2004) suggests that there is no quick solution to bush encroachment, and that it should be seen as a long-term management practice. This can be achieved by minimising the direct and indirect causes of bush encroachment, for instance by maintaining sound grazing practices especially during the wet seasons in order to ensure a vigorous and competitive herbaceous layer (Smit 2004). The woody component needs to be managed within a framework of economic viability and ecological responsibility (Smit 2004).

9.3 “Key assessment matrix” for rangeland monitoring and adaptive management purposes

9.3.1 Monitoring for adaptive management purposes

Experts across the world have tailored range monitoring to suit different types of environments (Friedel *et al.* 2000) (also refer to Chapter 10, Recommendations). Rangeland monitoring can be used to monitor the impact of different regimes on the rangeland (Aucamp *et al.* 1992). However, any monitoring programme needs to be planned carefully. Effective monitoring is considered as a critical component in rangeland management, regardless of the scale, with risk assessments, adaptive management analyses or management by hypothesis requiring an understanding of linkages between environmental and management options (Brown & Havstad 2004).

Classical rangeland monitoring and auditing is defined as getting measurements on the state of the vegetation and other organisms, also being stated in anthropomorphic terms as the “health” of the system (Zacharias 2004). Realistically, however, there are managers that are making decisions at various levels of organisations based on economic viabilities, tradition, cultural and religious beliefs, geographical locations, besides that of climate and the impacts of animals (Zacharias 2004). Monitoring of rangeland ecosystems primarily attempts to attain compliance and management, and a major challenge for adaptive management is the implementation of a monitoring programme that can identify rangeland dynamics in an efficient and widely understood manner (Brown & Havstad 2004). Interpreting monitoring data should thus acknowledge the multiple states within multi-equilibrium systems, which should govern the selection of management models to represent their behaviour (Briske *et al.* 2003), with the different states representing different management objectives (Westoby *et al.* 1989). The different states have different degrees of resilience, and the drivers of these systems need to be identified, monitored and managed (Brown & Havstad 2003). These authors suggest that thresholds, critical regions between two distinct states, need to be identified, since once a threshold is crossed, a different set of drivers is responsible for either changing or stabilising the ecosystem. Drivers of rangelands change dramatically across spatial scale, changing over time, making it unlikely that one set of attributes will function equally well at landscape, paddock, property, regional or national scale (Brown & Havstad 2003). Brown & Havstad (2003) suggest that analyses of major changes in rangeland ecosystem function showed that an incomplete understanding of biophysical, socio-economical and policy drivers, and the incorporation of that information into decision-making, dramatically improve sustainability. According to Darkoh (2003), there is a serious lack of natural resource inventories and other baseline data that are fundamental for monitoring biodiversity trends within the drylands of Africa, suggesting that there is an urgent need for regular ecological monitoring to establish these trends.

This study is the first comprehensive ecological study that has been conducted within the Molopo rangelands. The Molopo semi-arid rangelands have been described as a “black hole” in terms of information available with regard to the biophysical-, social- and economical environments (SOER 2002). This study thus serves as a baseline reference point for future research with regard to other biophysical aspects that can be interrelated with the socio-economical aspects. Different ecological transitional states pertaining to the different parameters have been identified (Section 9.1), and can serve as departure point in identifying thresholds between different ecological states. Results from future surveys/studies during different climatic seasons (temporal scale) should be incorporated to refine such a model. This baseline data is also presented in the form of a “Key assessment matrix” that can be employed for management and monitoring purposes by different levels of stakeholders, e.g. by tribal land users, commercial farmers, conservation agencies, agricultural extension officers, scientists and management agencies. This study is interrelated to some extent with the sociological environment. Land users/owners, extension officers and ecologists participated in compiling and implementing the experimental lay-out of this study, and assisted in formulating the research question by proposing focus areas in which the land users/owners - at different levels - need to be capacitated with knowledge regarding rangeland monitoring and management strategies.

This process was conducted since 2003 by means of multilateral consultative procedures with the different land users/owners of the Commercial, Tribal and Reserve land uses, as well as with the NW DACE’ Directorate Field Services (DFS; extension officers), the management of the Scientific Technical Support Services (STSS) of the NW DACE and other project coordinators and scientists participating in the DMP programme. Feedback and multilateral communication and co-operation in the form of informal and scientific reports, meetings, workshops and practical fields participatory surveys have been conducted in conjunction with the different land users, extension officers, other scientists and members from management. Formal workshops have been conducted by the NW DACE in the three Tribal land use areas as part of the larger DMP programme’s objectives, during which a platform was provided to establish the level of knowledge and perceptions of the local communities with regard to rangeland "health", while also incorporating results from this study for demonstration purposes (herbaceous composition and production, woody and soil components).

The purpose of these workshops were to identify the needs of the local communities, and what the level of departure for adaptive management procedures should be within these communities, while also creating the opportunity for agricultural extension officers, scientists of different disciplines participating in the DMP programme and land users to share and gain knowledge regarding the natural resources within the Molopo semi-arid rangelands. The approach towards providing monitoring and management information for the Reserve and Commercial land uses will be discussed by means of the "Key assessment matrix", and additional recommendation are also presented in Chapter 10 (Recommendations).

This study established that the parameters (components) surveyed within this study, displayed different heterogeneous patterns within and between land uses, thus showing different patterns at patch, paddock and landscape level. This study, as part of the larger NW DACE project and DMP programme, thus serves as baseline study towards understanding the complex dynamics pertaining to the Molopo semi-arid rangelands. These patterns should be quantified over different spatial and temporal scales, while thresholds for different biophysical, economical and sociological states through the integrated co-operation between these different disciplines in the long-term need to be identified. This is essential in ensuring that rangeland monitoring within the Molopo semi-arid rangelands is appropriate and widely understood.

This study concurs with Friedel *et al.* (2004), who suggest that monitoring applied within one land use, is not always suited for all land uses and client groups. Scientific monitoring may be considered as important by the monitoring agency, while the informal, local knowledge may be downplayed or even be discarded (Friedel *et al.* 2004). This study further supports Friedel *et al.* (2004) in that there is a fundamental difference between a "management monitoring system" envisioned for management, and a monitoring system for research purposes, with landowners tending to ignore the scientists and their proposed systems. A blueprint for integrated rangeland monitoring is an open-ended and adaptive process, and must be the product of both the producer and the consumer, in order to allow for continuous responses to new technology, scientific understanding, and demand of information, environmental awareness and social responsibility (Western 2004). Klinterberg and Seely (2004) state that key steps for the development of land degradation indicators, as were described for Namibia, should include: (i) the involvement of persons understanding both socio-economic and biophysical aspects of land degradation impacts; (ii) the development of relevant criteria at international level to ensure that land degradation indicators are globally acceptable; and (iii) accessibility of data, which are considered fundamental to the functioning of any monitoring system. However, getting land managers involved in monitoring is not always a quick process, with monitoring itself being as important as the decision-making about management (Friedel *et al.* 2004). This can only be achieved if the interest of land managers is engaged by developing partnerships between managers and scientists, in which managers identify their own priorities and are given assistance with monitoring tools (Friedel *et a*l. 2004). Land managers tend to want a "balanced" monitoring system that does not in depth cover several aspects, rather than have many details about only one or two components (Friedel *et al.* 2004).

Since the semi-arid rangelands of the Molopo are linked socio-ecological systems, it is not possible to address biophysical issues associated with land degradation without including the human dimensions. This study provides a "Key assessment matrix" as a baseline "balanced" monitoring and management system pertaining to land degradation and diversity aspects within and between the different land uses. This key can be used by the land user, agricultural extension officer and scientist (see Section 9.4). More recommendations are presented in Chapter 10 (Recommendations, also refer to Appendices 10.1 and 10.2). One of the proposed technologies will be to link photographic images with the rangeland condition states (index values, see Section 9.3.2) of the different land uses pertaining to the different parameters, as given in the "Key assessment matrix". Another output will be to link the groundtruthed data with spatial data, in order to provide web-based packages (see Chapter 10 for the use of spatial data together with groundtruthed data) (Figure 9.6, see Section 9.3.2.2; compiled by Van Den Berg 2007), in order to reflect on the spatial heterogeneity within and between land uses across different spatial and temporal scales.

9.3.2 Key assessment matrix

A "Key assessment matrix" was compiled as an adaptive and explanatory management procedure for the environmental variables that were most strongly associated with the first two axes. The relative position of herbaceous species along the first and second axes of the CCA ordination was indexed by rescaling the eigenvector scores of the variables to a scale of 0 to 10, with 0 representing the score of that herbaceous, woody, ant or soil variable located first and 10 the position of the last variable on the gradient (refer to Chapter 3, Material and Methods with regards to the rescaling) (after Hurt & Hardy 1989; Lawes *et al.* 2005). Stated differently, a value of 0 means that the specific species/variable was poorly associated with the environmental variable best representing that particular axis, while a score of 10 indicates that the particular species/variables is best associated with the strongest (highest r-value) environmental/passive variable along that specific axis. These scores can thus be used to calculate environmental-weighted total scores for comparative and monitoring purposes.

Commonly the variance of only a few species is represented along each axis, with several species displaying no relationship to the axis. Thus, more attention can be focused on influential species, also defined as "key species" within this study, by setting "Inclusion rules". The response of herbaceous species with at least 10% of their variance being accounted for by the first two canonical axes (after Lawes *et al.* 2005), was identified as key species in explaining the species-environment relation. These species were also indexed on a scale from 0 – 10 with regard to the environmental variables best associated with each specific axis (opposed to the scale of 1 – 10 employed by Hurt & Hardy 1989; Lawes *et al.* 2005).

This “Key assessment matrix” was compiled for the different parameters studied during a rainfall year (April/May 2004) representative of normal long-term average rainfall distributional pattern for the Molopo semi-arid rangelands (see Chapter 2, Study site). Rainfall figures that exceeded 800 mm and even 1000m within these semi-arid rangelands, were recorded for the period January to 1 May 2005, being far above the long-term average norm (see Chapter 2). It should be emphasised that analyses pertaining to such abnormal climatic events should be cautiously interpreted, evaluated and reconsidered before injudiciously applying it within a “Key assessment matrix” for adaptive management purposes, since such extreme events may in fact mask long-term degradation. However, the indexing of different parameters following such an abnormal event, may contribute to our scientific understanding of the non-equilibrium dynamics associated with the Molopo semi-arid rangelands.

The research question thus needs to be clearly formulated in order to correctly identify which monitoring techniques are transparent and appropriate for rangeland monitoring and management strategies. Extreme caution should also be taken before assuming that land use impacts may result in easy quantifiable changes within a relatively short time span (e.g. less than 3 years), since favourable climatic events may be conducive to the rangeland resilience and flexibility of the Molopo semi-arid rangelands. Thus, varying climatic events may mask degradation during favourable rainfall seasons, or exacerbate it during below long-term average rainfall norms. From a management perspective, livestock strategies need to be flexible and managed responsibly following variable climatic patterns, especially during the wet seasons in order to retain a vigorous and competitive herbaceous layer (Smit 2004), and hence to ensure long-term ecological and economical benefits with regard to these resources.

Thus, the purpose of this “Key assessment matrix” is to provide baseline data in a biophysical poorly described environment of the different anthropogenic land use impacts on rangeland condition and biodiversity under normal long-term average rainfall conditions. Future surveys can thus use this baseline information as departure point in order to better understand, distinguish, quantify and describe the ranges (states and thresholds) between which different parameters and selected key variables within these parameters vary due to climatic variability and/or land use impact.

The format of the “Key assessment matrix” with regards to each parameter will be as follows:

A. Summary of the primary aspects pertaining to the herbaceous, woody and ant components (e.g. most abundant species, Indicator species, typical species, discriminant species etc.).

B. Index values of all the species/variables for both the first and the second axes: applicable for the land user and extension officers to establish how each species/variable fit into the larger system.

C. Index values of only the species/variables responsive primarily to either the first or the second axis: a refinement and more in-depth evaluation of point A, extracting only the species responsive to each respective axis and hence environmental variable associated with that particular axis. Depending on the research question, this approach can be followed by the land user or extension officer to closely monitor species/variables responsive to a particular environmental variable.

D. Index values of all the key species/variables for both the first and the second axes: primarily applicable for higher levels of interpretation - the scientist, extension officer, management, other monitoring agencies and higher levels of interpretation by the land user for evaluating and monitoring the key species/variables primarily accounting for the species-environment relation within and between land uses.

E. Index values of only the key species/variables responsive to either the first or the second axis: a refinement and more in-depth evaluation of point D, extracting only the key species responsive to each respective axis and hence environmental variable associated with that particular axis. Depending on the research question, this approach can be followed for higher evaluation purposes to closely monitor key species/variables responsive to a particular environmental variable.

- ❖ A key species/variable thus has at least 10% of its ranges explained by the species-environment relation
- ❖ A responsive species/variable is thus associated mainly with either the first or the second axis, as indicated by the highest eigenvalue and cumulative variance explained for that variable/species for that particular axis.
- ❖ The index score (IS) for each species/variable is calculated as follows (Fig. 9.5):

  IS = (eigenvalue of species/variable + smallest eigenvalue/total length of eigenvalue along axis)*10; [simplified as: IS = EV/TL*10]:

  (i) total length (TL) of eigenvalue length along the axis = largest eigenvalue (positive value) + smallest eigenvalue (negative value: turn positive) (e.g. 1.5 + [-1] becomes 1.5 + 1 = 2.5) (Fig. 9.5). If both values are positive, then (ii) TL = the largest eigenvalue – smallest eigenvalue (e.g. = 1.5 - 1 = 0.5) (Fig. 9.5). If both values are negative, then (iii) TL = the largest value (turn positive) – the smallest eigenvalue (turn positive) (e.g. -1.5 – [-1] becomes 1.5 – 1 = 0.5) (Fig. 9.5). The same principles as described in sections (i) – (iii), apply to calculating EV.

  The environmental variable showing the strongest negative correlation (opposite association) with a specific index scale (thus 0 instead of 10 and so forth), are calculated as follows. If species x/variable x = 10 for the environmental associated best with that specific axis, then the index score (IS_{2i}) for species/variables (*i*) with environmental variable 2 that shows the highest negative r-value or association (CCA/RDA ordination) for that axis (if any), is: $IS_{2i} = 10 – IS_{1i}$.
- ❖ The environmental variable being best associated with either the first or the second axis, did not necessarily have a very high r-value (r = 1 represents the strongest association, and r = 0 the weakest association). Thus, the index values for the different matrices, are an approximate but useful indication of the most likely association of the species/variable with that particular environmental variable. Cross-reference to the tables indicating the r-values for the

environmental variable being best associated with the respective axes, will give an indication of the relative sensitivity of the different indices (0 – 10).

- Environmental variables and index values indicated in *italics*, were less informative (secondary) with regard to being indexed against a particular environmental variable.

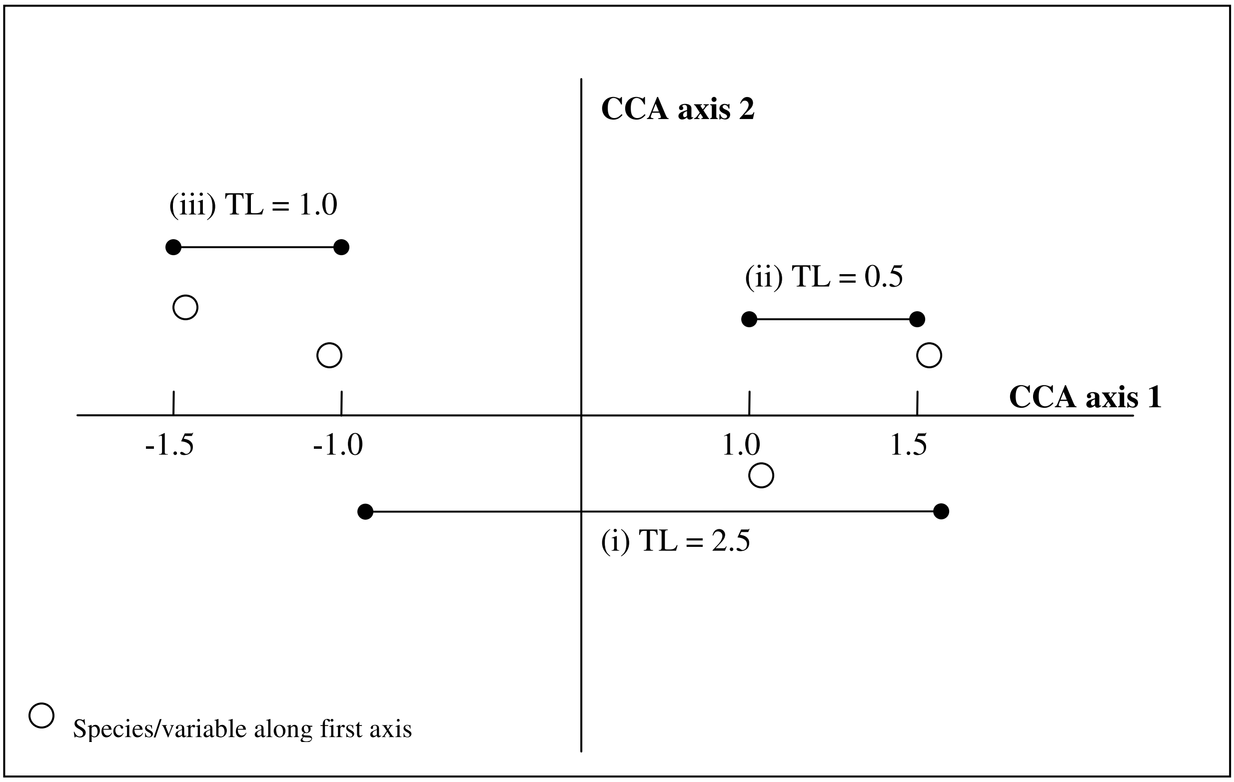


Fig. 9.5. Calculation of the Total length (TL) of eigenvalue ranges for species/variables along the first CCA axis.

9.3.2.1 "Annual" herbaceous species composition

The manner, in which the above-mentioned index was calculated for the species for the "annual" herbaceous matrix, is given for section B. The rest of the index scales for Section 9.3.2.1 as well for the remainder of the other components (Section 9.3.2.2 – 9.3.2.6), was calculated according to the same principle, and will thus not be repeated again. The cumulative variances and eigenvalues for the first two canonical axes, with regard to each different component, are given in the respective chapters.

A. Summary of the primary aspects pertaining to the "annual" herbaceous species composition

Refer to Table 9.3.2.1 A below.

A. Summary of the primary aspects pertaining to the "annual" herbaceous production

Land use	Most abundant species	Indicator (key species)	Typcial	Discriminant	Grazing class abundance	Grazing typical	Ecological status abundance	Ecological status typical	Life-form abundant	Life-form typical	Annual grazing range condition	Perennial grazing range condition	Annual ecological range condition	Perennial ecological range condition	Average DM yield kg/ha (Appendix 2)	Average ha/LSU (Appendix 2)	Average DM yield kg/ha: BENCHMARKS (Appendix 2)	Average ha/LSU: BENCHMARKS (Appendix 2)
Commercial-Good	*Schmidtia pappophoroides*	*Antephora pubescens; Centropodia glauca; Schmidtia pappophoroides*	*Schmidtia pappophoroides*	NA	HD	HD	Decreaser	Decreaser	Perennial	Perennial	799.79	858.18	804.61	863.25	687.32	27.85	807.29	18.28
Commercial-Poor	BP; *Eragrostis lehmanniana*	BP;*Schmidtia kalahariensis*; lesser extent *Eragrostis lehmanniana*	BP; *Eragrostis lehmanniana*	NA	BP	BP	BP	BP	BP	Perennial	371.60	397.72	372.85	398.97	337.34	89.00	570.08	42.04
Tribal-Good	*Aristida stipitata; Eragrostis lehmanniana*	*Eragrostis pallens; Triraphis andropogonoides; Aristida stipitata; Tragus koeleroides; Aristida congesta; Digitaria eriantha; Melinus repens; Eragrostis tricophora*	*Aristida stipitata; Schmidtia pappophoroides*	NA	LD; DE	DE	Inc II	Inc II	*Weak perennial*	*Perennial*	566.25	587.78	574.88	588.93	1193.62	22.44	1460.87	8.83
Tribal-Poor	*Aristida stipitata; Eragrostis lehmanniana*	*Eragrostis pallens; Triraphis andropogonoides; Aristida stipitata; Aristida congesta; Eragrostis tricophora; Tragus koeleroides; Digitaria eriantha; Melinus repens; Pogonathria squarrosa; lesser extent Eragrostis lehmanniana*	*Eragrostis lehmanniana; Aristida congesta*	NA	LD; DE	LD	Inc II	Inc II	*Weak perennial*	*Perennial*	453.73	477.97	467.68	475.10	464.31	173.77	801.03	78.33
Reserve-Good	*Schmidtia pappophoroides; Stipagrostis uniplumis*	*Schmidtia pappophoroides; Centropodia glauca*	*Schmidtia pappophoroides; Stipagrostis uniplumis*	NA	HD	HD	Decreaser	Decreaser	Perennial	Perennial	839.53	885.33	840.43	886.31	1445.44	10.09	1411.75	8.51
Reserve-Poor	BP	BP; *Schmidtia kalahariensis*; to lesser extent *Eragrostis lehmanniana*	BP; *Stipagrostis uniplumis*	NA	DE	DE	Inc I	Inc I	Perennial	Weak perennial	440.88	459.12	482.39	511.11	415.16	240.11	259.88	705.72
Commercial-Tribal	NA	See below (Point B, C, D, E)	NA	*Schmidtia pappophoroides; *Aristida stipitata*	NA	LD*; HD	NA	Inc II*; Decreaser	Weak perennial*; Perennial;	NA	NA	NA	NA	NA	NA	NA	NA	NA
Reserve-Tribal	NA	See below (Point B, C, D, E)	NA	*Stipagrostis uniplumis, Schmidtia pappophoroides; *Aristida stipitata*	NA	LD*; HD	NA	Inc II*; Decreaser	Weak perennial*; Perennial;	NA	NA	NA	NA	NA	NA	NA	NA	NA
Reserve-Commercial	NA	See below (Point B, C, D, E)	NA	*Schmidtia pappophoroides; Stipagrostis uniplumis*	NA	HD; DE	NA	Decreaser; Inc I	Perennial; Weak perennial	NA	NA	NA	NA	NA	NA	NA	NA	NA

Grey highlighted: Significant "Good" rangeland cond

Yellow highlighted: Significant "Poor" rangeland con

The highest average rangeland condition score within each land use type is indicated in *italics*, as to show which rangeland condition scoring method results in the highest rangeland condition scores. The highest average dry material yield (DM yield – kg/ha) between the benchmarks and the open survey sites within each land use, was also indicated in italics. This was done to establish whether herbaceous production was highest within the benchmarks or within the open survey sites within each land use type. With regard to the dry material yield, it was on average the highest within the Tribal land use. **However**, these Tribal benchmarks were not grazed since 1999, while the Commercial and Reserve benchmarks were grazed until 2002. Very important is that when rangeland condition in addition is considered, it can be seen that "higher" herbaceous production is not necessarily "better" production or thus rangeland condition. Hence, extreme caution should be taken in the correct calculation and application of herbaceous production figures. A sufficient number of sites should also be surveyed within each land use (pseudoreplication experimental design errors should be avoided) in order to cover as much as possible spatial variability (due to different patch, paddock and landscape level patterns). Refer to Chapter 10 (Recommendations) for more comments.

B. Index values of all the species/variables for both the first and the second axes

Refer to Table 9.3.2.1 B below.

* *Eragrostis lehmanniana* was responsive to both axes, and was thus included in the indexing of both axes. Although BP was consistently being associated rather with the Commercial-Poor and Reserve-Poor land uses, it was included in the indexing of both axes (hence with the Tribal land use as well), since in degradation terms it is considered the "poorest" form of rangeland condition. Hence, it was incorporated into the Tribal land use's model.

** When an index for total rangeland condition across the total study area was compiled (B.1), the species of all three land uses were included, thus "mixing" the Tribal land use's "Good" species with those of the other two land uses. This is further indicative of the transitional shift in the Tribal land use's herbaceous species composition, thus resulting in two different rangeland condition spectra for the larger study area, with the Tribal land use showing its own unique species associated with either the "Good" or "Poor" rangeland conditions (although the differences were not significant), as opposed to the Reserve and Commercial land uses, which showed a relatively similar rangeland condition gradient and index among each other (Chapter 4, Fig. 4.10). These results further support the argument that models applied within Reserve (conservation) and Commercial areas, should not be unthinkingly impositioned on Tribal land uses. Thus, the general rangeland condition index was refined, and the Tribal land use separated from the Reserve/Commercial land uses in order to compile two different indices (thus using CCA axis 2) indicative of rangeland condition scores for the Tribal vs. the Reserve/Commercial groups. This refined (separate) matrix is highlighted and presented in 9.3.2.1 B.2.

B.1 Key assessment matrix before further seperation/refinement of CCA axis 2

Species responsive to the respective axes indicated in BOLD	**AX1**	**AX2**	**AX1**	**AX2**	**ALL SPECIES**	**AX1**	**Tribal**	**Reserve/ Commercial**	****ALL SPECIES**	**AX2**	**Poor**
ANT PUB	**-1.4212**	-1.2181	**0.0714**	0.1112	*CYN DAC*	**1.7994**	10.0	0.0	*TRA RAC*	**1.6514**	0.0
BRAC NIG	**-1.4212**	-1.2181	**0.0332**	0.0518	*BRA MAR*	**1.7994**	10.0	0.0	*STIP CIL*	**1.1483**	1.7
DIG ERI	**1.616**	-0.73	**0.192**	0.2217	*TRA BER*	**1.77**	9.9	0.1	BP	**1.0514**	2.0
SCHM PAP	**-0.6929**	-0.6196	**0.3667**	0.5889	*ERA BIF*	**1.76**	9.9	0.1	*SCHM KAL*	**0.9856**	2.3
PAN MAX	**1.569**	-1.2425	**0.0224**	0.0331	*ARIST CON*	**1.7366**	9.8	0.2	*URU BRA*	**0.603**	3.6
CHRY SER	-1.2645	**-1.2976**	0.0144	**0.0258**	*TRA KOE*	**1.7149**	9.7	0.3	**ERA LEH*	**0.3756**	4.3
**ERA LEH*	**0.368**	**0.3756**	**0.0637**	**0.1139**	*CYM PO*	**1.6931**	9.7	0.3	*STIP UNI*	0.0634	5.4
ERA TRI	**1.5313**	-0.5883	0.1104	**0.1228**	*TRI AND*	**1.6732**	9.6	0.4	*POG SQU*	0.0045	5.6
STIP CIL	-0.5812	**1.1483**	**0.0068**	0.0268	*DIG ERI*	**1.616**	9.4	0.6	*CYN DAC*	-0.1799	6.2
STIP UNI	**-0.4571**	0.0634	**0.1242**	0.126	*ERA PAL*	**1.6112**	9.4	0.6	*BRA MAR*	-0.1799	6.2
CYM PO	**1.6931**	-0.6703	**0.053**	0.0593	*PER PAT*	**1.5903**	9.4	0.6	*TRA BER*	-0.3155	6.7
CEN TR	**-1.3736**	-1.0788	**0.0716**	0.1051	*PAN MAX*	**1.569**	9.3	0.7	*ERA BIF*	-0.3616	6.8
ARI STI	**1.408**	-0.4264	**0.4002**	0.428	*ERA RIG*	**1.569**	9.3	0.7	*ARI STI*	-0.4264	7.0
CYN DAC	**1.7994**	-0.1799	**0.0105**	0.0106	*CHLOR VIR*	**1.569**	9.3	0.7	*ARIST MED*	-0.4294	7.1
ERA PAL	**1.6112**	-1.0479	**0.2146**	0.2834	*ELEU COR*	**1.569**	9.3	0.7	*ARIST CON*	-0.4698	7.2
MEL REP	**1.4182**	-0.89	**0.1886**	0.2449	*ERA TRI*	**1.5313**	9.2	0.8	*TRA KOE*	-0.5697	7.5
TRI AND	**1.6732**	-0.7623	**0.1484**	0.1718	*POG SQU*	**1.4982**	9.1	0.9	*ERA TRI*	-0.5883	7.6
ERA RIG	**1.569**	-1.2425	**0.0381**	0.0563	*MEL REP*	**1.4182**	8.8	1.2	*SCHM PAP*	-0.6196	7.7
POG SQU	**1.4982**	0.0045	**0.1132**	0.1132	*ARI STI*	**1.408**	8.8	1.2	*CYM PO*	-0.6703	7.9
ARIST CON	**1.7366**	-0.4698	**0.3539**	0.3735	*ARIST MED*	**1.1568**	8.0	2.0	*DIG ERI*	-0.73	8.1
ARIST MED	**1.1568**	-0.4294	**0.03**	0.0331	**ERA LEH*	**0.368**	5.6	4.4	*TRI AND*	-0.7623	8.2
PER PAT	**1.5903**	-1.1443	**0.0263**	0.0366	BP	0.0599	4.6	5.4	*MEL REP*	-0.89	8.6
TRA KOE	**1.7149**	-0.5697	**0.1619**	0.1754	*TRA RAC*	-0.4407	3.0	7.0	*ERA PAL*	-1.0479	9.2
URU BRA	-0.455	**0.603**	0.0067	**0.0157**	*URU BRA*	-0.455	3.0	7.0	*CEN TR*	-1.0788	9.3
TRA BER	**1.77**	-0.3155	**0.0513**	0.0525	*STIP UNI*	**-0.4571**	3.0	7.0	*PER PAT*	-1.1443	9.5
BRA MAR	**1.7994**	-0.1799	**0.0278**	0.028	*STIP CIL*	-0.5812	2.6	7.4	*ANT PUB*	-1.2181	9.7
ERA BIF	**1.76**	-0.3616	**0.0908**	0.0937	*SCHM KAL*	-0.5863	2.6	7.4	*BRAC NIG*	-1.2181	9.7
CHLOR VIR	**1.569**	-1.2425	**0.0204**	0.0301	*SCHM PAP*	**-0.6929**	2.3	7.7	FORBS	-1.2181	9.7
ELEU COR	**1.569**	-1.2425	**0.0204**	0.0301	*CHRY SER*	-1.2645	0.5	9.5	*PAN MAX*	-1.2425	9.8
SCHM KAL	-0.5863	**0.9856**	0.0437	**0.1372**	*CEN TR*	**-1.3736**	0.1	9.9	*ERA RIG*	-1.2425	9.8
TRA RAC	-0.4407	**1.6514**	0.0016	0.0189	*ANT PUB*	**-1.4212**	0.0	10.0	*CHLOR VIR*	-1.2425	9.8
FORBS	**-1.4212**	-1.2181	**0.0165**	0.0257	*BRAC NIG*	**-1.4212**	0.0	10.0	*ELEU COR*	-1.2425	9.8
BP	0.0599	**1.0514**	0.0012	**0.2712**	FORBS	**-1.4212**	0.0	10.0	*CHRY SER*	**-1.2976**	10.0
						TL = 3.2206				**TL = 2.949**	**Good**

B.2 Key assessment matrix after refinement/seperation of CCA axis 2 (Chapter 4, Appendix 3)

AX2: (Commercial/Reserve species in bold)	**Good**	**AX2: Rangeland condition: Commercial/Reserve**	**Good**	**AX2: Rangeland condition: Tribal (including *E lehmanniana*)**	**Good**	**AX2: Rangeland condition: Tribal (adjusted for BP: consistently typical of Reserve-/Commercial-Poor)**	**Good**
CHRY SER	**10.0**	*CHRY SER*	10.0	*PAN MAX*	10	*PAN MAX*	10.0
PAN MAX	9.8	*ANT PUB*	9.7	*ERA R IG*	10.0	*ERA R IG*	10.0
ERA RIG	9.8	*BRAC NIG*	9.7	*CHLOR VIR*	10.0	*CHLOR VIR*	10.0
CHLOR VIR	9.8	*CEN TR*	9.3	*ELEU COR*	10.0	*ELEU COR*	10.0
ELEU COR	9.8	*SCHM PAP*	7.7	*PER PAT*	9.4	*PER PAT*	9.6
ANT PUB	**9.7**	*STIP UNI*	5.4	*ERA PAL*	8.8	*ERA PAL*	9.2
BRAC NIG	**9.7**	*ERA LEH*	4.3	*MEL REP*	7.8	*MEL REP*	8.5
PER PAT	9.5	*URU BRA*	3.6	*TRI AND*	7.0	*TRI AND*	7.9
CEN TR	**9.3**	*SCHM KAL*	2.3	*DIG ERI*	6.8	*DIG ERI*	7.8
ERA PAL	9.2	BP	2.0	*CYM PO*	6.5	*CYM PO*	7.5
MEL REP	8.6	*STIP CIL*	1.7	*ERA TRI*	6.0	*ERA TRI*	7.1
TRI AND	8.2	*TRA RAC*	0.0	*TRA KOE*	5.8	*TRA KOE*	7.1
DIG ERI	8.1		**Poor**	*ARIST CON*	5.2	*ARIST CON*	6.6
CYM PO	7.9			*ARIST MED*	5.0	*ARIST MED*	6.5
SCHM PAP	7.7			*ARI STI*	5.0	*ARI STI*	6.4
ERA TRI	7.6			*ERA BIF*	4.6	*ERA BIF*	6.2
TRA KOE	7.5			*TRA BER*	4.3	*TRA BER*	6.0
ARIST CON	7.2			*CYN DAC*	3.4	*CYN DAC*	5.4
ARIST MED	7.1			*BRA MAR*	3.4	*BRA MAR*	5.4
ARI STI	7.0			*POG SQU*	2.3	*POG SQU*	4.6
ERA BIF	6.8			*ERA LEH*	0.0	*ERA LEH*	2.9
TRA BER	6.7				**Poor**	BP	0.0
CYN DAC	6.2						**Poor**
BRA MAR	6.2						
POG SQU	5.6						
STIP UNI	5.4						
ERA LEH	4.3						
URU BRA	3.6						
SCHM KAL	2.3						
BP	2.0						
STIP CIL	1.7						
TRA RAC	0.0						
	Poor						

C. Index values of only the species/variables responsive primarily to either the first or the second axis

AX1	**Tribal**	**Commercial/Reserve**	**AX2**	**Poor**
CYN DAC	10.0	0.0	*TRA RAC*	0.0
BRA MAR	10.0	0.0	*STIP CIL*	1.7
TRA BER	9.9	0.1	BP	2.0
ERA BIF	9.9	0.1	*SCHM KAL*	2.3
ARIST CON	9.8	0.2	*URU BRA*	3.6
TRA KOE	9.7	0.3	*ERA LEH*	4.3
CYM PO	9.7	0.3	*CHRY SER*	10.0
TRI AND	9.6	0.4		**Good**
DIG ERI	9.4	0.6		
ERA PAL	9.4	0.6		
PER PAT	9.4	0.6		
PAN MAX	9.3	0.7		
ERA RIG	9.3	0.7		
CHLOR VIR	9.3	0.7		
ELEU COR	9.3	0.7		
ERA TRI	9.2	0.8		
POG SQU	9.1	0.9		
MEL REP	8.8	1.2		
ARI STI	8.8	1.2		
ARIST MED	8.0	2.0		
ERA LEH	5.6	4.4		
STIP UNI	3.0	7.0		
SCHM PAP	2.3	7.7		
CEN TR	0.1	9.9		
ANT PUB	0.0	10.0		
BRAC NIG	0.0	10.0		
FORBS	0.0	10.0		

D. Index values of all the key species/variables (10% and higher of ranges explained by the species-environment variance) for both the first and the second axes (Chapter 4, Appendix 4.3)

The same principles that applied to B.1 and B.2, apply to D.1 and D.2 respectively.

D.1 Key assessment matrix before further seperation/refinement of CCA axis 2

AX1	**Tribal**	**Commercial/Reserve**	**AX2: Commercial/Reserve in bold; underline shared by both land uses**	**Poor**
ARIST CON	10.0	0.0	BP	0.0
TRA KOE	9.9	0.1	***SCHM KAL***	0.3
TRI AND	9.8	0.2	*ERA LEH*	3.0
DIG ERI	9.6	0.4	***STIP UNI***	4.4
ERA PAL	9.6	0.4	*POG SQU*	4.6
ERA TRI	9.3	0.7	*ARI STI*	6.5
POG SQU	9.2	0.8	*ARIST CON*	6.7
MEL REP	9.0	1.0	*TRA KOE*	7.1
ARI STI	9.0	1.0	*ERA TRI*	7.2
ERA LEH	5.7	4.3	***SCHM PAP***	7.4
BP	4.7	5.3	*DIG ERI*	7.8
STIP UNI	3.1	6.9	*TRI AND*	8.0
SCHM KAL	2.6	7.4	*MEL REP*	8.6
SCHM PAP	2.3	7.7	*ERA PAL*	9.3
CEN TR	0.2	9.8	***CEN TR***	9.4
ANT PUB	0.0	10.0	***ANT PUB***	10.0
				Good

D.2 Key assessment matrix after refinement/seperation of CCA axis 2 (Chapter 4, Appendix 4.3)

AX2: Commercial/(*Reserve*)	**Poor**	**AX 2: Tribal**	**Poor**
BP	0.0	BP	0.0
SCHM KAL	0.3	*ERA LEH*	3.2
ERA LEH	3.0	*DIG ERI*	8.5
STIP UNI	4.4	*TRI AND*	8.6
SCHM PAP	7.4	*MEL REP*	9.2
CEN TR	9.4	*ERA PAL*	10.0
ANT PUB	10.0		**Good**
	Good		

E. Index values of only the key species/variables (10% and higher of ranges explained by the species-environment variance) responsive to either the first or the second axis

AX1	**Tribal**	**Commercial/Reserve**	**AX2**	**Poor (Commercial-Poor/*Reserve-Poor*)**
ARIST CON	10.0	0.0	BP	0.0
TRA KOE	9.9	0.1	*SCHM KAL*	9.0
TRI AND	9.8	0.2	*ERA LEH*	10.0
DIG ERI	9.6	0.4		**Intermediate-Poor**
ERA PAL	9.6	0.4		
ERA TRI	9.3	0.7		
POG SQU	9.2	0.8		
MEL REP	9.0	1.0		
ARI STI	9.0	1.0		
ERA LEH	5.7	4.3		
STIP UNI	3.1	6.9		
SCHM PAP	2.3	7.7		
CEN TR	0.2	9.8		
ANT PUB	0.0	10.0		

9.3.2.2 “Perennial” herbaceous species composition

A. Summary of the primary aspects pertaining to the "perennial" herbaceous species composition

The same comments presented in Section 9.3.2.2 A, apply to this section. The rangeland condition scores for both the “annual” and “perennial” grazing and ecological indices, as well as the herbaceous production are presented again, as quick comparative measure for the “perennial” herbaceous interpretation.

A. Summary "perennial" herbaceous composition (continue)

Land use	Most abundant species	Indicator (key species)	Typical	Discriminant	Grazing class abundance	Grazing typical	Ecological status abundance	Ecological status typical	Life-form abundant	Life-form typical	Annual grazing range condition	Perennial grazing range condition	Annual ecological range condition	Perennial ecological range condition	Average DM yield kg/ha (Appendix 2)	Average ha/LSU (Appendix 2)	Average DM yield kg/ha: BENCHMARKS (Appendix 2)	Average ha/LSU: BENCHMARKS (Appendix 2)
Commercial-Good	*Schmidtia pappophoroides*	*Antephora pubescens; Centropodia glauca; Schmidtia pappophoroides*	*Schmidtia pappophoroides*	NA	HD	HD	Decreaser	Decreaser	Perennial	Perennial	799.79	858.18	804.61	863.25	687.32	27.85	807.29	18.28
Commercial-Poor	BP; *Eragrostis lehmanniana*	BP; *Eragrostis lehmanniana*	BP; *Eragrostis lehmanniana*	NA	BP	BP	BP	BP	BP	Perennial	371.60	397.72	372.85	398.97	337.34	89.00	570.08	42.04
Tribal-Good	*Aristida stipitata; Schmidtia pappophoroides; Eragrostis lehmanniana*	*Eragrostis pallens; Triraphis andropogonoides; Aristida stipitata; Tragus koeleroides; Digitaria eriantha; Eragrosits tricophora*	*Aristida stipitata; Schmidtia pappophoroides*	NA	LD; DE	HD	Inc II	Inc II	*Weak perennial*	*Perennial*	566.25	587.78	574.88	588.93	1193.62	22.44	1460.87	8.83
Tribal-Poor	*Aristida stipitata; Eragrostis lehmanniana*	*Eragrostis pallens; Triraphis andropogonoides; Aristida stipitata; Tragus koeleroides; Digitaria eriantha; Eragrosits tricophora; Eragrostis lehmanniana*	*Eragrostis lehmanniana; Aristida stipitata*	NA	LD; DE	LD	Inc II	Inc II	*Weak perennial*	*Perennial*	453.73	477.97	467.68	475.10	464.31	173.77	801.03	78.33
Reserve-Good	*Schmidtia pappophoroides; Stipagrostis uniplumis*	*Schmidtia pappophoroides; Centropodia glauca*	*Schmidtia pappophoroides; Stipagrostis uniplumis*	NA	HD	HD	Decreaser	Decreaser	Perennial	Perennial	839.53	885.33	840.43	886.31	1445.44	10.09	1411.75	8.51
Reserve-Poor	BP	BP; *Stipagrostis uniplumis*	BP; *Stipagrostis uniplumis*	NA	DE	DE	Inc I	Inc I	Perennial	Weak perennial	440.88	459.12	482.39	511.11	415.16	240.11	259.88	705.72
Commercial-Tribal	NA	See below (Point B, C, D, E)	NA	_Schmidtia pappophoroides; *Aristida stipitata_	NA	LD*; DE	NA	Inc II*; Decreaser	Weak perennial	NA	NA	NA	NA	NA	NA	NA	NA	NA
Reserve-Tribal	NA	See below (Point B, C, D, E)	NA	_Stipagrostis uniplumis, Schmidtia pappophoroides; *Aristida stipitata_	NA	LD*; HD	NA	Inc II*; Decreaser	Weak perennial	NA	NA	NA	NA	NA	NA	NA	NA	NA
Reserve-Commercia	NA	See below (Point B, C, D, E)	NA	*Schmidtia pappophoroides; Stipagrostis uniplumis*	NA	HD; DE	NA	Decreaser; Inc I	Perennial; Weak	NA	NA	NA	NA	NA	NA	NA	NA	NA

Grey highlighted: Significant "Good" ran

Yellow highlighted: Significant "Poor" ra

B. Index values of all the herbaceous species for both the first and the second axes

Refer to Chapter 4, Appendix 4.3.

AX1	Commercial-Good/Reserve-Good	Tribal	AX2	Good: *(Tribal-Good)*
BRAC NIG	10.0	0.0	*ERA PAL*	10.0
ANT PUB	9.2	0.8	*TRI AND*	9.7
CHRY SER	9.0	1.0	*ERA RIG*	8.3
CEN TR	7.5	2.5	*DIG ERI*	7.9
FORBS	7.1	2.9	*CHRY SER*	7.8
SCHM PAP	6.7	3.3	*ERA TRI*	7.8
STIP CIL	5.6	4.4	*ARI STI*	7.5
STIP UNI	5.1	4.9	*POG SQU*	7.5
BP	2.9	7.1	*TRA KOE*	7.0
ERA LEH	2.5	7.5	*CYM PO*	6.8
ARIST MED	2.0	8.0	*MEL REP*	6.8
ERA RIG	1.2	8.8	*BRAC NIG*	6.1
ARI STI	0.7	9.3	*SCHM PAP*	6.0
MEL REP	0.6	9.4	*ANT PUB*	5.9
PAN MAX	0.6	9.4	*CEN TR*	5.6
CYN DAC	0.5	9.5	*FORBS*	5.4
TRA KOE	0.5	9.5	*ERA LEH*	4.7
POG SQU	0.4	9.6	*ARIST MED*	4.6
ERA TRI	0.4	9.6	*STIP UNI*	4.5
CYM PO	0.2	9.8	*PAN MAX*	4.2
DIG ERI	0.0	10.0	BP	2.1
ERA PAL	0.0	10.0	*STIP CIL*	1.5
TRI AND	0.0	10.0	*CYN DAC*	0.0
				Poor

C. Index values of only the herbaceous species responsive primarily to either the first or the second axis

AX1	Commercial-Good/Reserve-Good	Tribal	AX2	Good: *(Tribal-Good)*
BRAC NIG	10.0	0.0	*ERA PAL*	10.0
ANT PUB	9.2	0.8	*TRI AND*	9.7
CHRY SER	9.0	1.0	*ERA RIG*	8.3
CEN TR	7.5	2.5	BP	2.1
FORBS	7.1	2.9	*STIP CIL*	1.5
SCHM PAP	6.7	3.3	*CYN DAC*	0.0
STIP UNI	5.1	4.9		
ERA LEH	2.5	7.5		
ARIST MED	2.0	8.0		
ARI STI	0.7	9.3		
MEL REP	0.6	9.4		
PAN MAX	0.6	9.4		
TRA KOE	0.5	9.5		
POG SQU	0.4	9.6		
ERA TRI	0.4	9.6		
CYM PO	0.1	9.9		
DIG ERI	0.0	10.0		

D. Index values of all the key herbaceous species (10% and higher of ranges explained by the species-environment variance) for both the first and the second axes

AX1	**Commercial-Good/Reserve-Good**	**Tribal**	**AX2**	**Good:** ***(Tribal-Good)***
CEN TR	9.8	0.2	*TRI AND*	8.5
SCHM PAP	7.2	2.8	*DIG ERI*	8.3
STIP UNI	5.9	4.1	*ERA TRI*	7.9
BP	3.2	6.8	*TRA KOE*	7.5
ERA LEH	3.0	7.0	*ARI STI*	6.7
ARI STI	0.7	9.3	*ANT PUB*	5.9
ERA TRI	0.4	9.6	*CEN TR*	5.5
ERA PAL	0.4	9.6	*SCHM PAP*	4.8
DIG ERI	0.3	9.7	*ERA LEH*	2.7
TRI AND	0.1	9.9	*STIP UNI*	2.5
TRA KOE	0.0	10.0	BP	0.0

E. Index values of only the key herbaceous species (10% and higher of ranges explained by the species-environment variance) responsive to either the first or the second axis

AX1	**Commercial-Good/Reserve-Good**	**Tribal**	**AX2**	**Good:** ***(Tribal-Good)***
ANT PUB	10.0	0.0	*ERA PAL*	10.0
CEN TR	9.8	0.2	*TRI AND*	8.5
SCHM PAP	7.2	2.8	BP	0.0
STIP UNI	5.9	4.1		
ERA LEH	3.0	7.0		
ARI STI	0.7	9.3		
ERA TRI	0.4	9.6		
DIG ERI	0.3	9.7		
TRA KOE	0.0	10.0		

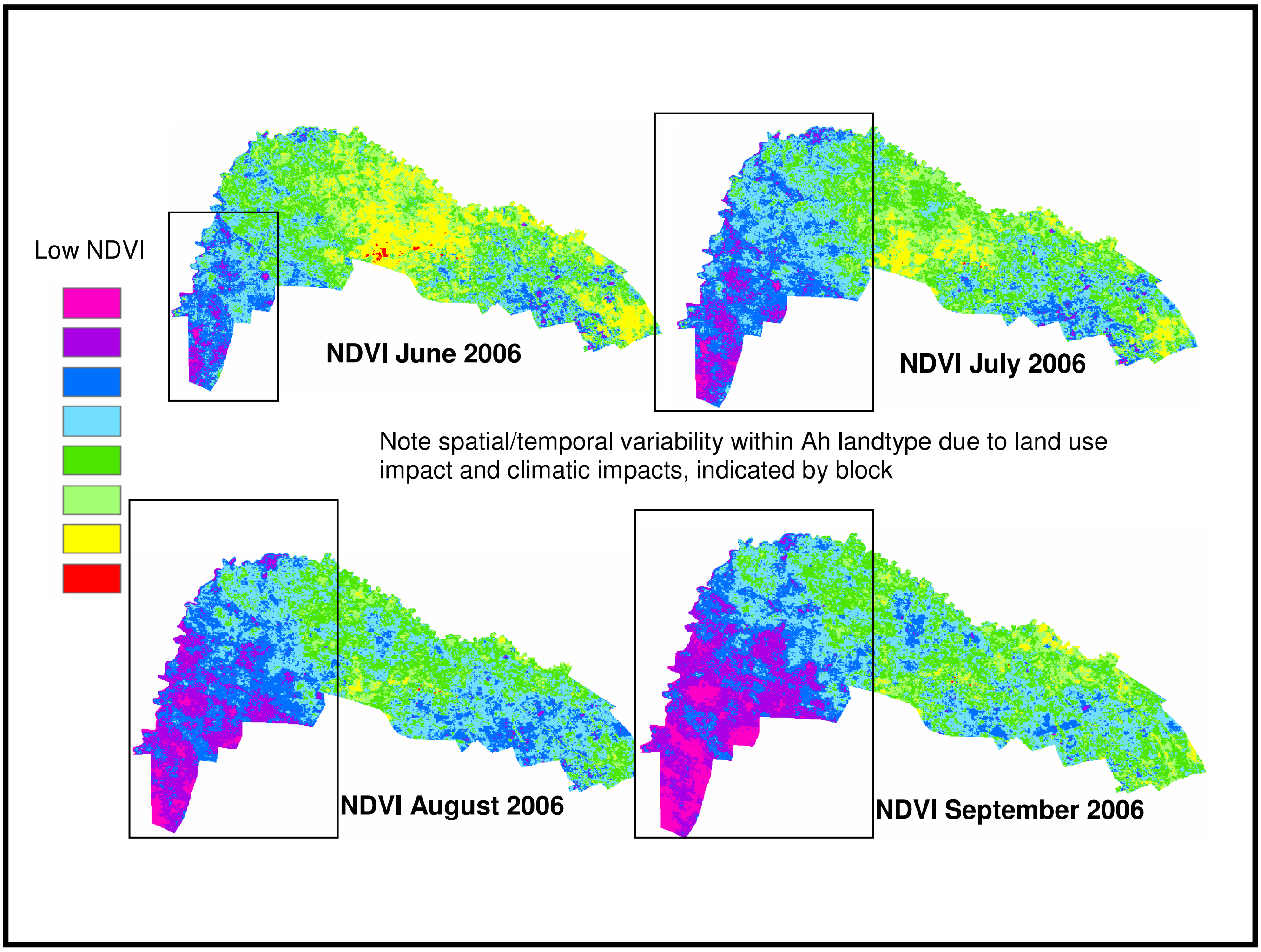


Fig. 9.6. Normalised Difference Vegetation Index (NDVI) for the larger Molopo study, showing spatial and temporal variability within the same Ah land type as indicated by the NDVI indices, with spatial data that will be linked to the groundtruthed data for the development of web-based packages (compiled by Van den Berg 2007).

9.3.2.3 Woody component

A. Summary of the primary aspects pertaining to the woody component

An interesting observation was that *Dichrostachys cinerea* (indicated in red), which is a declared bush encroacher, had the highest average abundance within the Tribal-Good land use. However, this species, as well as *Gymnosporia buxifolia*, showed an immense seedling explosion in a paddock that was burnt down by an accidental fire two years prior to the survey (2002). Thus, previous unsustainable land use management impacts, together with the accidental fire that initially appeared to improve the herbaceous production, in fact resulted in an explosion (germination and growth) of these woody species. Thus, previous (historical) unsustainable land-use impacts may in fact have secondary (indirect) detrimental effects in the medium and potentially long term.

A. Summary of the primary aspects pertaining to the woody component

Land use	Most abundant species (relative abundance)	Indicator (Chapter 5, Fig. 5.12) key species	Typcial (relative abundance)	Discriminant (relative abundance)	Average relative abundance %: most abundant species	Average density TE/ha: abundant species	Average density TE/ha: Total	Average numbers/ha: Total	Average area cover m2/ha: Total	Average growth form: species
Commercial-Good	_Grewia flava_	_Acacia haemotoxilyn_	_Grewia flava_	_Grewia flava; Acacia melifera_	42.02	170.14	429.58	506	1116.57	See Chapter 5, Appendix 8
Commercial-Poor	_Grewia flava_	_Boscia albitrunca_	_Grewia flava_		41.04	247.22	654.03	865	1889.14	See Chapter 5, Appendix 8
Tribal-Good	**_*Dichrostachys cinerea_**	_Dichrostachys cinerea; Terminalia sercia; Tarchonathus camphoratus; Gymnosporia buxifolia_	_Grewia flava_	_Gymnosporia buxifolia; Grewia flava; Acacia erioloba_	***19.64**	***421.53**	1755.42	3577	4289.32	See Chapter 5, Appendix 8
Tribal-Poor	_Grewia flava_	_Grewia flava (no unique strong indicator)_	_Grewia flava_		23.82	343.61	1625.56	3246	3862.39	See Chapter 5, Appendix 8
Reserve-Good	Grewia flava	_Boscia albitrunca_	_Grewia flava_	_Acacia mellifera; Grewia flava_	39.02	252.22	643.47	917	1965.43	See Chapter 5, Appendix 8
Reserve-Poor	_Acacia mellifera_	_Acacia luederitzii; Acacia mellifera_	_Grewia flava_		25.25	409.03	1795.56	2638	3690.03	See Chapter 5, Appendix 8
Commercial-*Tribal	NA	See below (Point B, C, D, E)	NA	_Grewia flava_	NA	NA	NA	NA	NA	NA
Reserve-*Tribal	NA	See below (Point B, C, D, E)	NA	_Grewia flava; *Protasparagus suleovons; Acacia mellifera_	NA	NA	NA	NA	NA	NA
***Reserve-*Commercial**	NA	See below (Point B, C, D, E)	NA	_Grewia flava; *Acacia mellifera_	NA	NA	NA	NA	NA	NA

Grey highlighted: Significant "Good" rangeland

Yellow highlighted: Significant "Poor" rangelanc

* Dichrostachys cinerea is described as an ecroahcer species

B. Index values of all the woody species for both the first and the second axes

Refer to Chapter 5, Table 5.7.

AX1	**Tribal/Herbaceous richness**	**Reserve *(Commercial)***	**AX2**	**Commercial-Good**	**Reserve-Poor *(Tribal)***
Ac tor	10.0	0.0	*Ac hae*	10.0	0.0
Ter ser	10.0	0.0	*Gre fla*	5.3	4.7
Ac kar	9.9	0.1	*Ac eri*	5.1	4.9
Gym bux	9.8	0.2	*Prot sul*	5.1	4.9
Dio lyc	9.7	0.3	*Bos alb*	4.7	5.3
Tar cam	9.5	0.5	*Ac heb*	4.6	5.4
Dic cin	9.2	0.8	*Dic cin*	4.3	5.7
Mun ser	8.4	1.6	*Ehr rig*	4.2	5.8
Ac rob	7.6	2.4	*Rhu cil*	4.2	5.8
Gre flsc	6.9	3.1	*Gre flsc*	4.1	5.9
Rhu cil	6.4	3.6	*Rhi bre*	4.0	6.0
Ziz muc	5.1	4.9	*Ziz muc*	3.5	6.5
Ac eri	5.0	5.0	*Lyc hir*	3.4	6.6
Ac heb	4.7	5.3	*Ac rob*	3.4	6.6
Prot sul	4.7	5.3	*Mun ser*	3.4	6.6
Ehr rig	4.5	5.5	*Tar cam*	3.4	6.6
Gre fla	3.5	6.5	*Ac kar*	3.4	6.6
Ach ae	3.1	6.9	*Gym bux*	3.4	6.6
Ac mel	2.9	7.1	*Ac tor*	3.4	6.6
Rhi bre	2.4	7.6	*Ter ser*	3.4	6.6
Bos alb	1.7	8.3	*Dio lyc*	3.3	6.7
Lyc hir	1.5	8.5	*Ac mel*	3.2	6.8
Ac lue	0.7	9.3	*Ac lue*	1.7	8.3
Cadaba	0.0	10.0	*Cadaba*	0.0	10.0

C. Index values of only the woody species responsive primarily to either the first or the second axis

AX1	Tribal/Herbaceous richness	Reserve *(Commercial)*	AX2	Commercial-Good	Reserve-Poor *(Tribal)*
Ac tor	10.0	0.0	*Ac hae*	10.0	0.0
Ter ser	10.0	0.0	*Gre flsc*	5.3	4.7
Ac kar	9.8	0.2	*Ac eri*	5.1	4.9
Gym bux	9.8	0.2	*Prot sul*	5.1	4.9
Dio lyc	9.7	0.3	*Ehr rig*	4.2	5.8
Tar cam	9.4	0.6	*Ziz muc*	3.5	6.5
Dic cin	9.1	0.9	*Ac mel*	3.2	6.8
Mun ser	8.2	1.8	*Ac lue*	1.7	8.3
Ac rob	7.2	2.8	*Cadaba*	0.0	10.0
Gre flsc	6.3	3.7			
Rhu cil	5.8	4.2			
Ac heb	3.8	6.2			
Rhi bre	1.1	8.9			
Bos alb	0.2	9.8			
Lyc hir	0.0	10.0			

D. Index values of all the key woody species (10% and higher of ranges explained by the species-environment variance) for both the first and the second axes

AX1	Tribal/Herbaceous richness	Reserve *(Commercial)*	AX2	Commercial-Good	Reserve-Poor *(Tribal)*
Ter ser	10.0	0.0	*Ac hae*	10.0	0.0
Gym bux	9.8	0.2	*Gre fla*	4.3	5.7
Tar cam	9.5	0.5	*Bos alb*	3.6	6.4
Dic cin	9.2	0.8	*Dic cin*	3.1	6.9
Gre fla	3.0	7.0	*Tar cam*	2.1	7.9
Ac hae	2.6	7.4	*Gym bux*	2.1	7.9
Ac mel	2.4	7.6	*Ter ser*	2.1	7.9
Bos alb	1.0	9.0	*Ac mel*	1.8	8.2
Ac lue	0.0	10.0	*Ac lue*	0.0	10.0

E. Index values of only the key woody species (10% and higher of ranges explained by the species-environment variance) responsive to either the first or the second axis

AX1	Tribal/Herbaceous richness	Reserve *(Commercial)*	AX2	Commercial-Good	Reserve-Poor *(Tribal)*
Ter ser	10.0	0.0	*Ac hae*	10.0	0.0
Gym bux	9.8	0.2	*Gre fla*	4.3	5.7
Tar cam	9.4	0.6	*Ac mel*	1.8	8.2
Dic cin	9.1	0.9	*Ac lue*	0.0	10.0
Bos alb	0.0	10.0			

9.3.2.4 Ant component

A. Summary of the primary aspects pertaining to the ant component

- Also refer to Table 8.15 and Appendices 8.2, 8.8, 8.10 (Chapter 8)

Land use	Most abundant species (absolute abundance)	Most abundant species (absolute abundance) - total land use	Most abundant species (relative abundance) - total land use	Highest contributing similarity (absolute abundance)	Highest contributing similarity (relative abundance - %)	Indicator (IndVal); (Chapter 8, Table 15)	Indicator (CCA 10% and higher range key species)	Typcial (absolute abundance)	Typcial (relative abundance)	Discriminant (absolute abundance)	Discriminant (relative abundance)	Absolute Average abundance: most abundant species	Average numbers within land use	Total abundance (sum of absolute numbers) within each land use group	Total abundance (sum of absolute numbers)
Commercial-Good	_Anoplolepis steingroeveri_	_Anoplolepis steigroeveri_	_Anoplolepis steingroeveri_	_Pheidole sp C_	_Pheidole sp C_	_Anoplolepis sp A;_ _Ocymyrmex sp B;_ _Ocymyrmex sp C;_ _Meranoplus spinisior_	_Ocymyrmex sp B; Ocymyrmex sp C; Meranoplus spinisior_	_Monomorium rufulum_	_Monomorium rufulum_	NA	NA	387	689	6198	8400
Commercial-Poor	_Ocymyrmex sp B_									NA	NA	35	245	2202	
Tribal-Good	_Myrmicaria sp A_	_Myrmicaria sp A_	_Myrmicaria sp A_	_Monomorium fastidium_	_Myrmicaria sp A_	_Camponotus fulvipilosus;_ _Tetramorium similum;_ _Tetromorium baufra;_ _Cardiocondyla sp A;_ _Crematogaster sp A_	_Camponotus fulvipilosus;_ _Tetramorium similum;_ _Tetromorium baufra;_ _Cardiocondyla sp A;_ _Crematogaster sp A_	_Monomorium fastidium;_ _Monomorium rufulum;_ _Monomorium sp B_	_Monomorium fastidium;_ _Monomorium rufulum_	NA	NA	90	389	3500	6835
Tribal-Poor	_Myrmicaria sp A_									NA	NA	120	371	3335	
Reserve-Good	_Anoplolepis steingroeveri_	_Anoplolepis steigroeveri_	_Myrmicaria sp A_	_Pheidole sp C_	_Myrmicaria sp A_	_Monomorium notulum;_ _Tetramorium sericeiventre_	_Monomorium notulum;_ _Tetramorium sericeiventre_	_Monomorium fastidium;_ _Monomorium notulum_	_Monomorium fastidium;_ _Monomorium notulum_	NA	NA	595	1057	9516	33437
Reserve-Poor	_Anoplolepis steingroeveri_									NA	NA	2338	2658	23921	
Commercial-*Tribal	NA	NA	NA	NA	NA	See below (Point B, C, D, E, F)	See below (Point B, C, D, E, F)	NA	NA	_Tetramorium setuliferum;_ _Monomorium rufulum_	_Monomorium rufulum;_ _*Monomorium fastidium;_ _Pheidole sp C_	NA	NA	NA	NA
Reserve-Tribal	NA	NA	NA	NA	NA	See below (Point B, C, D, E, F)	See below (Point B, C, D, E, F)	NA	NA	_Tetramorium setuliferum;_ _Pheidole sp C_	_*Monomorium fastidium;_ _Monomorium rufulum;_ _*Tetramorium setuliferum_	NA	NA	NA	NA
Reserve-*Commercial	NA	NA	NA	NA	NA	See below (Point B, C, D, E, F)	See below (Point B, C, D, E, F)	NA	NA	_Monomorium fastidium;_ _*Tetramorium setuliferum_	_*Pheidole sp C;_ _Monomorium fastidium;_ _Monomorium rufulum_	NA	NA	NA	NA

B. Index values of all the ant species for both the first and the second axes

Refer to Chapter 8, Table 8.13.

AX1	Tribal	Commercial/Reserve	AX2	Commercial	Reserve-Good
Myrm spB	10.0	0.0	*Tet spA*	10.0	0.0
Tet sp2	10.0	0.0	*Camp may*	9.6	0.4
Pac spA	9.8	0.2	*Anop spC*	9.2	0.8
Sp. XII	9.7	0.3	*Tetr spE*	9.0	1.0
Tap spA	9.6	0.4	*Mera spC*	7.7	2.3
Tetr spH	9.6	0.4	*Phei spD*	7.3	2.7
Tetr spG	9.5	0.5	*Mera spi*	7.2	2.8
Crem spI	9.3	0.7	*Anop spA*	7.2	2.8
Lepi spC	9.3	0.7	*Tet sp4*	6.9	3.1
Mera spD	9.3	0.7	*Mon spA*	6.8	3.2
Mon spC	9.3	0.7	*Tet V111*	6.8	3.2
Pac sha	9.3	0.7	*Ocym wei*	6.4	3.6
Tech spA	9.3	0.7	*Tetr sim*	6.3	3.7
Tet spXV	9.3	0.7	*Pac spC*	6.2	3.8
Lepi spi	8.7	1.3	*Anop spB*	6.1	3.9
Card spA	8.4	1.6	*Lepi sp*	6.1	3.9
Mon spE	8.2	1.8	*Tetr spC*	6.0	4.0
Crem spA	7.8	2.2	*Tetr spD*	5.9	4.1
Tetr sim	7.6	2.4	*Ocym spA*	5.9	4.1
Tetr wei	7.5	2.5	*Ocym spB*	5.8	4.2
Tet. n.se	7.4	2.6	*Ocym spC*	5.8	4.2
Tetr bau	6.8	3.2	*Crem spA*	5.7	4.3
Pac spC	6.7	3.3	*Mon spB*	5.6	4.4
Plag spA	6.5	3.5	*Phei spC*	5.6	4.4
Camp spB	6.3	3.7	*Camp spD*	5.6	4.4
Camp ful	6.1	3.9	*Plag spA*	5.5	4.5
Plec man	6.0	4.0	*Tet. n.se*	5.4	4.6
Mes. n.ca	5.9	4.1	*Phei spA*	5.4	4.6
Phei spD	5.8	4.2	*Crem spI*	5.3	4.7
Phei spB	5.5	4.5	*Lepi spC*	5.3	4.7
Camp may	5.5	4.5	*Mera spD*	5.3	4.7
Mon spB	5.3	4.7	*Mon spC*	5.3	4.7
Tetr spD	5.2	4.8	*Pac sha*	5.3	4.7
Myrm spA	5.0	5.0	*Tech spA*	5.3	4.7
Mera spB	4.9	5.1	*Tet spXV*	5.3	4.7
Phei spA	4.5	5.5	*Mon rufu*	5.3	4.7
Lepi spA	4.4	5.6	*Tetr set*	5.2	4.8
Tetr spC	4.3	5.7	*Tetr spG*	5.2	4.8
Mon fast	4.3	5.7	*Tetr bau*	5.1	4.9
Tetr ser	4.3	5.7	*Mera spB*	5.1	4.9
Anop spA	4.2	5.8	*Tetr spH*	5.1	4.9
Camp spD	4.2	5.8	*Lepi spA*	5.1	4.9
Camp spC	4.2	5.8	*Tap spA*	5.0	5.0
Ocym spD	4.1	5.9	*Sp. XII*	4.9	5.1
Tetr spV	4.0	6.0	*Camp spB*	4.9	5.1
Mon rufu	3.9	6.1	*Tetr wei*	4.9	5.1
Opt bert	3.7	6.3	*Pac spA*	4.9	5.1

9.3.2.4 B (continue)

AX1	Tribal	Commercial/Reserve	AX2	Commercial	Reserve-Good
Mera spC	3.6	6.4	*Mon fast*	4.8	5.2
Tetr set	3.5	6.5	*Camp spC*	4.8	5.2
Anoc spA	3.3	6.7	*Ocym spD*	4.7	5.3
Tetr spE	3.3	6.7	*Myrm spB*	4.7	5.3
Camp sp	3.0	7.0	*Tet sp2*	4.7	5.3
Phei spC	2.9	7.1	*Tetr spV*	4.6	5.4
Ocym spB	2.9	7.1	*Phei spB*	4.6	5.4
Mera spi	2.8	7.2	*Lepi spi*	4.6	5.4
Ocym spA	2.8	7.2	*Camp ful*	4.5	5.5
Lepi sp	2.5	7.5	*Card spA*	4.4	5.6
Mon notu	2.4	7.6	*Mon spE*	4.4	5.6
Anop spB	2.4	7.6	*Mon notu*	4.2	5.8
Tetr spI	2.0	8.0	*Plec man*	4.2	5.8
Tet sp3	2.0	8.0	*Camp spA*	4.2	5.8
Tetr po A	2.0	8.0	*Anop ste*	3.8	6.2
Tet V111	2.0	8.0	*Opt bert*	3.8	6.2
Tet spA	1.7	8.3	*Anoc spA*	3.1	6.9
Tet sp4	1.7	8.3	*Myrm spA*	2.8	7.2
Ocym spC	1.6	8.4	*Camp sp*	2.6	7.4
Anop ste	1.2	8.8	*Mes. n.ca*	2.5	7.5
Camp spA	1.1	8.9	*Tetr ser*	2.4	7.6
Ocym wei	0.8	9.2	*Dor helv*	1.0	9.0
Dor helv	0.7	9.3	*Ocym spE*	1.0	9.0
Ocym spE	0.7	9.3	*Tetr spI*	0.0	10.0
Mon spA	0.2	9.8	*Tet sp3*	0.0	10.0
Anop spC	0.0	10.0	*Tetr po A*	0.0	10.0

C. Index values of only the ant species responsive primarily to either the first or the second axis

AX1	Tribal	Commercial/Reserve	AX2	Commercial	Reserve-Good
Myrm spB	10.0	0.0	*Tet spA*	10.0	0.0
Tet sp2	10.0	0.0	*Camp may*	9.6	0.4
Pac spA	9.8	0.2	*Anop spC*	9.2	0.8
Sp. XII	9.7	0.3	*Tetr spE*	9.0	1.0
Tap spA	9.6	0.4	*Mera spC*	7.7	2.3
Tetr spH	9.6	0.4	*Phei spD*	7.3	2.7
Tetr spG	9.4	0.6	*Mera spi*	7.2	2.8
Crem spI	9.3	0.7	*Anop spA*	7.2	2.8
Lepi spC	9.3	0.7	*Tet V111*	6.8	3.2
Mera spD	9.3	0.7	*Tetr spC*	6.0	4.0
Mon spC	9.3	0.7	*Camp spD*	5.6	4.4
Pac sha	9.3	0.7	*Mon rufu*	5.3	4.7
Tech spA	9.3	0.7	*Mon fast*	4.8	5.2
Tet spXV	9.3	0.7	*Camp spC*	4.8	5.2
Lepi spi	8.7	1.3	*Ocym spD*	4.7	5.3

9.3.2.4 C (continue)

AX1	Tribal	Commercial/Reserve	AX2	Commercial	Reserve-Good
Card spA	8.3	1.7	*Tetr spV*	4.6	5.4
Mon spE	8.2	1.8	*Opt bert*	3.8	6.2
Crem spA	7.8	2.2	*Anoc spA*	3.1	6.9
Tetr sim	7.6	2.4	*Myrm spA*	2.8	7.2
Tetr wei	7.5	2.5	*Camp sp*	2.6	7.4
Tet. n.se	7.4	2.6	*Mes. n.ca*	2.5	7.5
Tetr bau	6.7	3.3	*Tetr ser*	2.4	7.6
Pac spC	6.6	3.4	*Dor helv*	1.0	9.0
Plag spA	6.4	3.6	*Ocym spE*	1.0	9.0
Camp spB	6.2	3.8	*Tetr spI*	0.0	10.0
Camp ful	6.0	4.0	*Tet sp3*	0.0	10.0
Plec man	5.9	4.1	*Tetr po A*	0.0	10.0
Phei spB	5.4	4.6			
Mon spB	5.2	4.8			
Tetr spD	5.1	4.9			
Mera spB	4.8	5.2			
Phei spA	4.4	5.6			
Lepi spA	4.3	5.7			
Tetr set	3.4	6.6			
Phei spC	3.4	6.6			
Ocym spB	2.8	7.2			
Ocym spA	2.7	7.3			
Lepi sp	2.6	7.4			
Mon notu	2.4	7.6			
Anop spB	2.3	7.7			
Tet sp4	2.3	7.7			
Ocym spC	1.5	8.5			
Anop ste	1.4	8.6			
Camp spA	1.0	9.0			
Ocym wei	1.0	9.0			
Mon spA	0.6	9.4			
	0.0	10.0			

D. Index values of all the key ant species (10% and higher of ranges explained by the species-environment variance) for both the first and the second axes

AX1	Tribal	Commercial/Reserve	AX2	Commercial	Reserve
Pac spA	10.0	0.0	*Tet spA*	10.0	0.0
Sp. XII	9.9	0.1	*Tetr spE*	8.6	1.4
Tap spA	9.8	0.2	*Mera spC*	6.9	3.1
Tetr spH	9.8	0.2	*Phei spD*	6.4	3.6
Lepi spi	8.9	1.1	*Mera spi*	6.4	3.6
Card spA	8.5	1.5	*Anop spA*	6.4	3.6
Crem spA	8.0	2.0	*Mon spA*	5.8	4.2
Tetr sim	7.8	2.2	*Tetr sim*	5.1	4.9
Tetr bau	6.9	3.1	*Ocym spB*	4.4	5.6
Camp spB	6.4	3.6	*Ocym spC*	4.4	5.6

9.3.2.4 D (continue)

AX1	Tribal	Commercial/Reserve	AX2	Commercial	Reserve
Camp ful	6.1	3.9	*Crem spA*	4.3	5.7
Plec man	6.1	3.9	*Mon spB*	4.2	5.8
Phei spD	5.8	4.2	*Phei spC*	4.2	5.8
Phei spB	5.5	4.5	*Tetr bau*	3.6	6.4
Mon spB	5.3	4.7	*Tetr spH*	3.5	6.5
Myrm spA	5.0	5.0	*Tap spA*	3.4	6.6
Tetr ser	4.2	5.8	*Sp. XII*	3.3	6.7
Anop spA	4.2	5.8	*Camp spB*	3.3	6.7
Anop spB	4.0	6.0	*Pac spA*	3.2	6.8
Mera spC	3.5	6.5	*Phei spB*	2.9	7.1
Tetr spE	3.2	6.8	*Lepi spi*	2.8	7.2
Phei spC	2.9	7.1	*Camp ful*	2.7	7.3
Ocym spB	2.8	7.2	*Card spA*	2.6	7.4
Mera spi	2.7	7.3	*Mon notu*	2.4	7.6
Mon notu	2.3	7.7	*Plec man*	2.3	7.7
Tet spA	1.6	8.4	*Anop ste*	1.9	8.1
Ocym spC	1.4	8.6	*Anop spB*	1.4	8.6
Anop ste	1.0	9.0	*Myrm spA*	0.5	9.5
Mon spA	0.0	10.0	*Tetr ser*	0.0	10.0

E. Index values of only the key ant species (10% and higher of ranges explained by the species-environment variance) responsive to either the first or the second axis

AX1	Tribal (Ant diversity and richness)	Commercial/Reserve	AX2	Commercial	Reserve
Mon spA	0.0	10.0	*Tetr ser*	0.0	10.0
Anop ste	1.0	9.0	*Myrm spA*	0.5	9.5
Ocym spC	1.4	8.6	*Anoc spA*	0.8	9.2
Mon notu	2.3	7.7	*Anop spB*	1.4	8.6
Ocym spB	2.8	7.2	*Anop spA*	6.4	3.6
Phei spC	2.9	7.1	*Mera spi*	6.4	3.6
Mon spB	5.3	4.7	*Phei spD*	6.4	3.6
Phei spB	5.5	4.5	*Mera spC*	6.9	3.1
Plec man	6.1	3.9	*Tetr spE*	8.6	1.4
Camp ful	6.1	3.9	*Tet spA*	10.0	0.0
Camp spB	6.4	3.6			
Tetr bau	6.9	3.1			
Tetr sim	7.8	2.2			
Crem spA	8.0	2.0			
Card spA	8.5	1.5			
Lepi spi	8.9	1.1			
Tetr spH	9.8	0.2			
Tap spA	9.8	0.2			
Sp. XII	9.9	0.1			
Pac spA	10.0	0.0			

F. Index values of all the key ant species (<u>20%</u> and higher of ranges explained by the species-environment variance) for both the first and the second axes

AX1	Tribal	Commercial/Reserve	AX2	Commercial	Reserve
Card spA	10.0	0.0	*Phei spD*	10.0	0.0
Crem spA	9.2	0.8	*Mera spi*	9.9	0.1
Tetr sim	8.9	1.1	*Tetr sim*	7.9	2.1
Tetr bau	7.7	2.3	*Ocym spB*	6.8	3.2
Camp ful	6.6	3.4	*Ocym spC*	6.8	3.2
Phei spD	6.2	3.8	*Crem spA*	6.7	3.3
Tetr ser	4.0	6.0	*Tetr bau*	5.5	4.5
Ocym spB	1.9	8.1	*Camp ful*	4.3	5.7
Mera spi	1.9	8.1	*Card spA*	4.1	5.9
Mon notu	1.3	8.7	*Mon notu*	3.7	6.3
Ocym spC	0.0	10.0	*Tetr ser*	0.0	10.0

G. Index values of only the key ant species (<u>20%</u> and higher of ranges explained by the species-environment variance) responsive to either the first or the second axis

AX1	Tribal	Commercial/Reserve	AX2	Commercial	Reserve
Card spA	10.0	0.0	*Phei spD*	10.0	0.0
Crem spA	9.2	0.8	*Mera spi*	9.9	0.1
Tetr sim	8.9	1.1	*Tetr ser*	0.0	10.0
Tetr bau	7.7	2.3			
Camp ful	6.6	3.4			
Ocym spB	1.9	8.1			
Mon notu	1.3	8.7			
Ocym spC	0.0	10.0			

9.3.2.5 Soil component

The “Key assessment matrix” with regard to the soil matrix, will address the following components:

- Total soil matrix: Sections 9.3.2.5 B.1 and 9.3.2.5 C.1 (See point 9.3.2)
- Topsoil open matrix: Sections 9.3.2.5 B.2 and C.2
- Subsoil open matrix: Sections 9.3.2.5 B.3 and C.3
- Topsoil woody matrix: Sections 9.3.2.5 B.4 and C.4
- Subsoil woody matrix: Sections 9.3.2.5 B.5 and C.5.

Although the different soil variables occur within all the land uses and rangeland condition groups, 0 = the lowest concentration/percentage and 10 = the highest concentration/percentage of a soil variable (appropriately transformed prior to ordination) associated with the particular environmental variable showing the strongest affinity for that particular axis.

A. Summary of the primary aspects

Refer to Chapter 6, Table 6.3 and Table 6.17 for additional information towards rangeland monitoring.

B. Index values of all the soil variables for both the first and the second axes

B. 1. A Key assessment matrix for the Total soil component (Chapter 6, Appendix 6.1)

AX1	**Open**	**Woody**	**AX2**	**Reserve (*Subsoil*)**	***Topsoil***
P Bray 1	10.0	0.0	Mg	10.0	*0.0*
Coarse sand	9.5	0.5	Silt	9.7	*0.3*
Med sand	5.7	4.3	K	7.6	*2.4*
Zn	5.6	4.4	Med sand	6.9	*3.1*
Na	5.3	4.7	pH	6.9	*3.1*
Fine sand	4.8	5.2	Ca	6.6	*3.4*
Clay	4.6	5.4	Conductivity	6.4	*3.6*
NO3- N	4.4	5.6	Fine sand	6.4	*3.6*
Organic material	4.3	5.7	Na	6.0	*4.0*
pH	4.2	5.8	Zn	5.9	*4.1*
C	4.1	5.9	NO3- N	5.4	*4.6*
K	2.6	7.4	Clay	5.0	*5.0*
Mg	2.5	7.5	C	4.2	*5.8*
Conductivity	2.4	7.6	Organic material	4.0	*6.0*
Silt	2.1	7.9	Coarse sand	3.4	*6.6*
Ca	0.0	10.0	P Bray 1	0.0	*10.0*

B. 2. A Key assessment matrix for the topsoil open component matrix, (Chapter 6, Appendix 6.2)

AX1	**Tribal**	**Reserve**	**AX2**	**Commercial**	***Tribal***
Clay	10.0	0.0	P Bray 1	10.0	*0.0*
Na	8.4	1.6	Med sand	8.7	*1.3*
Fine sand	7.0	3.0	Coarse sand	8.6	*1.4*
Coarse sand	7.0	3.0	NO3- N	8.3	*1.7*
Organic material	6.1	3.9	Zn	6.7	*3.3*
Zn	5.5	4.5	Na	6.0	*4.0*
C	5.1	4.9	Conductivity	4.7	*5.3*
P Bray 1	4.5	5.5	pH	4.4	*5.6*
Conductivity	3.3	6.7	K	4.3	*5.7*
Silt	2.4	7.6	C	4.2	*5.8*
pH	1.9	8.1	Organic material	4.1	*5.9*
Med sand	1.9	8.1	Mg	3.6	*6.4*
NO3- N	1.7	8.3	Clay	3.5	*6.5*
K	1.6	8.4	Ca	3.3	*6.7*
Mg	0.1	9.9	Silt	3.0	*7.0*
Ca	0.0	10.0	Fine sand	0.0	*10.0*

B. 3. A Key assessment matrix for the subsoil open component (Chapter 6, Appendix 6.3)

AX1	**Tribal**	**Reserve**	**AX2**	**Commercial**	***Reserve (Tribal)***
Clay	10.0	0.0	Med sand	10.0	*0.0*
Na	9.9	0.1	Coarse sand	10.0	*0.0*
Fine sand	9.7	0.3	NO3- N	9.6	*0.4*
Coarse sand	6.8	3.2	P Br ay 1	9.5	*0.5*
P Bray 1	6.0	4.0	Na	6.7	*3.3*
Zn	5.5	4.5	Organic material	6.5	*3.5*
Organic material	4.7	5.3	C	6.5	*3.5*
C	4.5	5.5	Conductivity	6.4	*3.6*
Silt	3.4	6.6	Zn	5.3	*4.7*
Conductivity	3.1	6.9	Clay	4.6	*5.4*
NO3- N	2.5	7.5	pH	3.6	*6.4*
pH	1.7	8.3	K	3.5	*6.5*
K	1.6	8.4	Silt	3.2	*6.8*
Mg	1.4	8.6	Ca	2.7	*7.3*
Ca	1.1	8.9	Mg	2.3	*7.7*
Med sand	0.0	10.0	Fine sand	0.0	*10.0*

B.4. A Key assessment matrix for the topsoil woody component matrix (Chapter 6, Appendix 6.4)

AX1	**Tribal**	**Commercial *(Reserve)***	**AX2**	**Reserve**	**Commercial (*Tribal*)**
Clay	10.0	0.0	K	10.0	0.0
Fine sand	9.9	0.1	Silt	9.9	0.1
Organic material	9.2	0.8	Mg	9.2	0.8
C	9.2	0.8	Ca	9.2	0.8
Na	8.3	1.7	pH	8.3	1.7
Ca	6.0	*4.0*	Fine sand	6.0	*4.0*
Silt	5.7	*4.3*	Conductivity	5.7	4.3
pH	5.3	*4.7*	Zn	5.3	4.7
K	5.2	*4.8*	C	5.2	*4.8*
Coarse sand	4.5	5.5	Organic material	4.5	*5.5*
Mg	4.4	*5.6*	NO3- N	4.4	5.6
Zn	4.2	*5.8*	Med sand	4.2	5.8
Conductivity	3.2	6.8	P Bray 1	3.2	6.8
NO3- N	1.3	8.7	Clay	1.3	*8.7*
P Bray 1	0.8	9.2	Na	0.8	*9.2*
Med sand	0.0	10.0	Coarse sand	0.0	10.0

B.5. A Key assessment matrix for the subsoil woody component (Chapter 6, Appendix 6.5)

AX1	Tribal	Reserve ***(Commercial)***	AX2	Commercial	Reserve/***Tribal***
Clay	10.0	0.0	Med sand	10.0	0.0
Na	9.4	0.6	Coarse sand	9.8	0.2
Fine sand	7.6	2.4	NO3- N	9.0	1.0
Coarse sand	6.2	*3.8*	P Bray 1	8.9	1.1
P Bray 1	5.7	*4.3*	Na	6.7	*3.3*
Zn	4.7	5.3	Conductivity	6.1	3.9
Silt	3.8	6.2	Zn	4.3	5.7
Organic material	3.8	6.2	Clay	3.7	*6.3*
C	3.6	6.4	Organic material	3.7	6.3
Ca	2.9	7.1	pH	3.4	6.6
Mg	1.7	8.3	C	3.3	6.7
K	1.6	8.4	K	3.2	6.8
pH	1.4	8.6	Ca	3.1	6.9
Med sand	0.8	*9.2*	Mg	2.1	7.9
NO3- N	0.4	*9.6*	Silt	1.9	8.1
Conductivity	0.0	10.0	Fine sand	0.0	*10.0*

C. Index values of only the soil variables responsive primarily to either the first or the second axis

C.1 A Key assessment matrix Total woody component: responsive variables (Chapter 6, Appendix 6.1)

AX1	Open	Woody	AX2	Reserve (Subsoil)	***Topsoil***
*P Bray 1	10.0	0.0	Mg	10.0	*0.0*
Coarse sand	9.5	0.5	Silt	9.7	*0.3*
Med sand	5.7	4.3	Conductivity	6.4	*3.6*
Zn	5.6	4.4	C	4.2	*5.8*
Na	5.3	4.7	Organic material	4.0	*6.0*
Fine sand	4.8	5.2	*P Bray 1	0.0	*10.0*
Clay	4.6	5.4			
NO3- N	4.4	5.6			
pH	4.2	5.8			
K	2.6	7.4			
Ca	0.0	10.0			

*P responsive to both axes

C. 2. A Key assessment matrix for the topsoil open soil variables responsive to the first two axes (Chapter 6, Appendix 6.2)

AX1	Tribal	Reserve	AX2	Commercial	***Tribal***
Clay	10.0	0.0	P Bray 1	10.0	*0.0*
Na	8.4	1.6	Med sand	8.7	*1.3*
Conductivity	3.3	6.7	Coarse sand	8.6	*1.4*
Silt	2.4	7.6	Zn	6.7	*3.3*
pH	1.9	8.1	C	4.2	*5.8*
NO3- N	1.7	8.3	Organic material	4.1	*5.9*
K	1.6	8.4	Fine sand	0.0	*10.0*
Mg	0.1	9.9			
Ca	0.0	10.0			

C.3. A Key assessment matrix for the soil variables responsive to the first two axes (Chapter 6, Appendix 6.3)

AX1	**Tribal**	**Reserve**	**AX2**	**Commercial**	***Reserve (Tribal)***
Clay	10.0	0.0	Coarse sand	10.0	0.0
Na	9.9	0.1	NO3- N	9.6	0.4
Organic material	4.7	5.3	P Bray 1	9.6	0.4
C	4.5	5.5	Zn	5.3	4.7
Conductivity	3.1	6.9	Silt	3.2	6.8
pH	1.7	8.3	Fine sand	0.0	10.0
K	1.6	8.4			
Mg	1.4	8.6			
Ca	1.1	8.9			
Med sand	0.0	10.0			

C. 4. A Key assessment matrix for the topsoil woody variables responsive to the first two axes (Chapter 6, Appendix 6.4)

AX1	**Tribal**	**Commercial *(Reserve)***	**AX2**	**Reserve**	**Commercial (*Tribal*)**
Clay	10.0	0.0	K	10.0	0.0
Fine sand	9.9	0.1	Silt	9.8	0.2
Organic material	9.2	0.8	Mg	9.2	0.8
C	9.2	0.8	Ca	8.0	2.0
Zn	4.2	*5.8*	pH	8.0	2.0
Conductivity	3.2	*6.8*	Na	0.2	*9.8*
NO3- N	1.3	*8.7*	Coarse sand	0.0	10.0
P Bray 1	0.8	9.2			
Med sand	0.0	10.0			

C.5. A Key assessment matrix for the subsoil woody variables responsive to the first two axes (Chapter 6, Appendix 6.5)

AX1	**Tribal**	**Reserve *(Commercial)***	**AX2**	**Commercial**	**Reserve*/Tribal***
Clay	10.0	0.0	Coarse sand	10.0	0.0
Na	9.4	0.6	P Bray 1	9.1	0.9
Ca	2.9	7.1	Zn	4.4	5.6
Mg	1.7	8.3	Organic material	3.8	6.2
K	1.6	8.4	C	3.4	6.6
pH	1.4	8.6	Silt	1.9	8.1
Med sand	0.8	*9.2*	Fine sand	0.0	*10.0*
NO3- N	0.4	9.6			
Conductivity	0.0	10.0			

9.3.2.6 Multivariate herbaceous, woody and soil analysis

Within this section, "Key assessment matrices" for two primary components are given (See Chapter 7, Sections 7.3 and 7.4):

- Herbaceous component (as interrelated with key woody species and soil variables)
- Woody component (as interrelated with key herbaceous species and soil variables)

These integrated matrices are particularly useful to reflect on the holistic, interdependent relationships between the different biotic-biotic and biotic-abiotic components. These matrices integrate and reflect on primary as well as secondary interactive and interdependent environmental dynamics (See Chapter 7, Sections 7.3.3, 7.4.3 and 7.5).

A. Summary of the primary aspects

Refer to Chapter 7, Fig. 7.1 – 7.8, Tables 7.6 and 7.14 and Appendices 7.2 and 7.4.

B. Index values of all the species/variables for both the first and the second axes

B.1. A Key assessment matrix for the interrelated herbaceous species (Chapter 7, Appendix 7.1)

AX1	**Tribal (Herbaceous richness)**	***Commercial/Reserve***	**AX2**	**Poor**
PER PAT	10.0	*0.0*	*CYN DAC*	0.0
CHLOR VIR	9.1	*0.9*	*BRA MAR*	0.0
ELEU COR	9.1	*0.9*	BP	2.9
TRI AND	9.1	*0.9*	*TRA RAC*	2.9
ERA PAL	8.5	*1.5*	*SCHM KAL*	3.3
ERA RIG	8.2	*1.8*	*STIP CIL*	3.9
TRA BER	7.9	*2.1*	*ERA LEH*	4.5
POG SQU	7.8	*2.2*	*URU BRA*	4.8
ERA TRI	7.7	*2.3*	*TRA BER*	4.9
MEL REP	7.5	*2.5*	*ARIST CON*	5.0
ARIST CON	7.4	*2.6*	*DIG ERI*	5.1
DIG ERI	7.2	*2.8*	*ARIST MED*	5.2
CYM PO	7.2	*2.8*	*CYM PO*	5.2
ERA BIF	7.0	*3.0*	*TRA KOE*	5.2
ARI STI	6.9	*3.1*	*ERA BIF*	5.3
TRA KOE	6.3	*3.7*	*STIP UNI*	5.4
PAN MAX	5.1	*4.9*	*ERA TRI*	5.6
ARIST MED	4.4	*5.6*	*ARI STI*	5.7
ERA LEH	4.0	*6.0*	*PAN MAX*	5.7
BRA MAR	3.7	*6.3*	*POG SQU*	6.1
CYN DAC	3.4	*6.6*	*PER PAT*	6.2
BP	2.2	*7.8*	*MEL REP*	6.4
STIP UNI	2.1	*7.9*	*ERA RIG*	6.6
SCHM PAP	1.9	*8.1*	*ERA PAL*	6.7
URU BRA	1.5	*8.5*	*TRI AND*	6.8
SCHM KAL	1.4	*8.6*	*CHLOR VIR*	7.0

9.3.2.6 B.1. (continue)

AX1	**Tribal (Herbaceous richness)**	***Commercial/Reserve***	**AX2**	**Poor**
STIP CIL	1.3	*8.7*	*ELEU COR*	7.0
TRA RAC	1.3	*8.7*	*SCHM PAP*	7.0
FORBS	1.1	*8.9*	FORBS	7.0
CHRY SER	1.1	*8.9*	*CEN TR*	7.7
CEN TR	0.8	*9.2*	*CHRY SER*	8.1
ANT PUB	0.2	*9.8*	*ANT PUB*	9.2
BRAC NIG	0.0	*10.0*	*BRAC NIG*	10.0

B.2. A Key assessment matrix for the woody species (Chapter 7, Appendix 7.3)

AX1	**Tribal (Herbaceous richness)**	***Reserve (Commercial)***	**AX2**	**Commercial-Good**
Ter ser	10.0	*0.0*	*Ac hae*	10.0
Gym bux	10.0	*0.0*	*Prot sul*	2.6
Tar cam	9.9	*0.1*	*Ac eri*	2.4
Dic cin	9.0	*1.0*	*Gre fla*	2.3
Dio lyc	8.3	*1.7*	*Dio lyc*	2.1
Ac tor	7.1	*2.9*	*Ac rob*	2.0
Ac kar	6.9	*3.1*	*Bos alb*	2.0
Mun ser	6.2	*3.8*	*Rhu cil*	2.0
Rhu cil	5.3	*4.7*	*Gre flsc*	1.9
Gre flsc	5.1	*4.9*	*Ac heb*	1.8
Ac rob	4.9	*5.1*	*Dic cin*	1.7
Ac eri	4.8	*5.2*	*Ehr rig*	1.7
Prot sul	4.4	*5.6*	*Ter ser*	1.6
Ac heb	3.9	*6.1*	*Mun ser*	1.6
Ziz muc	3.9	*6.1*	*Ac tor*	1.4
Ac hae	3.8	*6.2*	*Ac kar*	1.4
Ehr rig	3.7	*6.3*	*Lyc hir*	1.2
Gre fla	3.2	*6.8*	*Ziz muc*	1.2
Rhi bre	2.5	*7.5*	*Ac mel*	1.1
Ac mel	2.2	*7.8*	*Tar cam*	1.0
Bos alb	1.6	*8.4*	*Rhi bre*	0.9
Lyc hir	1.5	*8.5*	*Ac lue*	0.7
Ac lue	0.5	*9.5*	*Gym bux*	0.7
Cadaba	0.0	*10.0*	*Cadaba*	0.0

C. Index values of only the species/variables responsive primarily to either the first or the second axis

C.1. A Key assessment matrix for the interrelated herbaceous species responsive to the first two axes respectively (Chapter 7, Appendix 7.1)

AX1	**Tribal**	***Commercial/Reserve***	**AX2**	**Poor**
PER PAT	10.0	*0.0*	*CYN DAC*	0.0
CHLOR VIR	9.0	*1.0*	*BRA MAR*	0.1
ELEU COR	9.0	*1.0*	BP	2.9
TRI AND	8.9	*1.1*	*TRA RAC*	2.9
ERA PAL	8.3	*1.7*	*SCHM KAL*	3.3
ERA RIG	8.0	*2.0*	*ERA LEH*	4.5
TRA BER	7.7	*2.3*	*SCHM PAP*	7.0
POG SQU	7.5	*2.5*	*CEN TR*	7.7
ERA TRI	7.4	*2.6*	*CHRY SER*	8.1
MEL REP	7.2	*2.8*	*ANT PUB*	9.2
ARIST CON	7.1	*2.9*	*BRAC NIG*	10.0
DIG ERI	6.9	*3.1*		**Good**
CYM PO	6.8	*3.2*		
ERA BIF	6.6	*3.4*		
ARI STI	6.5	*3.5*		
TRA KOE	5.9	*4.1*		
PAN MAX	4.5	*5.5*		
ARIST MED	3.6	*6.4*		
STIP UNI	1.1	*8.9*		
URU BRA	0.4	*9.6*		
STIP CIL	0.2	*9.8*		
FORBS	0.0	*10.0*		

C.2. A Key assessment matrix for the woody species responsive to the first two axes (Chapter 7, Appendix 7.3)

AX1	**Tribal (Herbaceous richness)**	***Reserve (Commercial)***	**AX2**	**Commercial-Good**
Ter ser	10.0	*0.0*	*Ac hae*	10.0
Gym bux	9.9	*0.1*	*Prot sul*	2.6
Tar cam	9.9	*0.1*	*Ac eri*	2.4
Dic cin	9.0	*1.0*	*Gre fla*	2.3
Dio lyc	8.2	*1.8*	*Ac heb*	1.8
Ac tor	7.0	*3.0*	*Ehr rig*	1.7
Ac kar	6.7	*3.3*	*Ziz muc*	1.2
Mun ser	6.0	*4.0*	*Rhi bre*	0.9
Rhu cil	5.1	*4.9*	*Cadaba*	0.0
Gre flsc	4.8	*5.2*		
Ac rob	4.6	*5.4*		
Ac mel	1.8	*8.2*		
Bos alb	1.1	*8.9*		
Lyc hir	1.0	*9.0*		
Ac lue	0.0	*10.0*		

D. Index values of all the key species/variables (10% and higher of ranges explained by the species-environment variance) for both the first and the second axes

D.1. A Key assessment matrix for the key herbaceous species having 10% or higher of their ranges explained by the species-environment relation (Chapter 7, Appendix 7.1)

AX1	**Tribal (Herbaceous richness)**	***Commercial/Reserve***	**AX2**	**Poor**
TRI AND	10.0	*0.0*	BP	0.0
ERA PAL	9.4	*0.6*	*SCHM KAL*	0.6
POG SQU	8.6	*1.4*	*ERA LEH*	2.2
ERA TRI	8.5	*1.5*	*ARIST CON*	3.0
MEL REP	8.3	*1.7*	*DIG ERI*	3.1
ARIST CON	8.2	*1.8*	*STIP UNI*	3.6
DIG ERI	8.0	*2.0*	*ERA TRI*	3.8
ARI STI	7.6	*2.4*	*ARI STI*	3.9
ERA LEH	4.4	*5.6*	*POG SQU*	4.5
BP	2.4	*7.6*	*MEL REP*	5.0
STIP UNI	2.3	*7.7*	*ERA PAL*	5.3
SCHM PAP	2.1	*7.9*	*TRI AND*	5.5
SCHM KAL	1.6	*8.4*	*SCHM PAP*	5.8
ANT PUB	0.2	*9.8*	*ANT PUB*	8.8
BRAC NIG	0.0	*10.0*	*BRAC NIG*	10.0

Good

D.2. A Key assessment matrix for the key woody species having 10% or higher of their ranges explained by the species-environment relation (Chapter 7, Appendix 7.3)

AX1	**Tribal (Herbaceous richness)**	***Reserve (Commercial)***	**AX2**	**Commercial-Good**
Ter ser	10.0	0.0	*Ac hae*	10.0
Gym bux	9.9	0.1	*Gre fla*	1.7
Tar cam	9.9	0.1	*Bos alb*	1.4
Dic cin	9.0	1.0	*Dic cin*	1.1
Ac hae	3.5	6.5	*Ter ser*	1.0
Gre fla	2.8	7.2	*Ac mel*	0.5
Rhi bre	2.1	7.9	*Tar cam*	0.4
Ac mel	1.8	8.2	*Rhi bre*	0.2
Bos alb	1.1	8.9	*Ac lue*	0.0
Ac lue	0.0	10.0	*Gym bux*	0.0

E. Index values of only the key species/variables (10% and higher of ranges explained by the species-environment variance) responsive to either the first or the second axis

E.1. A Key assessment matrix for the key herbaceous species responsive to the first two axes (Chapter 7, Appendix 7.1)

AX1	Tribal (Herbaceous richness)	***Commercial/Reserve***	AX2	Poor
TRI AND	10.0	*0.0*	BP	0.0
ERA PAL	9.2	*0.8*	*SCHM KAL*	0.6
POG SQU	8.2	*1.8*	*ERA LEH*	2.2
ERA TRI	8.0	*2.0*	*SCHM PAP*	5.8
MEL REP	7.8	*2.2*	*ANT PUB*	8.8
ARIST CON	7.6	*2.4*	*BRAC NIG*	10.0
DIG ERI	7.4	*2.6*		**Good**
ARI STI	6.9	*3.1*		
STIP UNI	0.0	*10.0*		

E.2. A Key assessment matrix for the key woody species responsive to the first two axes respectively (Chapter 7, Appendix 7.3)

AX1	Tribal (Herbaceous richness)	***Reserve (Commercial)***	AX2	Commercial-Good
Ter ser	10.0	*0.0*	*Ac hae*	10.0
Gym bux	9.9	*0.1*	*Gre fla*	1.6
Tar cam	9.9	*0.1*	*Rhi bre*	0.0
Dic cin	9.0	*1.0*		
Ac mel	1.8	*8.2*		
Bos alb	1.1	*8.9*		
Ac lue	0.0	*10.0*		

- This complete “Key assessment matrix” thus represents vegetation, woody, soil and ant patterns associated with the Commercial “conservation farmer”, the Tribal land use and Reserve (conservation) areas, but a complete degradation model should be described for the Molopo semi-arid rangelands (refer to Chapter 10, Recommendations).
- Herbaceous grazing and ecological indices as well as herbaceous life-forms were not included in the “Key assessment matrix”, since it proved to be too robust (too few variables) to be indexed.

9.4 Final comments

It is envisaged that this study provided baseline information for the Molopo semi-arid rangelands that have been poorly described with regard to land use, biodiversity and degradation patterns (SOER 2002). This baseline data makes a contribution towards dealing with the root causes of biodiversity and ecosystem function loss, without merely dealing with the symptoms. This study also made contributions towards focus areas considered as very important by the GEF-DMP programme, Agenda 21, the “Strategic Plan for South African Agriculture”, LandCare and SOER (2002) (refer to Chapter 1, Introduction). It is also envisaged that this study can contribute the “Ambient Environmental Monitoring

Programme" of the North West Province (SOER 2002), with the mandate lying within the North West Department of Agriculture, Conservation and Environment. A "Key assessment matrix" for monitoring is provided and can be used at different levels by the land user/-owner, extension officer and scientist, but should be packaged in different forms for different client groups and levels (refer to Fig. 9.7 and to Chapter 10).

However, is should be emphasised that the purpose of this study was mainly to provide biophysical indicators of degradation and biodiversity loss due to different land use practices, but is envisaged to be incorporated into adaptive management packages, thus recognising the social and economic pillars of sustainable resource and development (SOER 2002). A proposed "Collaborative Terrestrial Ecosystems Research and Development Programme" for the North West Province between the North West Department of Agriculture, Conservation and Environment, North West Parks Board and Tourism and the Agricultural Research Council (ARC) (compiled by Newby 2007), initially focusing on the Molopo as pilot study area, is presented in Figure 9.7. This proposed programme will elaborate on the baseline findings of this study, which mainly falls within two key objectives, indicated by an asterisk (*). Future focuses will be to develop best practice technologies, guidelines, demonstrative and adaptive management packages (also see Chapter 10 for pamphlets already compiled, in Appendices 10.1 and 10.2.

Thus, this study is the first comprehensive ecological study that has been conducted within the Molopo rangelands, with no long-term biophysical data, or how it is interrelated with the socio-economic pillar, existing for the Molopo study area. No data or research is available for describing how sustainable livestock/game production is perceived by different land users, and how it is interrelated with rangeland "health", productivity and the socio-economic environment. Hence, this study serves as departure point towards describing the processes and models that govern systems within the Molopo semi-arid rangelands with regard to rangeland degradation/condition and diversity patterns, as reflected by the multivariate responses of the vegetation, soil and ant parameters. This holds important implications for monitoring and management practices, and the development of best bet technologies, including the biophysical as well as socio-economic pillars of sustainable development.

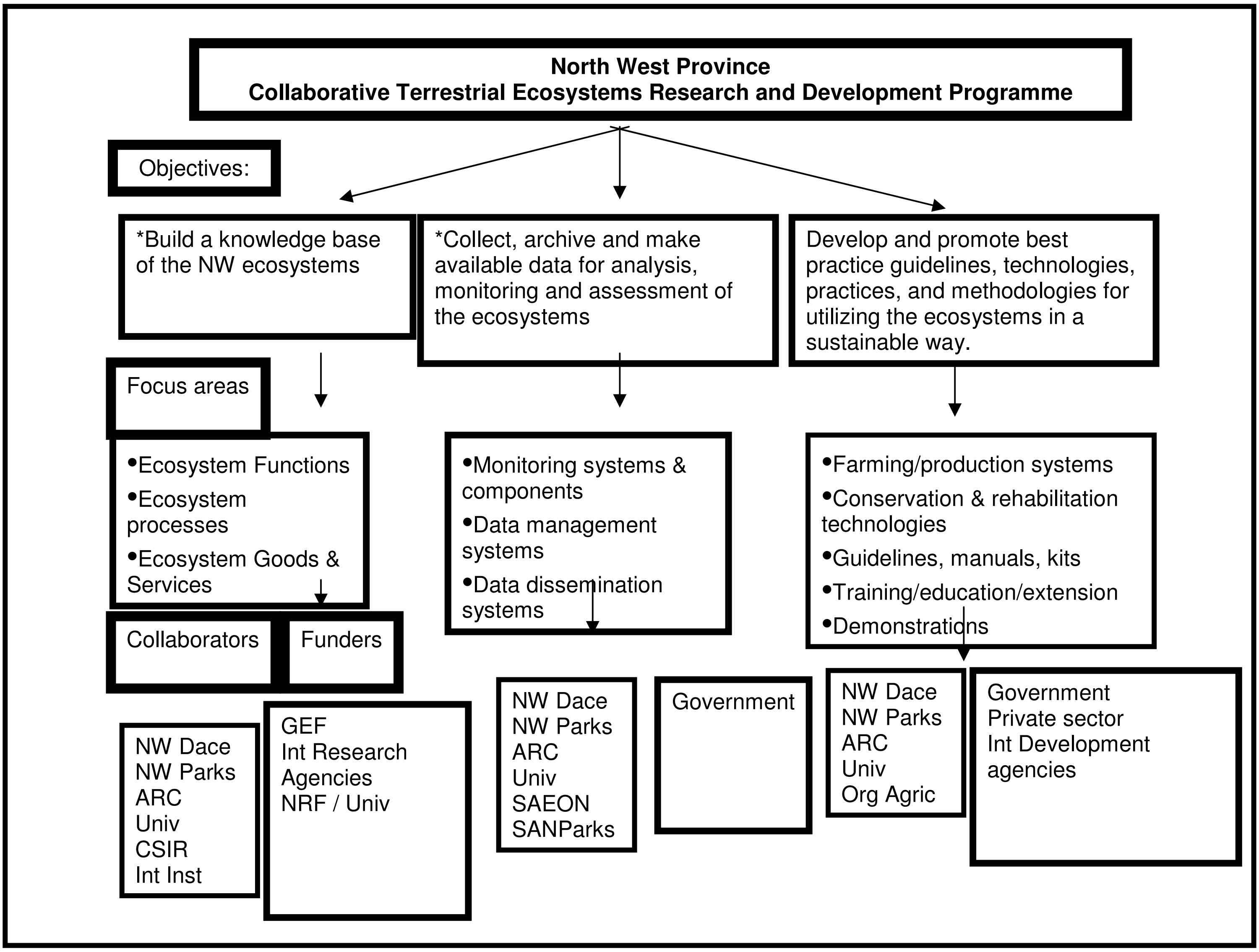


Fig. 9.7. The proposed "Collaborative Terrestrial Ecosystems Research and Development Programme" for the North West Province, focus on the Molopo region as pilot study area (compiled by Newby 2007).

Within agricultural systems, biodiversity provides different ecosystem functions. Thus, if the biological processes are impaired, the economic and environmental costs can be significant (Altieri 1999). Biodiversity in arid regions is often rated as poor and less valuable than biodiversity in other biogeographic regions (Ayyad 2003). However, since arid regions are often characterised by relatively few species, it is crucial that the biodiversity in such arid environments should be given a higher priority, with each species being lost resulting in a higher percentage of loss for the region's biodiversity than in more species-rich regions (McNeely 2003).

In conclusion, according to McNeely (2003), the major challenge in implementing the Convention on Biological Diversity (CBD) in arid regions lies in the social and political areas, rather than merely in the biology of the species concerned. Child (2003) suggests that the conservation of biological diversity depends as much on socio-economic as on biological processes, and that there should be maximum political support for the effective socio-politically, economically and ecologically rationalised implementation by an accountable authority through a conducive institutional framework. However, sustainable biodiversity and land degradation management remains the primary responsibility of the land user/owner.

CHAPTER 10

RECOMMENDATIONS

Recommendations pertaining to the different parameters/components were given within each chapter, and are summarised below. In addition, this study identified **additional** aspects, that **were not** stated as part of the objectives for this specific study, that need to be addressed in an integrated fashion towards the sustainable utilisation, management and monitoring of the semi-arid rangelands of the Molopo:

- This study acknowledges that only the "extreme condition spectra" of a rangeland condition/degradation gradient ("Good" vs. "Poor" rangeland condition sites) across the total study area and within each land use has been described, and that a complete gradient for the entire study area needs to be described. Thus, additional Commercial farms, and not just "conservation farmers" only, as well as other Tribal and Conservation areas need to be surveyed in order to compile a complete degradation gradient for the Molopo semi-arid rangelands. Degradation modeling can be done by employing "Integrated System for Plant Dynamics" (ISPD).
- The applicability of benchmark exclosures, as motivated in Chapter 3, will prove to be useful in the future as reference points of the ecosystem's potential and to monitor changes across survey seasons (temporal scale), since this study's survey year was only the first survey season after erecting it (for the Reserve and Commercial land uses, while the benchmarks within the Tribal areas were erected in 1999). It can also serve as comparative measure to reflect on spatial variability (spatial scale) to potentially reflect on heterogeneity patterns at patch, paddock and landscape scale.
- Additional information (Chapter 3, Section 3.6), was evaluated and used to described tendencies within the land uses (e.g. diversity of animals resulting in heterogeneous patch/paddock or landscape dynamics; degradation associated with key resources; herbaceous production tendencies; non-equilibrium vs. equilibrium models etc.). However, more reliable rainfall figures within especially the Tribal areas need to be obtained in order to fully quantify the effect of seasonal rainfall variability on especially the herbaceous production and composition (see discussions below), as well as on invertebrate assemblage structures. This can only be achieved once land users take ownership and thus responsibility for the resources by acknowledging that rangeland monitoring and management is an important livelihood strategy.
- Herbaceous quality analyses to examine crude protein and fibre content of the two to three most dominant grasses within each land use were conducted as part of the larger NW DACE project, and are repeated every year after the rainfall season (April/May). These results should be incorporated together with the herbaceous production surveys in calculating potential vs. absolute grazing capacity norms (for survey sites within and outside the benchmarks) with regard to different rainfall distributional patterns.
- Herbaceous production tendencies were congruent to that of the herbaceous compositional patterns (nearest plant-point-survey method), and were not discussed in depth within this study

(although employed in the multivariate analyses and for explanatory purposes in the "Key assessment matrix"), but form part of the larger NW DACE – DMP study. In order to distinguish between the impact of climatic variability on the herbaceous production vs. the impacts of different land uses on the dry material yield (utilised dry material yield = potential production within benchmark – available production outside benchmark), reliable accounts of the seasonal rainfall distribution patterns (which can spatially be very variable) at each benchmark need to be interrelated with the herbaceous production yields. Gaining reliable rainfall, livestock and grazing information from the Tribal areas has been problematic, and further consultative processes need to be followed in order to resolve this issue (see recommendations further on in this chapter). Thus, converting dry material yield simply to ha/LSU (especially in sites outside benchmarks) is potentially problematic, especially for comparative purposes. Differentiation between potential, available and utlised dry material needs to be made. To fully quantify, understand and distinguish between the effects of climatic vs. land use induced impacts, information regarding the number of grazing days of livestock within a paddock, the period/season of utilisation and the number of LSU numbers that utilised the herbaceous component within a paddock, need to be reliable. High rainfall events may result in increased dry material yields, provided that there is an adequate herbaceous seed bank, and depending on the composition of the seed bank (e.g. small-tufted annual and weak-perennial vs. larger tufted perennial life-forms). Thus, seed bank studies may prove to be fundamental towards "predicting" herbaceous composition and production tendencies.

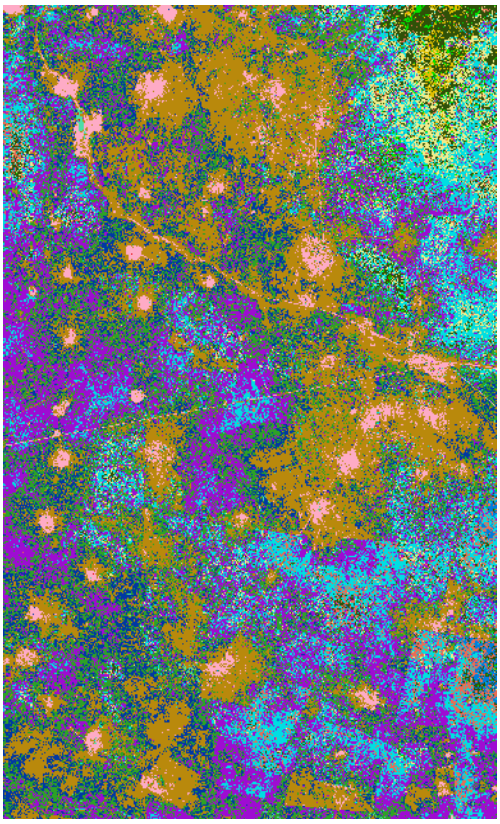
- Soil moisture studies may prove to be informative regarding the woody-herbaceous relationships.
- Herbaceous seed bank studies with regard to the seed bank under the dominant tree canopy (noting the type of woody species) within each survey site (sub-replicate) as well as within the open herbaceous areas, are currently being conducted within the greenhouse as part of the larger NW DACE project. This is done as to establish the effect of the woody component of herbaceous seedling recruitment (Coetzee, *in prep. I*) within different rangeland condition groups ("Good" vs. "Poor") within different rangeland condition groups. This is not presented within this study, but is considered to be important and informative with regard to monitoring these semi-arid rangelands.
- In addition to the point stated above, the purpose of the seed bank studies conducted as part of the larger NW DACE - DMP project, is to establish how the different land uses impacted on the herbaceous seed bank, by classifying the herbaceous seedlings according to ecological-, grazing- and life-form indices, as was described for the herbaceous species composition in Chapter 3. In addition, comparisons between seedling germination with regard to the above mentioned indices between the woody and open herbaceous component within each land use and rangeland condition group ("Good" vs. "Poor") were made.
- The evaluation of ants as bio-indicators in these semi-arid rangelands opposed to parallel studies of other taxa such as beetles with regard to the different land uses should be conducted. Seasonal surveys for the ants as well as other taxa can prove to be potentially useful in order to reflect on climatic/seasonal preferences. Another challenge that should be addressed and

described is the association between ant community patterns and the herbaceous seed bank (Coetzee, *in prep. I*). Once invertebrate bio-indicators become more common in land-management monitoring, one can consider what might be the “best” indicator taxon (Andersen *et al.* 2002).

- ❖ With regard to rangeland monitoring, Friedel (1988) stated that the nearest plant-point method (herbaceous composition) is not appropriate for rangeland condition assessment in arid savannas where short-lived herbaceous species are dominant, and consequently proposed the use of the dry-weight-rank method for determining pasture composition and amount in arid savannas. This is in contrast to findings by this study, where perennial and weak perennial species were most dominant in the Molopo semi-arid rangelands. For this study, herbaceous composition as deduced from the dry-weight-rank production surveys, as well as rangeland condition scores calculated from the production surveys, and adjusted to take into consideration the bare patches, was highly correlated with the species composition and rangeland condition scores calculated from the nearest plant-point survey method (Coetzee, *in prep. II*). Future surveys across different rainfall seasons, and not only for a “normal” rainfall season as experienced during this study’s survey year, should be conducted to verify how well correlated these two techniques are with regard to species composition and calculating rangeland condition scores. This may prove to be useful in proposing best rangeland monitoring techniques that can provide a multitude of information during one survey, thus being less time-consuming and more cost-effective (e.g. production surveys providing information towards absolute and potential dry material yield, rangeland condition and herbaceous species composition). The correlation between the dry-weight-rank and nearest plant-point technique can possibly also be ascribed to the relatively low species richness and variation within a land use group (thus taking also into account the relative rangeland condition status of sites within a land use).
- ❖ Rangeland monitoring is often typically descriptive and restricted to properties describing rangeland composition and structure, without addressing the functional attributes of ecosystems directly (Holm *et al.* 2002; Tongway & Hindley 2004). Landscape function analysis (LFA) can be used to examine rangeland functional state over time within a management context, to establish whether a critical threshold has been approached or exceeded (Tongway & Hindley 2004). LFAs can be used to identify critical missing processes, by determining LFA indices. It is suggested that the use of LFA studies as complementary monitoring measure in addition to the “conventional” monitoring techniques should be evaluated for the semi-arid rangelands of the Molopo. This should be done in order to refine the possible management “tools” that can be used in evaluating ecosystem “health”, and also to reflect more in depth on the state-and-transition model, and hence the dichotomous equilibrium and non-equilibrium events.
- ❖ Computer models are often considered as the intellectual property of the developers, and not local people, resulting in multi-agent systems remaining out of reach for local rural development institutions (Verlinden & Dayot 2005). GIS is considered to remain a primary platform to integrate indigenous environmental knowledge (IEK) with conventional methods (Verlinden & Dayot 2005). The widespread applicability of GIS systems serves as a useful platform towards integrating

multivariate information pertaining to the ecological and economical use of any resource. It is a relatively easily assessable system for the integration of various fields of interests (different disciplines) at different spatial and temporal scales. Thus, GIS should enjoy higher priority and development with regard to monitoring pressures, risks and opportunities (ecological and socio-economical) associated with the semi-arid rangelands of the Molopo.

- Satellite remote sensing is an important tool in understanding and monitoring various components of rangeland function and health, such as rangeland condition and production, rangeland inventory, biodiversity, detecting alien species, detecting changes, human and animal impact and establishing potential vegetation (Palmer & Fortescue 2004). Coarse resolution satellite data (e.g. the MODIS sensors) provide daily observations and it is suggested that such an approach has a central role in monitoring vegetation dynamics, soil erosion and land degradation in South Africa (Symeneokis & Drake 2004; Wessels *et al.* 2004). However, a major limiting factor for wider utilisation is the cost of imagery (Palmer & Fortescue 2004). Linking the surveyed (ground-) data may provide images that can render fast visual assessments of the rangeland "health". The "Key assessment matrix" provided in Chapter 9 can serve as departure point for such integrated groundtruthed-remote imagery exercises (see Appendix 10.1), and is also useful for "Drought risk management" and piosphere and/or other key resources ("sacrifical") monitoring purposes. Preliminary examples of such groundtruthed-remote sensing images are presented in Fig. 10.1a to Fig. 10.1c. Groundtruthing was performed by M. Coetzee, while the remote "signatures" to the groundtruthed data were conducted by A. van Rooyen. These images indicate bush encroachment associated with the unsustainable use of permanent and temporal water resources. However, data costs potentially remain a limiting factor, and we need to look at partnerships with other institutions.

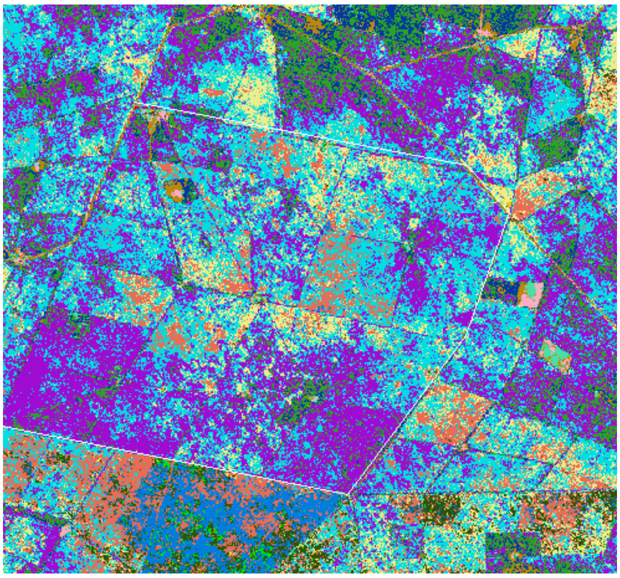


Preliminary results: NW Province Remote sensing study.

Text compiled by Dr. A van Rooyen – GIS imagery
M Coetzee – Groundtruthing

Pink: Bare soil
Brown: Dens stands of *Acacia mellifera*
The other colours represents a mixture of rangeland in better condition, further away from water

Fig. 10.1a. Imagery of the impact of uncontrolled grazing around water points in the communal areas of the North West Province, RSA.



Commercial farms are fenced and all paddocks do have water points; this infrastructure may allow certain farmers to manage natural resources better, while it is not the case in others. The farm in the center of this image is fairly well managed but it is clear that environmental impact on the farms to the north and south is severe.

Fig. 10.1b. Imagery of sustainable commercial farming practices versus bush encroachment of farms adjacent to the Commercial “conservation farmer”.

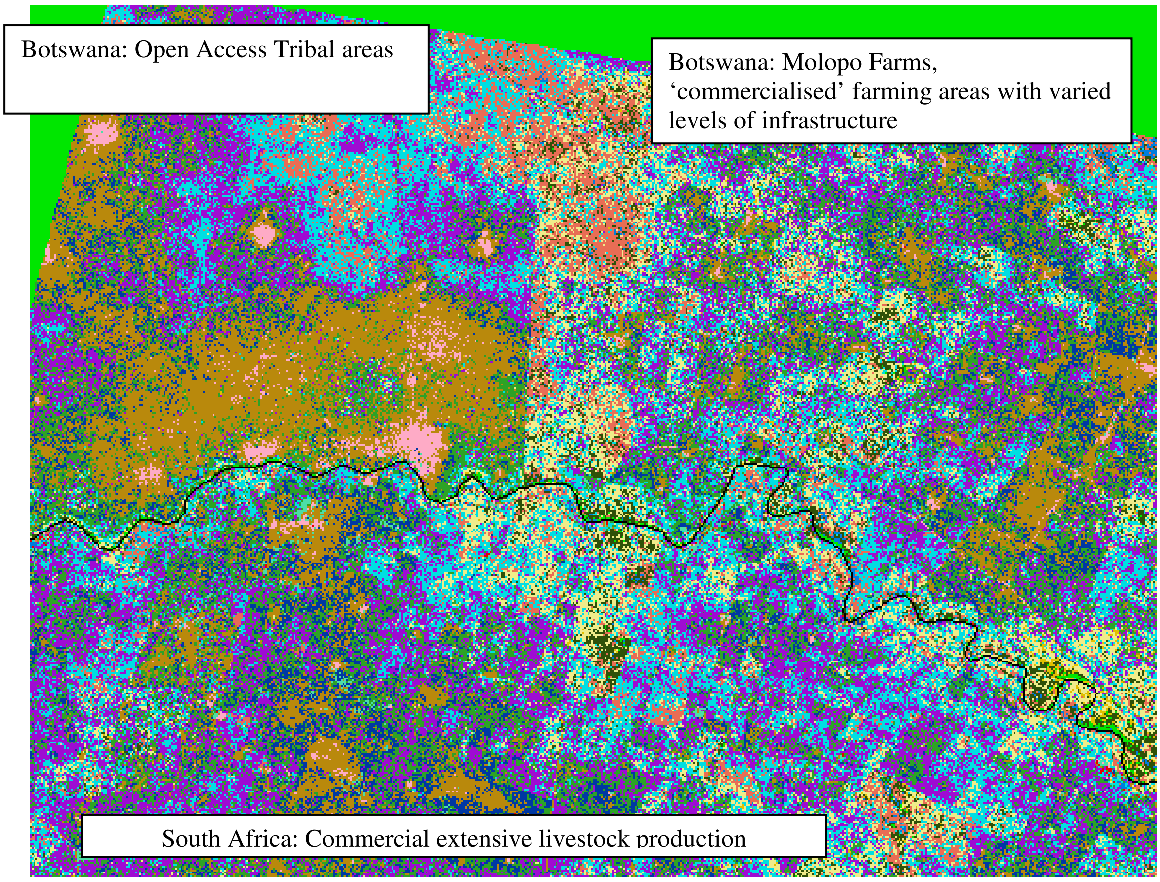


Fig. 10.1c. Imagery of the impacts of different land use impacts on the vegetation.

- Adopting integrated management systems, promoting awareness among the local people while increasing their participation in decision-making, are essential for sustainability (Pelser & Kherehloa 2000). Biodiversity strategies must respect and incorporate African values, priorities and knowledge systems (Darkoh 2003). Integrated monitoring and management strategies, as well as workshops within the Molopo study area as part of the larger DMP project, conducted in an integrated manner by the North West Department of Agriculture, Conservation and Environment (NW DACE) in collaboration with the other NW DMP stakeholders (Appendix 10.1), should attempt to attain the following: (i) establish the level of local communities knowledge (including Commercial farmers' knowledge) and perception regarding rangeland "health", degradation and biodiversity issues; (ii) provide a platform for an integrated approach towards rangeland monitoring between local communities, Commercial farmers, conservation areas, Agricultural Field Services (extension officers), scientists from Scientific Technical Support Services (NW DACE – STSS, Potchefstroom) and scientists from academic and other institutions; (iii) provide an opportunity to local communities/farmers/conservationists to present indigenous knowledge with regard to environmental/socio-economical aspects in their respective communities/farming rangelands/conservation areas; (iv) acknowledge the different needs of the different stakeholders (land users/owners; management; research; Extension Services; other institutions) towards rangeland monitoring and management; (v) provide feedback from this study as well as other DMP studies' results in the form of visual models, demonstrations and community/Farmer's union workshop participation; (vi) the handout of packages (package format depending on the level of stakeholders) as a first step towards visual adaptive management strategies (e.g. Appendix 10.3 for the Tribal land uses and Agricultural Extension officers), and the evaluation of the most appropriate capacity building and adaptive management strategies/packages (e.g. remote sensing vs. basic brochures, workshops etc.) for the different levels of stakeholders (refer to Appendices 10. 2 and 10.3).

- Ecological and economic aspects can be interrelated by means of indicator systems through the measurement of consumer-orientated values of landscapes and biodiversity issues (Osinski *et al.* 2003). This measurement is critically reviewed by especially critics in nature conservation circles (Osinski *et al.* 2003). However, economics play an important role in the development of sustainable land use, and do not necessarily represent a contradiction for ecological assessment, and should be included in the conservation of nature (Osinski *et al.* 2003). This study suggests that the long-term sustainability of these semi-arid rangelands within the Molopo depends on a dichotomous relationship between sound economical and ecologically responsible interactions/feedbacks. This relationship depends on knowledge of the ecological processes that operate within these semi-arid rangelands, while also acknowledging that there is a fundamental difference between a "management monitoring system" envisioned for management by the land owners/users, and a monitoring system for research purposes. Thus, partnerships between land users/owners and scientists from different disciplines, in which the different land users/owner client groups identify their own priorities and are given assistance, are essential for resources management and monitoring purposes.
- Different taxonomic groups perceive and respond differently to the environment at different spatial and temporal scales (Fleishman *et al.* 2003), reflecting differences in biotic and abiotic resource specificity. These authors suggest that the most appropriate scales for studying and conserving different taxonomic groups are not the same, implying that the ability of one taxon to serve as surrogate for other taxons' diversity, is scale-dependent. Fleishman *et al.* (2003) caution that this makes it potentially difficult to compare results of ecological studies from different taxonomic groups within the same landscape, and that resources abundance and the distribution of key resources for individual taxonomic groups are the most important mechanisms governing scale dependent diversity patterns. Both vegetation and ant functional and species compositional structures proved to be congruent indicators of diversity patterns pertaining to environmental disturbances. However, heterogeneity at patch, paddock and landscape level may result in different patterns among other taxonomic groups within these rangelands, depending on the spatial and temporal distribution of the resources on which these other taxonomic groups rely. It is suggested that other taxonomic groups such as beetles, that are relatively abundant and diverse within these rangelands, as well as other faunal groups such as avifauna, small mammals, reptiles and soil fauna may contribute towards an understanding of the impact of different land uses on the biodiversity and rangeland "health" of the Molopo semi-arid rangelands.
- Species richness has become the most common parameter of studying biodiversity, being a convenient surrogate of biodiversity. However, species richness is not always easily measured

for especially speciose taxonomic groups, and the potential of using higher taxa (e.g. genera, families etc.) should be investigated as potential reliable surrogate for numbers of species (Gaston 2000). The limited resources of available government land and funding need to be efficiently applied, and it is suggested that such a "coarse-filter" approach focuses on protecting higher levels of the biodiversity hierarchy (e.g. land use types), assuming that the broad-scale patterns represent the finer scale biodiversity aspects (Reyers *et al.* 2001). However, the "coarse-filter-approach" may not be sensitive to rare species confined to small patches, suggesting that a combination of species-based and broad-scale approaches need to be included in conservation planning (Maddock & du Plessis 1999). This study indicated that both vegetation and ant functional and species composition structures displayed congruent diversity patterns, being informative regarding the impact of different land uses on the rangeland "health" and biodiversity. Key indicators pertaining to each parameter (component) were presented in the form of a "Key assessment matrix" in Chapter 9 (Section 9.3). However, the use of other more appropriate surrogate taxa, as discussed in the point above, and the applicability of "coarse-filter-approaches" within these rangelands can only be verified by further groundtruthing studies/surveys for vegetation, ants and other taxa, in combination with GIS systems. Such "coarse-filter" approaches may provide to be useful, since funding remains a problems while the monitoring, sorting and identification of different taxonomic groups often are expensive, time-consuming, practically difficult to execute and taxonomically difficult. Hence indicator species in addition and complementary to a "coarse-filter" approach may provide important information and guidelines towards biodiversity measurement of the Molopo rangelands.

- Bio-indication studies should identify detector species for monitoring direction of change within and across states (McGeoch *et al.* 2002), following the initial identification of the potential bio-indicator (McGeoch 1998). Detector species are less likely to become vulnerable than indicator species, occurring in a variety of habitats or ecological states, making them more useful for monitoring change (McGeoch *et al.* 2002). This study provided key ant indicator species that can be employed as indicator species of land use type, and that can possibly serve as detector species. However, the IndVal ranges (refer to Chapter 3, Material and Methods) for detector vs. indicator species as employed by Van Rensburg *et al.* (1999) and McGeoch *et al.* (2002) for beetles in Maputuland, KwaZulu-Natal, possibly need to be refined, adjusted and tested further for ants and other taxonomic groups for the Molopo semi-arid rangelands.
- In addition to the points discussed above, more biological and functional information is required to be more predicative regarding biodiversity and rangeland degradation patterns associated with the different land uses of the semi-arid rangelands of the Molopo. Soil systems contribute significantly towards the total biodiversity, and are inhabited by a great diversity of soil fauna. Assessment of the soil component is likely to reflect environmental conditions not only within the soil, but also above it (Ayyad 2003). Soil fauna as bio-indicators of soil function can enable farmers to assess whether their resources are declining in quality/condition, whether they remain stable and whether they are resilient (De Bruyn 1999). Results from this study indicated that land use did impact on the soil component (Chapter 6). This study did not attempt to discuss the

physical, chemical and physiological processes related to the soil parameters, but rather attempted to provide criteria for selecting the most appropriate measures when incorporating the soil parameters as additive data in the multivariate analyses with the vegetation, ant and nominal environmental data. Since the quality of soil and vegetation are interdependent (Mills & Fey 2004), this study acknowledges that further investigations of the complex interrelationships between bush canopies, soil biochemical characteristics and herbaceous vegetation structures need to be researched to better understand ecological changes and degradation processes in the Molopo rangelands. Inherent differences pertaining to the soil particle size suggest that the landtype Ah classification for the larger study area should possibly be refined and verified.

- For adapting the animal factor to the vegetation component (refer to the Conclusions of Chapter 5, Woody component), the management of livestock distribution patterns requires a knowledge of pasture (and browse) characteristics as well as animal behavioural patterns, suggesting that a further challenge for range managers is to achieve rangeland management objectives in view of complex and dynamic livestock behavioural patterns (Launchbaugh & Howery 2005). These authors suggest that management practices can be designed to modify animal behaviour and alter habitat-use patterns. Results pertaining to the woody component especially (woody structure) illustrated that animal behaviour as a result of tenure type, can modify the habitat. Thus, livestock data and livestock behavioural patterns need to be acknowledged with regard to sustainable ecological and economical rangeland monitoring and management.
- The problem of overstocking as a major cause of the degradation of natural resources in communal farming areas has not been solved for decades (Dűvel & Afful 1997). Rangeland degradation is recognised in communal areas, but is not considered as a livelihood priority (Hoffman *et al.* 1999). The key role of land uses' behaviour (management pertaining to different land use types) in sustainable agricultural development needs to be acknowledged, implicating that the state of the natural resources is largely a function of their management or decisions (Dűvel & Afful 1997). A form of fatalism, being cultural related, among communal farmers results in a general attitude that the problem is not one of "too much stock, but too little land" (Dűvel & Afful 1997). Consequently, the potential solution of commercialising the grazing rights whereby those with large herds must compensate those making less use of the grazing resources is unlikely to succeed, suggesting that other ways of improving stock production need to be investigated (Dűvel & Afful 1997). Since socio-economic factors impact on the vegetation indirectly by influencing human behaviour, they are not immediately obvious, necessitating that research partnerships involving natural and social sciences will becoming increasingly important in rangeland ecology (Twine 2005). This study thus suggests that commercialising the livestock industry within Tribal (communal) rangelands within the Molopo rangelands alone is not sufficient to prevent land degradation. Communities should take ownership and thus responsibility for resources, acknowledging and understanding that rangeland degradation is a major livelihood priority. Thus, improved livestock production and quality of life for humans and livestock do not start only with the provisioning of infrastructures such as fencing and water resources, but with

the knowledge of sound rangeland strategies and the responsibility and commitment to sustainably utilise and monitor these resources. This principle applies to **all** land uses, thus to Commercial, Tribal, Reserve and game farming land tenure types.

- Following above-mentioned point, it should be recognised that land managers/users may tend to want a "balanced" monitoring system that in less depth covers *several* aspects, rather than have many details about only one or two components (Friedel *et al.* 2004). Scientific monitoring may be considered as important by the monitoring agency, while the informal, local knowledge may be downplayed or even be discarded (Friedel *et al.* 2004). The fundamental differences between "management monitoring system" envisioned for management, and a monitoring system for research purposes should be acknowledged (Friedel *et al.* 2004). Land degradation is diverse in form and impacts through and on farming systems. Thus, detailed case studies on well-monitored sites, which act as sub-regional "field laboratories" where the work of soil, plant and animal (vertebrates and invertebrates) scientists can be integrated with the studies performed by socio-economists, policy analysts and institutional analysts, should attempt to invest intellectual resources in the contextualisation of the problems of resource use. The land users/owners should be the primary beneficiaries from these multidisciplinary partnerships. According to Meadows and Hoffman (2002), the land degradation situation in South Africa suggests that several inappropriate decisions were made in the past, but if these mistakes are not to be repeated in the future, ecologically sound practices should not be compromised by political expedience, which holds the truth for the Molopo semi-arid rangelands. A proposal as to how this study can possibly be employed within the NW DACE and larger DMP programme, and in partnerships with other disciplines, is presented in Appendix 10.2.

LIST OF APPENDICES

Appendix 4.1. Herbaceous species surveyed within the study area, as well as each species ecological status, grazing value and life-form status

Species name	*Antephora pubscens*	*Brachiaria nigropedata*	*Digitaria eriantha*	*Schmidtia pappophoroides*	*Panicum maximum*	*Chrysopogon serrulatus*	*Eragrostis lehmannniana*	*Eragrostis tricophora*	*Stipagrostis ciliata*	*Aristida meriodinalis*	*Perotis patens*
After	Nees	(Fical. & Hiern) Stapf	Steud	Steud	Jacq.	Trin.	Nees	Coss. & Dur.	(Desf.) De Winter	Henr.	Gand.
Abreviation	**ANT PUB**	**BRAC NIG**	**DIG ERI**	**SCHM PAP**	**PAN MAX**	**CHRY SER**	**ERA LEH**	**ERA TRI**	**STIP CIL**	**ARIST MED**	**PER PAT**
Life-form	Perennial	Perennial	Perennial	Perennial	Perennial	Perennial	Perennial	Weak perennial	Perennial	Perennial	Annual
Palatability	HD	HD	HD	HD	HD	HD	DE	DE	DE	UD	UD
Ecological status	Decreaser	Decreaser	Decreaser	Decreaser	Decreaser	Decreaser	Increaser II	Increaser II	Decreaser	Increaser II	Increaser II
Species name	*Stipagrostis uniplumis*	*Cymbopogon plurinodis*	*Centropodia glauca*	*Aristida stipitata*	*Cynodon dactylon*	*Eragrostis pallens*	*Melinus repens*	*Triraphis andropogonoides*	*Eragrostis rigidior*	*Pogonathria squarrosa*	*Aristida congesta*
After	(Licht.) De Winter	Stapf) Stapf ex Burtt Dav	(Nees) T.A. Cope	Hack.	(L.) Pers.	Hack.	(Willd.) C.E. Hubb	(Steud.) Phill.	Pilg.	(Roem. & Schult.) Pilg.	Roem. & Schult.
Abreviation	**STIP UNI**	**CYMPO**	**CENTR**	**ARI STI**	**CYN DAC**	**ERA PAL**	**MEL REP**	**TRI AND**	**ERA RIG**	**POG SQU**	**ARIST CON**
Life-form	Perennial	Perennial	Perennial	Weak perennial	Perennial/creeping	Weak perennial	Weak perennial	Perennial	Weak perennial	Weak perennial	Annual
Palatability	DE	DE	HD	LD	LD	LD	LD	LD	LD	LD	UD
Ecological status	Decreaser	Increaser I	Decreaser	Increaser II	Increaser II	Increaser II	Increaser II	Increaser II	Increaser II	Increaser II	Increaser III
Species name	*Tragus koeleroides*	*Urochloa brachyura*	*Tragus berteronianus*	*Brachiaria marlothii*	*Eragrostis biflora*	*Chloris virgata*	*Eleucine coracana*	*Schmidtia kalihariensis*	*Tragus racemosa*	Forbs species	Bare patches
After	Aschers.	(Hack.) Stapf	Schult.	(Hack.) Stent	Hack. ex Schinz	Swartz	(L.) Gaertn.	Stent	(L.) All.		
Abreviation	**TRA KOE**	**URU BRA**	**TRA BER**	**BRA MAR**	**ERA BIF**	**CHLOR VIR**	**ELEU COR**	**SCHM KAL**	**TRA RAC**	**FORBS**	**BP**
Life-form	Perennial	Annual	Annual	Annual	Annual	Annual	Annual	Annual	Annual	NA	NA
Palatability	UD	UD	UD	UD	UD	UD	UD	UD	UD	NA	NA
Ecological status	Increaser III	Increaser III	Increaser III	Increaser II	Increaser II	Increaser III	Increaser II	Increaser III	Increaser III	NA	NA

Appendix 4.2. Average relative abundances for the herbaceous composition for the "Annual" interpretation

Total study: General	ANT PUB	BRAC NIG	DIG ERI	SCHM PAP	PAN MAX	CHRY SER	ERA LEH	ERA TRI	STIP CIL	STIP UNI	CYM PO	CEN TR	ARI STI	CYN DAC	ERA PAL	MEL REP	TRI AND
Mean	2.20	0.34	1.30	29.37	0.01	0.08	14.75	1.11	0.29	10.40	0.02	0.29	8.82	0.73	2.40	0.91	0.29
Standard Error	0.99	0.22	0.46	3.26	0.01	0.08	2.09	0.47	0.19	1.30	0.01	0.14	1.90	0.73	0.80	0.28	0.12
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	55.00	14.20	24.70	90.70	0.80	5.80	91.00	29.10	12.70	44.80	0.70	6.10	76.44	52.60	46.00	15.60	5.20
Total study: "Good"																	
Mean	4.41	0.69	1.34	44.74	0.02	0.16	9.96	1.13	0.10	11.21	0.02	0.54	7.93	0.00	3.93	1.21	0.32
Standard Error	1.91	0.44	0.58	4.46	0.02	0.16	1.65	0.82	0.07	1.71	0.02	0.27	2.44	0.00	1.52	0.36	0.19
Minimum	55.00	14.20	14.80	90.70	0.80	5.80	42.70	29.10	2.40	40.00	0.60	6.10	76.44	0.00	46.00	10.00	5.20
Maximum	0.00	0.00	0.00	1.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total study: "Poor"																	
Mean	0.00	0.00	1.25	13.99	0.00	0.00	19.54	1.10	0.49	9.59	0.02	0.03	9.72	1.46	0.88	0.61	0.26
Standard Error	0.00	0.00	0.71	3.10	0.00	0.00	3.69	0.47	0.37	1.98	0.02	0.03	2.94	1.46	0.41	0.43	0.16
Minimum	0.00	0.00	24.70	80.80	0.00	0.00	91.00	12.50	12.70	44.80	0.70	1.00	61.90	52.60	9.60	15.60	5.20
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Commercial: "Total land use"																	
Mean	6.61	1.03	0.08	31.01	0.00	0.00	14.03	0.03	0.00	9.79	0.00	0.82	2.69	0.00	0.00	0.00	0.00
Standard Error	2.78	0.65	0.06	5.71	0.00	0.00	4.48	0.03	0.00	2.14	0.00	0.39	1.80	0.00	0.00	0.00	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	55.00	14.20	1.00	80.80	0.00	0.00	91.00	0.70	0.00	31.80	0.00	6.10	43.00	0.00	0.00	0.00	0.00
Commercial: "Relative Good"																	
Mean	13.23	2.07	0.17	48.22	0.00	0.00	7.23	0.00	0.00	13.00	0.00	1.63	0.35	0.00	0.00	0.00	0.00
Standard Error	4.94	1.25	0.11	5.83	0.00	0.00	1.77	0.00	0.00	3.30	0.00	0.72	0.20	0.00	0.00	0.00	0.00
Minimum	55.00	14.20	1.00	74.30	0.00	0.00	17.00	0.00	0.00	31.80	0.00	6.10	2.20	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	10.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Commercial: "Relative Poor"																	
Mean	0.00	0.00	0.00	13.81	0.00	0.00	20.83	0.06	0.00	6.58	0.00	0.00	5.03	0.00	0.00	0.00	0.00
Standard Error	0.00	0.00	0.00	6.98	0.00	0.00	8.51	0.06	0.00	2.52	0.00	0.00	3.54	0.00	0.00	0.00	0.00
Minimum	0.00	0.00	0.00	80.80	0.00	0.00	91.00	0.70	0.00	27.50	0.00	0.00	43.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tribal: "General"																	
Mean	0.00	0.00	3.81	13.23	0.03	0.00	18.23	3.11	0.00	5.00	0.05	0.00	22.98	2.19	7.21	2.52	0.87
Standard Error	0.00	0.00	1.23	2.55	0.03	0.00	2.90	1.32	0.00	1.91	0.04	0.00	4.10	2.19	2.11	0.75	0.34
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	24.70	44.50	0.80	0.00	49.20	29.10	0.00	40.00	0.70	0.00	76.44	52.60	46.00	15.60	5.20
Tribal: "Good"																	
Mean	0.00	0.00	3.87	17.65	0.07	0.00	16.35	3.38	0.00	7.46	0.05	0.00	22.11	0.00	11.78	3.20	0.95
Standard Error	0.00	0.00	1.54	3.92	0.07	0.00	3.73	2.40	0.00	3.60	0.05	0.00	5.32	0.00	3.69	0.82	0.52
Minimum	0.00	0.00	14.80	44.50	0.80	0.00	42.70	29.10	0.00	40.00	0.60	0.00	76.44	0.00	46.00	10.00	5.20
Maximum	0.00	0.00	0.00	1.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.70	0.00	0.00	0.00	0.00
Tribal: "Poor"																	
Mean	0.00	0.00	3.75	8.80	0.00	0.00	20.10	2.83	0.00	2.54	0.06	0.00	23.85	4.38	2.64	1.84	0.78
Standard Error	0.00	0.00	2.00	2.86	0.00	0.00	4.54	1.24	0.00	1.09	0.06	0.00	6.46	4.38	1.09	1.26	0.44
Minimum	0.00	0.00	24.70	30.40	0.00	0.00	49.20	12.50	0.00	10.00	0.70	0.00	61.90	52.60	9.60	15.60	5.20
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Reserve: "General"																	
Mean	0.00	0.00	0.00	43.87	0.00	0.24	12.00	0.20	0.88	16.40	0.00	0.04	0.80	0.00	0.00	0.22	0.00
Standard Error	0.00	0.00	0.00	6.20	0.00	0.24	3.31	0.20	0.56	2.16	0.00	0.04	0.48	0.00	0.00	0.11	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	90.70	0.00	5.80	62.20	4.80	12.70	44.80	0.00	1.00	11.10	0.00	0.00	1.80	0.00
Reserve: "Good"																	
Mean	0.00	0.00	0.00	68.36	0.00	0.48	6.29	0.00	0.30	13.18	0.00	0.00	1.32	0.00	0.00	0.44	0.00
Standard Error	0.00	0.00	0.00	4.65	0.00	0.48	1.79	0.00	0.22	1.52	0.00	0.00	0.93	0.00	0.00	0.21	0.00
Minimum	0.00	0.00	0.00	90.70	0.00	5.80	16.40	0.00	2.40	21.00	0.00	0.00	11.10	0.00	0.00	1.80	0.00
Maximum	0.00	0.00	0.00	43.00	0.00	0.00	0.00	0.00	0.00	6.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Reserve: "Poor"																	
Mean	0.00	0.00	0.00	19.38	0.00	0.00	17.70	0.40	1.46	19.63	0.00	0.08	0.28	0.00	0.00	0.00	0.00
Standard Error	0.00	0.00	0.00	5.48	0.00	0.00	6.06	0.40	1.10	3.91	0.00	0.08	0.19	0.00	0.00	0.00	0.00
Minimum	0.00	0.00	0.00	68.30	0.00	0.00	62.20	4.80	12.70	44.80	0.00	1.00	1.90	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

APPENDIX 4.2 (continue . . .)

Total study: "General"	ERA RIG	POG SQU	ARIST CON	ARIST MED	PER PAT	TRA KOE	URU BRA	TRA BER	BRA MAR	ERA BIF	CHLOR VIR	ELEU COR	SCHM KAL	TRA RAC	FORBS	BP
Mean	0.04	0.19	1.35	0.29	0.26	0.28	0.83	0.07	0.66	0.11	0.01	0.01	6.08	0.05	0.16	16.34
Standard Error	0.03	0.08	0.37	0.18	0.22	0.11	0.42	0.05	0.43	0.06	0.01	0.01	1.66	0.05	0.16	2.75
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	1.80	3.80	15.80	11.40	16.10	4.50	27.60	3.30	28.20	3.30	0.60	0.60	97.80	3.30	11.30	100.00
Total study: "Good"																
Mean	0.08	0.05	0.74	0.44	0.46	0.20	0.70	0.02	0.00	0.04	0.02	0.02	3.79	0.00	0.31	5.44
Standard Error	0.06	0.05	0.28	0.34	0.45	0.14	0.34	0.02	0.00	0.04	0.02	0.02	1.22	0.00	0.31	1.83
Minimum	1.80	1.80	6.70	11.40	16.10	4.00	10.70	0.60	0.00	1.30	0.60	0.60	26.70	0.00	11.30	53.30
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total study: "Poor"																
Mean	0.00	0.33	1.97	0.14	0.05	0.35	0.96	0.11	1.32	0.18	0.00	0.00	8.36	0.09	0.00	27.24
Standard Error	0.00	0.15	0.68	0.14	0.05	0.17	0.77	0.09	0.86	0.11	0.00	0.00	3.07	0.09	0.00	4.53
Minimum	0.00	3.80	15.80	5.00	1.70	4.50	27.60	3.30	28.20	3.30	0.00	0.00	97.80	3.30	0.00	100.00
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Commercial: "Total land use"																
Mean	0.00	0.08	0.00	0.21	0.00	0.00	2.12	0.00	0.00	0.00	0.00	0.00	11.66	0.00	0.47	19.34
Standard Error	0.00	0.08	0.00	0.21	0.00	0.00	1.21	0.00	0.00	0.00	0.00	0.00	4.37	0.00	0.47	4.93
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	1.90	0.00	5.00	0.00	0.00	27.60	0.00	0.00	0.00	0.00	0.00	97.80	0.00	11.30	78.50
Commercial: "Relative Good"																
Mean	0.00	0.00	0.00	0.00	0.00	0.00	1.63	0.00	0.00	0.00	0.00	0.00	5.93	0.00	0.94	5.55
Standard Error	0.00	0.00	0.00	0.00	0.00	0.00	0.95	0.00	0.00	0.00	0.00	0.00	2.63	0.00	0.94	3.23
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	10.70	0.00	0.00	0.00	0.00	0.00	26.70	0.00	11.30	38.70
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Commercial: "Relative Poor"																
Mean	0.00	0.16	0.00	0.42	0.00	0.00	2.61	0.00	0.00	0.00	0.00	0.00	17.40	0.00	0.00	33.13
Standard Error	0.00	0.16	0.00	0.42	0.00	0.00	2.28	0.00	0.00	0.00	0.00	0.00	8.18	0.00	0.00	7.54
Minimum	0.00	1.90	0.00	5.00	0.00	0.00	27.60	0.00	0.00	0.00	0.00	0.00	97.80	0.00	0.00	78.50
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.20
Tribal: "General"																
Mean	0.11	0.49	4.06	0.66	0.77	0.83	0.23	0.20	1.98	0.32	0.03	0.03	0.00	0.00	0.00	11.12
Standard Error	0.08	0.22	0.89	0.50	0.67	0.30	0.09	0.14	1.27	0.17	0.03	0.03	0.00	0.00	0.00	4.20
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	1.80	3.80	15.80	11.40	16.10	4.50	1.50	3.30	28.20	3.30	0.60	0.60	0.00	0.00	0.00	74.30
Tribal: "Good"																
Mean	0.23	0.15	2.22	1.33	1.39	0.61	0.19	0.05	0.00	0.11	0.05	0.05	0.00	0.00	0.00	6.82
Standard Error	0.16	0.15	0.67	0.99	1.34	0.41	0.11	0.05	0.00	0.11	0.05	0.05	0.00	0.00	0.00	4.41
Minimum	1.80	1.80	6.70	11.40	16.10	4.00	1.10	0.60	0.00	1.30	0.60	0.60	0.00	0.00	0.00	53.30
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tribal: "Poor"																
Mean	0.00	0.83	5.91	0.00	0.14	1.05	0.28	0.34	3.97	0.53	0.00	0.00	0.00	0.00	0.00	15.43
Standard Error	0.00	0.40	1.50	0.00	0.14	0.46	0.15	0.28	2.46	0.31	0.00	0.00	0.00	0.00	0.00	7.13
Minimum	0.00	3.80	15.80	0.00	1.70	4.50	1.50	3.30	28.20	3.30	0.00	0.00	0.00	0.00	0.00	74.30
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Reseve: "General"																
Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00	6.56	0.14	0.00	18.56
Standard Error	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00	1.88	0.14	0.00	5.13
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	3.30	0.00	0.00	0.00	0.00	0.00	30.60	3.30	0.00	100.00
Reserve: "Good"																
Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.00	0.00	5.44	0.00	0.00	3.94
Standard Error	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.00	0.00	2.29	0.00	0.00	1.35
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	3.30	0.00	0.00	0.00	0.00	0.00	24.20	0.00	0.00	15.80
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Reserve: "Poor"																
Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.68	0.28	0.00	33.18
Standard Error	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.05	0.28	0.00	8.32
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30.60	3.30	0.00	100.00
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.80

Appendix 4.3. Cumulative variance explained and the eigenvector scores of all the herbaceous species for the “annual” and “perennial” interpretation, as well as species having at least 10% and higher of their ranges explained by the species-environment variance. Species responsive to the respective axes are indicated in **bold.**

	"Annual" matrix					"Perennial" matrix			
	Eigen values		Cumulative variance			Eigen values		Cumulative variance	
NAME	**AX1**	**AX2**	**AX1**	**AX2**	**NAME**	**AX1**	**AX2**	**AX1**	**AX2**
*ANT PUB **	**-1.4212**	-1.2181	**0.0714**	0.1112	*ANT PUB**	**1.7485**	0.3115	**0.1099**	0.113
BRAC NIG	**-1.4212**	-1.2181	**0.0332**	0.0518	*BRAC NIG*	**2.0264**	0.3954	**0.0675**	0.0698
*DIG ERI **	**1.616**	-0.73	**0.192**	0.2217	*DIG ERI **	**-1.401**	1.1176	**0.1551**	0.2435
*SCHM PAP**	**-0.6929**	-0.6196	**0.3667**	0.5889	*CYN DAC*	-1.2207	**-1.9714**	0.0051	**0.017**
PAN MAX	**1.569**	-1.2425	**0.0224**	0.0331	*SCHM PAP**	**0.8988**	0.3739	**0.6289**	0.7264
CHRY SER	-1.2645	**-1.2976**	0.0144	**0.0258**	*PAN MAX*	**-1.2091**	-0.3288	**0.0133**	0.0142
*ERA LEH**	0.368	0.3756	0.0637	0.1139	*CHRY SER*	**1.6715**	1.0761	**0.025**	0.0343
*ERA TRI**	**1.5313**	-0.5883	0.1104	**0.1228**	*ERA LEH**	**-0.5347**	-0.1399	**0.1332**	0.1414
STIP CIL	-0.5812	**1.1483**	**0.0068**	0.0268	*ERA TRI**	**-1.2636**	1.0411	**0.0814**	0.1308
*STIP UNI **	**-0.4571**	0.0634	**0.1242**	0.126	*STIP CIL*	0.4988	**-1.3727**	0.0045	**0.035**
CYM PO	**1.6931**	-0.6703	**0.053**	0.0593	*STIP UNI**	**0.3387**	-0.2419	**0.0674**	0.0981
*CEN TR**	**-1.3736**	-1.0788	**0.0716**	0.1051	*CEN TR**	**1.1775**	0.1898	**0.0524**	0.0536
*ARI STI **	**1.408**	-0.4264	**0.4002**	0.428	*CYM PO*	**-1.3508**	0.6756	**0.0337**	0.0412
CYN DAC	**1.7994**	-0.1799	**0.0105**	0.0106	*ARI STI**	**-1.1523**	0.9617	**0.268**	0.435
*ERA PAL**	**1.6112**	-1.0479	**0.2146**	0.2834	*ERA PAL**	-1.4048	**1.9142**	0.176	**0.4687**
*MEL REP**	**1.4182**	-0.89	**0.1886**	0.2449	*MEL REP*	**-1.1879**	0.6649	**0.0131**	0.0168
*TRI AND **	**1.6732**	-0.7623	**0.1484**	0.1718	*TRI AND**	-1.4084	**1.7791**	0.1045	**0.2537**
ERA RIG	**1.569**	-1.2425	**0.0381**	0.0563	*ERA RIG*	-0.9995	**1.246**	0.0157	**0.0375**
*POG SQU**	**1.4982**	0.0045	**0.1132**	0.1132	*POG SQU*	**-1.2632**	0.9251	**0.0821**	0.1216
*ARIST CON**	**1.7366**	-0.4698	**0.3539**	0.3735	*ARIST MED*	**-0.7079**	-0.1813	**0.0113**	0.012
ARIST MED	**1.1568**	-0.4294	**0.03**	0.0331	*TRA KOE**	**-1.2277**	0.743	**0.0852**	0.1131
PER PAT	**1.5903**	-1.1443	**0.0263**	0.0366	FORBS	**1.0252**	0.1381	**0.0085**	0.0086
*TRA KOE**	**1.7149**	-0.5697	**0.1619**	0.1754	BP *	-0.3952	**-1.1617**	0.061	**0.5328**
URU BRA	-0.455	**0.603**	0.0067	**0.0157**					
TRA BER	**1.77**	-0.3155	**0.0513**	0.0525					
BRA MAR	**1.7994**	-0.1799	**0.0278**	0.028					
ERA BIF	**1.76**	-0.3616	**0.0908**	0.0937					
CHLOR VIR	**1.569**	-1.2425	**0.0204**	0.0301					
ELEU COR	**1.569**	-1.2425	**0.0204**	0.0301					
*SCHM KAL**	-0.5863	**0.9856**	0.0437	**0.1372**					
TRA RAC	-0.4407	**1.6514**	0.0016	0.0189					
FORBS	**-1.4212**	-1.2181	**0.0165**	0.0257					
BP*	0.0599	**1.0514**	0.0012	**0.2712**					

ERA LEH responsive to both axes

*Key herbaceous species having 10% and higher of their ranges explained by the species-environment relation

Appendix 4.4. Descriptive statistics for the grazing index

	"Annual" grazing index						"Perennial" grazing index					
	HD	**DE**	**LD**	**UD**	**FORBS**	**BP**	**HD**	**DE**	**LD**	**UD**	**FORBS**	**BP**
Total: "General"												
Mean	33.31	26.86	13.39	9.98	0.16	16.35	34.89	29.59	12.88	0.57	0.17	21.13
Standard Error	3.48	2.46	2.58	1.67	0.16	2.75	3.68	2.78	2.59	0.21	0.17	3.22
Maximum	98.70	91.00	77.35	97.80	11.30	100.00	98.70	93.00	77.35	11.40	12.00	100.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total: "Good"												
Mean	50.90	23.53	13.41	6.51	0.31	5.38	34.89	29.59	12.88	0.57	0.17	21.13
Standard Error	4.45	2.64	3.41	1.23	0.31	1.78	3.68	2.78	2.59	0.21	0.17	3.22
Maximum	98.70	72.00	77.35	26.70	11.30	53.30	98.70	93.00	77.35	11.40	12.00	100.00
Minimum	1.30	1.30	0.00	0.00	0.00	0.00	0.00	1.30	0.00	0.00	0.00	0.00
Total "Poor"												
Mean	15.24	30.76	13.27	13.52	0.00	27.27	16.26	33.82	12.95	0.49	0.00	34.90
Standard Error	3.13	4.09	3.84	3.00	0.00	4.53	3.19	4.69	3.94	0.21	0.00	5.12
Maximum	80.80	91.00	72.20	97.80	0.00	100.00	81.60	93.00	72.60	5.00	0.00	100.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.80
Commercial: "General"												
Mean	38.74	24.67	2.77	14.03	0.47	19.34	39.46	28.67	3.45	0.21	0.50	27.74
Standard Error	6.87	4.87	1.80	4.27	0.47	4.93	7.53	5.51	2.36	0.21	0.50	6.38
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	98.70	93.00	56.60	5.00	12.00	100.00
Minimum	98.70	91.00	43.00	97.80	11.30	78.50	0.00	0.00	0.00	0.00	0.00	0.00
Commercial: "Good"												
Mean	63.68	21.87	0.35	7.63	0.94	5.55	64.38	25.07	0.37	0.00	1.00	9.20
Standard Error	5.98	4.73	0.20	2.50	0.94	3.23	8.64	5.46	0.22	0.00	1.00	5.02
Maximum	35.40	1.30	0.00	0.00	0.00	0.00	98.70	52.00	2.40	0.00	12.00	48.00
Minimum	98.70	47.10	2.20	26.70	11.30	38.70	0.00	1.30	0.00	0.00	0.00	0.00
Commercial: "Poor												
Mean	13.81	27.48	5.19	20.43	0.00	33.13	14.53	32.27	6.53	0.42	0.00	46.28
Standard Error	6.98	8.68	3.53	7.91	0.00	7.54	7.06	9.74	4.64	0.42	0.00	9.07
Maximum	0.00	0.00	0.00	0.00	0.00	2.20	81.60	93.00	56.60	5.00	0.00	100.00
Minimum	80.80	91.00	43.00	97.80	0.00	78.50	0.00	0.00	0.00	0.00	0.00	7.00

APPENDIX 4 (continue . . .)

	"Annual" grazing index						"Perennial" grazing index					
	HD	**DE**	**LD**	**UD**	**FORBS**	**BP**	**HD**	**DE**	**LD**	**UD**	**FORBS**	**BP**
Tribal: "General"												
Mean	17.07	26.39	36.38	9.08	0.00	11.16	18.47	28.03	34.30	1.51	0.00	15.31
Standard Error	2.87	3.81	4.86	1.64	0.00	4.19	3.04	4.55	5.11	0.55	0.00	4.63
Maximum	1.00	0.80	1.90	0.00	0.00	0.00	53.80	74.40	77.35	11.40	0.00	84.90
Minimum	52.00	72.00	77.35	29.00	0.00	74.30	1.10	0.00	0.00	0.00	0.00	0.00
Tribal: "Good"												
Mean	22.54	28.53	36.23	6.19	0.00	6.55	23.18	29.69	36.56	1.95	0.00	8.68
Standard Error	4.04	5.51	5.62	1.72	0.00	4.06	4.38	6.03	5.72	1.00	0.00	4.22
Maximum	1.30	1.93	10.00	0.00	0.00	0.00	53.80	72.00	77.35	11.40	0.00	53.30
Minimum	52.00	72.00	77.35	22.80	0.00	53.30	1.30	1.93	12.00	0.00	0.00	0.00
Tribal: "Poor"												
Mean	12.55	25.53	34.33	12.17	0.00	15.50	13.77	26.38	32.03	1.07	0.00	21.94
Standard Error	3.55	5.15	8.15	2.46	0.00	7.12	3.93	7.05	8.68	0.46	0.00	8.00
Maximum	1.00	0.80	1.90	1.10	0.00	0.00	39.10	74.40	72.60	4.50	0.00	84.90
Minimum	34.10	58.40	72.20	29.00	0.00	74.30	1.10	0.00	0.00	0.00	0.00	2.80
Reserve: "General"												
Mean	44.11	29.52	1.02	6.84	0.00	18.56	46.73	32.09	0.91	0.00	0.00	20.33
Standard Error	6.24	4.17	0.48	1.92	0.00	5.13	6.37	4.46	0.57	0.00	0.00	5.50
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	90.70	80.90	13.50	0.00	0.00	100.00
Maximum	90.70	80.10	11.10	30.60	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00
Reserve: "Good"												
Mean	68.84	19.77	1.76	5.72	0.00	3.94	72.98	21.35	1.53	0.00	0.00	4.17
Standard Error	4.64	2.82	0.91	2.31	0.00	1.35	3.86	3.07	1.12	0.00	0.00	1.41
Maximum	43.00	6.70	0.00	0.00	0.00	0.00	90.70	39.40	13.50	0.00	0.00	16.30
Minimum	90.70	38.20	11.10	24.20	0.00	15.80	44.30	6.70	0.00	0.00	0.00	0.00
Reserve: "Poor"												
Mean	19.38	39.28	0.28	7.96	0.00	33.18	20.48	42.83	0.28	0.00	0.00	36.48
Standard Error	5.48	6.88	0.19	3.14	0.00	8.32	5.42	7.26	0.19	0.00	0.00	8.77
Maximum	0.00	0.00	0.00	0.00	0.00	3.80	68.30	80.90	1.90	0.00	0.00	100.00
Minimum	68.30	80.10	1.90	30.60	0.00	100.00	0.00	0.00	0.00	0.00	0.00	3.90

Appendix 4.5. SIMPER analyses displaying the similarities within and dissimilarities between the "Good" and "Poor" rangeland condition groups within each land use for the "perennial" grazing index.

Commercial

Group Poor - Average similarity: 44.23

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
BP	46.28	27.63	1.25	62.46	62.46
DE	32.27	12.80	0.62	28.93	91.39

Group Good - Average similarity: 62.33

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
HD	64.38	47.06	1.75	75.51	75.51
DE	25.07	13.81	1.01	22.16	97.67

Groups Poor & Good - Average dissimilarity: 67.28

	Group Poor	Group Good				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
HD	14.53	64.38	27.38	1.87	40.70	40.70
BP	46.28	9.20	20.69	1.42	30.75	71.45
DE	32.27	25.07	15.22	1.36	22.63	94.08

Tribal

Group Poor - Average similarity: 43.57

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
LD	32.03	15.48	0.73	35.54	35.54
DE	26.38	12.77	0.85	29.31	64.85
BP	21.94	8.65	0.75	19.85	84.69
HD	13.77	6.40	0.93	14.68	99.37

Group Good - Average similarity: 59.90

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
LD	36.56	25.02	2.13	41.78	41.78
DE	29.69	17.41	1.29	29.07	70.85
HD	23.18	14.42	1.51	24.08	94.93

Groups Poor & Good - Average dissimilarity: 49.07

	Group Poor	Group Good				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
LD	32.03	36.56	15.27	1.58	31.12	31.12
DE	26.38	29.69	12.77	1.36	26.02	57.14
BP	21.94	8.68	10.84	0.82	22.09	79.23
HD	13.77	23.18	8.99	1.33	18.33	97.56

APPENDIX 4.5 (continue . . .)

Group Poor - Average similarity: 57.66

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
DE	42.83	28.19	1.59	48.88	48.88
BP	36.48	19.08	1.05	33.10	81.98
HD	20.48	10.37	1.18	17.98	99.96

Group Good - Average similarity: 81.98

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
HD	72.98	65.24	5.58	79.57	79.57
DE	21.35	15.06	2.16	18.37	97.94

Groups Poor & Good - Average dissimilarity: 57.30

	Group Poor	Group Good				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
HD	20.48	72.98	26.49	2.54	46.23	46.23
BP	36.48	4.17	16.52	1.15	28.83	75.06
DE	42.83	21.35	13.46	1.31	23.48	98.54

Reserve

Group Poor - Average similarity: 57.66

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
DE	42.83	28.19	1.59	48.88	48.88
BP	36.48	19.08	1.05	33.10	81.98
HD	20.48	10.37	1.18	17.98	99.96

Group Good - Average similarity: 81.98

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
HD	72.98	65.24	5.58	79.57	79.57
DE	21.35	15.06	2.16	18.37	97.94

Groups Poor & Good - Average dissimilarity: 57.30

	Group Poor	Group Good				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
HD	20.48	72.98	26.49	2.54	46.23	46.23
BP	36.48	4.17	16.52	1.15	28.83	75.06
DE	42.83	21.35	13.46	1.31	23.48	98.54

Appendix 4.6. Descriptive statistics for the ecological index

	"Annual" ecological index						"Perennial" ecological index					
	Decreaser	**Incr I**	**Incr II**	**Incr III**	**FORBS**	**BP**	**Decreaser**	**Incr I**	**Incr II**	**Incr III**	**FORBS**	**BP**
Total: "General"												
Mean	43.89	0.04	30.57	8.65	0.16	16.34	47.72	0.02	30.95	0.57	0.17	20.61
Standard Error	3.84	0.02	3.43	1.64	0.16	2.75	3.99	0.01	3.46	0.16	0.17	3.20
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	98.70	1.30	91.00	97.80	11.30	100.00	100.10	0.70	93.00	5.40	12.00	100.00
Total: "Good"												
Mean	63.22	0.05	25.55	5.46	0.31	5.44	67.80	0.02	25.04	0.52	0.33	6.32
Standard Error	4.79	0.04	4.61	1.17	0.31	1.83	5.02	0.02	4.45	0.23	0.33	1.88
Minimum	7.60	0.00	0.00	0.00	0.00	0.00	7.60	0.00	0.00	0.00	0.00	0.00
Maximum	98.70	1.30	83.30	26.70	11.30	53.30	100.10	0.60	79.10	5.20	12.00	53.30
Total: "Poor"												
Mean	24.56	0.02	35.59	11.85	0.00	27.24	27.64	0.02	36.85	0.62	0.00	34.90
Standard Error	3.94	0.02	5.01	3.00	0.00	4.53	4.04	0.02	5.16	0.24	0.00	5.12
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.80
Maximum	90.80	0.70	91.00	97.80	0.00	100.00	90.80	0.70	93.00	5.40	0.00	100.00
Commercial: "General"												
Mean	48.17	0.00	17.04	13.78	0.47	19.34	54.01	0.00	19.31	0.00	0.50	26.20
Standard Error	7.40	0.00	4.76	4.29	0.47	4.93	7.56	0.00	5.45	0.00	0.50	6.35
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	98.70	0.00	91.00	97.80	11.30	78.50	100.10	0.00	93.00	0.00	12.00	100.00
Commercial: "Good"												
Mean	78.31	0.00	7.58	7.55	0.94	5.55	23.07	0.00	30.68	0.00	0.00	46.28
Standard Error	4.14	0.00	1.90	2.46	0.94	3.23	6.92	0.00	9.83	0.00	0.00	9.07
Minimum	44.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.00
Maximum	98.70	0.00	19.20	26.70	11.30	38.70	84.10	0.00	93.00	0.00	0.00	100.00
Commercial: "Poor"												
Mean	18.03	0.00	26.50	20.01	0.00	33.13	23.07	0.00	30.68	0.00	0.00	46.28
Standard Error	6.83	0.00	8.66	7.99	0.00	7.54	6.92	0.00	9.83	0.00	0.00	9.07
Minimum	0.00	0.00	0.00	0.00	0.00	2.20	0.00	0.00	0.00	0.00	0.00	7.00
Maximum	83.30	0.00	91.00	97.80	0.00	78.50	84.10	0.00	93.00	0.00	0.00	100.00

APPENDIX 4.6 (continue . . .)

	"Annual" ecological index						"Perennial" ecological index					
	Decreaser	**Incr I**	**Incr II**	**Incr III**	**FORBS**	**BP**	**Decreaser**	**Incr I**	**Incr II**	**Incr III**	**FORBS**	**BP**
Tribal: "General"												
Mean	22.07	0.05	61.46	5.35	0.00	11.12	23.59	0.05	59.36	1.72	0.00	15.31
Standard Error	3.44	0.04	3.57	1.10	0.00	4.20	3.61	0.04	3.85	0.40	0.00	4.63
Minimum	1.00	0.00	23.80	0.00	0.00	0.00	1.10	0.00	14.10	0.00	0.00	0.00
Maximum	63.30	0.70	83.30	17.40	0.00	74.30	67.30	0.70	82.70	5.40	0.00	84.90
Tribal: "Good"												
Mean	29.05	0.05	61.03	3.12	0.00	6.82	30.87	0.05	58.89	1.57	0.00	8.68
Standard Error	5.19	0.05	4.87	0.89	0.00	4.41	5.31	0.05	4.94	0.58	0.00	4.22
Minimum	7.60	0.00	34.40	0.00	0.00	0.00	7.60	0.00	32.60	0.00	0.00	0.00
Maximum	63.30	0.60	83.30	7.30	0.00	53.30	67.30	0.60	79.10	5.20	0.00	53.30
Tribal: "Poor"												
Mean	15.09	0.06	61.90	7.58	0.00	15.43	16.31	0.06	59.84	1.87	0.00	21.94
Standard Error	3.69	0.06	5.42	1.83	0.00	7.13	4.07	0.06	6.12	0.56	0.00	8.00
Minimum	1.00	0.00	23.80	1.00	0.00	0.00	1.10	0.00	14.10	0.00	0.00	2.80
Maximum	36.30	0.70	81.60	17.40	0.00	74.30	41.30	0.70	82.70	5.40	0.00	84.90
Reserve: "General"												
Mean	61.43	0.05	13.22	6.84	0.00	18.56	65.55	0.00	14.17	0.00	0.00	20.33
Standard Error	5.92	0.05	3.34	1.92	0.00	5.13	6.01	0.00	3.58	0.00	0.00	5.50
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	98.30	1.30	62.20	30.60	0.00	100.00	98.30	0.00	62.90	0.00	0.00	100.00
Reserve: "Good"												
Mean	82.32	0.11	8.05	5.72	0.00	3.94	87.56	0.00	8.30	0.00	0.00	4.17
Standard Error	3.81	0.11	2.00	2.31	0.00	1.35	2.94	0.00	2.13	0.00	0.00	1.41
Minimum	64.80	0.00	0.00	0.00	0.00	0.00	66.80	0.00	0.00	0.00	0.00	0.00
Maximum	98.30	1.30	18.20	24.20	0.00	15.80	98.30	0.00	19.00	0.00	0.00	16.30
Reserve: "Poor"												
Mean	40.55	0.00	18.38	7.96	0.00	33.18	43.54	0.00	20.04	0.00	0.00	36.48
Standard Error	7.27	0.00	6.14	3.14	0.00	8.32	7.38	0.00	6.55	0.00	0.00	8.77
Minimum	0.00	0.00	0.00	0.00	0.00	3.80	0.00	0.00	0.00	0.00	0.00	3.90
Maximum	90.80	0.00	62.20	30.60	0.00	100.00	90.80	0.00	62.90	0.00	0.00	100.00

Appendix 4.7. SIMPER analyses displaying the similarities within and dissimilarities between the “land uses for the “perennial” ecological index.

Group Commercial - Average similarity: 48.48

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Decreaser	54.01	32.73	1.05	67.51	67.51
BP	26.20	9.46	0.57	19.51	87.02
Incr II	19.31	6.29	0.58	12.98	100.00

Group Tribal - Average similarity: 67.99

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Incr II	59.36	48.66	2.72	71.57	71.57
Decreaser	23.59	13.56	1.22	19.94	91.51

Group Reserve - Average similarity: 61.10

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Decreaser	65.55	48.77	1.75	79.82	79.82
BP	20.33	6.92	0.59	11.33	91.15

Groups Commercial & Tribal - Average dissimilarity: 58.85

	Group Commercial	Group Tribal				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Incr II	19.31	59.36	23.03	2.05	39.13	39.13
Decreaser	54.01	23.59	20.81	1.47	35.37	74.50
BP	26.20	15.31	13.87	1.00	23.58	98.07

Groups Commercial & Reserve - Average dissimilarity: 44.94

	Group Commercial	Group Reserve				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Decreaser	54.01	65.55	19.21	1.36	42.75	42.75
BP	26.20	20.33	14.77	1.06	32.87	75.62
Incr II	19.31	14.17	10.71	0.92	23.82	99.44

Groups Tribal & Reserve - Average dissimilarity: 59.21

	Group Tribal	Group Reserve				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Incr II	59.36	14.17	23.44	2.14	39.59	39.59
Decreaser	23.59	65.55	23.32	1.74	39.38	78.97
BP	15.31	20.33	11.56	0.89	19.53	98.51

APPENDIX 4.7 (continue . . .)

Group Poor - Average similarity: 51.05

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Incr II	36.85	19.06	0.82	37.34	37.34
BP	34.90	17.68	0.92	34.64	71.98
Decreaser	27.64	14.22	0.98	27.86	99.85

Group Good - Average similarity: 63.53

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Decreaser	67.80	51.04	1.74	80.35	80.35
Incr II	25.04	10.62	0.71	16.71	97.06

Groups Poor & Good - Average dissimilarity: 56.99

	Group Poor	Group Good				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Decreaser	27.64	67.80	23.74	1.67	41.64	41.64
Incr II	36.85	25.04	16.67	1.31	29.25	70.90
BP	34.90	6.32	15.91	1.09	27.91	98.81

Appendix 4.8. SIMPER analyses displaying the similarities within and dissimilarities between the “Good” and “Poor” rangeland condition groups within each land use for the “perennial” ecological index.

Commercial

Group Poor - Average similarity: 49.37

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
BP	46.28	27.63	1.25	55.96	55.96
Incr II	30.68	11.40	0.59	23.09	79.05
Decreaser	23.07	10.34	0.95	20.95	100.00

Group Good - Average similarity: 81.95

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Decreaser	84.96	77.09	5.49	94.07	94.07

Groups Poor & Good - Average dissimilarity: 67.27

	Group Poor	Group Good				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Decreaser	23.07	84.96	31.34	2.52	46.59	46.59
BP	46.28	6.12	21.15	1.43	31.45	78.04
Incr II	30.68	7.94	14.27	1.00	21.22	99.26

Tribal

Group Poor - Average similarity: 65.01

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Incr II	59.84	48.04	2.28	73.90	73.90
Decreaser	16.31	8.20	0.96	12.62	86.51
BP	21.94	8.02	0.78	12.33	98.85

Group Good - Average similarity: 72.08

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Incr II	58.89	48.81	3.56	67.72	67.72
Decreaser	30.87	20.09	1.79	27.87	95.59

Groups Poor & Good - Average dissimilarity: 32.52

	Group Poor	Group Good				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Decreaser	16.31	30.87	10.57	1.31	32.50	32.50
Incr II	59.84	58.89	10.46	1.34	32.18	64.68
BP	21.94	8.68	10.40	0.82	31.98	96.65

APPENDIX 4.8 (continue . . .)

Reserve

Group Poor - Average similarity: 55.03

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Decreaser	43.54	28.44	1.50	51.68	51.68
BP	36.48	19.08	1.05	34.68	86.36
Incr II	20.04	7.51	0.65	13.64	100.00

Group Good - Average similarity: 87.26

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Decreaser	87.56	81.71	8.50	93.64	93.64

Groups Poor & Good - Average dissimilarity: 48.10

	Group Poor	Group Good				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Decreaser	43.54	87.56	22.52	1.83	46.82	46.82
BP	36.48	4.17	16.52	1.15	34.34	81.16
Incr II	20.04	8.30	9.06	0.99	18.84	100.00

Appendix 4.9. Descriptive statistics for the life-form data

	"Annual" life-form					**"Perennial" life-form**			
	Perennial	**Weak perennial**	**ANNUAL**	**Forbs**	**BP**	**Perennial**	**Weak perennial**	**Forbs**	**BP**
Total: "General"									
Mean	50.24	23.88	9.41	0.16	16.34	37.96	41.30	0.17	20.61
Standard Error	3.21	2.55	1.68	0.16	2.75	3.68	3.33	0.17	3.20
Maximum	100.00	82.20	97.80	11.30	100.00	98.70	93.00	12.00	100.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total: "Good"									
Mean	62.95	25.53	5.78	0.31	5.44	56.62	36.76	0.33	6.32
Standard Error	3.67	3.39	1.27	0.31	1.83	4.61	4.24	0.33	1.88
Maximum	100.00	79.28	26.70	11.30	53.30	98.70	84.40	12.00	53.30
Minimum	13.14	0.00	0.00	0.00	0.00	1.30	1.30	0.00	0.00
Total: "Poor"									
Mean	37.53	22.23	13.04	0.00	27.24	19.31	45.83	0.00	34.90
Standard Error	4.38	3.84	3.01	0.00	4.53	3.70	5.09	0.00	5.12
Maximum	91.00	82.20	97.80	0.00	100.00	86.60	93.00	0.00	100.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.80
Commercial: "General"									
Mean	53.80	12.59	13.78	0.47	19.34	42.98	30.34	0.50	26.20
Standard Error	6.35	2.88	4.29	0.47	4.93	7.48	5.90	0.50	6.35
Maximum	100.00	55.10	97.80	11.30	78.50	98.70	93.00	12.00	100.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Commercial: "Good"									
Mean	72.54	13.35	7.55	0.94	5.55	14.95	38.79	0.00	46.28
Standard Error	5.35	3.38	2.46	0.94	3.23	7.42	10.58	0.00	9.07
Maximum	100.00	32.10	26.70	11.30	38.70	86.60	93.00	0.00	100.00
Minimum	45.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.00
Commercial: "Poor"									
Mean	35.06	11.83	20.01	0.00	33.13	71.02	21.88	1.00	6.12
Standard Error	8.74	4.81	7.99	0.00	7.54	6.02	4.54	1.00	3.59
Maximum	91.00	55.10	97.80	0.00	78.50	98.70	45.90	12.00	43.40
Minimum	0.00	0.00	0.00	0.00	2.20	42.10	1.30	0.00	0.00

APPENDIX 4.9 (continue . . .)

	"Annual" life-form					"Perennial" life-form			
	Perennial	**Weak perennial**	**ANNUAL**	**Forbs**	**BP**	**Perennial**	**Weak perennial**	**Forbs**	**BP**
Tribal: "General"									
Mean	39.90	41.43	7.61	0.00	11.12	23.10	61.62	0.00	15.31
Standard Error	3.95	5.13	1.65	0.00	4.20	3.78	4.76	0.00	4.63
Maximum	74.90	82.20	28.20	0.00	74.30	75.00	84.40	0.00	84.90
Minimum	11.50	0.00	0.00	0.00	0.00	1.10	2.70	0.00	0.00
Tribal: "Good"									
Mean	40.87	48.32	4.06	0.00	6.82	25.53	65.85	0.00	8.68
Standard Error	4.54	4.96	1.84	0.00	4.41	4.51	5.13	0.00	4.22
Maximum	66.90	79.28	22.80	0.00	53.30	58.50	84.40	0.00	53.30
Minimum	13.14	15.20	0.00	0.00	0.00	1.30	27.60	0.00	0.00
Tribal: "Poor"									
Mean	38.93	34.54	11.16	0.00	15.43	20.68	57.40	0.00	21.94
Standard Error	6.67	8.77	2.40	0.00	7.13	6.19	8.07	0.00	8.00
Maximum	74.90	82.20	28.20	0.00	74.30	75.00	84.10	0.00	84.90
Minimum	11.50	0.00	1.10	0.00	0.00	1.10	2.70	0.00	2.80
Reserve: General									
Mean	57.03	17.63	6.84	0.00	18.56	47.80	31.93	0.00	20.33
Standard Error	5.69	2.24	1.92	0.00	5.13	6.32	4.27	0.00	5.50
Maximum	90.70	49.60	30.60	0.00	100.00	90.70	80.90	0.00	100.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Reserve: "Good"									
Mean	75.43	14.93	5.72	0.00	3.94	73.30	22.56	0.00	4.17
Standard Error	3.58	1.58	2.31	0.00	1.35	3.79	3.00	0.00	1.41
Maximum	90.70	22.40	24.20	0.00	15.80	90.70	38.20	0.00	16.30
Minimum	56.60	6.70	0.00	0.00	0.00	45.50	6.70	0.00	0.00
Reserve: "Poor"									
Mean	38.62	20.32	7.96	0.00	33.18	22.29	41.29	0.00	36.48
Standard Error	7.82	4.15	3.14	0.00	8.32	5.86	7.16	0.00	8.77
Maximum	87.80	49.60	30.60	0.00	100.00	68.30	80.90	0.00	100.00
Minimum	0.00	0.00	0.00	0.00	3.80	0.00	0.00	0.00	3.90

Appendix 4.10. SIMPER analyses displaying the similarities within each land use and rangeland condition group ("Good" vs. "Poor") and dissimilarities between each land use and between each rangeland condition group for the "perennial" life-form data.

Group Commercial - Average similarity: 45.23

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
PEREN	42.98	21.76	0.80	48.11	48.11
WEAKPEN	30.34	14.01	0.80	30.99	79.09
BP	26.20	9.46	0.57	20.91	100.00

Group Tribal - Average similarity: 67.17

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
WEAKPEN	61.62	49.13	2.02	73.14	73.14
PEREN	23.10	12.92	1.22	19.23	92.37

Group Reserve - Average similarity: 57.29

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
PEREN	47.80	29.81	1.15	52.04	52.04
WEAKPEN	31.93	20.55	1.67	35.88	87.92
BP	20.33	6.92	0.59	12.08	100.00

Groups Commercial & Tribal - Average dissimilarity: 52.95

	Group Commercial	Group Tribal				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
WEAKPEN	30.34	61.62	20.58	1.67	38.87	38.87
PEREN	42.98	23.10	18.25	1.40	34.46	73.33
BP	26.20	15.31	13.87	1.00	26.20	99.53

Groups Commercial & Reserve - Average dissimilarity: 48.24

	Group Commercial	Group Reserve				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
PEREN	42.98	47.80	19.26	1.41	39.92	39.92
BP	26.20	20.33	14.77	1.06	30.62	70.54
WEAKPEN	30.34	31.93	13.96	1.33	28.94	99.48

Groups Tribal & Reserve - Average dissimilarity: 47.97

	Group Tribal	Group Reserve				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
WEAKPEN	61.62	31.93	18.60	1.78	38.77	38.77
PEREN	23.10	47.80	17.81	1.47	37.12	75.89
BP	15.31	20.33	11.56	0.89	24.11	100.00

APPENDIX 4.10 (continue . . .)

Group Poor - Average similarity: 53.73

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
WEAKPEN	45.83	28.12	1.10	52.33	52.33
BP	34.90	17.68	0.92	32.91	85.24
PEREN	19.31	7.93	0.76	14.76	100.00

Group Good - Average similarity: 64.62

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
PEREN	56.62	40.54	1.70	62.74	62.74
WEAKPEN	36.76	22.26	1.30	34.45	97.19

Groups Poor & Good - Average dissimilarity: 54.35

	Group Poor	Group Good				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
PEREN	19.31	56.62	21.76	1.62	40.04	40.04
WEAKPEN	45.83	36.76	16.52	1.44	30.40	70.43
BP	34.90	6.32	15.91	1.09	29.26	99.69

Appendix 4.11. SIMPER analyses displaying the similarities within and dissimilarities between the "Good" and "Poor" rangeland condition groups within each land use for the "annual" life-form.

Commercial

Group Poor - Average similarity: 45.23

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
BP	33.13	17.74	1.00	39.22	39.22
PERENNIAL	35.06	17.61	1.02	38.92	78.14
ANNUAL	20.01	6.52	0.70	14.42	92.56

Group Good - Average similarity: 71.95

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
PERENNIAL	72.54	61.60	4.64	85.61	85.61
WEAKPER	13.35	6.49	0.87	9.02	94.63

Groups Poor & Good - Average dissimilarity: 54.44

	Group Poor	Group Good				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
PERENNIAL	35.06	72.54	21.91	1.73	40.25	40.25
BP	33.13	5.55	15.29	1.28	28.08	68.33
ANNUAL	20.01	7.55	9.33	0.78	17.15	85.47
WEAKPER	11.83	13.35	7.44	1.17	13.66	99.14

Tribal

Group Poor - Average similarity: 52.04

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
PERENNIAL	38.93	25.29	1.67	48.60	48.60
WEAKPER	34.54	16.91	0.89	32.48	81.08
ANNUAL	11.16	6.32	1.24	12.14	93.22

Group Good - Average similarity: 72.08

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
WEAKPER	48.32	38.24	2.78	53.06	53.06
PERENNIAL	40.87	31.80	2.87	44.11	97.17

APPENDIX 4.11 (continue . . .)

Groups Poor & Good - Average dissimilarity: 40.36

	Group Poor	Group Good				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
WEAKPER	34.54	48.32	15.54	1.69	38.51	38.51
PERENNIAL	38.93	40.87	11.20	1.51	27.76	66.27
BP	15.43	6.82	8.78	0.75	21.75	88.02
ANNUAL	11.16	4.06	4.84	1.28	11.98	100.00

Reserve

Group Poor - Average similarity: 53.71

Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
PERENNIAL	38.62	22.65	1.16	42.17	42.17
BP	33.18	16.96	1.09	31.58	73.74
WEAKPER	20.32	11.88	1.24	22.13	95.87

Group Good - Average similarity: 82.84

Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
PERENNIAL	75.43	68.13	6.77	82.25	82.25
WEAKPER	14.93	11.68	2.90	14.11	96.35

Groups Poor & Good - Average dissimilarity: 45.62

	Group Poor	Group Good				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
PERENNIAL	38.62	75.43	19.67	1.57	43.11	43.11
BP	33.18	3.94	14.96	1.10	32.79	75.90
WEAKPER	20.32	14.93	6.28	1.34	13.78	89.68
ANNUAL	7.96	5.72	4.71	1.03	10.32	100.00

Appendix 4.12. SIMPER analyses displaying the similarities within and dissimilarities between the "Good" and "Poor" rangeland condition groups within each land use for the "perennial" life-form.

Commercial

Group Poor - Average similarity: 48.18

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
BP	46.28	27.63	1.25	57.34	57.34
WEAKPEN	38.79	17.43	0.68	36.18	93.52

Group Good - Average similarity: 72.02

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
PEREN	71.02	58.58	3.70	81.34	81.34
WEAKPEN	21.88	12.52	1.10	17.38	98.72

Groups Poor & Good - Average dissimilarity: 68.40

	Group Poor	Group Good				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
PEREN	14.95	71.02	29.55	2.31	43.20	43.20
BP	46.28	6.12	21.15	1.43	30.93	74.13
WEAKPEN	38.79	21.88	17.20	1.45	25.14	99.27

Tribal

Group Poor - Average similarity: 59.18

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
WEAKPEN	57.40	41.85	1.52	70.71	70.71
PEREN	20.68	9.31	1.02	15.74	86.45
BP	21.94	8.02	0.78	13.55	100.00

Group Good - Average similarity: 75.17

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
WEAKPEN	65.85	55.94	3.20	74.41	74.41
PEREN	25.53	16.54	1.68	22.00	96.41

Groups Poor & Good - Average dissimilarity: 32.84

	Group Poor	Group Good				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
WEAKPEN	57.40	65.85	12.26	1.12	37.34	37.34
BP	21.94	8.68	10.40	0.82	31.67	69.01
PEREN	20.68	25.53	10.18	1.27	30.99	100.00

APPENDIX 4.12 (continue . . .)

Reserve

Group Poor - Average similarity: 56.97

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
WEAKPEN	41.29	26.95	1.61	47.30	47.30
BP	36.48	19.08	1.05	33.50	80.80
PEREN	22.29	10.94	1.06	19.20	100.00

Group Good - Average similarity: 83.56

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
PEREN	73.30	65.64	5.73	78.55	78.55
WEAKPEN	22.56	16.34	2.11	19.56	98.11

Groups Poor & Good - Average dissimilarity: 54.61

	Group Poor	Group Good				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
PEREN	22.29	73.30	25.74	2.33	47.13	47.13
BP	36.48	4.17	16.52	1.15	30.25	77.37
WEAKPEN	41.29	22.56	12.36	1.23	22.63	100.00

Appendix 4.13. SIMPER analyses displaying the similarities within and dissimilarities between the "Good" and "Poor" rangeland condition groups within each land use for the different rangeland condition indices.

Commercial

Group Poor - Average similarity: 63.79

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
VCSAGRAZ	371.60	17.56	3.35	27.53	27.53
VCSPGRAZ	397.72	16.97	1.84	26.60	54.13
VCSPECOL	353.37	15.44	1.88	24.20	78.33
VCSAECOL	306.34	13.82	2.40	21.67	100.00

Group Good - Average similarity: 90.49

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
VCSPECOL	882.35	24.09	9.75	26.62	26.62
VCSPGRAZ	858.18	23.09	10.32	25.52	52.14
VCSAECOL	821.91	22.09	9.16	24.41	76.55
VCSAGRAZ	799.79	21.22	10.37	23.45	100.00

Groups Poor & Good - Average dissimilarity: 43.95

	Group Poor	Group Good				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
VCSPECOL	353.37	882.35	11.90	1.96	27.09	27.09
VCSAECOL	306.34	821.91	11.62	2.20	26.44	53.53
VCSPGRAZ	397.72	858.18	10.57	1.66	24.05	77.58
VCSAGRAZ	371.60	799.79	9.85	1.81	22.42	100.00

Tribal

Group Poor - Average similarity: 72.26

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
VCSPGRAZ	477.97	19.45	3.24	26.91	26.91
VCSAGRAZ	453.73	18.95	3.34	26.22	53.13
VCSAECOL	406.50	17.54	3.59	24.27	77.41
VCSPECOL	404.73	16.33	2.72	22.59	100.00

APPENDIX 4.13 (continue . . .)

Group Good - Average similarity: 84.71

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
VCSPGRAZ	587.78	22.56	5.38	26.63	26.63
VCSAGRAZ	566.25	21.65	5.75	25.55	52.19
VCSPECOL	546.19	20.40	6.31	24.09	76.27
VCSAECOL	538.06	20.10	6.31	23.73	100.00

Groups Poor & Good - Average dissimilarity: 22.60

	Group Poor	Group Good				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
VCSPGRAZ	477.97	587.78	5.99	1.10	26.49	26.49
VCSPECOL	404.73	546.19	5.76	1.07	25.49	51.99
VCSAGRAZ	453.73	566.25	5.54	1.06	24.50	76.49
VCSAECOL	406.50	538.06	5.31	1.10	23.51	100.00

Reserve

Group Poor: Average similarity: 61.80

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
VCSPECOL	515.58	17.75	1.93	28.72	28.72
VCSAECOL	486.99	16.29	1.89	26.35	55.07
VCSPGRAZ	459.12	14.46	1.69	23.40	78.47
VCSAGRAZ	440.88	13.31	1.68	21.53	100.00

Group Good - Average similarity: 94.16

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
VCSPECOL	908.78	24.76	18.41	26.30	26.30
VCSPGRAZ	885.33	24.24	20.96	25.75	52.05
VCSAECOL	861.84	22.87	16.68	24.29	76.34
VCSAGRAZ	839.53	22.28	16.01	23.66	100.00

Groups Poor & Good - Average dissimilarity: 33.99

	Group Poor	Group Good				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
VCSPGRAZ	459.12	885.33	8.98	1.33	26.43	26.43
VCSAGRAZ	440.88	839.53	8.53	1.29	25.10	51.53
VCSPECOL	515.58	908.78	8.38	1.23	24.66	76.19
VCSAECOL	486.99	861.84	8.09	1.24	23.81	100.00

Appendix 5.1. Woody species surveyed within the study area.

Scientific name	**After**	**Abreviation**	**Growth form**	**Encroacher**
Acacia erioloba	E. Meyer	***Ac eri***	**Medium/ large tree**	No/potentially overutilised areas
Acacia haematoxylon	Willd	***Ac hae***	Shrub/small tree	No
Acacia hebeclada	DC	***Ac heb***	Shrub/small tree	Yes
Acacia luederitzii	Engl.	***Ac lue***	Shrub/medium tree	No
Acacia mellifera	(Vahl) Benth.	***Ac mel***	Shrub/small tree	Yes
Acacia karroo	Hayne	***Ac kar***	Shrub/medium tree	No/potentially
Acacia robusta	Burch.	***Ac rob***	Small/medium tree	No
Acacia tortilis	(Forsk.) Hayne	***Ac tor***	Small/medium tree	No/potentially
Boscia albitrunca	(Burch.) Gilg & Benedict	***Bos alb***	Small tree	No
Dichrostachys cinerea	(L.) Wight & Arn.	***Dic cin***	Shrub/small tree	Yes
Diospyros lycoides	Desf.	***Dio lyc***	Shrub/medium tree	Yes
Ehretia rigida	(Thunb.) Druce	***Ehr rig***	Shrub/small tree	No/potentially
Grewia flava	DC	***Gre fla***	Shrub/small tree	Yes
Grewia flavescens	Juss.	***Gre flsc***	Shrub/small tree	No
Gymnosporia buxifolia	(L.) Szyszyl.	***Gym bux***	Shrub/small tree	Yes
Cadaba sp.	(Thunb.) Wild	***Cadaba***	Shrub/small tree	No
Lycium hirsitum	Dunal	***Lyc hir***	Shrub	Yes
Mundulea sericea	(Wild.) Chev.	***Mun ser***	Shrub/small tree	No
Protasparagus suleovons	Burch	***Prot sul***	Shrub	Yes
Rhigozum brevispinosum	Kuntze	***Rhi bre***	Shrub/small tree	No
Rhus ciliata	Licht ex Schult	***Rhu cil***	Small tree	No
Tarchonanthus camphoratus	L. (Linnaues)	***Tar cam***	Shrub/small tree	Yes
Terminalia sericea	Burch. Ex DC	***Ter ser***	Small/medium tree	Yes
Ziziphus mucronata	Willd.	***Ziz muc***	Shrub/medium tree	Yes

Appendix 5.2. The mean relative abundances of woody species for the TE-matrix, with the two species showing the highest average relative abundance within a land use group, indicated in **bold**

Land Use Type	***Ac eri***	***Ac hae***	***Ac heb***	***Ac lue***	***Ac mel***	***Ac kar***	***Ac rob***	***Ac tor***	***Bos alb***	***Dic cin***	***Dio lyc***	***Ehr rig***	***Gre fla***	***Gre flsc***	***Gym bux***	***Cadaba***	***Lyc hir***	***Mun ser***	***Prot sul***	***Rhi bre***	***Rhu cil***	***Tar cam***	***Ter ser***	***Ziz muc***
Total: "General"																								
Mean	7.72	2.30	2.66	4.07	**12.63**	0.36	0.02	0.03	3.19	5.42	0.12	1.21	**31.10**	1.42	3.93	0.01	1.45	0.30	7.18	7.08	2.65	0.69	2.84	1.62
Standard Error	1.36	1.19	0.90	1.21	1.87	0.21	0.02	0.02	0.78	1.56	0.08	0.25	2.19	0.56	1.13	0.01	0.49	0.18	1.59	1.55	0.64	0.30	0.90	0.49
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	44.97	67.95	51.95	49.91	66.33	10.42	1.76	1.04	41.73	79.82	5.74	8.73	92.13	29.74	50.00	0.37	19.50	10.41	100.00	73.16	22.67	14.26	41.99	24.50
Total: "Good"																								
Mean	**9.12**	4.27	2.60	1.98	6.25	0.43	0.00	0.04	1.81	7.99	0.16	0.73	**32.27**	0.63	4.57	0.00	2.28	0.13	8.50	6.54	3.95	0.69	3.58	1.47
Standard Error	2.05	2.32	1.03	1.02	1.83	0.31	0.00	0.03	0.62	2.85	0.16	0.21	3.46	0.44	1.69	0.00	0.88	0.13	2.82	1.68	1.10	0.43	1.48	0.72
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	44.97	67.95	25.21	32.80	50.79	9.55	0.00	1.04	13.76	79.82	5.74	4.58	92.13	14.78	50.00	0.00	19.50	4.62	100.00	38.05	22.67	13.77	41.99	24.50
Total: "Poor"																								
Mean	6.33	0.33	2.72	6.16	**19.01**	0.29	0.05	0.02	4.58	2.86	0.09	1.70	**29.92**	2.20	3.28	0.01	0.63	0.47	5.86	7.62	1.35	0.68	2.09	1.77
Standard Error	1.77	0.33	1.50	2.16	2.91	0.29	0.05	0.02	1.42	1.15	0.06	0.44	2.73	1.02	1.51	0.01	0.41	0.34	1.51	2.62	0.60	0.42	1.02	0.69
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	44.78	11.78	51.95	49.91	66.33	10.42	1.76	0.82	41.73	29.35	1.74	8.73	64.95	29.74	40.71	0.37	13.90	10.41	42.95	73.16	19.66	14.26	33.58	16.90
Commercial: "General"																								
Mean	7.87	6.87	2.86	1.33	9.77	0.00	0.00	0.00	5.51	2.10	0.00	1.50	**41.53**	1.20	0.00	0.00	0.00	0.00	**12.05**	6.14	0.60	0.00	0.00	0.67
Standard Error	2.80	3.42	2.17	0.86	2.84	0.00	0.00	0.00	2.01	2.02	0.00	0.50	4.53	0.67	0.00	0.00	0.00	0.00	4.42	2.44	0.36	0.00	0.00	0.67
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	44.97	67.95	51.95	17.65	43.65	0.00	0.00	0.00	41.73	48.44	0.00	8.28	92.13	10.55	0.00	0.00	0.00	0.00	100.00	38.05	8.02	0.00	0.00	16.07
Commercial: "Good"																								
Mean	10.54	12.76	0.94	0.23	1.97	0.00	0.00	0.00	2.59	4.20	0.00	0.46	**42.02**	0.00	0.00	0.00	0.00	0.00	**13.81**	9.52	0.95	0.00	0.00	0.00
Standard Error	5.17	6.45	0.69	0.23	0.75	0.00	0.00	0.00	1.30	4.02	0.00	0.34	7.55	0.00	0.00	0.00	0.00	0.00	8.16	4.35	0.70	0.00	0.00	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	44.97	67.95	7.87	2.73	8.33	0.00	0.00	0.00	10.28	48.44	0.00	4.11	92.13	0.00	0.00	0.00	0.00	0.00	100.00	38.05	8.02	0.00	0.00	0.00
Commercial: "Poor"																								
Mean	5.20	0.98	4.77	2.43	**17.56**	0.00	0.00	0.00	8.44	0.00	0.00	2.55	**41.04**	2.40	0.00	0.00	0.00	0.00	10.28	2.76	0.25	0.00	0.00	1.34
Standard Error	2.18	0.98	4.31	1.68	4.71	0.00	0.00	0.00	3.69	0.00	0.00	0.86	5.36	1.26	0.00	0.00	0.00	0.00	3.81	2.00	0.18	0.00	0.00	1.34
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	24.26	11.78	51.95	17.65	43.65	0.00	0.00	0.00	41.73	0.00	0.00	8.28	64.95	10.55	0.00	0.00	0.00	0.00	42.95	23.87	2.01	0.00	0.00	16.07

APPENDIX 5.2 (continue . . .)

Land Use Type	***Ac eri***	***Ac hae***	***Ac heb***	***Ac lue***	***Ac mel***	***Ac kar***	***Ac rob***	***Ac tor***	***Bos alb***	***Dic cin***	***Dio lyc***	***Ehr rig***	***Gre fla***	***Gre flsc***	***Gym bux***	***Cadaba***	***Lyc hir***	***Mun ser***	***Prot sul***	***Rhi bre***	***Rhu cil***	***Tar cam***	***Ter ser***	***Ziz muc***
Tribal: "General"																								
Mean	9.26	0.03	2.90	0.02	9.07	1.08	0.07	0.09	0.10	**13.99**	0.36	1.36	**19.79**	3.05	11.78	0.00	0.00	0.90	5.88	2.93	4.49	2.06	8.51	2.26
Standard Error	2.21	0.03	1.13	0.02	3.26	0.61	0.07	0.05	0.07	3.67	0.25	0.39	2.14	1.50	2.79	0.00	0.00	0.53	1.07	1.52	1.39	0.84	2.31	0.79
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	44.78	0.70	21.63	0.59	66.33	10.42	1.76	1.04	1.66	79.82	5.74	7.17	53.61	29.74	50.00	0.00	0.00	10.41	18.45	34.63	20.48	14.26	41.99	16.90
Tribal: "Good"																								
Mean	9.07	0.06	3.07	0.00	3.91	1.30	0.00	0.12	0.00	**19.64**	0.48	1.31	**15.77**	1.90	13.71	0.00	0.00	0.39	7.09	1.97	5.32	2.07	10.75	2.07
Standard Error	1.85	0.06	1.84	0.00	2.39	0.90	0.00	0.09	0.00	6.49	0.48	0.45	1.97	1.27	3.99	0.00	0.00	0.39	1.37	1.20	2.29	1.23	3.73	0.66
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.57	0.00	0.00	3.44	0.00	0.00	0.00	0.00	0.00	0.68	0.00	0.00	0.00	0.00	0.00
Maximum	19.33	0.70	21.63	0.00	28.41	9.55	0.00	1.04	0.00	79.82	5.74	4.58	30.25	14.78	50.00	0.00	0.00	4.62	15.66	14.12	20.48	13.77	41.99	5.82
Tribal: "Poor"																								
Mean	9.45	0.00	2.74	0.05	**14.22**	0.87	0.15	0.07	0.20	8.33	0.23	1.42	**23.82**	4.20	9.84	0.00	0.00	1.41	4.68	3.89	3.66	2.05	6.27	2.46
Standard Error	4.13	0.00	1.39	0.05	5.82	0.87	0.15	0.07	0.15	2.92	0.16	0.65	3.52	2.76	4.00	0.00	0.00	0.98	1.64	2.84	1.64	1.19	2.73	1.47
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	44.78	0.00	16.61	0.59	66.33	10.42	1.76	0.82	1.66	29.35	1.74	7.17	53.61	29.74	40.71	0.00	0.00	10.41	18.45	34.63	19.66	14.26	33.58	16.90
Reserve: "General"																								
Mean	6.04	0.00	2.22	10.85	**19.06**	0.00	0.00	0.00	3.97	0.18	0.02	0.77	**31.97**	0.00	0.00	0.02	4.35	0.00	3.60	12.16	2.86	0.00	0.00	1.92
Standard Error	2.01	0.00	1.25	3.13	3.30	0.00	0.00	0.00	1.00	0.13	0.02	0.40	3.02	0.00	0.00	0.02	1.30	0.00	1.09	3.46	1.19	0.00	0.00	1.06
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	32.01	0.00	25.21	49.91	54.83	0.00	0.00	0.00	16.40	2.86	0.37	8.73	61.89	0.00	0.00	0.37	19.50	0.00	15.38	73.16	22.67	0.00	0.00	24.50
Reserve: "Good"																								
Mean	7.75	0.00	3.78	5.70	**12.88**	0.00	0.00	0.00	2.84	0.12	0.00	0.42	**39.02**	0.00	0.00	0.00	6.83	0.00	4.59	8.13	5.58	0.00	0.00	2.35
Standard Error	3.10	0.00	2.43	2.81	4.42	0.00	0.00	0.00	1.21	0.12	0.00	0.23	3.95	0.00	0.00	0.00	2.14	0.00	1.80	1.88	2.15	0.00	0.00	2.04
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.70	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.00	0.00	0.00	0.00
Maximum	26.65	0.00	25.21	32.80	50.79	0.00	0.00	0.00	13.76	1.40	0.00	1.95	61.89	0.00	0.00	0.00	19.50	0.00	13.24	19.73	22.67	0.00	0.00	24.50
Reserve: "Poor"																								
Mean	4.34	0.00	0.65	15.99	**25.25**	0.00	0.00	0.00	5.10	0.24	0.03	1.13	**24.92**	0.00	0.00	0.03	1.88	0.00	2.61	16.20	0.14	0.00	0.00	1.50
Standard Error	2.61	0.00	0.38	5.32	4.36	0.00	0.00	0.00	1.57	0.24	0.03	0.77	3.66	0.00	0.00	0.03	1.17	0.00	1.25	6.59	0.11	0.00	0.00	0.72
Minimum	0.00	0.00	0.00	0.00	5.76	0.00	0.00	0.00	0.71	0.00	0.00	0.00	6.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	32.01	0.00	3.69	49.91	54.83	0.00	0.00	0.00	16.40	2.86	0.37	8.73	48.34	0.00	0.00	0.37	13.90	0.00	15.38	73.16	1.30	0.00	0.00	8.46

Appendix 5.3. The mean relative abundances of woody species for the Bush numbers per individual species/ha-matrix, with the two species showing the highest average relative abundance within a land use group, indicated in **bold**

	Ac eri	*Ac hae*	*Ac heb*	*Ac lue*	*Ac mel*	*Ac kar*	*Ac rob*	*Ac tor*	*Bos alb*	*Dic cin*	*Dio lyc*	*Ehr rig*	*Gre fla*	*Gre flsc*	*Gym bux*	*Cadaba*	*Mun ser*	*Lic hir*	*Prot sul*	*Rhi bre*	*Rhu cil*	*Tar cam*	*Ter ser*	*Ziz muc*
Total: "General"																								
Mean	6.06	3.32	1.88	0.10	2.73	11.06	0.01	0.07	3.67	4.77	0.14	1.51	**24.65**	1.03	8.09	0.01	2.11	0.45	**12.70**	9.34	2.87	0.41	2.04	1.00
Standard Error	0.94	1.21	1.06	0.06	0.81	1.83	0.01	0.04	0.95	1.50	0.08	0.30	2.17	0.45	2.07	0.01	0.73	0.27	1.94	1.86	0.64	0.15	0.59	0.31
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	28.21	75.24	66.67	3.72	31.86	75.83	0.70	2.13	41.38	76.30	4.00	12.50	80.00	25.87	72.22	1.03	33.33	14.36	75.00	78.52	27.03	6.80	27.27	13.51
Total: "Good"																								
Mean	7.13	3.22	3.57	0.10	1.15	6.02	0.00	0.09	1.90	7.04	0.11	1.03	25.55	0.42	9.02	0.00	3.47	0.19	13.59	9.15	4.11	0.35	2.01	0.79
Standard Error	1.51	1.25	2.09	0.07	0.39	1.85	0.00	0.06	0.67	2.71	0.11	0.30	3.31	0.29	2.92	0.00	1.35	0.19	2.73	2.31	1.05	0.20	0.77	0.40
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	28.21	27.91	66.67	2.13	8.89	57.14	0.00	2.13	15.56	76.30	3.88	6.67	80.00	10.19	72.22	0.00	33.33	6.90	75.00	50.00	27.03	5.56	19.86	13.51
Total: "Poor"																								
Mean	4.99	3.42	0.19	0.10	4.31	16.09	0.02	0.04	5.45	2.50	0.17	1.99	23.74	1.65	7.15	0.03	0.75	0.71	11.81	9.53	1.62	0.47	2.07	1.21
Standard Error	1.11	2.10	0.19	0.10	1.55	2.94	0.02	0.04	1.73	1.20	0.12	0.52	2.86	0.85	2.96	0.03	0.50	0.50	2.79	2.96	0.67	0.23	0.91	0.47
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	21.88	75.24	6.67	3.72	31.86	75.83	0.70	1.60	41.38	36.00	4.00	12.50	71.05	25.87	67.88	1.03	17.24	14.36	68.00	78.52	21.88	6.80	27.27	12.70
Commercial: "General"																								
Mean	5.53	4.70	5.61	0.00	1.08	7.37	0.00	0.00	4.84	2.49	0.00	2.00	**35.32**	0.64	0.00	0.00	0.00	0.00	**19.53**	9.76	0.84	0.00	0.00	0.29
Standard Error	1.65	3.21	3.08	0.00	0.58	1.90	0.00	0.00	1.50	2.27	0.00	0.66	4.59	0.38	0.00	0.00	0.00	0.00	4.72	3.29	0.45	0.00	0.00	0.29
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	28.21	75.24	66.67	0.00	12.50	29.41	0.00	0.00	21.05	54.55	0.00	12.50	80.00	7.89	0.00	0.00	0.00	0.00	75.00	50.00	9.09	0.00	0.00	6.90
Commercial: "Good"																								
Mean	6.18	2.31	10.66	0.00	0.80	2.98	0.00	0.00	2.78	4.97	0.00	0.62	36.80	0.00	0.00	0.00	0.00	0.00	16.07	14.63	1.21	0.00	0.00	0.00
Standard Error	3.06	1.73	5.89	0.00	0.54	1.12	0.00	0.00	1.48	4.53	0.00	0.32	7.23	0.00	0.00	0.00	0.00	0.00	6.72	5.58	0.85	0.00	0.00	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	28.21	20.00	66.67	0.00	5.13	12.50	0.00	0.00	15.56	54.55	0.00	2.70	80.00	0.00	0.00	0.00	0.00	0.00	75.00	50.00	9.09	0.00	0.00	0.00
Commercial: "Poor"																								
Mean	4.88	7.09	0.56	0.00	1.36	11.76	0.00	0.00	6.90	0.00	0.00	3.39	33.85	1.28	0.00	0.00	0.00	0.00	23.00	4.89	0.48	0.00	0.00	0.57
Standard Error	1.42	6.25	0.56	0.00	1.06	3.21	0.00	0.00	2.54	0.00	0.00	1.16	5.95	0.73	0.00	0.00	0.00	0.00	6.77	3.12	0.35	0.00	0.00	0.57
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	12.50	75.24	6.67	0.00	12.50	29.41	0.00	0.00	21.05	0.00	0.00	12.50	71.05	7.89	0.00	0.00	0.00	0.00	68.00	36.36	4.00	0.00	0.00	6.90

APPENDIX 5.3 (continue . . .)

	Ac eri	***Ac hae***	***Ac heb***	***Ac lue***	***Ac mel***	***Ac kar***	***Ac rob***	***Ac tor***	***Bos alb***	***Dic cin***	***Dio lyc***	***Ehr rig***	***Gre fla***	***Gre flsc***	***Gym bux***	***Cadaba***	***Mun ser***	***Lic hir***	***Prot sul***	***Rhi bre***	***Rhu cil***	***Tar cam***	***Ter ser***	***Ziz muc***
Tribal: "General"																								
Mean	7.25	2.66	0.02	0.30	0.02	8.01	0.03	0.20	0.08	11.56	0.39	1.39	13.75	2.46	**24.26**	0.00	0.00	1.35	10.82	2.40	4.19	1.22	6.11	1.53
Standard Error	1.60	0.95	0.02	0.18	0.02	2.87	0.03	0.11	0.06	3.52	0.23	0.37	1.97	1.26	4.74	0.00	0.00	0.78	2.12	1.06	1.18	0.41	1.47	0.63
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	26.07	20.27	0.49	3.72	0.53	54.86	0.70	2.13	1.47	76.30	4.00	6.38	40.54	25.87	72.22	0.00	0.00	14.36	31.67	23.81	21.88	6.80	27.27	12.70
Tribal: "Good"																								
Mean	8.28	2.80	0.04	0.29	0.00	3.65	0.00	0.27	0.00	15.88	0.32	1.37	10.50	1.25	27.07	0.00	0.00	0.57	14.22	1.13	4.23	1.04	6.03	1.05
Standard Error	2.19	1.73	0.04	0.20	0.00	2.62	0.00	0.18	0.00	6.15	0.32	0.53	1.44	0.83	6.09	0.00	0.00	0.57	3.19	0.61	1.60	0.56	1.86	0.40
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	0.00	0.00	1.11	0.00	0.00	0.00	0.00	0.00	2.70	0.00	0.00	0.00	0.00	0.00
Maximum	26.07	20.27	0.49	2.13	0.00	31.67	0.00	2.13	0.00	76.30	3.88	6.38	19.40	10.19	72.22	0.00	0.00	6.90	31.67	6.90	13.95	5.56	19.86	4.26
Tribal: "Poor"																								
Mean	6.22	2.52	0.00	0.31	0.04	12.36	0.06	0.13	0.17	7.24	0.46	1.41	17.01	3.66	21.46	0.00	0.00	2.12	7.42	3.67	4.15	1.40	6.20	2.01
Standard Error	2.38	0.89	0.00	0.31	0.04	4.91	0.06	0.13	0.13	3.25	0.34	0.53	3.49	2.39	7.45	0.00	0.00	1.44	2.56	2.02	1.80	0.63	2.38	1.21
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	21.88	10.94	0.00	3.72	0.53	54.86	0.70	1.60	1.47	36.00	4.00	5.15	40.54	25.87	67.88	0.00	0.00	14.36	26.98	23.81	21.88	6.80	27.27	12.70
Reserve: "General"																								
Mean	5.39	2.61	0.00	0.00	7.09	**17.79**	0.00	0.00	6.10	0.27	0.02	1.14	**24.86**	0.00	0.00	0.04	6.34	0.00	7.73	15.86	3.57	0.00	0.00	1.18
Standard Error	1.68	1.50	0.00	0.00	2.13	4.00	0.00	0.00	2.27	0.18	0.02	0.51	2.95	0.00	0.00	0.04	1.95	0.00	2.22	4.03	1.37	0.00	0.00	0.60
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	26.92	27.91	0.00	0.00	31.86	75.83	0.00	0.00	41.38	3.23	0.49	9.79	57.69	0.00	0.00	1.03	33.33	0.00	29.03	78.52	27.03	0.00	0.00	13.51
Reserve: "Good"																								
Mean	6.92	4.57	0.00	0.00	2.66	11.43	0.00	0.00	2.91	0.27	0.00	1.11	29.35	0.00	0.00	0.00	10.42	0.00	10.47	11.69	6.89	0.00	0.00	1.32
Standard Error	2.74	2.94	0.00	0.00	0.91	4.52	0.00	0.00	1.27	0.27	0.00	0.66	4.08	0.00	0.00	0.00	3.29	0.00	3.82	3.20	2.42	0.00	0.00	1.13
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.29	0.00	0.00	0.00	0.00	0.00	0.00	2.70	0.00	0.00	0.00	0.00
Maximum	26.92	27.91	0.00	0.00	8.89	57.14	0.00	0.00	12.50	3.23	0.00	6.67	57.69	0.00	0.00	0.00	33.33	0.00	29.03	34.88	27.03	0.00	0.00	13.51
Reserve: "Poor"																								
Mean	3.86	0.66	0.00	0.00	11.53	24.16	0.00	0.00	9.29	0.26	0.04	1.18	20.38	0.00	0.00	0.09	2.25	0.00	5.00	20.03	0.24	0.00	0.00	1.03
Standard Error	1.95	0.39	0.00	0.00	3.81	6.27	0.00	0.00	4.26	0.26	0.04	0.81	4.01	0.00	0.00	0.09	1.44	0.00	2.17	7.39	0.20	0.00	0.00	0.46
Minimum	0.00	0.00	0.00	0.00	0.00	3.85	0.00	0.00	1.15	0.00	0.00	0.00	3.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	20.69	3.45	0.00	0.00	31.86	75.83	0.00	0.00	41.38	3.15	0.49	9.79	42.31	0.00	0.00	1.03	17.24	0.00	25.77	78.52	2.38	0.00	0.00	4.55

Appendix 5.4. The mean relative abundances of woody species for the Bush area coverage-matrix (m²/ha), with the two species showing the highest average relative abundance within a land use group, indicated in **bold**

	Ac eri	***Ac hae***	***Ac heb***	***Ac lue***	***Ac mel***	***Ac kar***	***Ac rob***	***Ac tor***	***Bos alb***	***Dic cin***	***Dio lyc***	***Ehr rig***	***Gre fla***	***Gre flsc***	***Gym bux***	***Cadaba***	***Mun ser***	***Lic hir***	***Prot sul***	***Rhi bre***	***Rhu cil***	***Tar cam***	***Ter ser***	***Ziz muc***
Total: "General"																								
Mean	6.85	2.64	1.31	0.79	5.63	16.97	0.01	0.00	2.59	5.99	0.02	0.71	36.79	1.04	0.45	0.00	0.21	1.43	3.34	4.87	2.08	0.72	3.99	1.58
Standard Error	1.50	0.85	0.72	0.55	1.79	2.43	0.01	0.00	0.80	1.79	0.02	0.19	2.73	0.43	0.17	0.00	0.14	0.63	1.42	1.25	0.62	0.33	1.47	0.64
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	65.96	41.52	39.38	35.50	83.61	69.86	0.85	0.19	44.71	82.93	1.12	8.93	93.69	21.65	8.57	0.28	9.40	37.57	100.00	66.50	31.01	16.79	68.22	32.93
Total: "Good"																								
Mean	7.49	2.09	2.56	0.58	3.84	8.66	0.00	0.00	2.68	9.89	0.03	0.42	37.26	0.30	0.54	0.00	0.08	2.37	5.11	4.76	3.47	0.78	5.63	1.45
Standard Error	2.01	0.82	1.42	0.49	2.53	2.47	0.00	0.00	1.36	3.36	0.03	0.23	3.98	0.21	0.25	0.00	0.08	1.19	2.79	1.35	1.16	0.50	2.51	0.88
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	44.74	19.29	39.38	17.20	83.61	54.00	0.00	0.08	44.71	82.93	1.12	6.81	93.69	7.19	7.81	0.00	2.90	37.57	100.00	33.38	31.01	16.79	68.22	30.77
Total: "Poor"																								
Mean	6.21	3.19	0.06	0.99	7.42	25.27	0.02	0.01	2.49	2.09	0.02	0.99	36.32	1.77	0.37	0.01	0.34	0.49	1.57	4.99	0.68	0.65	2.34	1.72
Standard Error	2.25	1.51	0.06	0.99	2.52	3.73	0.02	0.01	0.84	0.89	0.01	0.31	3.78	0.82	0.24	0.01	0.27	0.35	0.38	2.14	0.30	0.43	1.52	0.95
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	65.96	41.52	2.11	35.50	57.64	69.86	0.85	0.19	19.94	23.26	0.38	8.93	82.39	21.65	8.57	0.28	9.40	11.88	8.85	66.50	7.61	14.37	53.02	32.93
Commercial: "General"																								
Mean	7.16	1.99	3.92	0.00	1.88	12.88	0.00	0.00	3.98	1.15	0.00	0.58	51.77	1.43	0.00	0.00	0.00	0.00	7.00	4.48	0.39	0.00	0.00	1.37
Standard Error	2.91	1.50	2.09	0.00	1.25	3.65	0.00	0.00	1.31	1.09	0.00	0.23	5.59	0.95	0.00	0.00	0.00	0.00	4.13	1.91	0.33	0.00	0.00	1.37
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	44.74	35.74	39.38	0.00	22.92	57.55	0.00	0.00	19.94	26.07	0.00	4.38	93.69	21.65	0.00	0.00	0.00	0.00	100.00	33.38	7.83	0.00	0.00	32.93
Commercial: "Good"																								
Mean	10.46	0.66	7.66	0.00	0.14	3.64	0.00	0.00	2.35	2.31	0.00	0.04	52.71	0.00	0.00	0.00	0.00	0.00	11.68	7.65	0.71	0.00	0.00	0.00
Standard Error	5.36	0.53	3.96	0.00	0.14	2.47	0.00	0.00	1.31	2.16	0.00	0.02	8.61	0.00	0.00	0.00	0.00	0.00	8.18	3.52	0.65	0.00	0.00	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	44.74	6.31	39.38	0.00	1.67	30.16	0.00	0.00	14.28	26.07	0.00	0.26	93.69	0.00	0.00	0.00	0.00	0.00	100.00	33.38	7.83	0.00	0.00	0.00
Commercial: "Poor"																								
Mean	3.86	3.31	0.18	0.00	3.63	22.13	0.00	0.00	5.62	0.00	0.00	1.13	50.82	2.86	0.00	0.00	0.00	0.00	2.33	1.32	0.08	0.00	0.00	2.74
Standard Error	2.18	2.97	0.18	0.00	2.45	5.84	0.00	0.00	2.22	0.00	0.00	0.41	7.52	1.85	0.00	0.00	0.00	0.00	0.77	1.05	0.05	0.00	0.00	2.74
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	22.92	35.74	2.11	0.00	22.92	57.55	0.00	0.00	19.94	0.00	0.00	4.38	82.39	21.65	0.00	0.00	0.00	0.00	8.01	12.70	0.49	0.00	0.00	32.93

APPENDIX 5.4 (continue . . .)

	Ac eri	*Ac hae*	*Ac heb*	*Ac lue*	*Ac mel*	*Ac kar*	*Ac rob*	*Ac tor*	*Bos alb*	*Dic cin*	*Dio lyc*	*Ehr rig*	*Gre fla*	*Gre flsc*	*Gym bux*	*Cadaba*	*Mun ser*	*Lic hir*	*Prot sul*	*Rhi bre*	*Rhu cil*	*Tar cam*	*Ter ser*	*Ziz muc*
Tribal: "General"																								
Mean	9.54	4.02	0.01	2.36	0.03	11.75	0.04	0.01	0.04	16.71	0.07	1.18	27.49	1.68	1.36	0.00	0.63	0.00	1.07	2.19	4.25	2.15	11.96	1.48
Standard Error	3.07	1.93	0.01	1.61	0.03	3.92	0.04	0.01	0.04	4.58	0.05	0.48	3.65	0.86	0.47	0.00	0.41	0.00	0.29	1.30	1.62	0.92	3.99	0.55
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	65.96	41.52	0.25	35.50	0.66	64.49	0.85	0.19	0.85	82.93	1.12	8.93	75.40	14.98	8.57	0.00	9.40	0.00	5.06	26.53	31.01	16.79	68.22	10.88
Tribal: "Good"																								
Mean	6.52	3.21	0.02	1.75	0.00	5.72	0.00	0.01	0.00	27.37	0.09	1.17	20.65	0.90	1.63	0.00	0.24	0.00	1.43	1.79	6.61	2.33	16.90	1.66
Standard Error	1.51	2.00	0.02	1.44	0.00	3.35	0.00	0.01	0.00	7.84	0.09	0.64	3.11	0.62	0.65	0.00	0.24	0.00	0.51	1.49	3.04	1.44	6.56	0.68
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.98	0.00	0.00	3.94	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
Maximum	16.89	19.29	0.25	17.20	0.00	36.70	0.00	0.08	0.00	82.93	1.12	6.81	39.98	7.19	7.81	0.00	2.90	0.00	5.06	18.05	31.01	16.79	68.22	7.44
Tribal: "Poor"																								
Mean	12.56	4.83	0.00	2.96	0.05	17.78	0.07	0.02	0.07	6.04	0.05	1.19	34.34	2.46	1.10	0.00	1.01	0.00	0.71	2.60	1.89	1.96	7.02	1.29
Standard Error	5.96	3.39	0.00	2.96	0.05	6.83	0.07	0.02	0.07	2.32	0.03	0.74	6.12	1.62	0.70	0.00	0.80	0.00	0.28	2.19	0.81	1.23	4.37	0.89
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	65.96	41.52	0.00	35.50	0.66	64.49	0.85	0.19	0.85	23.26	0.38	8.93	75.40	14.98	8.57	0.00	9.40	0.00	2.38	26.53	7.61	14.37	53.02	10.88
Reserve: "General"																								
Mean	3.85	1.91	0.00	0.00	14.98	26.26	0.00	0.00	3.74	0.12	0.00	0.36	31.11	0.00	0.00	0.01	0.00	4.29	1.94	7.95	1.58	0.00	0.00	1.91
Standard Error	1.48	0.80	0.00	0.00	4.72	4.51	0.00	0.00	1.93	0.11	0.00	0.21	3.06	0.00	0.00	0.01	0.00	1.76	0.72	2.92	0.71	0.00	0.00	1.28
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	27.72	14.44	0.00	0.00	83.61	69.86	0.00	0.00	44.71	2.71	0.03	4.05	57.21	0.00	0.00	0.28	0.00	37.57	14.15	66.50	10.61	0.00	0.00	30.77
Reserve: "Good"																								
Mean	5.47	2.39	0.00	0.00	11.37	16.62	0.00	0.00	5.70	0.01	0.00	0.06	38.43	0.00	0.00	0.00	0.00	7.11	2.23	4.84	3.09	0.00	0.00	2.68
Standard Error	2.53	1.35	0.00	0.00	7.31	5.68	0.00	0.00	3.82	0.01	0.00	0.05	4.52	0.00	0.00	0.00	0.00	3.24	1.23	1.14	1.29	0.00	0.00	2.56
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.64	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
Maximum	27.72	14.44	0.00	0.00	83.61	54.00	0.00	0.00	44.71	0.09	0.00	0.58	57.21	0.00	0.00	0.00	0.00	37.57	14.15	11.37	10.61	0.00	0.00	30.77
Reserve: "Poor"																								
Mean	2.22	1.43	0.00	0.00	18.58	35.91	0.00	0.00	1.77	0.23	0.00	0.66	23.79	0.00	0.00	0.02	0.00	1.46	1.65	11.06	0.08	0.00	0.00	1.14
Standard Error	1.51	0.90	0.00	0.00	6.10	6.00	0.00	0.00	0.53	0.23	0.00	0.41	2.99	0.00	0.00	0.02	0.00	1.01	0.78	5.71	0.07	0.00	0.00	0.48
Minimum	0.00	0.00	0.00	0.00	0.00	5.05	0.00	0.00	0.07	0.00	0.00	0.00	8.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	18.64	8.69	0.00	0.00	57.64	69.86	0.00	0.00	5.73	2.71	0.03	4.05	40.86	0.00	0.00	0.28	0.00	11.88	8.85	66.50	0.81	0.00	0.00	5.36

Appendix 5.5. SIMPER analyses based on relative abundances (TE/ha), displaying similarities measures within land uses and dissimilarity measures between land uses.

Group Commercial - Average similarity: 39.81

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Gre fla	41.53	28.78	1.65	72.31	72.31
Prot sul	12.05	3.12	0.54	7.83	80.14
Ac mel	9.77	2.81	0.46	7.05	87.20
Ac eri	7.87	1.62	0.32	4.06	91.26

Group Tribal - Average similarity: 39.87

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Gre fla	19.79	14.25	2.47	35.74	35.74
Dic cin	13.99	5.45	0.76	13.67	49.41
Gym bux	11.78	4.61	0.69	11.56	60.97
Ac eri	9.26	3.81	0.81	9.54	70.51
Prot sul	5.88	2.91	0.88	7.31	77.82
Ter ser	8.51	2.88	0.61	7.23	85.05
Ac mel	9.07	2.06	0.41	5.17	90.22

Group Reserve - Average similarity: 46.86

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Gre fla	31.97	23.45	2.20	50.04	50.04
Ac mel	19.06	9.94	1.02	21.20	71.24
Rhi bre	12.16	4.40	0.76	9.39	80.63
Ac lue	10.85	3.19	0.48	6.81	87.44
Bos alb	3.97	1.44	0.63	3.08	90.52

Groups Commercial & Tribal - Average dissimilarity: 72.02

	Group Commercial	Group Tribal				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Gre fla	41.53	19.79	13.35	1.45	18.54	18.54
Dic cin	2.10	13.99	7.45	0.83	10.34	28.87
Ac mel	9.77	9.07	6.77	0.86	9.40	38.28
Prot sul	12.05	5.88	6.08	0.64	8.44	46.72
Ac eri	7.87	9.26	5.97	0.97	8.29	55.01
Gym bux	0.00	11.78	5.89	0.88	8.18	63.18
Ter ser	0.00	8.51	4.25	0.77	5.91	69.09
Rhi bre	6.14	2.93	3.90	0.66	5.41	74.50

APPENDIX 5.5 (continue . . .)

Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Ac hae	6.87	0.03	3.44	0.42	4.78	79.28
Bos alb	5.51	0.10	2.77	0.58	3.84	83.12
Ac heb	2.86	2.90	2.56	0.48	3.56	86.68
Rhu cil	0.60	4.49	2.30	0.72	3.19	89.88
Gre flsc	1.20	3.05	1.92	0.54	2.67	92.54

Groups Commercial & Reserve - Average dissimilarity: 60.80

Group Commercial Group Reserve

Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Gre fla	41.53	31.97	11.20	1.36	18.41	18.41
Ac mel	9.77	19.06	8.87	1.23	14.60	33.01
Rhi bre	6.14	12.16	6.95	0.87	11.42	44.44
Prot sul	12.05	3.60	6.06	0.61	9.97	54.41
Ac lue	1.33	10.85	5.53	0.76	9.09	63.50
Ac eri	7.87	6.04	5.30	0.83	8.72	72.23
Bos alb	5.51	3.97	3.46	0.83	5.69	77.91
Ac hae	6.87	0.00	3.43	0.42	5.65	83.56
Ac heb	2.86	2.22	2.33	0.42	3.84	87.40
Lyc hir	0.00	4.35	2.18	0.70	3.58	90.98

Groups Tribal & Reserve - Average dissimilarity: 70.32

Group Tribal Group Reserve

Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Ac mel	9.07	19.06	9.30	1.18	13.22	13.22
Gre fla	19.79	31.97	8.67	1.36	12.33	25.55
Dic cin	13.99	0.18	6.93	0.79	9.86	35.41
Rhi bre	2.93	12.16	6.14	0.76	8.73	44.14
Gym bux	11.78	0.00	5.89	0.88	8.37	52.51
Ac lue	0.02	10.85	5.42	0.72	7.71	60.22
Ac eri	9.26	6.04	5.20	1.00	7.39	67.61
Ter ser	8.51	0.00	4.25	0.77	6.05	73.66
Prot sul	5.88	3.60	2.99	1.24	4.25	77.91
Rhu cil	4.49	2.86	2.84	0.82	4.04	81.94
Lyc hir	0.00	4.35	2.18	0.70	3.10	85.04
Ac heb	2.90	2.22	2.16	0.63	3.08	88.12
Bos alb	0.10	3.97	1.96	0.83	2.79	90.91

Appendix 5.6. SIMPER analyses based on relative abundances (TE/ha), displaying similarities measures within the rangeland condition groups ("Good" and "Poor") and dissimilarity measures between the rangeland condition groups.

Group Poor - Average similarity: 38.60

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Gre fla	29.92	20.46	1.78	53.01	53.01
Ac mel	19.01	9.24	0.86	23.93	76.94
Prot sul	5.86	1.87	0.62	4.86	81.80
Ac eri	6.33	1.64	0.45	4.26	86.06
Rhi bre	7.62	1.33	0.30	3.43	89.50
Bos alb	4.58	0.99	0.36	2.56	92.05

Group Good - Average similarity: 34.35

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Gre fla	32.27	20.77	1.62	60.48	60.48
Ac eri	9.12	2.87	0.50	8.37	68.85
Prot sul	8.50	2.55	0.58	7.43	76.28
Rhi bre	6.54	1.75	0.43	5.10	81.38
Ac mel	6.25	1.54	0.44	4.50	85.88
Dic cin	7.99	1.26	0.26	3.68	89.56
Rhu cil	3.95	0.89	0.33	2.60	92.15

Groups Poor & Good - Average dissimilarity: 65.46

	Group Poor	Group Good				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Gre fla	29.92	32.27	10.28	1.27	15.71	15.71
Ac mel	19.01	6.25	8.96	1.12	13.69	29.40
Ac eri	6.33	9.12	5.49	0.91	8.38	37.78
Rhi bre	7.62	6.54	5.46	0.74	8.34	46.12
Prot sul	5.86	8.50	4.99	0.61	7.63	53.75
Dic cin	2.86	7.99	4.70	0.57	7.19	60.94
Ac lue	6.16	1.98	3.64	0.57	5.57	66.50
Gym bux	3.28	4.57	3.41	0.59	5.21	71.71
Bos alb	4.58	1.81	2.63	0.66	4.02	75.73
Ter ser	2.09	3.58	2.51	0.53	3.84	79.57
Ac heb	2.72	2.60	2.34	0.48	3.58	83.15
Ac hae	0.33	4.27	2.26	0.33	3.46	86.60
Rhu cil	1.35	3.95	2.25	0.70	3.44	90.04

Appendix 5.7. SIMPER analyses based on relative abundances (TE/ha), displaying dissimilarity measures between the rangeland condition groups ("Good" and "Poor") within each land use.

Commericial

Group Poor - Average similarity: 47.20

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Gre fla	41.04	30.36	1.77	64.33	64.33
Ac mel	17.56	8.00	0.76	16.94	81.27
Prot sul	10.28	3.65	0.78	7.74	89.01
Bos alb	8.44	2.05	0.43	4.34	93.35

Group Good - Average similarity: 36.45

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Gre fla	42.02	26.71	1.51	73.26	73.26
Prot sul	13.81	2.33	0.43	6.40	79.66
Ac hae	12.76	2.16	0.29	5.92	85.57
Rhi bre	*9.52*	*2.01*	*0.30*	*5.51*	*91.08*

Groups Poor & Good - Average dissimilarity: 62.04

	Group Poor	Group Good				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Gre fla	41.04	42.02	12.52	1.40	20.17	20.17
Prot sul	10.28	13.81	8.81	0.72	14.20	34.38
Ac mel	17.56	1.97	8.33	1.13	13.43	47.81
Ac hae	0.98	12.76	6.54	0.63	10.54	58.35
Ac eri	5.20	10.54	6.32	0.86	10.19	68.54
Rhi bre	2.76	9.52	5.28	0.77	8.50	77.04
Bos alb	8.44	2.59	4.42	0.79	7.12	84.17
Ac heb	4.77	0.94	2.72	0.39	4.38	88.55
Dic cin	*0.00*	*4.20*	*2.10*	*0.31*	*3.39*	*91.93*

Tribal land use

Group Poor - Average similarity: 36.27

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Gre fla	23.82	17.12	2.76	47.21	47.21
Ac mel	14.22	4.16	0.58	11.48	58.69
Dic cin	8.33	2.95	0.66	8.14	66.83

APPENDIX 5.7 (continue . . .)

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Gym bux	9.84	2.66	0.47	7.33	74.16
Ac eri	9.45	2.50	0.53	6.90	81.06
Ter ser	6.27	1.83	0.67	5.04	86.09
Prot sul	4.68	1.66	0.69	4.58	90.68

Group Good - Average similarity: 44.15

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Gre fla	15.77	11.89	2.51	26.92	26.92
Dic cin	19.64	8.28	0.94	18.75	45.67
Gym bux	13.71	6.47	1.05	14.65	60.32
Ac eri	9.07	5.24	1.11	11.86	72.18
Prot sul	7.09	4.32	1.20	9.79	81.97
Ter ser	10.75	3.84	0.68	8.71	90.68

Groups Poor & Good - Average dissimilarity: 60.44

	Group Poor	Group Good				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Dic cin	8.33	19.64	8.69	0.89	14.38	14.38
Ac mel	14.22	3.91	7.25	0.79	12.00	26.38
Gym bux	9.84	13.71	7.13	1.11	11.80	38.17
Gre fla	23.82	15.77	5.77	1.10	9.55	47.72
Ter ser	6.27	10.75	5.58	0.97	9.24	56.96
Ac eri	9.45	9.07	5.51	1.08	9.12	66.08
Rhu cil	3.66	5.32	3.25	0.93	5.37	71.45
Prot sul	4.68	7.09	3.04	1.40	5.03	76.48
Gre flsc	4.20	1.90	2.67	0.60	4.42	80.90
Rhi bre	3.89	1.97	2.50	0.55	4.14	85.04
Ac heb	2.74	3.07	2.27	0.73	3.75	88.79
Ziz muc	2.46	2.07	1.73	0.84	2.86	91.65

APPENDIX 5.7 (continue . . .)

Reserve land use

Group Poor - Average similarity: 48.53

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Gre fla	24.92	17.42	1.96	35.89	35.89
Ac mel	25.25	16.48	1.75	33.96	69.85
Ac lue	15.99	5.80	0.60	11.95	81.80
Rhi bre	*16.20*	*4.58*	*0.55*	*9.43*	*91.24*

Group Good - Average similarity: 50.32

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Gre fla	39.02	30.96	3.47	61.52	61.52
Ac mel	12.88	4.80	0.77	9.54	71.06
Rhi bre	8.13	4.44	1.23	8.82	79.88
Lyc hir	6.83	2.59	0.59	5.15	85.03
Ac eri	7.75	2.09	0.40	4.15	89.19
Rhu cil	*5.58*	*1.67*	*0.54*	*3.32*	*92.50*

Groups Poor & Good - Average dissimilarity: 55.48

	Group Poor	Group Good				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Ac mel	25.25	12.88	9.77	1.40	17.61	17.61
Gre fla	24.92	39.02	9.20	1.37	16.58	34.19
Ac lue	15.99	5.70	7.94	1.00	14.31	48.50
Rhi bre	16.20	8.13	7.86	0.86	14.17	62.67
Ac eri	4.34	7.75	4.62	0.89	8.33	71.00
Lyc hir	1.88	6.83	3.44	1.05	6.21	77.21
Rhu cil	0.14	5.58	2.77	0.78	5.00	82.21
Prot sul	2.61	4.59	2.68	1.01	4.83	87.03
Bos alb	*5.10*	*2.84*	*2.53*	*1.06*	*4.57*	*91.60*

Appendix 5.8. The average height (m) and canopy diameter (m) of each woody species within each land use

Land use	**Parameter**	***Acacia erioloba***	***Acacia haematoxylon***	***Acacia hebeclada***	***Acacia karroo***	***Acacia luederitzii***	***Acacia mellifera***	***Acacia robusta***	***Acacia tortilis***
Commercial	Height (m)	**2.24**	**1.98**	0.64	0.00	**2.19**	**1.85**	0.00	0.00
	Canopy diameter (m)	**1.76**	**1.38**	0.94	0.00	**2.64**	**2.21**	0.00	0.00
	Ratio (height: diameter)	**1.27**	**1.43**	**0.68**	**0.00**	**0.83**	**0.84**	**0.00**	**0.00**
Tribal	Height (m)	0.92	0.60	**0.86**	**2.16**	0.50	0.92	**1.60**	**0.32**
	Canopy diameter (m)	0.88	0.50	**1.32**	**2.42**	1.20	1.08	**1.40**	**0.25**
	Ratio (height: diameter)	1.05	1.20	0.65	0.89	0.42	0.85	1.14	1.27
Reserve	Height (m)	1.33	0.00	0.82	0.00	1.75	1.08	0.00	0.00
	Canopy diameter (m)	1.10	0.00	1.04	0.00	1.65	1.26	0.00	0.00
	Ratio (height: diameter)	1.21	0.00	0.78	0.00	1.06	0.86	0.00	0.00

Land use	**Parameter**	***Boscia albitrunca***	***Cadaba sp.***	***Dichrostachys cinerea***	***Diospyros lycioides***	***Ehretia rigida***	***Grewia flava***	***Grewia flavescens***	***Gymnosporia buxifolia***
Commercial	Height (m)	**1.45**	0.00	0.76	0.00	0.76	**1.44**	**1.87**	0.00
	Canopy diameter (m)	**1.27**	0.00	0.71	0.00	0.71	**1.73**	**1.78**	0.00
	Ratio (height: diameter)	**1.14**	0.00	**1.08**	**0.00**	**1.07**	**0.83**	**1.05**	0.00
Tribal	Height (m)	0.83	0.00	0.82	**0.98**	**0.95**	1.22	0.90	**0.32**
	Canopy diameter (m)	0.67	0.00	0.92	**0.55**	**0.90**	1.47	0.73	**0.20**
	Ratio (height: diameter)	1.25	0.00	0.89	1.80	1.05	0.83	1.22	**1.60**
Reserve	Height (m)	0.84	**0.25**	**1.06**	0.80	0.63	1.36	0.00	0
	Canopy diameter (m)	0.76	**0.50**	**1.06**	0.30	0.59	1.43	0.00	0
	Ratio (height: diameter)	1.10	0.50	1.00	2.67	1.07	0.95	0.00	0.00

Land use	**Parameter**	***Lycium hirsitum***	***Mundulea sericea***	***Protasparagus suleovons***	***Rhigozum brevispinosum***	***Rhus ciliata***	***Tarchonanthus camphoratus***	***Terminalia sericea***	***Ziziphus mucronata***
Commercial	Height (m)	0.00	0.00	**0.48**	**0.72**	0.55	0.00	0.00	**2.03**
	Canopy diameter (m)	0.00	0.00	0.48	**0.92**	0.65	0.00	0.00	**2.33**
	Ratio (height: diameter)	0.00	0.00	**1.01**	**0.79**	**0.85**	**0.00**	0.00	**0.87**
Tribal	Height (m)	0.00	**0.44**	0.42	0.68	**0.95**	**1.26**	**1.27**	1.35
	Canopy diameter (m)	0.00	**0.49**	0.27	0.65	**0.90**	**1.42**	**1.39**	1.12
	Ratio (height: diameter)	0.00	**0.90**	1.55	1.04	1.05	0.89	**0.92**	1.21
Reserve	Height (m)	**0.65**	0.00	0.42	0.68	0.80	0.00	0.00	1.97
	Canopy diameter (m)	**0.90**	0.00	**0.53**	0.75	0.90	0.00	0.00	1.79
	Ratio (height: diameter)	**0.72**	0.00	0.79	0.91	0.89	0.00	0.00	1.10

Appendix 5.9. Descriptive statistics for mean TE/ha for each woody species within the different land use groups

TE/HA	*Acacia erioloba*	*Acacia haematoxilyn*	*Acacia hebeclada*	*Acacia luederitzii*	*Acacia mellifera*	*Acacia karroo*	*Acacia robusta*	*Acacia tortilis*	*Boscia albutranca*	*Dichrostachys cinerea*	*Diospyros lycioides*	*Ehretia rigida*	*Grewia flava*	*Grewia flavescens*	*Gymnosporia buxifolia*	*Cadaba sp.*	*Lycium hirsitum*	*Mundulea sericea*	*Protasparagus suleovons*	*Rhigozum brevispinosum*	*Rhus ciliata*	*Tarchonanthus camphoratus*	*Terminalia sericea*	*Ziziphus mucronata*	*TOTAL TE/ha*
Total: "General"																									
Mean	76.41	8.03	31.27	77.15	174.91	5.00	0.37	0.44	26.57	96.39	3.15	14.95	272.43	16.50	67.38	0.12	10.76	5.32	58.61	80.97	30.65	8.47	61.67	23.06	1150.60
Standard Error	14.26	3.92	12.57	32.51	41.84	2.90	0.37	0.23	5.21	35.78	2.54	3.98	21.52	7.62	21.03	0.12	3.64	3.26	9.61	26.46	9.88	3.51	22.72	7.25	109.22
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	28.33
Maximum	526.67	186.67	823.33	1796.67	1996.67	148.33	26.67	11.67	163.33	2255.00	181.67	196.67	843.33	450.00	1171.67	8.33	163.33	198.33	346.67	1621.67	620.00	153.33	1078.33	425.00	3641.67
Total: "Good"																									
Mean	100.83	10.88	24.54	11.53	42.64	5.88	0.00	0.56	17.18	145.65	5.05	9.86	229.86	9.40	69.40	0.00	12.55	2.55	58.98	40.65	41.34	9.49	77.22	16.81	942.82
Standard Error	25.39	5.91	10.31	5.42	14.56	4.14	0.00	0.33	5.97	67.69	5.05	4.26	29.72	7.15	23.11	0.00	4.99	2.55	13.06	10.52	17.81	5.36	36.97	7.09	137.93
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	28.33
Maximum	526.67	185.00	275.00	171.67	476.67	120.00	0.00	10.00	118.33	2255.00	181.67	145.00	773.33	255.00	556.67	0.00	141.67	91.67	345.00	235.00	620.00	153.33	1078.33	185.00	3166.67
Total: "Poor"																									
Mean	51.99	5.19	38.01	142.78	307.18	4.12	0.74	0.32	35.97	47.13	1.25	20.05	315.00	23.61	65.37	0.23	8.98	8.10	58.24	121.30	19.95	7.45	46.11	29.31	1358.38
Standard Error	12.10	5.19	23.07	63.34	76.75	4.12	0.74	0.32	8.32	21.76	0.72	6.68	29.87	13.48	35.50	0.23	5.35	6.02	14.28	51.35	8.53	4.62	26.73	12.68	164.03
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	23.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	226.67
Maximum	300.00	186.67	823.33	1796.67	1996.67	148.33	26.67	11.67	163.33	670.00	20.00	196.67	843.33	450.00	1171.67	8.33	163.33	198.33	346.67	1621.67	206.67	150.00	923.33	425.00	3641.67
Commercial: "General"																									
Mean	56.11	23.68	38.82	10.63	69.10	0.00	0.00	0.00	33.13	7.43	0.00	8.40	208.68	7.78	0.00	0.00	0.00	0.00	40.49	29.65	2.29	0.00	0.00	5.63	541.81
Standard Error	26.39	11.23	34.23	7.79	24.08	0.00	0.00	0.00	10.53	6.49	0.00	2.66	37.88	4.77	0.00	0.00	0.00	0.00	11.72	12.84	1.26	0.00	0.00	5.63	86.26
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	28.33
Maximum	521.67	186.67	823.33	183.33	470.00	0.00	0.00	0.00	163.33	155.00	0.00	43.33	773.33	93.33	0.00	0.00	0.00	0.00	251.67	235.00	25.00	0.00	0.00	135.00	1585.00
Commercial: "Good"																									
Mean	85.69	31.81	4.31	2.64	12.08	0.00	0.00	0.00	27.08	14.86	0.00	2.92	170.14	0.00	0.00	0.00	0.00	0.00	30.28	44.31	3.47	0.00	0.00	0.00	429.58
Standard Error	50.62	16.53	3.39	2.64	4.25	0.00	0.00	0.00	13.95	12.89	0.00	1.77	58.00	0.00	0.00	0.00	0.00	0.00	12.55	23.02	2.40	0.00	0.00	0.00	115.84
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	28.33
Maximum	521.67	185.00	40.00	31.67	41.67	0.00	0.00	0.00	118.33	155.00	0.00	20.00	773.33	0.00	0.00	0.00	0.00	0.00	138.33	235.00	25.00	0.00	0.00	0.00	1160.00
Commercial: "Poor"																									
Mean	26.53	15.56	73.33	18.61	126.11	0.00	0.00	0.00	39.17	0.00	0.00	13.89	247.22	15.56	0.00	0.00	0.00	0.00	50.69	15.00	1.11	0.00	0.00	11.25	654.03
Standard Error	13.84	15.56	68.34	15.34	42.62	0.00	0.00	0.00	16.19	0.00	0.00	4.59	48.65	9.17	0.00	0.00	0.00	0.00	19.94	10.98	0.78	0.00	0.00	11.25	124.13
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	23.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	226.67
Maximum	168.33	186.67	823.33	183.33	470.00	0.00	0.00	0.00	163.33	0.00	0.00	43.33	538.33	93.33	0.00	0.00	0.00	0.00	251.67	131.67	8.33	0.00	0.00	135.00	1585.00
Tribal: "General"																									
Mean	126.88	0.42	36.32	0.35	181.32	15.00	1.11	1.32	1.74	278.06	8.89	23.68	305.42	41.74	202.15	0.00	0.00	15.97	97.01	33.40	69.03	25.42	185.00	40.28	1690.49
Standard Error	28.64	0.42	13.68	0.35	85.37	8.45	1.11	0.67	1.37	98.24	7.57	8.14	38.11	21.73	53.96	0.00	0.00	9.55	20.09	12.01	27.10	9.78	61.56	18.44	181.11
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	38.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	485.00
Maximum	526.67	10.00	275.00	8.33	1868.33	148.33	26.67	11.67	31.67	2255.00	181.67	145.00	843.33	450.00	1171.67	0.00	0.00	198.33	345.00	201.67	620.00	153.33	1078.33	425.00	3166.67
Tribal: "Good"																									
Mean	166.81	0.83	40.14	0.00	34.58	17.64	0.00	1.67	0.00	421.53	15.14	22.78	267.22	28.19	208.19	0.00	0.00	7.64	116.67	32.50	80.97	28.47	231.67	32.78	1755.42
Standard Error	49.72	0.83	24.26	0.00	18.11	12.02	0.00	0.94	0.00	182.17	15.14	11.85	46.10	20.98	49.73	0.00	0.00	7.64	29.85	18.51	50.41	14.99	98.96	13.95	255.86
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.67	0.00	0.00	38.33	0.00	0.00	0.00	0.00	0.00	10.00	0.00	0.00	0.00	0.00	0.00	553.33
Maximum	526.67	10.00	275.00	0.00	211.67	120.00	0.00	10.00	0.00	2255.00	181.67	145.00	600.00	255.00	556.67	0.00	0.00	91.67	345.00	201.67	620.00	153.33	1078.33	165.00	3166.67
Tribal: "Poor"																									
Mean	86.94	0.00	32.50	0.69	328.06	12.36	2.22	0.97	3.47	134.58	2.64	24.58	343.61	55.28	196.11	0.00	0.00	24.31	77.36	34.31	57.08	22.36	138.33	47.78	1625.56
Standard Error	25.84	0.00	13.82	0.69	161.97	12.36	2.22	0.97	2.69	58.55	1.85	11.67	60.69	38.76	98.48	0.00	0.00	17.62	26.95	16.14	22.46	13.16	75.23	34.89	266.35
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	113.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	485.00
Maximum	300.00	0.00	163.33	8.33	1868.33	148.33	26.67	11.67	31.67	670.00	20.00	136.67	843.33	450.00	1171.67	0.00	0.00	198.33	310.00	178.33	206.67	150.00	923.33	425.00	2878.33
Reserve: "General"																									
Mean	46.25	0.00	18.68	220.49	274.31	0.00	0.00	0.00	44.86	3.68	0.56	12.78	303.19	0.00	0.00	0.35	32.29	0.00	38.33	179.86	20.63	0.00	0.00	23.26	1219.51
Standard Error	14.08	0.00	9.71	91.56	86.17	0.00	0.00	0.00	9.75	3.40	0.56	8.25	33.71	0.00	0.00	0.35	9.62	0.00	14.75	74.41	8.09	0.00	0.00	9.42	203.05
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	31.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	105.00
Maximum	223.33	0.00	200.00	1796.67	1996.67	0.00	0.00	0.00	163.33	81.67	13.33	196.67	690.00	0.00	0.00	8.33	163.33	0.00	346.67	1621.67	130.00	0.00	0.00	185.00	3641.67
Reserve: "Good"																									
Mean	50.00	0.00	29.17	31.94	81.25	0.00	0.00	0.00	24.44	0.56	0.00	3.89	252.22	0.00	0.00	0.00	37.64	0.00	30.00	45.14	39.58	0.00	0.00	17.64	643.47
Standard Error	21.57	0.00	18.82	14.70	38.09	0.00	0.00	0.00	10.25	0.56	0.00	2.56	49.45	0.00	0.00	0.00	12.34	0.00	11.26	13.23	14.40	0.00	0.00	15.37	102.89
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	31.67	0.00	0.00	0.00	0.00	0.00	0.00	5.00	0.00	0.00	0.00	0.00	105.00
Maximum	223.33	0.00	200.00	171.67	476.67	0.00	0.00	0.00	100.00	6.67	0.00	30.00	690.00	0.00	0.00	0.00	141.67	0.00	105.00	170.00	130.00	0.00	0.00	185.00	1538.33
Reserve: "Poor"																									
Mean	42.50	0.00	8.19	409.03	467.36	0.00	0.00	0.00	65.28	6.81	1.11	21.67	354.17	0.00	0.00	0.69	26.94	0.00	46.67	314.58	1.67	0.00	0.00	28.89	1795.56
Standard Error	18.99	0.00	4.52	168.47	151.06	0.00	0.00	0.00	14.72	6.81	1.11	16.24	42.82	0.00	0.00	0.69	15.15	0.00	27.76	140.29	1.14	0.00	0.00	11.37	318.59
Minimum	0.00	0.00	0.00	0.00	86.67	0.00	0.00	0.00	8.33	0.00	0.00	0.00	145.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	576.67
Maximum	201.67	0.00	43.33	1796.67	1996.67	0.00	0.00	0.00	163.33	81.67	13.33	196.67	633.33	0.00	0.00	8.33	163.33	0.00	346.67	1621.67	11.67	0.00	0.00	113.33	3641.67

Appendix 5.10. Descriptive statistics for mean Bush numbers/ha for each woody species within the different land use groups

Area cover	***Acacia erioloba***	***Acacia hebeclada***	***Acacia haematoxylon***	***Acacia karroo***	***Acacia luederitzii***	***Acacia mellifera***	***Acacia robusta***	***Acacia tortilis***	***Boscia albutranca***	***Dichrostachys cinerea***	***Diospyros lycioides***	***Ehretia rigida***	***Grewia flava***	***Grewia flavescens***	***Gymnosporia buxifolia***	***Cadaba sp.***	***Lycium hirsitum***	***Mundulea sericea***	***Protasparagus suleovons***	***Rhigozum brevispinosum***	***Rhus ciliata***	***Tarchonanthus camphoratus***	***Terminalia sericea***	***Ziziphus mucronata***	***TOTAL individuals***
Total: "General"																									
Mean	99	63	6	3	66	245	0	2	39	170	5	28	305	25	319	1	25	18	203	179	52	10	72	22	1958
Standard Error	24	29	3	3	28	58	0	1	9	85	4	8	27	14	103	1	8	11	35	55	15	4	22	7	220
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	75
Maximum	1375	1975	175	175	1625	2275	25	75	500	5875	250	475	1225	925	6075	50	375	675	1400	2925	900	175	975	300	8950
Total: "Good"																									
Mean	134	42	8	2	12	55	0	2	19	290	7	16	260	12	308	0	29	7	218	78	69	10	72	16	1667
Standard Error	45	17	4	2	4	16	0	1	7	168	7	4	34	8	104	0	11	7	51	20	26	6	30	8	309
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	75
Maximum	1375	375	150	50	100	475	0	25	175	5875	250	75	750	275	2725	0	250	250	1400	450	900	175	725	275	7700
Total: "Poor"																									
Mean	63	85	5	5	121	435	1	2	59	51	3	40	350	39	329	1	20	29	188	280	35	10	71	28	2249
Standard Error	15	55	5	5	55	106	1	2	17	24	2	15	40	26	181	1	12	21	48	106	14	5	33	10	309
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	200
Maximum	350	1975	175	175	1625	2275	25	75	500	825	50	475	1225	925	6075	50	375	675	1250	2925	350	175	975	300	8950
Commercial: "General"																									
Mean	38	**92**	**18**	0	9	56	0	0	34	15	0	17	203	6	0	0	0	0	125	63	6	0	0	4	685
Standard Error	14	82	9	0	5	18	0	0	12	13	0	6	40	4	0	0	0	0	39	26	3	0	0	4	121
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	75
Maximum	275	1975	175	0	100	375	0	0	200	300	0	125	750	75	0	0	0	0	850	450	50	0	0	100	2625
Commercial: "Good"																									
Mean	46	8	21	0	8	21	0	0	29	29	0	6	158	0	0	0	0	0	83	88	8	0	0	0	506
Standard Error	26	6	13	0	6	7	0	0	16	25	0	3	57	0	0	0	0	0	33	44	6	0	0	0	126
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	75
Maximum	275	75	150	0	50	75	0	0	175	300	0	25	750	0	0	0	0	0	325	450	50	0	0	0	1175
Commercial: "Poor"																									
Mean	29	175	15	0	10	92	0	0	40	0	0	27	248	13	0	0	0	0	167	38	4	0	0	8	865
Standard Error	12	164	15	0	8	32	0	0	18	0	0	10	56	7	0	0	0	0	70	26	3	0	0	8	199
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	200
Maximum	150	1975	175	0	100	375	0	0	200	0	0	125	675	75	0	0	0	0	850	300	25	0	0	100	2625
Tribal: "General"																									
Mean	**206**	64	1	**10**	1	297	**1**	**6**	3	**492**	14	**38**	**376**	**70**	**956**	0	0	**54**	**347**	74	**113**	30	**215**	**45**	**3411**
Standard Error	65	19	1	8	1	115	1	3	2	246	11	11	49	40	270	0	0	33	73	26	40	11	57	18	434
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	625
Maximum	1375	375	25	175	25	1975	25	75	50	5875	250	175	1225	925	6075	0	0	675	1400	375	900	175	975	300	8950
Tribal: "Good"																									
Mean	306	60	2	6	0	63	0	6	0	840	21	29	350	35	925	0	0	21	450	52	127	31	217	35	3577
Standard Error	121	34	2	4	0	39	0	3	0	476	21	9	57	22	226	0	0	21	119	32	73	17	77	22	613
Minimum	0	0	0	0	0	0	0	0	0	25	0	0	25	0	0	0	0	0	50	0	0	0	0	0	1175
Maximum	1375	375	25	50	0	475	0	25	0	5875	250	75	650	275	2725	0	0	250	1400	350	900	175	725	275	7700
Tribal: "Poor"																									
Mean	106	67	0	15	2	531	2	6	6	144	6	46	402	104	988	0	0	88	244	96	98	29	213	54	3246
Standard Error	36	20	0	15	2	209	2	6	4	66	4	19	83	77	503	0	0	62	79	40	36	15	88	28	638
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	200	0	0	0	0	0	0	0	0	0	0	0	625
Maximum	350	200	0	175	25	1975	25	75	50	825	50	175	1225	925	6075	0	0	675	900	375	350	175	975	300	8950
Reserve: "General"																									
Mean	52	34	0	0	**189**	**381**	0	0	**80**	5	1	30	335	0	0	**2**	74	0	136	**400**	39	0	0	18	1777
Standard Error	15	19	0	0	80	123	0	0	23	4	1	20	42	0	0	2	21	0	54	153	14	0	0	7	283
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	175
Maximum	250	350	0	0	1625	2275	0	0	500	100	25	475	875	0	0	50	375	0	1250	2925	250	0	0	125	5100
Reserve: "Good"																									
Mean	50	56	0	0	27	81	0	0	29	2	0	13	271	0	0	0	88	0	121	94	73	0	0	13	917
Standard Error	19	36	0	0	10	24	0	0	12	2	0	7	54	0	0	0	25	0	44	29	25	0	0	10	123
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	25	0	0	0	0	0	0	25	0	0	0	0	175
Maximum	175	350	0	0	100	300	0	0	125	25	0	75	750	0	0	0	250	0	375	375	250	0	0	125	1700
Reserve: "Poor"																									
Mean	54	13	0	0	350	681	0	0	131	8	2	48	400	0	0	4	60	0	152	706	4	0	0	23	2638
Standard Error	23	7	0	0	148	214	0	0	40	8	2	39	60	0	0	4	34	0	100	282	3	0	0	8	431
Minimum	0	0	0	0	0	50	0	0	25	0	0	0	125	0	0	0	0	0	0	0	0	0	0	0	725
Maximum	250	75	0	0	1625	2275	0	0	500	100	25	475	875	0	0	50	375	0	1250	2925	25	0	0	75	5100

Appendix 5.11. Descriptive statistics for mean Bush area coverage (m^2/ha) for each woody species within the different land use groups

Area cover	***Acacia erioloba***	***Acacia hebeclada***	***Acacia haematoxylon***	***Acacia karroo***	***Acacia luederitzii***	***Acacia mellifera***	***Acacia robusta***	***Acacia tortilis***	***Boscia albutranca***	***Dichrostachys cinerea***	***Diospyros lycioides***	***Ehretia rigida***	***Grewia flava***	***Grewia flavescens***	***Gymnosporia buxifolia***	***Cadaba sp.***	***Lycium hirsitum***	***Mundulea sericea***	***Protasparagus suleovons***	***Rhigozum brevispinosum***	***Rhus ciliata***	***Tarchonanthus camphoratus***	***Terminalia sericea***	***Ziziphus mucronata***	***Total m^2/ha***
Total: "General"																									
Mean	186.11	79.39	12.60	33.21	220.86	535.81	0.53	0.16	66.57	297.36	1.24	22.76	775.85	27.38	18.29	0.16	26.75	8.38	41.49	106.29	61.75	20.47	211.06	47.69	2802.16
Standard Error	42.91	28.85	6.30	23.31	76.94	108.85	0.53	0.12	21.30	131.53	0.95	7.89	61.59	12.26	7.56	0.16	11.79	5.56	8.22	37.63	27.23	8.49	84.35	15.98	254.22
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30.05
Maximum	2195.68	1474.79	291.89	1526.84	3093.55	4598.00	38.50	8.05	990.20	8844.59	67.38	407.98	2586.96	675.52	417.21	11.39	730.71	367.52	361.04	2488.95	1858.02	408.57	3965.30	724.23	12091.36
Total: "Good"																									
Mean	203.57	54.52	22.79	24.01	103.99	168.20	0.00	0.10	77.76	500.62	1.87	16.18	645.97	12.67	20.71	0.00	39.13	3.30	43.06	67.89	95.08	23.49	296.31	35.91	2457.13
Standard Error	56.15	24.51	12.22	20.00	80.75	85.89	0.00	0.09	38.46	256.95	1.87	11.39	81.71	10.20	9.83	0.00	21.70	3.30	11.67	20.15	52.51	13.49	145.80	17.25	401.46
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30.05
Maximum	1224.34	754.29	291.89	707.14	2864.91	3078.23	0.00	3.14	990.20	8844.59	67.38	407.98	2586.96	362.61	319.59	0.00	730.71	118.84	298.96	596.36	1858.02	408.57	3965.30	510.71	12091.36
Total: "Poor"																									
Mean	168.64	104.25	2.42	42.41	337.74	903.42	1.07	0.22	55.38	94.10	0.62	29.34	905.73	42.09	15.87	0.32	14.37	13.45	39.91	144.69	28.42	17.44	125.80	59.47	3147.18
Standard Error	65.58	52.35	2.42	42.41	129.30	181.58	1.07	0.22	18.80	42.46	0.41	10.98	88.04	22.22	11.63	0.32	9.20	10.62	11.73	72.49	13.64	10.49	84.83	27.02	306.96
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	78.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	363.00
Maximum	2195.68	1474.79	87.02	1526.84	3093.55	4598.00	38.50	8.05	491.07	1220.61	12.57	349.45	2176.63	675.52	417.21	11.39	288.95	367.52	361.04	2488.95	408.57	308.98	2941.91	724.23	7822.96
Commercial: "General"																									
Mean	142.57	69.76	37.61	0.00	47.38	268.23	0.00	0.00	82.14	7.00	0.00	8.52	701.90	16.59	0.00	0.00	0.00	0.00	35.50	52.90	2.56	0.00	0.00	30.18	1502.85
Standard Error	67.86	61.30	18.08	0.00	36.36	93.00	0.00	0.00	30.08	5.40	0.00	3.38	126.83	9.59	0.00	0.00	0.00	0.00	10.19	27.05	1.84	0.00	0.00	30.18	236.04
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30.05
Maximum	1224.34	1474.79	291.89	0.00	850.73	1590.68	0.00	0.00	491.07	123.75	0.00	57.75	2586.96	168.54	0.00	0.00	0.00	0.00	210.57	596.36	43.41	0.00	0.00	724.23	4126.18
Commercial: "Good"																									
Mean	219.61	7.45	67.96	0.00	3.81	32.51	0.00	0.00	64.36	14.00	0.00	0.80	573.47	0.00	0.00	0.00	0.00	0.00	39.88	88.54	4.17	0.00	0.00	0.00	1116.57
Standard Error	128.63	5.02	33.86	0.00	3.81	14.37	0.00	0.00	36.26	10.63	0.00	0.59	193.72	0.00	0.00	0.00	0.00	0.00	18.82	51.58	3.61	0.00	0.00	0.00	303.87
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30.05
Maximum	1224.34	45.18	291.89	0.00	45.77	143.20	0.00	0.00	390.89	123.75	0.00	7.07	2586.96	0.00	0.00	0.00	0.00	0.00	210.57	596.36	43.41	0.00	0.00	0.00	3000.25
Commercial: "Poor"																									
Mean	65.54	132.07	7.25	0.00	90.95	503.95	0.00	0.00	99.92	0.00	0.00	16.24	830.34	33.18	0.00	0.00	0.00	0.00	31.13	17.27	0.95	0.00	0.00	60.35	1889.14
Standard Error	40.37	122.41	7.25	0.00	71.90	160.82	0.00	0.00	49.11	0.00	0.00	6.06	163.52	18.30	0.00	0.00	0.00	0.00	8.76	12.97	0.80	0.00	0.00	60.35	336.93
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	78.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	363.00
Maximum	453.95	1474.79	87.02	0.00	850.73	1590.68	0.00	0.00	491.07	0.00	0.00	57.75	2034.61	168.54	0.00	0.00	0.00	0.00	105.09	155.77	9.63	0.00	0.00	724.23	4126.18
Tribal: "General"																									
Mean	343.69	129.86	0.20	99.64	1.18	509.48	1.60	0.48	1.42	878.84	3.66	46.55	924.86	65.55	54.86	0.00	0.00	25.13	37.58	40.24	151.72	61.40	633.17	64.78	4075.89
Standard Error	99.97	59.48	0.20	68.86	1.18	208.54	1.60	0.35	1.39	371.60	2.84	21.74	115.76	34.64	21.04	0.00	0.00	16.36	13.26	17.33	78.52	23.64	232.97	30.06	502.46
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	108.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	604.41
Maximum	2195.68	1237.50	4.91	1526.84	28.29	4107.52	38.50	8.05	33.39	8844.59	67.38	407.98	2176.63	675.52	417.21	0.00	0.00	367.52	298.96	351.41	1858.02	408.57	3965.30	656.46	12091.36
Tribal: "Good"																									
Mean	297.47	113.88	0.41	72.04	0.00	94.04	0.00	0.29	0.00	1487.72	5.61	44.77	727.41	38.01	62.12	0.00	0.00	9.90	48.76	43.87	220.87	70.47	888.94	62.81	4289.39
Standard Error	97.69	68.22	0.41	59.19	0.00	41.75	0.00	0.26	0.00	705.13	5.61	33.45	123.62	30.08	26.23	0.00	0.00	9.90	23.72	29.47	153.42	37.91	393.73	29.17	888.21
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.63	0.00	0.00	108.82	0.00	0.00	0.00	0.00	0.00	1.18	0.00	0.00	0.00	0.00	0.00	604.41
Maximum	1001.59	754.29	4.91	707.14	0.00	396.39	0.00	3.14	0.00	8844.59	67.38	407.98	1636.05	362.61	319.59	0.00	0.00	118.84	298.96	351.41	1858.02	408.57	3965.30	290.91	12091.36
Tribal: "Poor"																									
Mean	389.91	145.83	0.00	127.24	2.36	924.92	3.21	0.67	2.85	269.96	1.70	48.32	1122.31	93.09	47.60	0.00	0.00	40.35	26.40	36.60	82.58	52.33	377.40	66.75	3862.39
Standard Error	178.50	100.47	0.00	127.24	2.36	385.68	3.21	0.67	2.78	113.29	1.18	29.25	183.48	63.05	33.96	0.00	0.00	31.28	12.22	19.63	37.07	29.73	245.06	54.10	508.46
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	248.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	858.00
Maximum	2195.68	1237.50	0.00	1526.84	28.29	4107.52	38.50	8.05	33.39	1220.61	12.57	349.45	2176.63	675.52	417.21	0.00	0.00	367.52	138.09	227.66	408.57	308.98	2941.91	656.46	6369.20
Reserve: "General"																									
Mean	72.05	38.55	0.00	0.00	614.03	829.73	0.00	0.00	116.15	6.24	0.07	13.23	700.78	0.00	0.00	0.47	80.24	0.00	51.37	225.73	30.97	0.00	0.00	48.12	2827.73
Standard Error	26.97	14.95	0.00	0.00	208.26	225.14	0.00	0.00	54.69	6.17	0.07	7.47	64.81	0.00	0.00	0.47	33.19	0.00	18.41	105.58	12.27	0.00	0.00	22.89	382.56
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	78.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	195.25
Maximum	530.75	221.77	0.00	0.00	3093.55	4598.00	0.00	0.00	990.20	148.11	1.77	165.20	1286.02	0.00	0.00	11.39	730.71	0.00	361.04	2488.95	176.20	0.00	0.00	510.71	7822.96
Reserve: "Good"																									
Mean	93.63	42.23	0.00	0.00	308.15	378.06	0.00	0.00	168.91	0.15	0.00	2.98	637.02	0.00	0.00	0.00	117.38	0.00	40.55	71.25	60.21	0.00	0.00	44.92	1965.43
Standard Error	45.66	22.76	0.00	0.00	237.78	249.57	0.00	0.00	107.16	0.15	0.00	2.75	99.19	0.00	0.00	0.00	60.50	0.00	19.46	16.00	21.73	0.00	0.00	42.41	408.21
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	78.57	0.00	0.00	0.00	0.00	0.00	0.00	0.79	0.00	0.00	0.00	0.00	195.25
Maximum	530.75	221.77	0.00	0.00	2864.91	3078.23	0.00	0.00	990.20	1.77	0.00	33.20	1164.04	0.00	0.00	0.00	730.71	0.00	217.25	163.63	176.20	0.00	0.00	510.71	5700.55
Reserve: "Poor"																									
Mean	50.47	34.87	0.00	0.00	919.91	1281.40	0.00	0.00	63.38	12.34	0.15	23.47	764.53	0.00	0.00	0.95	43.10	0.00	62.20	380.20	1.74	0.00	0.00	51.32	3690.03
Standard Error	29.51	20.35	0.00	0.00	328.37	335.53	0.00	0.00	22.77	12.34	0.15	14.37	83.59	0.00	0.00	0.95	26.36	0.00	31.90	205.00	1.35	0.00	0.00	19.75	556.95
Minimum	0.00	0.00	0.00	0.00	0.00	210.77	0.00	0.00	1.77	0.00	0.00	0.00	216.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1212.36
Maximum	360.45	211.36	0.00	0.00	3093.55	4598.00	0.00	0.00	239.25	148.11	1.77	165.20	1286.02	0.00	0.00	11.39	288.95	0.00	361.04	2488.95	15.91	0.00	0.00	180.91	7822.96

Appendix 6.1. A CCA ordination (total soil) showing the cumulative variances and eigenvalues for the first two axes, with the soil variables showing the highest association with the respective axes, indicated in **bold**. Indexed key matrices (0 – 10) pertaining to different environmental variables are presented, with environmental variables showing a “poorer” fit indicated in *italics*

	Cumulative variance explained		Eigenvalues	
	Axis 1	Axis 2	Axis 1	Axis 2
pH	**0.2293**	0.2313	**0.4046**	-0.0458
*P Bray 1	**0.0919**	**0.1746**	**1.368**	**-1.5784**
Conductivity	0.0037	**0.0101**	0.0927	**-0.1487**
K	**0.012**	0.0167	**0.1354**	0.102
Ca	**0.1606**	0.1764	**-0.3043**	-0.1158
Mg	0.0107	**0.2133**	0.1214	**0.6418**
Na	**0.2381**	0.2697	**0.5738**	-0.2543
NO3- N	**0.0233**	0.0356	**0.4374**	-0.3868
Zn	**0.0611**	0.0686	**0.636**	-0.2701
C	0.0769	**0.2289**	0.3837	**-0.6559**
Organic material	0.0773	**0.212**	0.4231	**-0.6794**
Coarse sand	**0.1159**	0.1487	**1.2799**	-0.8284
Med sand	**0.2885**	0.2891	**0.6442**	-0.036
Fine sand	**0.2054**	0.2196	**0.5029**	-0.1608
Silt	0.0001	**0.012**	0.0398	**0.583**
Clay	**0.0534**	0.0895	**0.4583**	-0.4578

Variables	Open	Woody	Variables	Reserve (Subsoil)	*Topsoil*	Variables	Axis 1	Open	Woody	Variables	Axis 2	Reserve (Subsoil)	*Topsoil*
P Bray 1	**10.0**	0.0	**Mg**	***10.0***	*0.0*	*P Bray 1	**1.368**	10.0	0.0	Mg	**0.6418**	10.0	*0.0*
Coarse sand	**9.5**	0.5	**Silt**	***9.7***	*0.3*	Coarse sand	**1.2799**	9.5	0.5	Silt	**0.583**	9.7	*0.3*
Med sand	**5.7**	4.3	K	*7.6*	*2.4*	Med sand	**0.6442**	5.7	4.3	Conductivity	**-0.1487**	6.4	*3.6*
Zn	**5.6**	4.4	Med sand	*6.9*	*3.1*	Zn	**0.636**	5.6	4.4	C	**-0.6559**	4.2	*5.8*
Na	**5.3**	4.7	pH	*6.9*	*3.1*	Na	**0.5738**	5.3	4.7	Organic material	**-0.6794**	4.0	*6.0*
Fine sand	**4.8**	5.2	Ca	*6.6*	*3.4*	Fine sand	**0.5029**	4.8	5.2	*P Bray 1	**-1.5784**	0.0	*10.0*
Clay	**4.6**	5.4	**Conductivity**	***6.4***	*3.6*	Clay	**0.4583**	4.6	5.4		2.2202		
NO3- N	**4.4**	5.6	Fine sand	*6.4*	*3.6*	NO3- N	**0.4374**	4.4	5.6				
Organic material	4.3	5.7	Na	*6.0*	*4.0*	pH	**0.4046**	4.2	5.8				
pH	**4.2**	5.8	Zn	*5.9*	*4.1*	K	**0.1354**	2.6	7.4				
C	4.1	5.9	NO3- N	*5.4*	*4.6*	Ca	**-0.3043**	0.0	10.0				
K	**2.6**	7.4	Clay	*5.0*	*5.0*		1.6723						
Mg	2.5	7.5	**C**	***4.2***	*5.8*								
Conductivity	2.4	7.6	**Organic material**	***4.0***	*6.0*								
Silt	2.1	7.9	**Coarse sand**	***3.4***	*6.6*								
Ca	**0.0**	10.0	P Bray 1	*0.0*	*10.0*								

* P associated with both axes

Appendix 6.2. A RDA ordination (topsoil open) showing the cumulative variances and eigenvalues for the first two axes, with the soil variables showing the highest association with the respective axes, indicated in **bold**. Indexed key matrices (0 – 10) pertaining to different environmental variables are presented, with environmental variables showing a "poorer" fit indicated in *italics.*

	Cumulative variance explained		**Eigenvalues**	
	Axis 1	**Axis 2**	**Axis 1**	**Axis 2**
pH	**0.1056**	0.1157	**-0.5876**	-0.2003
P Bray 1	0.006	**0.2012**	-0.14	**0.8843**
Conductivity	**0.0357**	0.0417	**-0.3418**	-0.1542
K	**0.1285**	0.1408	**-0.6482**	-0.2214
Ca	**0.2678**	0.3107	**-0.9356**	-0.4149
Mg	**0.2596**	0.2936	**-0.9213**	-0.3686
Na	**0.0954**	0.0982	**0.5586**	0.1047
NO3- N	**0.1199**	0.195	**-0.626**	0.5487
Zn	0.0006	**0.0163**	0.0435	**0.251**
C	0.0001	**0.0159**	-0.0164	**-0.2517**
Organic material	0.0073	**0.0249**	0.1544	**-0.2653**
Coarse sand	0.0287	**0.124**	0.3063	**0.618**
Med sand	0.1084	**0.2098**	-0.5952	**0.6373**
Fine sand	0.0312	**0.3121**	0.3193	**-1.0607**
Silt	**0.0812**	0.1374	**-0.5151**	-0.4747
Clay	**0.2212**	0.2571	**0.8504**	-0.3794

Variables	**Tribal**	**Reserve**	**Variables**	**Commercial**	***Tribal***	**Variables**	**Axis 1**	**Tribal**	**Reserve**	**Variables**	**Axis 2**	**Commercial**	***Tribal***
Clay	10.0	0.0	**P Bray 1**	10.0	*0.0*	Clay	**0.8504**	10.0	0.0	P Bray 1	**0.8843**	10.0	*0.0*
Na	8.4	1.6	**Med sand**	8.7	*1.3*	Na	**0.5586**	8.4	1.6	Med sand	**0.6373**	8.7	*1.3*
Fine sand	7.0	3.0	**Coarse sand**	8.6	*1.4*	Conductivity	**-0.3418**	3.3	6.7	Coarse sand	**0.618**	8.6	*1.4*
Coarse sand	7.0	3.0	NO3- N	8.3	*1.7*	Silt	**-0.5151**	2.4	7.6	Zn	**0.251**	6.7	*3.3*
Organic material	6.1	3.9	**Zn**	6.7	*3.3*	pH	**-0.5876**	1.9	8.1	C	**-0.2517**	4.2	*5.8*
Zn	5.5	4.5	Na	6.0	*4.0*	NO3- N	**-0.626**	1.7	8.3	Organic material	**-0.2653**	4.1	*5.9*
C	5.1	4.9	Conductivity	4.7	*5.3*	K	**-0.6482**	1.6	8.4	Fine sand	**-1.0607**	0.0	*10.0*
P Bray 1	4.5	5.5	pH	4.4	*5.6*	Mg	**-0.9213**	0.1	9.9		1.945		
Conductivity	3.3	6.7	K	4.3	*5.7*	Ca	**-0.9356**	0.0	10.0				
Silt	2.4	7.6	**C**	4.2	*5.8*		1.786						
pH	1.9	8.1	**Organic material**	4.1	*5.9*								
Med sand	1.9	8.1	Mg	3.6	*6.4*								
NO3- N	1.7	8.3	Clay	3.5	*6.5*								
K	1.6	8.4	Ca	3.3	*6.7*								
Mg	0.1	9.9	Silt	3.0	*7.0*								
Ca	0.0	10.0	**Fine sand**	0.0	*10.0*								

Appendix 6.3. A RDA ordination (subsoil open) showing the cumulative variances and eigenvalues for the first two axes, with the soil variables showing the highest association with the respective axes, indicated in **bold**. Indexed key matrices (0 – 10) pertaining to different environmental variables are presented, with environmental variables showing a "poorer" fit indicated in *italics.*

	Cumulative variance explained		**Eigenvalues**	
	Axis 1	**Axis 2**	**Axis 1**	**Axis 2**
pH	**0.1516**	0.1952	**-0.6755**	-0.4151
P Bray 1	0.0009	**0.0882**	0.0522	**0.5873**
Conductivity	**0.0627**	0.0636	**-0.4345**	0.0593
K	**0.1593**	0.2055	**-0.6926**	-0.4271
Ca	**0.2015**	0.2849	**-0.7788**	-0.5741
Mg	**0.1751**	0.2783	**-0.726**	-0.6384
Na	**0.1747**	0.1776	**0.7251**	0.1071
NO3- N	0.0974	**0.1853**	-0.5415	**0.5893**
Zn	0.0004	**0.0049**	-0.0335	**-0.1331**
C	**0.0142**	0.0155	**-0.2064**	0.074
Organic material	**0.0098**	0.0112	**-0.172**	0.0743
Coarse sand	0.0116	**0.1211**	0.1868	**0.6577**
Med sand	**0.3139**	0.4255	**-0.9721**	0.664
Fine sand	0.16	**0.4248**	0.694	**-1.0227**
Silt	0.0502	**0.1111**	-0.3889	**-0.4904**
Clay	**0.1822**	0.198	**0.7407**	-0.2498

Variables	**Tribal**	**Reserve**	**Variables**	**Commercial**	***Reserve (Tribal)***	**Variables**	**Axis 1**	**Tribal**	**Reserve**	**Variables**	**Axis 2**	**Commercial**	***Reserve (Tribal)***
Clay	10.0	0.0	Med sand	10.0	*0.0*	Clay	**0.7407**	10.0	0.0	Coarse sand	**0.6577**	10.0	0.0
Na	9.9	0.1	**Coarse sand**	10.0	*0.0*	Na	**0.7251**	9.9	0.1	NO3- N	**0.5893**	9.6	0.4
Fine sand	9.7	0.3	**NO3- N**	9.6	*0.4*	Organic material	**-0.172**	4.7	5.3	P Bray 1	**0.5873**	9.6	0.4
Coarse sand	6.8	3.2	**P Bray 1**	9.5	*0.5*	C	**-0.2064**	4.5	5.5	Zn	**-0.1331**	5.3	4.7
P Bray 1	6.0	4.0	Na	6.7	*3.3*	Conductivity	**-0.4345**	3.1	6.9	Silt	**-0.4904**	3.2	6.8
Zn	5.5	4.5	Organic material	6.5	*3.5*	pH	**-0.6755**	1.7	8.3	Fine sand	**-1.0227**	0.0	10.0
Organic material	4.7	5.3	C	6.5	*3.5*	K	**-0.6926**	1.6	8.4		1.6804		
C	4.5	5.5	Conductivity	6.4	*3.6*	Mg	**-0.726**	1.4	8.6				
Silt	3.4	6.6	**Zn**	5.3	*4.7*	Ca	**-0.7788**	1.1	8.9				
Conductivity	3.1	6.9	Clay	4.6	*5.4*	Med sand	**-0.9721**	0.0	10.0				
NO3- N	2.5	7.5	pH	3.6	*6.4*		1.7128						
pH	1.7	8.3	K	3.5	*6.5*								
K	1.6	8.4	**Silt**	3.2	*6.8*								
Mg	1.4	8.6	Ca	2.7	*7.3*								
Ca	1.1	8.9	Mg	2.3	*7.7*								
Med sand	0.0	10.0	**Fine sand**	0.0	*10.0*								

Appendix 6.4. A RDA ordination (topsoil woody) showing the cumulative variances and eigenvalues for the first two axes, with the soil variables showing the highest association with the respective axes, indicated in **bold**. Indexed key matrices (0 – 10) pertaining to different environmental variables are presented, with environmental variables showing a “poorer” fit indicated in *italics.*

	Cumulative variance explained		Eigenvalues	
	Axis 1	**Axis 2**	**Axis 1**	**Axis 2**
pH	0.0011	**0.0638**	-0.0575	**0.5209**
P Bray 1	**0.2472**	0.2748	**-0.8721**	-0.3456
Conductivity	**0.0627**	0.0777	**-0.4393**	0.2542
K	0.0017	**0.1501**	-0.0713	**0.8016**
Ca	0.0016	**0.066**	0.071	**0.5277**
Mg	0.0144	**0.1262**	-0.2103	**0.6958**
Na	0.0799	**0.1552**	0.4959	**-0.5707**
NO3- N	**0.1988**	0.1989	**-0.7819**	0.0179
Zn	**0.0221**	0.027	**-0.2607**	0.1462
C	**0.144**	0.1488	**0.6656**	0.1443
Organic material	**0.1445**	0.1476	**0.6667**	0.1159
Coarse sand	0.0121	**0.0931**	-0.1932	**-0.5922**
Med sand	**0.3412**	0.3421	**-1.0244**	-0.0626
Fine sand	**0.2048**	0.2594	**0.7937**	0.4862
Silt	0.0003	**0.1378**	0.0316	**0.7713**
Clay	**0.2145**	0.2765	**0.8124**	-0.5179

Variables	**Tribal**	**Commercial *(Reserve)***	**Variables**	**Reserve**	**Commercial (*Tribal*)**	**Variables**	**Axis 1**	**Tribal**	**Commercial *(Reserve)***	**Variables**	**Axis 2**	**Reserve**	**Commercial (*Tribal*)**
Clay	10.0	0.0	**K**	10.0	0.0	Clay	**0.8124**	10.0	0.0	K	**0.8016**	10.0	0.0
Fine sand	9.9	0.1	**Silt**	9.9	0.1	Fine sand	**0.7937**	9.9	0.1	Silt	**0.7713**	9.8	0.2
Organic material	9.2	0.8	**Mg**	9.2	0.8	Organic material	**0.6667**	9.2	0.8	Mg	**0.6958**	9.2	0.8
C	9.2	0.8	**Ca**	9.2	0.8	C	**0.6656**	9.2	0.8	Ca	**0.5277**	8.0	2.0
Na	8.3	1.7	**pH**	8.3	1.7	Zn	**-0.2607**	4.2	*5.8*	pH	**0.5209**	8.0	2.0
Ca	6.0	*4.0*	Fine sand	6.0	*4.0*	Conductivity	**-0.4393**	3.2	*6.8*	Na	**-0.5707**	0.2	*9.8*
Silt	5.7	*4.3*	Conductivity	5.7	4.3	NO3- N	**-0.7819**	1.3	*8.7*	Coarse sand	**-0.5922**	0.0	10.0
pH	5.3	*4.7*	Zn	5.3	4.7	P Bray 1	**-0.8721**	0.8	9.2		1.3938		
K	5.2	*4.8*	C	5.2	*4.8*	Med sand	**-1.0244**	0.0	10.0				
Coarse sand	4.5	5.5	Organic material	4.5	*5.5*		1.8368						
Mg	4.4	*5.6*	NO3- N	4.4	5.6								
Zn	4.2	*5.8*	Med sand	4.2	5.8								
Conductivity	3.2	6.8	P Br ay 1	3.2	6.8								
NO3- N	1.3	8.7	Clay	1.3	*8.7*								
P Bray 1	0.8	9.2	**Na**	0.8	*9.2*								
Med sand	0.0	10.0	**Coarse sand**	0.0	10.0								

Appendix 6.5. A RDA ordination (subsoil woody) showing the cumulative variances and eigenvalues for the first two axes, with the soil variables showing the highest association with the respective axes, indicated in **bold**. Indexed key matrices (0 – 10) pertaining to different environmental variables are presented, with environmental variables showing a “poorer” fit indicated in *italics.*

	Cumulative variance explained		Eigenvalues	
	Axis 1	Axis 2	Axis 1	Axis 2
pH	**0.1826**	0.2162	**-0.7138**	-0.3652
P Bray 1	0.0009	**0.0747**	0.0489	**0.5414**
Conductivity	**0.3382**	0.3399	**-0.9716**	0.0808
K	**0.1654**	0.2049	**-0.6795**	-0.396
Ca	**0.0742**	0.1168	**-0.4549**	-0.4115
Mg	**0.1604**	0.2455	**-0.6691**	-0.581
Na	**0.1907**	0.1984	**0.7296**	0.1742
NO3- N	**0.2861**	0.3617	**-0.8936**	0.5478
Zn	0.0054	**0.0175**	-0.1224	**-0.2197**
C	0.0369	**0.073**	-0.3208	**-0.3787**
Organic material	0.0303	**0.0553**	-0.291	**-0.3146**
Coarse sand	0.0084	**0.1261**	0.1532	**0.6833**
Med sand	**0.2411**	0.3703	**-0.8203**	0.7161
Fine sand	0.0563	**0.2728**	0.3964	**-0.9269**
Silt	0.0299	**0.1251**	-0.289	**-0.6146**
Clay	**0.247**	0.2715	**0.8303**	-0.3116

Variables	Tribal	Reserve *(Commercial)*	Variables	Commercial	Reserve/*Tribal*	Variables	Axis 1	Tribal	Reserve *(Commercial)*	Variables	Axis 2	Commercial	Reserve/ *Tribal*
Clay	10.0	0.0	Med sand	10.0	0.0	Clay	**0.8303**	10.0	0.0	Coarse sand	**0.6833**	10.0	0.0
Na	9.4	0.6	**Coar ses**	9.8	0.2	Na	**0.7296**	9.4	0.6	P Br ay 1	**0.5414**	9.1	0.9
Fine sand	7.6	2.4	NO3- N	9.0	1.0	Ca	**-0.4549**	2.9	7.1	Zn	**-0.2197**	4.4	5.6
Coarse sand	6.2	*3.8*	**P Br ay 1**	8.9	1.1	Mg	**-0.6691**	1.7	8.3	Organic material	**-0.3146**	3.8	6.2
P Bray 1	5.7	*4.3*	Na	6.7	*3.3*	K	**-0.6795**	1.6	8.4	C	**-0.3787**	3.4	6.6
Zn	4.7	5.3	Conductivity	6.1	3.9	pH	**-0.7138**	1.4	8.6	Silt	**-0.6146**	1.9	8.1
Silt	3.8	6.2	**Zn**	4.3	5.7	Med sand	**-0.8203**	0.8	*9.2*	Fine sand	**-0.9269**	0.0	*10.0*
Organic material	3.8	6.2	**Clay**	3.7	*6.3*	NO3- N	**-0.8936**	0.4	9.6		1.6102		
C	3.6	6.4	**Organic material**	3.7	6.3	Conductivity	**-0.9716**	0.0	10.0				
Ca	2.9	7.1	pH	3.4	6.6		1.8019						
Mg	1.7	8.3	C	3.3	6.7								
K	1.6	8.4	K	3.2	6.8								
pH	1.4	8.6	Ca	3.1	6.9								
Med sand	0.8	*9.2*	Mg	2.1	7.9								
NO3- N	0.4	*9.6*	**Silt**	1.9	8.1								
Conductivity	0.0	10.0	**Fine sand**	0.0	*10.0*								

Appendix 7.1. Cumulative variances and eigenvalues of herbaceous species for the first two canonical axes. Species responsive to the respective axes are indicated in **bold.**

	Eigen values		Cumulative variance	
NAME	**AX1**	**AX2**	**AX1**	**AX2**
*ANT PUB**	-1.2058	**-1.8158**	0.055	**0.1627**
*BRAC NIG**	-1.2862	**-2.2033**	0.0291	**0.1029**
*DIG ERI**	**1.6532**	0.1137	**0.215**	0.2159
*SCHM PAP**	-0.5023	**-0.8145**	0.2062	**0.6739**
PAN MAX	**0.7959**	-0.1671	**0.0062**	0.0064
CHRY SER	-0.8219	**-1.3056**	0.0065	**0.0206**
*ERA LEH**	0.3204	**0.4003**	0.0516	**0.1212**
*ERA TRI**	**1.8276**	-0.1435	**0.1683**	0.1692
STIP CIL	**-0.7469**	0.64	**0.0119**	0.0195
*STIP UNI**	**-0.4233**	-0.0544	**0.1139**	0.1156
CYM PO	**1.6237**	0.0399	**0.0522**	0.0522
CEN TR	-0.9554	**-1.145**	0.0371	0.083
*ARI STI**	**1.514**	-0.1667	**0.4951**	**0.5003**
CYN DAC	0.0811	**2.4879**	0	**0.0186**
*ERA PAL**	**2.1758**	-0.6331	0.4188	**0.4494**
*MEL REP**	**1.7659**	-0.5316	**0.3129**	0.3374
*TRI AND**	**2.3909**	-0.7162	**0.3243**	0.3495
ERA RIG	**2.0453**	-0.5979	**0.0694**	0.0745
*POG SQU**	**1.8881**	-0.3604	**0.1924**	0.1985
*ARIST CON**	**1.7158**	0.1243	**0.3697**	0.3714
ARIST MED	**0.4809**	0.0454	**0.0056**	0.0056
PER PAT	**2.775**	-0.423	**0.0857**	0.0874
TRA KOE	**1.2891**	0.0374	**0.0979**	0.0979
URU BRA	**-0.6932**	0.2545	**0.0167**	0.0186
TRA BER	**1.9314**	0.1966	**0.0653**	0.0659
BRA MAR	0.2135	**2.4648**	0.0004	**0.0485**
ERA BIF	**1.5414**	0.0081	**0.0745**	0.0745
CHLOR VIR	**2.4056**	-0.8072	**0.0513**	0.0563
ELEU COR	**2.4056**	-0.8072	**0.0513**	0.0563
*SCHM KAL**	-0.7039	**0.9222**	0.0674	**0.1671**
TRA RAC	-0.7479	**1.1127**	0.005	**0.0145**
FORBS	**-0.8217**	-0.8154	**0.0059**	0.0109
BP*	-0.3854	**1.131**	0.0512	**0.4318**

*Key species having 10% and higher of their ranges explained by the species-environment relation

Appendix 7.2. A CCA weighted correlation matrix showing the correlation coefficients (r-values) between the integrated woody and soil environmental variables for the “annual” herbaceous composition. The highest correlation coefficients (r-values) are indicated in **bold.**

P Bray 1	1							
K	-0.0981	1						
Ca	-0.0576	**0.4756**	1					
Na	-0.038	-0.0383	-0.0446	1				
Org.mat	-0.0625	0.3216	0.0004	-0.1055	1			
Coarse sand	**0.585**	-0.0188	-0.4066	-0.0012	0.1086	1		
Med sand	0.2794	-0.2174	0.1054	-0.0174	-0.4136	-0.0466	1	
Fine sand	-0.5913	0.2444	0.1028	0.003	**0.2853**	-0.5284	-0.6557	1
Silt	-0.1837	**0.405**	0.2293	-0.5295	**0.3452**	-0.1648	-0.2464	**0.3368**
Clay	-0.0857	-0.0126	-0.1387	**0.5222**	0.2335	0.2096	-0.4104	0.2495
Ac lue	0.186	0.1675	0.2407	-0.2385	-0.0337	0.0247	0.1216	-0.1111
Ac mel	0.1871	-0.1534	0.1492	-0.1381	-0.2134	0.0651	0.1997	-0.2226
Bos alb	**0.4356**	-0.0164	-0.1302	-0.0375	0.0174	**0.3296**	0.1588	-0.3756
Dio lyc	0.0236	0.0334	-0.1705	0.0451	0.0517	0.185	0.2434	0.1516
Gre flsc	-0.0953	-0.2718	0.009	**0.2383**	-0.2539	-0.2923	0.0828	0.0619
Gym bux	-0.2272	0.1335	0.0451	0.1899	0.0977	-0.0452	-0.2933	0.2538
Mun ser	-0.052	-0.1143	-0.2777	0.0289	0.067	**0.3144**	-0.392	0.1342
Ter ser	-0.1766	-0.1836	-0.2752	-0.0098	-0.012	-0.1162	-0.2482	0.2902
Commercial	0.323	-0.0876	-0.2209	0.1647	-0.1235	0.27	**0.3455**	-0.5003
Tribal	-0.3041	-0.1895	-0.2554	0.2355	0.1568	-0.0406	-0.4791	**0.4659**
Reserve	-0.0199	0.2734	**0.4703**	-0.395	-0.0324	-0.2271	0.1302	0.0358
Good	-0.3386	0.2498	0.0208	0.0834	-0.0306	-0.1654	0.0675	0.1099
Poor	0.3386	-0.2498	-0.0208	-0.0834	0.0306	0.1654	-0.0675	-0.1099
Com*Good	-0.0432	0.0119	-0.0082	0.0804	-0.0459	-0.0203	**0.2681**	-0.2349
Com*Poor	**0.4449**	-0.1208	-0.2678	0.1276	-0.1095	**0.3566**	0.1712	-0.3965
Tri*Poor	-0.1549	-0.3799	-0.3145	-0.0314	0.1352	0.0246	-0.3677	0.2534
Tri*Good	-0.2304	0.1338	-0.0131	**0.3266**	0.0647	-0.0751	-0.2419	0.3373
Res*Good	-0.1788	0.187	0.0483	-0.2893	-0.0598	-0.1251	0.0688	0.0397
Res*Poor	0.1542	0.157	**0.544**	-0.2076	0.0192	-0.1607	0.0952	0.0054
	P	**K**	**Ca**	**Na**	**Org.mat**	**Coarse sand**	**Med sand**	**Fine sand**

APPENDIX 7.2 (continue . . .)

	Silt	**Clay**	***Ac lue***	***Ac mel***	***Bos alb***	***Dio lyc***	***Gre flsc***	***Gym bux***
Silt	1							
Clay	-0.4994	1						
Ac lue	0.1181	-0.2052	1					
Ac mel	0.0298	-0.2562	0.164	1				
Bos alb	-0.1706	-0.0984	-0.0179	0.0165	1			
Dio lyc	-0.0654	0.2948	-0.0313	-0.1219	-0.0766	1		
Gre flsc	-0.3114	0.0557	-0.1146	-0.0505	-0.0562	-0.0447	1	
Gym bux	0.0066	0.3387	-0.1669	-0.1314	-0.2	0.0452	-0.0094	1
Mun ser	-0.0559	**0.4186**	-0.0768	-0.0062	-0.0664	0.1159	-0.0237	0.065
Ter ser	0.0626	0.0899	-0.1502	-0.2141	-0.1774	0.0347	0.1469	0.2111
Commercial	-0.2745	-0.1416	-0.1902	-0.1202	0.252	-0.1204	-0.0099	-0.2901
Tribal	-0.1059	**0.5301**	-0.2805	-0.1665	-0.3288	**0.2301**	**0.2181**	**0.5956**
Reserve	**0.3759**	-0.3822	**0.4645**	0.283	0.0747	-0.1076	-0.2051	-0.2999
Good	0.1707	-0.1694	-0.2069	-0.4052	-0.2107	0.0395	-0.1339	0.062
Poor	-0.1707	0.1694	0.2069	**0.4052**	0.2107	-0.0395	0.1339	-0.062
Com*Good	-0.1129	-0.0978	-0.1661	-0.299	-0.0321	-0.0745	-0.1227	-0.1795
Com*Poor	-0.233	-0.0819	-0.0763	0.1398	**0.3455**	-0.078	0.1066	-0.188
Tri*Poor	-0.1046	0.4091	-0.1742	0.0425	-0.1985	0.0854	**0.2066**	0.3039
Tri*Good	-0.0307	0.2656	-0.1819	-0.2508	-0.2187	**0.2055**	0.0718	**0.4508**
Res*Good	**0.365**	-0.3913	0.0663	0.0003	-0.0319	-0.0784	-0.1293	-0.189
Res*Poor	0.1077	-0.0893	**0.5188**	**0.3562**	0.126	-0.057	-0.1288	-0.1883

	Mun ser	***Ter ser***	**Commercial**	**Tribal**	**Reserve**	**Good**	**Poor**	**Com*Good**
Mun ser	1							
Ter ser	0.1024	1						
Commercial	-0.1383	-0.2599	1					
Tribal	**0.2839**	**0.5337**	-0.4871	1				
Reserve	-0.1429	-0.2687	-0.5093	-0.5035	1			
Good	-0.1102	0.108	-0.025	0.0206	0.0044	1		
Poor	0.1102	-0.108	0.025	-0.0206	-0.0044	-1	1	
Com*Good	-0.0855	-0.1608	**0.6187**	-0.3014	-0.3151	**0.4356**	-0.4356	1
Com*Poor	-0.0896	-0.1684	**0.648**	-0.3156	-0.33	-0.4534	**0.4534**	-0.1975
Tri*Poor	**0.3362**	0.2004	-0.3043	**0.6247**	-0.3145	-0.4322	**0.4322**	-0.1883
Tri*Good	0.0275	**0.4743**	-0.3141	**0.6449**	-0.3247	**0.4488**	-0.4488	-0.1943
Res*Good	-0.0901	-0.1694	-0.321	-0.3174	**0.6303**	**0.4587**	-0.4587	-0.1986
Res*Poor	-0.0898	-0.1687	-0.3198	-0.3162	**0.628**	-0.4543	**0.4543**	-0.1979

	Com*Poor	**Tri*Poor**	**Tri*Good**	**Res*Good**	**Res*Poor**
Com*Poor	1				
Tri*Poor	-0.1972	1			
Tri*Good	-0.2035	-0.194	1		
Res*Good	-0.208	-0.1983	-0.2047	1	
Res*Poor	-0.2072	-0.1975	-0.2039	-0.2084	1

Appendix 7.3. Cumulative variances and eigenvalues of woody species for the first two canonical axes. Species responsive to the respective axes are indicated in **bold.**

	Eigen values		**Cumulative variance**	
NAME	**AX1**	**AX2**	**AX1**	**AX2**
Ac eri	0.2824	**0.3397**	0.0234	**0.0487**
Ac hae*	-0.0411	**5.813**	0.000	**0.5504**
Ac heb	-0.0236	**-0.0489**	0.000	**0.0002**
Ac lue*	**-1.1633**	-0.8494	**0.1408**	0.1971
Ac mel*	**-0.5932**	-0.5277	**0.1545**	0.2461
Ac kar	**0.9978**	-0.3704	**0.0241**	0.0266
Ac rob	**0.3202**	0.1148	**0.0008**	0.0009
Ac tor	**1.0729**	-0.3387	**0.0273**	0.0293
Bos alb*	**-0.8078**	0.1067	**0.1029**	0.1042
Dic cin*	**1.7205**	-0.1094	**0.332**	0.333
Dio lyc	**1.4781**	0.1713	**0.0422**	0.0426
Ehr rig	-0.1062	**-0.118**	0.0025	**0.0047**
Gre fla*	-0.2684	**0.3066**	0.1355	**0.2681**
Gre flsc	**0.3923**	-0.0067	**0.0081**	0.0081
Gym bux*	**2.0287**	-0.8499	**0.4413**	0.4993
Cada ba	-1.3452	**-1.347**	0.0172	**0.0302**
Lyc hir	**-0.8315**	-0.4962	**0.0539**	0.0683
Mun ser	**0.7506**	-0.2321	**0.0129**	0.0139
Prot sul	0.1387	**0.5163**	0.0037	**0.0423**
Rhi bre*	-0.4969	**-0.7101**	0.0492	**0.1246**
Rhu cil	**0.4606**	0.0713	**0.0326**	0.0332
Tar cam*	**2.0191**	-0.5989	**0.1863**	0.1986
Ter ser*	**2.0448**	-0.1815	**0.3719**	0.3741
Ziz muc	-0.0274	**-0.5041**	0.0001	**0.0189**

*Key species having 10% and higher of their ranges explained by the species-environment relation

Appendix 7.4. A CCA weighted correlation matrix showing the correlation coefficients (r-values) between the integrated herbaceous and soil environmental variables for the woody component. The highest correlation coefficients (r-values) are indicated in **bold.**

Commercial	1							
Tribal	-0.49	1						
Reserve	-0.5072	-0.5027	1					
Good	-0.0123	0.0093	0.003	1				
Poor	0.0123	-0.0093	-0.003	-1	1			
Conductivity	0.033	-0.5008	**0.4623**	0.0423	-0.0423	1		
Mg	-0.2462	-0.2369	**0.4783**	0.0992	-0.0992	**0.4218**	1	
NO3-N	0.2469	-0.5862	0.3347	-0.111	0.111	0.79	0.1571	1
Org.mat	-0.1195	-0.0687	0.1864	0.2113	-0.2113	0.2617	0.3212	0.013
Med sand	**0.4187**	-0.6191	0.1968	0.0399	-0.0399	**0.3792**	-0.0519	**0.4517**
Silt	-0.309	0.0002	0.3063	0.0841	-0.0841	0.0936	**0.3945**	-0.0343
ANT PUB	0.3597	-0.1763	-0.1825	0.2558	-0.2558	-0.1378	-0.1468	-0.139
BRAC NIG	0.2705	-0.1326	-0.1372	0.1924	-0.1924	-0.1409	-0.1173	-0.2422
ERA TRI	-0.1891	0.3538	-0.1623	0.0027	-0.0027	-0.2492	-0.0577	-0.2142
STIP UNI	-0.0629	-0.3351	0.3936	0.0646	-0.0646	0.2951	0.1169	0.3277
CYM PO	-0.1208	0.2465	-0.1239	-0.0107	0.0107	-0.0791	-0.0231	-0.1356
CEN TR	0.2923	-0.1574	-0.1342	0.2012	-0.2012	0.1281	0.0096	0.3275
ARIS TI	-0.2629	**0.628**	-0.3601	-0.0577	0.0577	-0.383	-0.1752	-0.3768
ERA PAL	-0.248	**0.506**	-0.2544	0.2267	-0.2267	-0.3947	0.0306	-0.4236
TRI AND	-0.2004	0.409	-0.2056	0.0317	-0.0317	-0.3065	-0.0065	-0.3384
ERA RIG	-0.1096	0.2237	-0.1124	0.1577	-0.1577	-0.1092	-0.0732	-0.084
CHLOR VIR	-0.0816	0.1664	-0.0837	0.1173	-0.1173	-0.1058	-0.0241	-0.0823
SCHM KAL	0.288	-0.3059	0.0168	-0.17	0.17	0.1991	-0.1662	**0.4277**
BP	0.0892	-0.1593	0.0691	-0.4682	**0.4682**	0.0639	-0.0172	0.0946
Com*Good	**0.6222**	-0.3049	-0.3156	**0.4425**	-0.4425	-0.0791	-0.0547	0.0272
Com*Poor	**0.6441**	-0.3156	-0.3267	-0.4477	**0.4477**	0.1187	-0.2548	0.2825
Tri*Poor	-0.3105	**0.6336**	-0.3185	-0.4365	**0.4365**	-0.3358	-0.226	-0.357
Tri*Good	-0.3111	**0.635**	-0.3192	**0.4476**	-0.4476	-0.2995	-0.0746	-0.3866
Res*Good	-0.3181	-0.3153	**0.6271**	**0.4576**	-0.4576	**0.4289**	0.2591	0.2067
Res*Poor	-0.3209	-0.3181	**0.6327**	-0.4512	**0.4512**	0.1544	**0.3433**	0.215
	Commercial	**Tribal**	**Reserve**	**Good**	**Poor**	**Conductivity**	**Mg**	**NO3-N**

APPENDIX 7.4 (continue . . .)

Org.mat	1							
Med sand	-0.1908	1						
Silt	**0.393**	-0.3213	1					
ANT PUB	-0.0742	0.1475	-0.2518	1				
BRAC NIG	-0.0518	0.084	-0.2064	**0.9325**	1			
ERA TRI	-0.0267	-0.4411	-0.0905	-0.07	-0.0527	1		
STIP UNI	**0.2483**	0.2418	0.195	-0.0547	-0.1226	-0.1804	1	
CYM PO	-0.0439	0.0506	-0.0125	-0.0435	-0.0327	0.0947	-0.1228	1
CEN TR	0.0385	0.2303	-0.1057	**0.2311**	-0.043	-0.0626	**0.2609**	-0.0388
ARI STI	-0.1337	-0.3047	0.012	-0.1369	-0.1046	0.0861	-0.2158	**0.2297**
ERA PAL	0.1758	-0.5016	0.1739	-0.0892	-0.0671	0.186	-0.1553	0.1116
TRI AND	0.0224	-0.2372	0.1683	-0.0721	-0.0542	0.0326	-0.0578	**0.4067**
ERA RIG	-0.1389	-0.1542	-0.049	-0.0394	-0.0297	**0.7369**	-0.1384	-0.0268
CHLOR VIR	-0.0078	-0.2167	0.0078	-0.0293	-0.0221	**0.8354**	-0.1097	-0.0199
SCHM KAL	-0.0714	0.2586	-0.0337	-0.0935	-0.0835	-0.1187	0.015	-0.0754
BP	-0.2092	**0.2833**	-0.2152	-0.1574	-0.1342	-0.1529	-0.0725	-0.0189
Com*Good	-0.0153	**0.2983**	-0.1413	**0.5782**	**0.4349**	-0.1211	0.0856	-0.0752
Com*Poor	-0.1346	0.2328	-0.2488	-0.1145	-0.0861	-0.1184	-0.1624	-0.0778
Tri*Poor	-0.1584	-0.4468	0.0285	-0.1117	-0.084	0.1978	-0.313	0.1738
Tri*Good	0.0711	-0.3386	-0.0283	-0.1119	-0.0842	0.251	-0.1122	0.139
Res*Good	**0.2263**	0.0951	**0.2781**	-0.1144	-0.0861	-0.1253	0.1128	-0.0777
Res*Poor	0.0092	0.1527	0.1083	-0.1154	-0.0868	-0.0793	**0.3823**	-0.0784
	Org.mat	**Med sand**	**Silt**	***ANT PUB***	***BRAC NIG***	***ERA TRI***	***STIP UNI***	***CYM PO***

CEN TR	1							
ARI STI	-0.1144	1						
ERA PAL	-0.0797	0.2769	1					
TRI AND	-0.0644	**0.4641**	**0.4616**	1				
ERA RIG	-0.0352	0.2518	0.1135	0.0173	1			
CHLOR VIR	-0.0262	0.0372	0.1465	0.0356	**0.8932**	1		
SCHM KAL	-0.0478	-0.1523	-0.1548	-0.1251	-0.0684	-0.0509	1	
BP	-0.0955	-0.2152	-0.2359	-0.1693	-0.0931	-0.0818	-0.0481	1
Com*Good	**0.4793**	-0.2311	-0.1543	-0.1247	-0.0682	-0.0507	-0.0096	-0.2056
Com*Poor	-0.1023	-0.1034	-0.1597	-0.1291	-0.0706	-0.0525	**0.37**	**0.3126**
Tri*Poor	-0.0997	**0.4315**	0.0202	**0.2214**	-0.0688	-0.0512	-0.1938	-0.0182
Tri*Good	-0.0999	0.3652	**0.6213**	**0.2973**	**0.3523**	**0.2621**	-0.1942	-0.1838
Res*Good	-0.1022	-0.2108	-0.1595	-0.1289	-0.0705	-0.0525	-0.0256	-0.2412
Res*Poor	-0.0671	-0.2428	-0.161	-0.1301	-0.0711	-0.0529	0.0465	**0.3266**
	CEN TR	***ARI STI***	***ERA PAL***	***TRI AND***	***ERA RIG***	***CHLOR VIR***	***SCHM KAL***	**BP**

APPENDIX 7.4 (continue . . .)

Com*Good	1					
Com*Poor	-0.1981	1				
Tri*Poor	-0.1932	-0.2	1			
Tri*Good	-0.1936	-0.2004	-0.1954	1		
Res*Good	-0.1979	-0.2049	-0.1997	-0.2002	1	
Res*Poor	-0.1996	-0.2067	-0.2015	-0.202	-0.2065	1
	Com*Good	**Com*Poor**	**Tri*Poor**	**Tri*Good**	**Res*Good**	**Res*Poor**

Appendix 8.1a. Ant functional classification; absolute abundances; relative abundances; percentage (%) of species of sub-replicate; % of within sub-replicate of the land use; % of species of total survey area; and % of species per land use from the total survey area

			ABSOLUTE ABUNDANCE FOR SITE (#):													(%) PERCENTAGE OF SPECIES AS TOTAL OF SUB-REPLICATE/SITE (GRID):									(%) PERCENTAGE of SITE/SUB-REPLICATE (GRID) FROM LAND-USE:									(%) of SPECIES OF THE TOTAL SURVEY AREA:									(%) OF SPECIES/LAND USE FROM TOTAL SURVEY AREA:		
Species name	**Species abbreviation**	**Functional classification**	**B**	**SC**	**O**	**COMMER-CIAL TOTAL**	**A**	**S**	**T**	**TRIBAL TOTAL**	**M1**	**M2**	**M3**	**RESERVE TOTAL**	**TOTAL study area**	**B**	**SC**	**O**	**A**	**S**	**T**	**M1**	**M2**	**M3**	**B**	**SC**	**O**	**A**	**S**	**T**	**M1**	**M2**	**M3**	**B**	**SC**	**O**	**A**	**S**	**T**	**M1**	**M2**	**M3**	**COMM-ERCIAL**	**COM-MUNAL**	**RESER-VE**
Anochetus sp A	**Anoc spA**	Specialist predator	1	0	0	1	0	2	0	2	5	3	0	8	11	0.027	0.000	0.000	0.000	0.100	0.000	0.128	0.141	0.000	0.012	0.000	0.000	0.000	0.029	0.000	0.015	0.009	0.000	0.002	0.000	0.000	0.000	0.004	0.000	0.010	0.006	0.000	0.002	0.004	0.016
Anoplolepis sp A	**Anop spA**	Hot Climate Specialists	45	3	144	192	22	16	40	78	7	3	14	24	295	1.196	0.134	6.010	1.041	0.799	1.490	0.179	0.141	0.053	0.536	0.036	1.714	0.327	0.234	0.585	0.021	0.009	0.043	0.092	0.006	0.296	0.046	0.033	0.082	0.014	0.006	0.030	0.394	0.161	0.050
Anoplolepis sp B	**Anop spB**	Hot Climate Specialists	77	3	47	127	3	4	7	14	41	16	25	82	223	2.046	0.134	1.962	0.140	0.200	0.261	1.050	0.753	0.092	0.917	0.036	0.560	0.044	0.059	0.102	0.123	0.048	0.075	0.158	0.006	0.097	0.006	0.008	0.014	0.084	0.033	0.052	0.261	0.029	0.169
Anoplolepis sp C	**Anop spC**	Hot Climate Specialists	0	3	0	3	0	0	0	0	0	0	0	0	3	0.000	0.134	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.036	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000
Anoplolepis steingroeveri	**Anop stei**	Hot Climate Specialists	2096	989	462	3547	1	0	244	245	1	0	26398	26399	30191	55.700	44.132	19.282	0.047	0.000	9.088	0.026	0.000	96.316	24.952	11.774	5.500	0.015	0.000	3.570	0.003	0.000	78.949	4.306	2.032	0.949	0.002	0.000	0.501	0.002	0.000	54.237	7.288	0.503	54.239
Camponotus fulvipilosus	**Camp ful**	Subordinate Camponotini	2	0	18	20	22	29	44	95	29	14	3	46	161	0.053	0.000	0.751	1.041	1.448	1.639	0.743	0.659	0.011	0.024	0.000	0.214	0.327	0.424	0.644	0.087	0.042	0.009	0.004	0.000	0.037	0.046	0.060	0.090	0.060	0.029	0.006	0.041	0.196	0.095
Camponotus sp B	**Camp spB**	Subordinate Camponotini	2	1	2	5	5	12	9	26	7	3	1	11	42	0.053	0.045	0.083	0.233	0.599	0.335	0.179	0.141	0.004	0.024	0.012	0.024	0.073	0.176	0.132	0.021	0.009	0.003	0.004	0.002	0.004	0.010	0.025	0.018	0.014	0.006	0.002	0.010	0.053	0.023
Camponotus sp C	**Camp spC**	Subordinate Camponotini	9	6	4	19	1	12	9	22	13	9	13	35	76	0.239	0.268	0.167	0.047	0.599	0.335	0.333	0.424	0.049	0.107	0.071	0.048	0.015	0.176	0.132	0.039	0.027	0.040	0.018	0.012	0.008	0.002	0.025	0.018	0.027	0.018	0.027	0.039	0.045	0.073
Camponotus sp D	**Camp spD**	Subordinate Camponotini	5	11	2	18	13	1	5	19	4	7	10	21	58	0.133	0.491	0.083	0.606	0.050	0.186	0.102	0.329	0.037	0.060	0.131	0.024	0.190	0.015	0.073	0.012	0.021	0.030	0.010	0.023	0.004	0.027	0.002	0.010	0.008	0.014	0.021	0.037	0.039	0.043
Camponotus sp A	**Camp spA**	Subordinate Camponotini	2	0	0	2	0	0	0	0	0	0	10	10	12	0.053	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.037	0.024	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.031	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.021	0.004	0.000	0.021
Camponotus sp E	**Camp sp E**	Subordinate Camponotini	4	0	0	4	0	1	1	2	12	2	0	14	20	0.106	0.000	0.000	0.000	0.050	0.037	0.307	0.094	0.000	0.048	0.000	0.000	0.000	0.015	0.015	0.036	0.006	0.000	0.008	0.000	0.000	0.000	0.002	0.002	0.025	0.004	0.000	0.008	0.004	0.029
Camponotus mayri	**Camp may**	Subordinate Camponotini	2	0	0	2	0	1	0	1	0	0	0	0	3	0.053	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.000	0.024	0.000	0.000	0.000	0.015	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.004	0.002	0.000
Cardioncondyla sp A	**Card spA**	Opportunist	0	0	0	0	19	49	48	116	16	0	0	16	132	0.000	0.000	0.000	0.885	2.446	1.788	0.410	0.000	0.000	0.000	0.000	0.000	0.278	0.717	0.702	0.048	0.000	0.000	0.000	0.000	0.000	0.039	0.101	0.099	0.033	0.000	0.000	0.000	0.238	0.033
Crematogaster sp A	**Crem spA**	Generalised Myrmicinae	7	0	22	29	26	288	12	326	2	0	10	12	367	0.186	0.000	0.918	1.224	14.378	0.447	0.051	0.000	0.037	0.083	0.000	0.262	0.385	4.214	0.176	0.006	0.000	0.030	0.014	0.000	0.045	0.054	0.592	0.025	0.004	0.000	0.021	0.060	0.670	0.025
Crematogaster sp I	**Crem spI**	Generalised Myrmicinae	0	0	0	0	0	1	0	1	0	0	0	0	1	0.000	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.002	0.000
Dorylus helvolus	**Dor helv**	Tropical Climate Specialist	0	0	0	0	0	0	0	0	0	0	1	1	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.002
Lepisiota sp A	**Lepi spA**	Opportunist	21	0	9	30	1	5	48	54	15	16	20	51	135	0.558	0.000	0.376	0.047	0.250	1.788	0.384	0.753	0.074	0.250	0.000	0.107	0.015	0.073	0.702	0.045	0.048	0.060	0.043	0.000	0.018	0.002	0.010	0.099	0.031	0.033	0.041	0.062	0.111	0.105
Lepisiota sp B	**Lepi spB**	Opportunist	8	29	1	38	1	2	0	3	2	4	4	10	51	0.213	1.294	0.042	0.047	0.100	0.000	0.051	0.188	0.015	0.095	0.345	0.012	0.015	0.029	0.000	0.006	0.012	0.012	0.016	0.060	0.002	0.002	0.004	0.000	0.004	0.008	0.008	0.078	0.006	0.021
Lepisiota spinisior	**Lepi spi**	Opportunist	0	0	0	0	5	3	4	12	1	0	0	1	13	0.000	0.000	0.000	0.233	0.150	0.149	0.026	0.000	0.000	0.000	0.000	0.000	0.073	0.044	0.059	0.003	0.000	0.000	0.000	0.000	0.000	0.010	0.006	0.008	0.002	0.000	0.000	0.000	0.025	0.002
Lepisiota sp C	**Lepi spC**	Opportunist	0	0	0	0	0	0	2	2	0	0	0	0	2	0.000	0.000	0.000	0.000	0.000	0.074	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.029	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.004	0.000
Meranoplus spinisior	**Mera spi**	Hot Climate Specialists	26	2	17	45	2	3	4	9	5	10	0	15	69	0.691	0.089	0.710	0.096	0.150	0.149	0.128	0.471	0.000	0.310	0.024	0.202	0.030	0.044	0.059	0.015	0.030	0.000	0.053	0.004	0.035	0.004	0.006	0.008	0.010	0.021	0.000	0.092	0.019	0.031
Meranoplus sp B	**Mera spB**	Hot Climate Specialists	12	0	9	21	30	4	2	36	19	1	10	30	87	0.319	0.000	0.376	1.397	0.200	0.074	0.487	0.047	0.035	0.143	0.000	0.107	0.439	0.059	0.029	0.057	0.003	0.029	0.025	0.000	0.018	0.062	0.008	0.004	0.039	0.002	0.020	0.043	0.074	0.061
Meranoplus sp C	**Mera spC**	Hot Climate Specialists	30	6	18	54	0	5	50	55	6	0	1	7	116	0.797	0.268	0.751	0.000	0.250	1.862	0.154	0.000	0.004	0.357	0.071	0.214	0.000	0.073	0.732	0.018	0.000	0.003	0.062	0.012	0.037	0.000	0.010	0.103	0.012	0.000	0.002	0.111	0.113	0.015
Meranoplus sp D	**Mera spD**	Hot Climate Specialists	0	0	0	0	0	0	1	1	0	0	0	0	1	0.000	0.000	0.000	0.000	0.000	0.037	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.002	0.000
Messor nr. Capensis	**Mes.n.cap**	Hot Climate Specialists	0	0	0	0	3	0	4	7	13	0	0	13	20	0.000	0.000	0.000	0.140	0.000	0.149	0.333	0.000	0.000	0.000	0.000	0.000	0.044	0.000	0.059	0.039	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.008	0.027	0.000	0.000	0.000	0.014	0.027
Monomorium fastidium	**Mon fasti**	Generalised Myrmicinae	164	132	76	372	178	250	113	541	178	163	164	505	1417	4.358	5.890	3.172	8.278	12.481	4.209	4.559	7.671	0.597	1.952	1.571	0.905	2.600	3.658	1.653	0.532	0.487	0.490	0.337	0.271	0.156	0.365	0.514	0.232	0.366	0.335	0.336	0.764	1.111	1.037
Monomorium notulum	**Mon notu**	Hot Climate Specialists	86	4	22	112	0	2	45	47	105	48	70	223	382	2.285	0.178	0.918	0.000	0.100	1.676	2.690	2.259	0.255	1.024	0.048	0.262	0.000	0.029	0.658	0.314	0.144	0.209	0.177	0.008	0.045	0.000	0.004	0.092	0.216	0.099	0.144	0.230	0.097	0.458
Monomorium rufulum	**Mon rufu**	Generalised Myrmicinae	163	124	94	381	172	67	139	378	206	156	86	448	1208	4.332	5.533	3.923	8.025	3.345	5.177	5.277	7.341	0.315	1.940	1.476	1.119	2.521	0.980	2.034	0.616	0.467	0.258	0.335	0.255	0.193	0.354	0.138	0.286	0.423	0.321	0.177	0.783	0.777	0.921
Monomorium sp A	**Mon spA**	Hot Climate Specialists	24	0	1	25	0	0	0	0	5	0	1	6	31	0.638	0.000	0.042	0.000	0.000	0.000	0.128	0.000	0.004	0.286	0.000	0.012	0.000	0.000	0.000	0.015	0.000	0.003	0.049	0.000	0.002	0.000	0.000	0.000	0.010	0.000	0.002	0.051	0.000	0.012
Monomorium sp B	**Mon spB**	Hot Climate Specialists	142	14	70	226	59	157	117	333	76	4	27	107	666	3.774	0.625	2.922	2.731	7.838	4.358	1.947	0.188	0.100	1.690	0.167	0.833	0.858	2.297	1.712	0.227	0.012	0.082	0.292	0.029	0.144	0.120	0.323	0.240	0.156	0.008	0.056	0.464	0.683	0.221
Monorium sp C	**Mon spC**	Hot Climate Specialists	0	0	0	0	0	12	0	12	0	0	0	0	12	0.000	0.000	0.000	0.000	0.599	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.176	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.025	0.000	0.000	0.000	0.000	0.000	0.025	0.000
Monomorium sp E	**Mon spE**	Hot Climate Specialists	0	0	0	0	0	8	2	10	1	0	0	1	11	0.000	0.000	0.000	0.000	0.399	0.074	0.026	0.000	0.000	0.000	0.000	0.000	0.000	0.117	0.029	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.016	0.004	0.002	0.000	0.000	0.000	0.021	0.002
Myrmicaria sp A	**Myrm spA**	Tropical Climate Specialist	0	31	1	32	841	1	1047	1889	2215	858	42	3115	5036	0.000	1.383	0.042	39.182	0.050	38.994	56.737	40.376	0.152	0.000	0.369	0.012	12.308	0.015	15.318	6.624	2.566	0.125	0.000	0.064	0.002	1.728	0.002	2.151	4.551	1.763	0.086	0.066	3.882	6.400
Myrmicaria sp B	**Myrm spB**	Tropical Climate Specialist	0	0	0	0	1	0	0	1	0	0	0	0	1	0.000	0.000	0.000	0.047	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000
Ocymyrmex sp A	**Ocym spA**	Hot Climate Specialists	109	11	35	155	0	1	45	46	33	7	73	113	314	2.897	0.491	1.461	0.000	0.050	1.676	0.845	0.329	0.267	1.298	0.131	0.417	0.000	0.015	0.658	0.099	0.021	0.219	0.224	0.023	0.072	0.000	0.002	0.092	0.068	0.014	0.151	0.318	0.095	0.233
Ocymyrmex sp B	**Ocym spB**	Hot Climate Specialists	203	27	452	682	6	11	170	187	225	156	128	509	1378	5.395	1.205	18.865	0.279	0.549	6.331	5.763	7.341	0.465	2.417	0.321	5.381	0.088	0.161	2.487	0.673	0.467	0.381	0.417	0.055	0.929	0.012	0.023	0.349	0.462	0.321	0.262	1.401	0.384	1.045
Ocymyrmex sp C	**Ocym spC**	Hot Climate Specialists	13	3	32	48	1	1	0	2	16	22	2	40	90	0.345	0.134	1.336	0.050	0.050	0.000	0.410	1.035	0.008	0.155	0.036	0.381	0.016	0.015	0.000	0.048	0.066	0.006	0.027	0.006	0.066	0.002	0.002	0.000	0.033	0.045	0.004	0.099	0.004	0.082
Ocymyrmex sp D	**Ocym spD**	Hot Climate Specialists	9	12	29	50	8	13	40	61	41	11	10	62	173	0.239	0.535	1.210	0.373	0.649	1.490	1.050	0.518	0.038	0.107	0.143	0.345	0.117	0.190	0.585	0.123	0.033	0.031	0.018	0.025	0.060	0.016	0.027	0.082	0.084	0.023	0.021	0.103	0.125	0.128
Ocymyrmex sp E	**Ocym spE**	Hot Climate Specialists	0	0	0	0	0	0	0	0	0	0	5	5	5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.000	0.000	0.009
Ocymyrmex weitzeckeri	**Ocym wei**	Hot Climate Specialists	54	45	0	99	2	0	0	2	0	1	25	26	127	1.435	2.008	0.000	0.100	0.000	0.000	0.000	0.047	0.091	0.643	0.536	0.000	0.031	0.000	0.000	0.000	0.003	0.075	0.111	0.092	0.000	0.004	0.000	0.000	0.000	0.002	0.051	0.203	0.004	0.053
Opthalmopone berthoudi	**Opt bert**	Specialist predator	3	2	4	9	14	3	0	17	18	8	1	27	53	0.080	0.089	0.167	0.655	0.150	0.000	0.461	0.376	0.004	0.036	0.024	0.048	0.206	0.044	0.000	0.054	0.024	0.003	0.006	0.004	0.008	0.029	0.006	0.000	0.037	0.016	0.002	0.018	0.035	0.055
Pachycondyla sp A	**Pac spA**	Specialist predator	0	0	0	0	0	4	0	4	0	0	0	0	4	0.000	0.000	0.000	0.000	0.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.059	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.000	0.000	0.000	0.000	0.000	0.008	0.000
Pachycondyla sharpi	**Pac sha**	Specialist predator	0	0	0	0	0	1	0	1	0	0	0	0	1	0.000	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.002	0.000
Pachycondyla sp C	**Pac spC**	Specialist predator	0	1	0	1	4	0	0	4	0	0	0	0	5	0.000	0.045	0.000	0.200	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.000	0.063	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.009	0.000	0.000	0.000	0.000	0.000	0.002	0.009	0.000
Pheidole sp A	**Phei spA**	Generalised Myrmicinae	4	27	26	57	2	9	109	120	16	6	18	40	217	0.106	1.205	1.085	0.093	0.449	4.060	0.410	0.282	0.064	0.048	0.321	0.310	0.029	0.132	1.595	0.048	0.018	0.052	0.008	0.055	0.053	0.004	0.018	0.224	0.033	0.012	0.036	0.117	0.247	0.081
Pheidole sp B	**Phei spB**	Generalised Myrmicinae	8	121	6	135	70	299	93	462	89	133	6	228	825	0.213	5.399	0.250	3.274	14.928	3.464	2.280	6.259	0.022	0.095	1.440	0.071	1.028	4.375	1.361	0.266	0.398	0.018	0.016	0.249	0.012	0.144	0.614	0.191	0.183	0.273	0.012	0.277	0.950	0.468
Pheidole sp C	**Phei spC**	Generalised Myrmicinae	162	258	321	741	100	56	20	176	273	335	28	636	1553	4.305	11.513	13.397	4.638	2.796	0.745	6.993	15.765	0.104	1.929	3.071	3.821	1.457	0.819	0.293	0.816	1.002	0.085	0.333	0.530	0.660	0.205	0.115	0.041	0.561	0.688	0.058	1.522	0.361	1.308
Pheidole sp D	**Phei spD**	Generalised Myrmicinae	18	173	138	329	142	79	124	345	1	0	24	25	699	0.478	7.720	5.760	6.611	3.944	4.618	0.026	0.000	0.088	0.214	2.060	1.643	2.077	1.156	1.814	0.003	0.000	0.072	0.037	0.355	0.284	0.292	0.162	0.255	0.002	0.000	0.049	0.676	0.709	0.051
Plagiolepis sp A	**Plag spA**	Cryptic species	0	2	1	3	3	4	7	14	0	2	0	2	19	0.000	0.089	0.042	0.143	0.200	0.261	0.000	0.094	0.000	0.000	0.024	0.012	0.045	0.059	0.102	0.000	0.006	0.000	0.000	0.004	0.002	0.006	0.008	0.014	0.000	0.004	0.000	0.006	0.029	0.004
Plectrotena mandibularis	**Plec man**	Specialist predator	1	7	0	8	14	3	11	28	5	4	2	11	47	0.027	0.312	0.000	0.652	0.150	0.410	0.128	0.188	0.007	0.012	0.083	0.000	0.205	0.044	0.161	0.015	0.012	0.006	0.002	0.014	0.000	0.029	0.006	0.023	0.010	0.008	0.004	0.016	0.058	0.023
Sp XII (Coded)	**Sp. XII**	Coded	0	0	0	0	1	6	0	7	0	0	0	0	7	0.000	0.000	0.000	0.047	0.300	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.088	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.012	0.000	0.000	0.000	0.000	0.000	0.014	0.000
Tapinoma sp A	**Tap spA**	Opportunist	0	0	0	0	0	21	0	21	0	0	0	0	21	0.000	0.000	0.000	0.000	1.048	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.307	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.043	0.000	0.000	0.000	0.000	0.000	0.043	0.000
Tetramorium baufra	**Tetr bau**	Opportunist	8	60	0	68	144	344	44	532	35	7	13	55	655	0.213	2.677	0.000	6.694	17.174	1.639	0.897	0.329	0.049	0.095	0.714	0.000	2.103	5.033	0.644	0.105	0.021	0.040	0.016	0.123	0.000	0.295	0.707	0.090	0.072	0.014	0.028	0.140	1.092	0.114
Technomyrmex sp A	**Tech spA**	Opportunist	0	0	0	0	1	0	0	1	0	0	0	0	1	0.000	0.000	0.000	0.047	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000
Tetramorium sericeiventre	**Tetr ser**	Opportunist	0	0	4	4	61	8	0	69	62	39	20	121	195	0.000	0.000	0.167	2.858	0.399	0.000	1.588	1.835	0.075	0.000	0.000	0.048	0.898	0.117	0.000	0.185	0.117	0.061	0.000	0.000	0.008	0.126	0.016	0.000	0.127	0.080	0.042	0.008	0.143	0.249
Tetramorium setuliferum	**Tetr set**	Hot Climate Specialists	148	91	46	285	69	81	0	150	82	31	78	191	626	3.933	4.061	1.920	3.207	4.044	0.000	2.100	1.459	0.285	1.762	1.083	0.548	1.007	1.185	0.000	0.245	0.093	0.234	0.304	0.187	0.095	0.141	0.166	0.000	0.168	0.064	0.160	0.586	0.308	0.393
Tetramorium sp A	**Tet spA**	Opportunist	0	0	206	206	0	0	0	0	0	14	1	15	221	0.000	0.000	8.598	0.000	0.000	0.000	0.000	0.659	0.004	0.000	0.000	2.452	0.000	0.000	0.000	0.000	0.042	0.003	0.000	0.000	0.423	0.000	0.000	0.000	0.000	0.029	0.002	0.423	0.000	0.031
Tetramorium simulator	**Tetr sim**	Opportunist	0	7	0	7	13	38	0	51	0	0	0	0	58	0.000	0.312	0.000	0.612	1.897	0.000	0.000	0.000	0.000	0.000	0.083	0.000	0.192	0.556	0.000	0.000	0.000	0.000	0.000	0.014	0.000	0.027	0.078	0.000	0.000	0.000	0.000	0.014	0.105	0.000
Tetramorium sp C	**Tetr spC**	Opportunist	77	2	63	142	43	54	21	118	18	27	15	60	320	2.046	0.089	2.629	2.010	2.696	0.782	0.461	1.271	0.056	0.917	0.024	0.750	0.631	0.790	0.307	0.054	0.081	0.046	0.158	0.004	0.129	0.089	0.111	0.043	0.037	0.055	0.031	0.292	0.243	0.124
Tetramorium sp D	**Tetr spD**	Opportunist	8	1	13	22	15	9	0	24	0	0	14	14	60	0.213	0.045	0.543	0.715	0.449	0.000	0.000	0.000	0.051	0.095	0.012	0.155	0.225	0.132	0.000	0.000	0.000	0.042	0.016	0.002	0.027	0.032	0.018	0.000	0.000	0.000	0.029	0.045	0.050	0.029
Tetramorium sp E	**Tetr spE**	Opportunist	3	29	0	32	0	1	4	5	1	0	1	2	39	0.080	1.294	0.000	0.000	0.050	0.149	0.026	0.000	0.004	0.036	0.345	0.000	0.000	0.015	0.059	0.003	0.000	0.003	0.006	0.060	0.000	0.000	0.002	0.008	0.002	0.000	0.002	0.066	0.010	0.004
Tetramorium sp G	**Tetr spG**	Opportunist	0	0	0	0	10	1	0	11	0	0	0	0	11	0.000	0.000	0.000	0.466	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.146	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.021	0.002	0.000	0.000	0.000	0.000	0.000	0.023	0.000
Tetramorium sp H	**Tetr spH**	Opportunist	0	0	0	0	2	7	0	9	0	0	0	0	9	0.000	0.000	0.000	0.093	0.349	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.029	0.102	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.014	0.000	0.000	0.000	0.000	0.000	0.018	0.000
Tetramorium nr. setigerum	**Tet.n.se**	Opportunist	0	1	0	1	0	8	0	8	1	0	0	1	10	0.000	0.045	0.000	0.000	0.399	0.000	0.026	0.000	0.000	0.000	0.012	0.000	0.000	0.117	0.000	0.003	0.000	0.000	0.000	0.002	0.000	0.000	0.016	0.000	0.002	0.000	0.000	0.002	0.016	0.002
Tetramorium sp III	**Tetr spIII**	Opportunist	0	0	0	0	0	0	0	0	0	0	5	5	5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.018	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.000	0.010
Tetramorium sp V	**Tetr spV**	Opportunist	0	1	0	1	0	1	0	1	0	1	0	1	3	0.000	0.045	0.000	0.000	0.050	0.000	0.000	0.047	0.000	0.000	0.012	0.000	0.000	0.015	0.000	0.000	0.003	0.000	0.000	0.002	0.000	0.000	0.002	0.000	0.000	0.002	0.000	0.002	0.002	0.002
Tetramorium VIII	**Tet V111**	Opportunist	6	1	1	8	0	1	0	1	2	1	0	3	12	0.159	0.045	0.042	0.000	0.050	0.000	0.051	0.047	0.000	0.071	0.012	0.012	0.000	0.015	0.000	0.006	0.003	0.000	0.012	0.002	0.002	0.000	0.002	0.000	0.004	0.002	0.000	0.016	0.002	0.006
Tetramorium **?** *weitzeckeri*	**Tetr wei**	Opportunist	0	1	0	1	15	0	0	15	1	0	0	1	17	0.000	0.045	0.000	0.699	0.000	0.000	0.026	0.000	0.000	0.000	0.012	0.000	0.219	0.000	0.000	0.003	0.000	0.000	0.000	0.002	0.000	0.031	0.000	0.000	0.002	0.000	0.000	0.002	0.031	0.002
Tetramorium sp XVI	**Tet spXVI**	Opportunist	0	0	0	0	0	2	0	2	0	0	0	0	2	0.000	0.000	0.000	0.000	0.100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.029	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.004	0.000
Tetramorium sp 2	**Tet sp2**	Opportunist	0	0	0	0	0	2	0	2	0	0	0	0	2	0.000	0.000	0.000	0.000	0.100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.029	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.004	0.000
Tetramorium sp 3	**Tet sp3**	Opportunist	0	0	0	0	0	0	0	0	1	1	26	28	28	0.000	0.000	0.000	0.000	0.000	0.000	0.026	0.047	0.095	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.003	0.078	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.002	0.053	0.000	0.000	0.058
Tetramorium sp 4	**Tet sp4**	Opportunist	1	0	0	1	0	0	0	0	0	1	0	1	2	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.047	0.000	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.002	0.000	0.002
Tetraponera sp A	**Tetrpo A**	Tropical Climate Specialist	0	0	0	0	0	0	0	0	0	1	0	1	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.047	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.002
TOTAL FOR SPECIES:			**3763**	**2241**	**2396**	**8400**	**2147**	**2003**	**2685**	**6835**	**3904**	**2125**	**27408**	**33437**	**48671**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**44.80**	**26.68**	**28.52**	**31.41**	**29.31**	**39.28**	**11.68**	**6.36**	**81.97**	**7.73**	**4.60**	**4.92**	**4.41**	**4.12**	**5.52**	**8.02**	**4.37**	**56.31**	**17.26**	**14.04**	**68.70**

Appendix 8.1b. Descriptive statistics of the mean absolute ant abundances.

Replicate	***Anoc spA***	***Anop spA***	***Anop spB***	***Anop spC***	***Anop stei***	***Camp ful***	***Camp spB***
Total: General							
Mean	0.20	5.46	4.13	0.06	559.09	2.99	0.78
Standard Error	0.11	1.61	1.05	0.06	383.73	0.68	0.18
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	5.00	59.00	38.00	3.00	20361.00	25.00	6.00
Total: Good							
Mean	0.30	4.89	3.44	0.11	336.40	1.93	0.52
Standard Error	0.20	2.13	0.93	0.11	169.72	0.57	0.18
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	5.00	54.00	18.00	3.00	4381.00	12.00	3.00
Total: Poor							
Mean	0.11	6.02	4.83	0.00	781.78	4.05	1.04
Standard Error	0.08	2.45	1.89	0.00	753.47	1.20	0.32
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	2.00	59.00	38.00	0.00	20361.00	25.00	6.00
Commercial: General							
Mean	0.06	10.67	7.06	0.17	197.06	1.11	0.28
Standard Error	0.06	4.35	2.67	0.17	88.15	0.65	0.14
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	1.00	59.00	38.00	3.00	1261.00	10.00	2.00
Commercial: Good							
Mean	0.00	9.33	4.89	0.33	**387.00**	1.00	0.22
Standard Error	0.00	5.68	1.98	0.33	154.86	0.76	0.15
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	54.00	18.00	3.00	1261.00	7.00	1.00
Commercial: Poor							
Mean	0.11	12.00	9.22	0.00	7.11	1.22	0.33
Standard Error	0.11	6.92	5.01	0.00	4.88	1.10	0.24
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	1.00	59.00	38.00	0.00	45.00	10.00	2.00
Tribal: General							
Mean	0.11	4.35	0.78	0.00	13.61	5.30	1.44
Standard Error	0.11	1.55	0.40	0.00	13.55	1.19	0.41
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	2.00	25.00	7.00	0.00	244.00	16.00	6.00
Tribal: Good							
Mean	0.22	4.22	1.11	0.00	27.11	3.22	0.89
Standard Error	0.22	2.72	0.77	0.00	27.11	1.34	0.39
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	2.00	25.00	7.00	0.00	244.00	12.00	3.00
Tribal: Poor							
Mean	0.00	4.48	0.44	0.00	0.11	7.37	2.00
Standard Error	0.00	1.66	0.24	0.00	0.11	1.77	0.69
Minimum	0.00	0.00	0.00	0.00	0.00	1.00	0.00
Maximum	0.00	16.00	2.00	0.00	1.00	16.00	6.00
Reserve: General							
Mean	0.44	1.36	4.57	0.00	1466.61	2.56	0.61
Standard Error	0.29	0.49	1.35	0.00	1138.25	1.38	0.30
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	5.00	6.00	21.00	0.00	20361.00	25.00	4.00
Reserve: Good							
Mean	0.67	1.13	4.33	0.00	595.10	1.56	0.44
Standard Error	0.55	0.61	1.69	0.00	485.26	0.71	0.34
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	5.00	5.00	13.93	0.00	4381.00	6.00	3.00
Reserve: Poor							
Mean	0.22	1.59	4.81	0.00	2338.11	3.56	0.78
Standard Error	0.22	0.79	2.21	0.00	2254.12	2.71	0.52
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	2.00	6.00	21.00	0.00	20361.00	25.00	4.00

Appendix 8.1b (continue …)

	Camp spC	*Camp spD*	*Camp spA*	*Camp sp E*	*Camp may*	*Card spA*	*Crem spA*
Total: General							
Mean	1.41	1.08	0.23	0.37	0.06	2.44	6.80
Standard Error	0.27	0.26	0.17	0.16	0.04	0.62	3.51
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	10.00	8.00	9.23	6.00	2.00	18.00	185.00
Total: Good							
Mean	1.52	1.56	0.07	0.74	0.04	1.89	9.11
Standard Error	0.45	0.42	0.05	0.31	0.04	0.87	6.85
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	10.00	8.00	1.00	6.00	1.00	18.00	185.00
Total: Poor							
Mean	1.30	0.59	0.38	0.00	0.07	3.00	4.49
Standard Error	0.31	0.28	0.34	0.00	0.07	0.89	1.73
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	7.00	7.00	9.23	0.00	2.00	13.00	37.00
Commercial: General							
Mean	1.06	1.00	0.11	0.22	0.11	0.00	1.61
Standard Error	0.38	0.43	0.08	0.22	0.11	0.00	1.22
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	6.00	7.00	1.00	4.00	2.00	0.00	22.00
Commercial: Good							
Mean	0.78	0.78	0.11	0.44	0.00	0.00	0.00
Standard Error	0.66	0.46	0.11	0.44	0.00	0.00	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	6.00	4.00	1.00	4.00	0.00	0.00	0.00
Commercial: Poor							
Mean	1.33	1.22	0.11	0.00	0.22	0.00	3.22
Standard Error	0.41	0.74	0.11	0.00	0.22	0.00	2.39
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	4.00	7.00	1.00	0.00	2.00	0.00	22.00
Tribal: General							
Mean	1.22	1.06	0.00	0.11	0.06	6.44	18.13
Standard Error	0.42	0.40	0.00	0.08	0.06	1.35	10.11
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	7.00	5.00	0.00	1.00	1.00	18.00	185.00
Tribal: Good							
Mean	0.56	1.78	0.00	0.22	0.11	5.67	27.00
Standard Error	0.24	0.66	0.00	0.15	0.11	2.15	19.92
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	2.00	5.00	0.00	1.00	1.00	18.00	185.00
Tribal: Poor							
Mean	1.89	0.33	0.00	0.00	0.00	7.22	9.25
Standard Error	0.77	0.33	0.00	0.00	0.00	1.71	4.27
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	7.00	3.00	0.00	0.00	0.00	13.00	37.00
Reserve: General							
Mean	1.96	1.17	0.57	0.78	0.00	0.89	0.67
Standard Error	0.58	0.53	0.51	0.42	0.00	0.59	0.45
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	10.00	8.00	9.23	6.00	0.00	10.00	8.08
Reserve: Good							
Mean	3.24	2.13	0.11	1.56	0.00	0.00	0.33
Standard Error	0.95	0.98	0.11	0.78	0.00	0.00	0.24
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	10.00	8.00	1.00	6.00	0.00	0.00	2.00
Reserve: Poor							
Mean	0.68	0.22	1.03	0.00	0.00	1.78	1.01
Standard Error	0.34	0.15	1.03	0.00	0.00	1.13	0.89
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	3.00	1.00	9.23	0.00	0.00	10.00	8.08

Appendix 8.1b (continue …)

	Crem spI	***Dor helv***	***Lepi spA***	***Lepi spB***	***Lepi spi***	***Lepi spC***	***Mera spi***	***Mera spB***
Total: General								
Mean	0.02	0.02	2.50	0.94	0.24	0.04	1.28	1.60
Standard Error	0.02	0.02	0.63	0.56	0.10	0.04	0.28	0.37
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	1.00	1.15	22.00	29.00	3.00	2.00	8.00	10.00
Total: Good								
Mean	0.04	0.00	1.22	1.41	0.19	0.07	1.15	1.23
Standard Error	0.04	0.00	0.40	1.07	0.12	0.07	0.39	0.44
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	1.00	0.00	7.00	29.00	3.00	2.00	8.00	8.00
Total: Poor								
Mean	0.00	0.04	3.78	0.48	0.30	0.00	1.41	1.97
Standard Error	0.00	0.04	1.15	0.33	0.16	0.00	0.39	0.59
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	1.15	22.00	8.00	3.00	0.00	7.00	10.00
Commercial: General								
Mean	0.00	0.00	1.67	2.11	0.00	0.00	2.50	1.17
Standard Error	0.00	0.00	0.87	1.64	0.00	0.00	0.63	0.65
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	16.00	29.00	0.00	0.00	8.00	10.00
Commercial: Good								
Mean	0.00	0.00	0.56	3.33	0.00	0.00	2.89	0.33
Standard Error	0.00	0.00	0.34	3.21	0.00	0.00	0.95	0.24
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	3.00	29.00	0.00	0.00	8.00	2.00
Commercial: Poor								
Mean	0.00	0.00	2.78	0.89	0.00	0.00	2.11	2.00
Standard Error	0.00	0.00	1.68	0.89	0.00	0.00	0.87	1.26
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	16.00	8.00	0.00	0.00	7.00	10.00
Tribal: General								
Mean	0.06	0.00	3.00	0.17	0.67	0.11	0.50	2.00
Standard Error	0.06	0.00	1.30	0.09	0.27	0.11	0.19	0.66
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	1.00	0.00	22.00	1.00	3.00	2.00	3.00	8.00
Tribal: Good								
Mean	0.11	0.00	1.56	0.22	0.56	0.22	0.33	2.67
Standard Error	0.11	0.00	0.82	0.15	0.34	0.22	0.17	1.09
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	1.00	0.00	7.00	1.00	3.00	2.00	1.00	8.00
Tribal: Poor								
Mean	0.00	0.00	4.44	0.11	0.78	0.00	0.67	1.33
Standard Error	0.00	0.00	2.45	0.11	0.43	0.00	0.33	0.73
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	22.00	1.00	3.00	0.00	3.00	6.00
Reserve: General								
Mean	0.00	0.06	2.84	0.56	0.06	0.00	0.83	1.64
Standard Error	0.00	0.06	1.08	0.28	0.06	0.00	0.38	0.61
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	1.15	19.00	4.00	1.00	0.00	6.00	9.00
Reserve: Good								
Mean	0.00	0.00	1.56	0.67	0.00	0.00	0.22	0.70
Standard Error	0.00	0.00	0.82	0.37	0.00	0.00	0.15	0.47
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	7.00	3.00	0.00	0.00	1.00	4.29
Reserve: Poor								
Mean	0.00	0.13	4.13	0.44	0.11	0.00	1.44	2.59
Standard Error	0.00	0.13	1.96	0.44	0.11	0.00	0.71	1.07
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	1.15	19.00	4.00	1.00	0.00	6.00	9.00

Appendix 8.1b (continue …)

	Mera spC	*Mera spD*	*Mes.n.cap*	*Mon fasti*	*Mon notu*	*Mon rufu*	*Mon spA*
Total: General							
Mean	2.15	0.02	0.37	26.25	7.07	22.36	0.57
Standard Error	0.97	0.02	0.26	2.49	1.40	2.27	0.32
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	49.00	1.00	13.00	77.00	53.00	78.00	13.00
Total: Good							
Mean	3.41	0.04	0.59	28.19	7.57	25.05	0.93
Standard Error	1.90	0.04	0.49	3.39	1.69	3.64	0.62
Minimum	0.00	0.00	0.00	0.00	0.00	1.00	0.00
Maximum	49.00	1.00	13.00	70.00	34.29	78.00	13.00
Total: Poor							
Mean	0.89	0.00	0.15	24.31	6.58	19.67	0.22
Standard Error	0.33	0.00	0.15	3.69	2.25	2.68	0.19
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	7.00	0.00	4.00	77.00	53.00	60.00	5.00
Commercial: General							
Mean	3.00	0.00	0.00	20.67	6.22	21.17	1.39
Standard Error	1.08	0.00	0.00	4.94	1.99	3.18	0.92
Minimum	0.00	0.00	0.00	0.00	0.00	3.00	0.00
Maximum	16.00	0.00	0.00	65.00	27.00	54.00	13.00
Commercial: Good							
Mean	4.33	0.00	0.00	27.67	7.44	27.78	2.78
Standard Error	1.96	0.00	0.00	7.80	2.55	4.84	1.75
Minimum	0.00	0.00	0.00	0.00	0.00	7.00	0.00
Maximum	16.00	0.00	0.00	65.00	24.00	54.00	13.00
Commercial: Poor							
Mean	1.67	0.00	0.00	13.67	5.00	14.56	0.00
Standard Error	0.83	0.00	0.00	5.52	3.15	2.93	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	3.00	0.00
Maximum	7.00	0.00	0.00	52.00	27.00	33.00	0.00
Tribal: General							
Mean	3.06	0.06	0.39	30.04	2.61	21.02	0.00
Standard Error	2.71	0.06	0.27	5.16	1.17	4.34	0.00
Minimum	0.00	0.00	0.00	3.00	0.00	1.00	0.00
Maximum	49.00	1.00	4.00	77.00	15.00	63.00	0.00
Tribal: Good							
Mean	5.89	0.11	0.33	26.00	3.44	18.67	0.00
Standard Error	5.39	0.11	0.33	6.58	1.72	6.59	0.00
Minimum	0.00	0.00	0.00	3.00	0.00	1.00	0.00
Maximum	49.00	1.00	3.00	70.00	13.00	63.00	0.00
Tribal: Poor							
Mean	0.22	0.00	0.44	34.08	1.78	23.37	0.00
Standard Error	0.22	0.00	0.44	8.11	1.66	5.92	0.00
Minimum	0.00	0.00	0.00	10.00	0.00	8.00	0.00
Maximum	2.00	0.00	4.00	77.00	15.00	60.00	0.00
Reserve: General							
Mean	0.40	0.00	0.72	28.04	12.38	24.90	0.33
Standard Error	0.25	0.00	0.72	2.08	3.16	4.32	0.28
Minimum	0.00	0.00	0.00	11.54	1.00	0.00	0.00
Maximum	4.00	0.00	13.00	45.00	53.00	78.00	5.00
Reserve: Good							
Mean	0.00	0.00	1.44	30.91	11.81	28.71	0.00
Standard Error	0.00	0.00	1.44	2.46	3.75	7.38	0.00
Minimum	0.00	0.00	0.00	20.00	1.00	4.00	0.00
Maximum	0.00	0.00	13.00	43.00	34.29	78.00	0.00
Reserve: Poor							
Mean	0.79	0.00	0.00	25.17	12.96	21.09	0.67
Standard Error	0.47	0.00	0.00	3.19	5.33	4.59	0.55
Minimum	0.00	0.00	0.00	11.54	2.00	0.00	0.00
Maximum	4.00	0.00	0.00	45.00	53.00	43.85	5.00

Appendix 8.1b (continue …)

	Mon spB	***Mon spC***	***Mon spE***	***Myrm spA***	***Myrm spB***	***Ocym spA***	***Ocym spB***
Total: General							
Mean	12.33	0.22	0.20	93.26	0.02	5.82	25.51
Standard Error	2.34	0.22	0.12	31.08	0.02	1.75	3.77
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	86.00	12.00	6.00	1209.00	1.00	76.00	106.00
Total: Good							
Mean	12.50	0.44	0.22	108.74	0.00	3.44	27.71
Standard Error	3.96	0.44	0.22	53.87	0.00	1.34	5.21
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	86.00	12.00	6.00	1209.00	0.00	25.00	101.00
Total: Poor							
Mean	12.17	0.00	0.19	77.78	0.04	8.20	23.31
Standard Error	2.56	0.00	0.11	31.90	0.04	3.20	5.51
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	49.00	0.00	2.00	673.00	1.00	76.00	106.00
Commercial: General							
Mean	12.56	0.00	0.00	1.78	0.00	8.61	37.89
Standard Error	5.13	0.00	0.00	1.01	0.00	4.27	8.49
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	86.00	0.00	0.00	16.00	0.00	76.00	106.00
Commercial: Good							
Mean	18.00	0.00	0.00	0.00	0.00	4.67	40.67
Standard Error	9.51	0.00	0.00	0.00	0.00	2.62	11.73
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	86.00	0.00	0.00	0.00	0.00	20.00	101.00
Commercial: Poor							
Mean	7.11	0.00	0.00	3.56	0.00	12.56	35.11
Standard Error	3.71	0.00	0.00	1.89	0.00	8.17	12.92
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Maximum	30.00	0.00	0.00	16.00	0.00	76.00	106.00
Tribal: General							
Mean	18.48	0.67	0.56	104.96	0.06	2.56	10.39
Standard Error	4.03	0.67	0.35	41.99	0.06	1.65	3.74
Minimum	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	59.00	12.00	6.00	574.00	1.00	25.00	54.00
Tribal: Good							
Mean	16.33	1.33	0.67	89.56	0.00	2.89	12.11
Standard Error	6.60	1.33	0.67	62.82	0.00	2.77	6.09
Minimum	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	59.00	12.00	6.00	574.00	0.00	25.00	54.00
Tribal: Poor							
Mean	20.63	0.00	0.44	120.36	0.11	2.22	8.67
Standard Error	4.94	0.00	0.29	59.07	0.11	1.98	4.66
Minimum	4.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	49.00	0.00	2.00	476.00	1.00	18.00	36.00
Reserve: General							
Mean	5.97	0.00	0.06	173.04	0.00	6.29	28.25
Standard Error	1.98	0.00	0.06	79.96	0.00	2.55	4.88
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	28.00	0.00	1.00	1209.00	0.00	36.00	61.00
Reserve: Good							
Mean	3.16	0.00	0.00	236.67	0.00	2.78	30.34
Standard Error	1.53	0.00	0.00	144.13	0.00	1.64	6.13
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	4.00
Maximum	14.00	0.00	0.00	1209.00	0.00	15.00	56.00
Reserve: Poor							
Mean	8.78	0.00	0.11	109.42	0.00	9.81	26.16
Standard Error	3.51	0.00	0.11	73.39	0.00	4.68	7.90
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	28.00	0.00	1.00	673.00	0.00	36.00	61.00

Appendix 8.1b (continue …)

	Ocym spC	***Ocym spD***	***Ocym spE***	***Ocym wei***	***Opt bert***	***Pac spA***	***Pac sha***	***Pac spC***
Total: General								
Mean	1.67	3.21	0.09	2.35	0.98	0.07	0.02	0.10
Standard Error	0.37	0.67	0.09	1.22	0.22	0.04	0.02	0.08
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	13.00	26.00	4.62	54.00	6.00	2.00	1.00	4.29
Total: Good								
Mean	1.74	3.23	0.00	3.70	1.30	0.04	0.04	0.04
Standard Error	0.60	0.79	0.00	2.32	0.35	0.04	0.04	0.04
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	13.00	15.00	0.00	54.00	6.00	1.00	1.00	1.00
Total: Poor								
Mean	1.60	3.19	0.17	1.01	0.67	0.11	0.00	0.16
Standard Error	0.45	1.09	0.17	0.71	0.24	0.08	0.00	0.16
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	9.00	26.00	4.62	18.00	5.00	2.00	0.00	4.29
Commercial: General								
Mean	2.67	2.78	0.00	5.50	0.50	0.00	0.00	0.06
Standard Error	0.89	1.02	0.00	3.43	0.23	0.00	0.00	0.06
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	13.00	15.00	0.00	54.00	3.00	0.00	0.00	1.00
Commercial: Good								
Mean	3.44	3.33	0.00	11.00	0.67	0.00	0.00	0.11
Standard Error	1.52	1.69	0.00	6.52	0.44	0.00	0.00	0.11
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	13.00	15.00	0.00	54.00	3.00	0.00	0.00	1.00
Commercial: Poor								
Mean	1.89	2.22	0.00	0.00	0.33	0.00	0.00	0.00
Standard Error	0.93	1.21	0.00	0.00	0.17	0.00	0.00	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	9.00	9.00	0.00	0.00	1.00	0.00	0.00	0.00
Tribal: General								
Mean	0.12	3.39	0.00	0.12	0.95	0.22	0.06	0.24
Standard Error	0.08	1.47	0.00	0.12	0.44	0.13	0.06	0.24
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	1.07	26.00	0.00	2.14	6.00	2.00	1.00	4.29
Tribal: Good								
Mean	0.11	2.56	0.00	0.00	1.22	0.11	0.11	0.00
Standard Error	0.11	1.17	0.00	0.00	0.70	0.11	0.11	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	1.00	9.00	0.00	0.00	6.00	1.00	1.00	0.00
Tribal: Poor								
Mean	0.12	4.22	0.00	0.24	0.67	0.33	0.00	0.48
Standard Error	0.12	2.77	0.00	0.24	0.55	0.24	0.00	0.48
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	1.07	26.00	0.00	2.14	5.00	2.00	0.00	4.29
Reserve: General								
Mean	2.23	3.46	0.26	1.44	1.50	0.00	0.00	0.00
Standard Error	0.55	0.98	0.26	1.05	0.40	0.00	0.00	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	6.00	14.00	4.62	18.00	6.00	0.00	0.00	0.00
Reserve: Good								
Mean	1.67	3.81	0.00	0.11	2.00	0.00	0.00	0.00
Standard Error	0.73	1.35	0.00	0.11	0.65	0.00	0.00	0.00
Minimum	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	6.00	14.00	0.00	1.00	6.00	0.00	0.00	0.00
Reserve: Poor								
Mean	2.78	3.11	0.51	2.78	1.00	0.00	0.00	0.00
Standard Error	0.81	1.50	0.51	2.05	0.44	0.00	0.00	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	6.00	14.00	4.62	18.00	3.00	0.00	0.00	0.00

Appendix 8.1b (continue …)

	Phei spA	*Phei spB*	*Phei spC*	*Phei spD*	*Plag spA*	*Plec man*	*Sp. XII*	*Tap spA*
Total: General								
Mean	4.01	15.28	28.76	12.94	0.35	0.87	0.13	0.39
Standard Error	1.47	2.96	4.32	2.54	0.15	0.22	0.07	0.22
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	75.00	106.00	159.00	64.00	7.00	7.00	3.00	9.00
Total: Good								
Mean	6.53	12.96	33.96	9.78	0.59	1.11	0.07	0.41
Standard Error	2.81	3.20	7.30	2.73	0.28	0.36	0.05	0.29
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	75.00	65.00	159.00	56.00	7.00	7.00	1.00	7.00
Total: Poor								
Mean	1.49	17.60	23.55	16.11	0.11	0.63	0.19	0.37
Standard Error	0.67	5.00	4.55	4.25	0.08	0.27	0.13	0.33
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	16.00	106.00	70.00	64.00	2.00	6.00	3.00	9.00
Commercial: General								
Mean	3.17	7.50	41.17	18.28	0.17	0.44	0.00	0.00
Standard Error	1.40	3.98	9.68	5.29	0.12	0.39	0.00	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	21.00	70.00	159.00	64.00	2.00	7.00	0.00	0.00
Commercial: Good								
Mean	4.33	4.11	52.67	13.44	0.33	0.89	0.00	0.00
Standard Error	2.22	2.18	17.19	6.19	0.24	0.77	0.00	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	21.00	20.00	159.00	56.00	2.00	7.00	0.00	0.00
Commercial: Poor								
Mean	2.00	10.89	29.67	23.11	0.00	0.00	0.00	0.00
Standard Error	1.76	7.73	8.36	8.64	0.00	0.00	0.00	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	16.00	70.00	63.00	64.00	0.00	0.00	0.00	0.00
Tribal: General								
Mean	6.67	25.68	9.75	19.16	0.78	1.56	0.39	1.17
Standard Error	4.15	6.78	2.48	4.43	0.41	0.48	0.20	0.63
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	75.00	106.00	38.00	57.00	7.00	6.00	3.00	9.00
Tribal: Good								
Mean	11.33	19.33	10.00	13.11	1.44	1.56	0.22	1.22
Standard Error	8.17	7.56	4.06	4.64	0.77	0.69	0.15	0.85
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	75.00	65.00	38.00	37.00	7.00	5.00	1.00	7.00
Tribal: Poor								
Mean	2.00	32.03	9.51	25.21	0.12	1.56	0.56	1.11
Standard Error	1.04	11.32	3.12	7.27	0.12	0.71	0.38	0.99
Minimum	0.00	1.00	0.00	2.00	0.00	0.00	0.00	0.00
Maximum	9.00	106.00	27.00	57.00	1.07	6.00	3.00	9.00
Reserve: General								
Mean	2.20	12.67	35.35	1.39	0.11	0.61	0.00	0.00
Standard Error	0.69	3.10	6.44	1.00	0.11	0.22	0.00	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	10.00	37.00	79.00	17.00	2.00	2.00	0.00	0.00
Reserve: Good								
Mean	3.93	15.44	39.22	2.78	0.00	0.89	0.00	0.00
Standard Error	1.10	4.71	9.38	1.93	0.00	0.35	0.00	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	10.00	34.00	79.00	17.00	0.00	2.00	0.00	0.00
Reserve: Poor								
Mean	0.46	9.89	31.49	0.00	0.22	0.33	0.00	0.00
Standard Error	0.25	4.08	9.20	0.00	0.22	0.24	0.00	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	2.00	37.00	70.00	0.00	2.00	2.00	0.00	0.00

Appendix 8.1b (continue …)

	Tetr bau	*Tech spA*	*Tetr ser*	*Tetr set*	*Tet spA*	*Tetr sim*	*Tetr spC*	*Tetr spD*
Total: General								
Mean	12.13	0.02	3.61	11.59	4.09	1.08	5.93	1.12
Standard Error	3.32	0.02	0.76	2.17	2.29	0.41	1.10	0.40
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	154.00	1.00	29.00	91.00	100.00	17.00	39.00	14.00
Total: Good								
Mean	15.52	0.04	3.79	15.50	1.30	1.30	7.79	1.26
Standard Error	6.15	0.04	1.01	3.84	0.96	0.67	1.91	0.58
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	154.00	1.00	17.00	91.00	24.00	17.00	39.00	13.00
Total: Poor								
Mean	8.75	0.00	3.42	7.68	6.89	0.86	4.08	0.98
Standard Error	2.49	0.00	1.16	1.81	4.46	0.46	1.01	0.55
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	42.00	0.00	29.00	33.00	100.00	12.00	20.00	14.00
Commercial: General								
Mean	3.78	0.00	0.22	15.83	11.44	0.39	7.89	1.22
Standard Error	2.21	0.00	0.22	5.69	6.61	0.16	2.42	0.79
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	39.00	0.00	4.00	91.00	100.00	2.00	39.00	13.00
Commercial: Good								
Mean	5.67	0.00	0.44	25.33	3.89	0.56	9.33	2.33
Standard Error	4.22	0.00	0.44	10.23	2.79	0.29	4.16	1.54
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	39.00	0.00	4.00	91.00	24.00	2.00	39.00	13.00
Commercial: Poor								
Mean	1.89	0.00	0.00	6.33	19.00	0.22	6.44	0.11
Standard Error	1.43	0.00	0.00	3.17	12.80	0.15	2.65	0.11
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	13.00	0.00	0.00	25.00	100.00	1.00	20.00	1.00
Tribal: General								
Mean	29.54	0.06	3.85	8.33	0.00	2.84	6.56	1.35
Standard Error	8.38	0.06	1.26	2.13	0.00	1.11	2.07	0.47
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	154.00	1.00	17.00	26.00	0.00	17.00	35.00	5.36
Tribal: Good								
Mean	38.67	0.11	4.89	9.56	0.00	3.33	10.56	1.44
Standard Error	15.75	0.11	2.24	3.45	0.00	1.89	3.66	0.73
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	2.00	0.00
Maximum	154.00	1.00	17.00	26.00	0.00	17.00	35.00	5.00
Tribal: Poor								
Mean	20.41	0.00	2.82	7.10	0.00	2.35	2.57	1.26
Standard Error	5.44	0.00	1.20	2.64	0.00	1.28	0.88	0.63
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	42.00	0.00	9.00	21.00	0.00	12.00	7.00	5.36
Reserve: General								
Mean	3.08	0.00	6.75	10.62	0.83	0.00	3.35	0.78
Standard Error	1.03	0.00	1.60	2.35	0.78	0.00	0.77	0.78
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	13.00	0.00	29.00	33.00	14.00	0.00	12.00	14.00
Reserve: Good								
Mean	2.22	0.00	6.05	11.61	0.00	0.00	3.47	0.00
Standard Error	1.04	0.00	1.58	2.98	0.00	0.00	1.21	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	9.00	0.00	14.00	26.00	0.00	0.00	12.00	0.00
Reserve: Poor								
Mean	3.94	0.00	7.44	9.62	1.67	0.00	3.22	1.56
Standard Error	1.81	0.00	2.87	3.78	1.55	0.00	1.01	1.56
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	13.00	0.00	29.00	33.00	14.00	0.00	8.00	14.00

Appendix 8.1b (continue …)

	Tetr spE	***Tetr spG***	***Tetr spH***	***Tet.n.se***	***Tetr spIII***	***Tetr spV***	***Tet V111***	***Tetr wei***
Total: General								
Mean	0.72	0.20	0.17	0.19	0.09	0.06	0.22	0.31
Standard Error	0.42	0.19	0.10	0.12	0.09	0.03	0.09	0.21
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	22.00	10.00	5.00	6.00	5.00	1.00	4.00	11.00
Total: Good								
Mean	0.41	0.37	0.15	0.11	0.19	0.07	0.30	0.22
Standard Error	0.18	0.37	0.09	0.06	0.19	0.05	0.16	0.11
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	4.00	10.00	2.00	1.00	5.00	1.00	4.00	2.00
Total: Poor								
Mean	1.04	0.04	0.19	0.26	0.00	0.04	0.15	0.41
Standard Error	0.82	0.04	0.19	0.22	0.00	0.04	0.07	0.41
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	22.00	1.00	5.00	6.00	0.00	1.00	1.00	11.00
Commercial: General								
Mean	1.78	0.00	0.00	0.06	0.00	0.06	0.44	0.06
Standard Error	1.22	0.00	0.00	0.06	0.00	0.06	0.23	0.06
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	22.00	0.00	0.00	1.00	0.00	1.00	4.00	1.00
Commercial: Good								
Mean	0.56	0.00	0.00	0.00	0.00	0.11	0.67	0.11
Standard Error	0.29	0.00	0.00	0.00	0.00	0.11	0.44	0.11
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	2.00	0.00	0.00	0.00	0.00	1.00	4.00	1.00
Commercial: Poor								
Mean	3.00	0.00	0.00	0.11	0.00	0.00	0.22	0.00
Standard Error	2.42	0.00	0.00	0.11	0.00	0.00	0.15	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	22.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00
Tribal: General								
Mean	0.28	0.61	0.50	0.44	0.00	0.06	0.06	0.83
Standard Error	0.23	0.56	0.29	0.34	0.00	0.06	0.06	0.62
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	4.00	10.00	5.00	6.00	0.00	1.00	1.00	11.00
Tribal: Good								
Mean	0.44	1.11	0.44	0.22	0.00	0.00	0.00	0.44
Standard Error	0.44	1.11	0.24	0.15	0.00	0.00	0.00	0.29
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	4.00	10.00	2.00	1.00	0.00	0.00	0.00	2.00
Tribal: Poor								
Mean	0.11	0.11	0.56	0.67	0.00	0.11	0.11	1.22
Standard Error	0.11	0.11	0.56	0.67	0.00	0.11	0.11	1.22
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	1.00	1.00	5.00	6.00	0.00	1.00	1.00	11.00
Reserve: General								
Mean	0.11	0.00	0.00	0.06	0.28	0.06	0.17	0.06
Standard Error	0.08	0.00	0.00	0.06	0.28	0.06	0.09	0.06
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	1.00	0.00	0.00	1.00	5.00	1.00	1.00	1.00
Reserve: Good								
Mean	0.22	0.00	0.00	0.11	0.56	0.11	0.22	0.11
Standard Error	0.15	0.00	0.00	0.11	0.56	0.11	0.15	0.11
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	1.00	0.00	0.00	1.00	5.00	1.00	1.00	1.00
Reserve: Poor								
Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00
Standard Error	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00

Appendix 8.1b (continue …)

	Tet spXVI	***Tet sp2***	***Tet sp3***	***Tet sp4***	***Tetrpo A***	**Average**
Total: General						
Mean	0.04	0.04	0.52	0.04	0.02	901
Standard Error	0.04	0.04	0.48	0.03	0.02	380
Minimum	0.00	0.00	0.00	0.00	0.00	102
Maximum	2.00	2.00	26.00	1.00	1.00	20475
Total: Good						
Mean	0.07	0.00	1.04	0.00	0.04	712
Standard Error	0.07	0.00	0.96	0.00	0.04	168
Minimum	0.00	0.00	0.00	0.00	0.00	144
Maximum	2.00	0.00	26.00	0.00	1.00	4548
Total: Poor						
Mean	0.00	0.07	0.00	0.07	0.00	1091
Standard Error	0.00	0.07	0.00	0.05	0.00	747
Minimum	0.00	0.00	0.00	0.00	0.00	102
Maximum	0.00	2.00	0.00	1.00	0.00	20475
Commercial: General						
Mean	0.00	0.00	0.00	0.06	0.00	467
Standard Error	0.00	0.00	0.00	0.06	0.00	96
Minimum	0.00	0.00	0.00	0.00	0.00	134
Maximum	0.00	0.00	0.00	1.00	0.00	1649
Commercial: Good						
Mean	0.00	0.00	0.00	0.00	0.00	689
Standard Error	0.00	0.00	0.00	0.00	0.00	162
Minimum	0.00	0.00	0.00	0.00	0.00	144
Maximum	0.00	0.00	0.00	0.00	0.00	1649
Commercial: Poor						
Mean	0.00	0.00	0.00	0.11	0.00	245
Standard Error	0.00	0.00	0.00	0.11	0.00	25
Minimum	0.00	0.00	0.00	0.00	0.00	134
Maximum	0.00	0.00	0.00	1.00	0.00	343
Tribal: General						
Mean	0.11	0.11	0.00	0.00	0.00	380
Standard Error	0.11	0.11	0.00	0.00	0.00	43
Minimum	0.00	0.00	0.00	0.00	0.00	164
Maximum	2.00	2.00	0.00	0.00	0.00	764
Tribal: Good						
Mean	0.22	0.00	0.00	0.00	0.00	389
Standard Error	0.22	0.00	0.00	0.00	0.00	68
Minimum	0.00	0.00	0.00	0.00	0.00	176
Maximum	2.00	0.00	0.00	0.00	0.00	764
Tribal: Poor						
Mean	0.00	0.22	0.00	0.00	0.00	371
Standard Error	0.00	0.22	0.00	0.00	0.00	57
Minimum	0.00	0.00	0.00	0.00	0.00	164
Maximum	0.00	2.00	0.00	0.00	0.00	693
Reserve: General						
Mean	0.00	0.00	1.56	0.06	0.06	1858
Standard Error	0.00	0.00	1.44	0.06	0.06	1122
Minimum	0.00	0.00	0.00	0.00	0.00	102
Maximum	0.00	0.00	26.00	1.00	1.00	20475
Reserve: Good						
Mean	0.00	0.00	3.11	0.00	0.11	1057
Standard Error	0.00	0.00	2.86	0.00	0.11	467
Minimum	0.00	0.00	0.00	0.00	0.00	164
Maximum	0.00	0.00	26.00	0.00	1.00	4548
Reserve: Poor						
Mean	0.00	0.00	0.00	0.11	0.00	2658
Standard Error	0.00	0.00	0.00	0.11	0.00	2230
Minimum	0.00	0.00	0.00	0.00	0.00	102
Maximum	0.00	0.00	0.00	1.00	0.00	20475

Appendix 8.2. Key ant species related to the different environmental parameters

Species	Bush numbers	Bush-BE	Soil	Annual species composition	Annual ecological	Annual grazing	Annual lifeform	Land use	Production kgspc	Specialist	Generalist	Association
	r = 0.509	r = 0.539	r = 0.6	r = 0.441	r = 0.366	r = 0.377	r = 0.383	r = 0.318	r = 0.448			
Anoc spA												Reserve land use
Anop spA			🟨							Soil		
Anop spB									🟨	Herbaceous production		
Anop spC				🟨						Herbaceous species composition		
Anop stei							🟨			Herbaceous lifeform		
Camp ful				🟨	🟨	🟨	🟨	🟨		Herbaceous composition properties; Land use		
Camp spB												Tribal land use
Camp spC				🟨		🟨			🟨	Herbaceous composition; grazing index		
Camp spD			🟨	🟨	🟨	🟨				Herbaceous composition; grazing & ecological indices; soil		
Camp spA												Reserve land use
Camp sp E												Reserve land use
Camp may	🟨	🟨								Woody component		
Card spA	🟨	🟨		🟨	🟨	🟨	🟨	🟨	🟨		All except soil	
Crem spA		0.535								Woody component		
Crem spI	🟨	🟨								Woody component		
Dor helv												? (behavioural?)
Lepi spA	🟨	🟨	🟨	🟨		🟨	🟨				Woody component; Herbaceous composition; grazing index; herbaceous lifeform	
Lepi spB												Commercial land use
Lepi spi		🟨	🟨	0.436					🟨	Woody component; soil; annual species composition		
Lepi spC				🟨	🟨	🟨	🟨		🟨	Herbaceous components; Herbaceous production		
Mera spi												Commercial land use
Mera spB			🟨		🟨	🟨				Soil; grazing and ecological indices		
Mera spC												Commercial land use
Mera spD				🟨	🟨		🟨		🟨	Herbaceous composition; ecological index and lifeform		
Mes.n.cap												Reserve Good
Mon fasti			🟨							Soil		
Mon notu								🟨	🟨	Land use; Production kgspc		
Mon rufu												Generalist land uses
Mon spA												Commercial good
Mon spB		🟨								Woody		
Mon spC		🟨					🟨			Woody; Lifeform		
Mon spE				🟨		🟨				Annual spcies composition; grazing index		
Myrm spA												Reserve/Tribal
Myrm spB				🟨					🟨	Annual species composition; Herbaceous production		
Ocym spA					🟨	🟨	🟨			Grazing- and ecological indices; ecological index		
Ocym spB			🟨	🟨		🟨	🟨			Soil; herbaceous species composition; grazing index; lifeform		
Ocym spC	🟨	🟨	🟨					🟨		Woody; soil; land use		
Ocym spD	🟨	🟨								Woody component		
Ocym spE												Reserve land use
Ocym wei		🟨								Woody component		
Opt bert			🟨							Soil		
Pac spA	🟨				🟨	🟨	🟨			Woody; grazing and ecological indices; lifeform		
Pac sha												Tribal land use
Pac spC			🟨	🟨					🟨	Soil; annual species composition; herbaceous production		
Phei spA					🟨	🟨	🟨			Grazing and ecological indices; lifeform		
Phei spB												Tribal land use/general
Phei spC								🟨				Commercial land use/general
Phei spD	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨			All except production	
Plag spA			🟨						🟨	Soil; herbaceous production		
Plec man		🟨							🟨	Woody; herbaceous production		
Sp. XII	🟨	🟨								Woody component		
Tap spA		🟨								Woody component		
Tetr bau	🟨	🟨		🟨				🟨		Woody component; annual species composition; Land use		
Tech spA												Tribal land use
Tetr ser		🟨					🟨	🟨		Woody; lifeform; Land use		
Tetr set		🟨				0.376			🟨	Woody; grazing index; herbaceous production		
Tet spA			🟨	🟨	🟨	🟨			🟨	Soil; annual species composition, grazing and ecological indices; herbaceous production		
Tetr sim	🟨			🟨			🟨		🟨	Woody; annual species composition; lifeform; herbaceous production		
Tetr spC									🟨	Herbaceous production		
Tetr spD	🟨					🟨	🟨			Woody; grazing index; lifeform		
Tetr spE						0.376				Grazing index		
Tetr spG				🟨					🟨	Annual species composition; Herbaceous production		
Tetr spH												Tribal land use
Tet.n.se						0.376	🟨			Grazing index; lifeform		
Tetr spIII									0.44	Herbaceous production		
Tetr spV												General all land uses
Tet V111												Commercial land use
Tetr wei	🟨	🟨	🟨						🟨	Woody; soil; Herbaceous production		
Tet spXVI												Tribal land use
Tet sp2					🟨	🟨	🟨		🟨	Ecological and grazing indices; lifeform		
Tet sp3												Reserve land use
Tet sp4							🟨			Lifeform		
Tetrpo A						0.376				Grazing index		

(1) Green highligthed blocks indicated "marginal" ant species (second-best BVSTEP stepwise fit) associated with the environmental variables (columns)

Appendix 8.3. SIMPER analyses based on absolute ant abundances, displaying similarities measures within land uses and dissimilarity measures between land uses.

Group Commercial - Average similarity: 27.99

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Phei spC	41.17	5.87	0.77	20.97	20.97
Ocym spB	37.89	4.23	0.76	15.09	36.07
Mon rufu	21.17	3.66	1.51	13.08	49.15
Anop stei	197.06	3.40	0.30	12.16	61.30
Mon fasti	20.67	2.42	0.80	8.65	69.96
Phei spD	18.28	2.21	0.47	7.90	77.86
Tetr set	15.83	0.70	0.51	2.49	80.35
Tetr spC	7.89	0.67	0.48	2.39	82.74
Anop spA	10.67	0.59	0.31	2.12	84.86
Mon spB	12.56	0.59	0.38	2.09	86.95
Anop spB	7.06	0.45	0.46	1.62	88.57
Ocym spA	8.61	0.43	0.39	1.54	90.11

Group Tribal - Average similarity: 33.52

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Mon fasti	30.04	5.54	1.26	16.53	16.53
Myrm spA	104.96	4.48	0.42	13.37	29.90
Tetr bau	29.54	3.81	0.99	11.36	41.26
Mon rufu	21.02	2.97	1.13	8.87	50.13
Mon spB	18.48	2.74	1.00	8.19	58.32
Phei spB	25.68	2.66	0.71	7.94	66.26
Phei spD	19.16	2.39	0.81	7.13	73.39
Phei spC	9.75	1.29	0.78	3.85	77.24
Crem spA	18.13	1.12	0.55	3.33	80.57
Tetr set	8.33	0.99	0.60	2.96	83.53
Card spA	6.44	0.81	0.78	2.41	85.95
Tetr spC	6.56	0.73	0.77	2.19	88.13
Camp ful	5.30	0.73	0.86	2.18	90.31

Group Reserve - Average similarity: 28.69

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Phei spC	35.35	5.31	0.83	18.51	18.51
Mon fasti	28.04	4.52	1.26	15.76	34.27
Myrm spA	173.04	4.23	0.43	14.73	49.00
Mon rufu	24.90	3.42	0.96	11.91	60.92
Ocym spB	28.25	2.91	0.83	10.15	71.07
Phei spB	12.67	1.38	0.53	4.81	75.88
Anop stei	1466.61	1.16	0.17	4.03	79.91
Tetr set	10.62	0.97	0.83	3.37	83.28
Tetr ser	6.75	0.96	0.83	3.36	86.64
Mon notu	12.38	0.96	1.05	3.36	90.00

APPENDIX 8.3 (continue . . .)

Groups Commercial & Tribal - Average dissimilarity: 78.32

Species	Group Commercial Av.Abund	Group Tribal Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Anop stei	197.06	13.61	14.63	0.66	18.69	18.69
Myrm spA	1.78	104.96	11.27	0.67	14.39	33.08
Phei spC	41.17	9.75	5.38	0.92	6.87	39.94
Ocym spB	37.89	10.39	4.76	0.98	6.08	46.02
Tetr bau	3.78	29.54	4.08	0.78	5.20	51.23
Phei spB	7.50	25.68	3.62	0.87	4.62	55.85
Mon fasti	20.67	30.04	3.55	1.05	4.54	60.38
Phei spD	18.28	19.16	3.30	0.99	4.21	64.59
Mon spB	12.56	18.48	2.81	1.05	3.59	68.18
Crem spA	1.61	18.13	2.50	0.48	3.19	71.37
Mon rufu	21.17	21.02	2.31	1.12	2.95	74.32
Tetr set	15.83	8.33	1.80	1.20	2.30	76.63
Tet spA	11.44	0.00	1.79	0.39	2.28	78.91
Anop spA	10.67	4.35	1.70	0.63	2.17	81.08
Ocym spA	8.61	2.56	1.41	0.53	1.79	82.88
Tetr spC	7.89	6.56	1.26	0.98	1.61	84.49
Phei spA	3.17	6.67	1.13	0.47	1.44	85.93
Anop spB	7.06	0.78	0.93	0.56	1.19	87.12
Card spA	0.00	6.44	0.88	0.97	1.13	88.25
Mon notu	6.22	2.61	0.84	0.80	1.07	89.32
Camp ful	1.11	5.30	0.74	1.03	0.95	90.26

Groups Commercial & Reserve - Average dissimilarity: 75.29

Species	Group Commercial Av.Abund	Group Reserve Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Anop stei	197.06	1466.61	26.42	0.79	35.09	35.09
Myrm spA	1.78	173.04	13.04	0.65	17.33	52.42
Phei spC	41.17	35.35	4.35	0.90	5.78	58.20
Ocym spB	37.89	28.25	4.02	0.91	5.34	63.54
Phei spD	18.28	1.39	2.58	0.66	3.43	66.96
Mon fasti	20.67	28.04	2.38	1.17	3.16	70.13
Phei spB	7.50	12.67	2.04	0.77	2.71	72.84
Mon rufu	21.17	24.90	1.94	1.04	2.57	75.41
Tet spA	11.44	0.83	1.61	0.38	2.14	77.55
Tetr set	15.83	10.62	1.56	1.15	2.07	79.63
Mon spB	12.56	5.97	1.51	0.68	2.01	81.63
Ocym spA	8.61	6.29	1.34	0.51	1.79	83.42
Anop spA	10.67	1.36	1.33	0.48	1.77	85.19
Mon notu	6.22	12.38	1.27	0.83	1.69	86.88
Tetr ser	0.22	6.75	0.98	0.83	1.30	88.18
Anop spB	7.06	4.57	0.96	0.62	1.27	89.45
Tetr spC	7.89	3.35	0.87	0.83	1.16	90.61

APPENDIX 8.3 (continue . . .)

Groups Tribal & Reserve - Average dissimilarity: 47.89

	Group Tribal	Group Reserve				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Myrm spA	104.96	173.04	18.36	0.88	24.55	24.55
Anop stei	13.61	1466.61	17.98	0.55	24.05	48.60
Phei spC	9.75	35.35	4.06	1.10	5.42	54.02
Tetr bau	29.54	3.08	3.43	0.69	4.59	58.61
Ocym spB	10.39	28.25	2.91	1.01	3.88	62.49
Phei spB	25.68	12.67	2.90	0.83	3.88	66.38
Mon rufu	21.02	24.90	2.34	1.03	3.13	69.51
Phei spD	19.16	1.39	2.29	0.81	3.06	72.57
Mon fasti	30.04	28.04	2.17	0.82	2.91	75.48
Crem spA	18.13	0.67	2.12	0.44	2.83	78.31
Mon spB	18.48	5.97	2.12	0.84	2.83	81.14
Mon notu	2.61	12.38	1.24	0.85	1.65	82.79
Tetr set	8.33	10.62	1.18	1.11	1.58	84.37
Tetr ser	3.85	6.75	0.88	0.85	1.18	85.55
Phei spA	6.67	2.20	0.87	0.39	1.17	86.72
Ocym spA	2.56	6.29	0.78	0.51	1.04	87.76
Card spA	6.44	0.89	0.75	0.87	1.00	88.76
Tetr spC	6.56	3.35	0.73	0.66	0.97	89.73
Camp ful	5.30	2.56	0.66	0.92	0.88	90.60

Appendix 8.4. SIMPER analyses based on relative ant abundances, displaying similarities measures within land uses and dissimilarity measures between land uses.

Group Commercial - Average similarity: 30.70

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Phei spC	14.42	6.15	0.71	20.05	20.05
Ocym spB	10.45	4.62	0.80	15.06	35.11
Anop stei	19.26	4.52	0.33	14.72	49.82
Mon rufu	6.22	3.89	1.58	12.68	62.51
Mon fasti	6.17	2.70	0.79	8.81	71.31
Phei spD	7.47	2.14	0.46	6.97	78.28
Tetr set	2.69	0.88	0.56	2.88	81.16
Mon spB	2.87	0.67	0.34	2.18	83.34
Tetr spC	2.31	0.66	0.50	2.16	85.50
Anop spA	3.24	0.55	0.31	1.79	87.29
Anop spB	1.99	0.50	0.47	1.63	88.92
Ocym spA	2.81	0.45	0.34	1.47	90.38

Group Tribal - Average similarity: 35.67

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Myrm spA	19.72	5.87	0.45	16.47	16.47
Mon fasti	10.04	5.41	1.09	15.16	31.63
Tetr bau	9.02	3.98	0.97	11.16	42.79
Mon rufu	6.05	3.13	1.07	8.79	51.57
Mon spB	5.89	2.84	0.97	7.96	59.53
Phei spB	7.03	2.83	0.75	7.93	67.46
Phei spD	5.69	2.41	0.83	6.75	74.20
Phei spC	3.39	1.29	0.78	3.61	77.81
Crem spA	5.05	1.24	0.54	3.48	81.29
Tetr set	2.70	1.01	0.59	2.83	84.13
Card spA	1.83	0.77	0.81	2.16	86.28
Camp ful	1.65	0.77	0.88	2.16	88.44
Tetr spC	2.13	0.74	0.72	2.08	90.52

Group Reserve - Average similarity: 33.39

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Myrm spA	20.63	6.37	0.49	19.09	19.09
Phei spC	11.44	5.44	0.81	16.28	35.36
Mon fasti	7.64	4.21	1.20	12.60	47.97
Mon rufu	6.79	3.42	1.05	10.23	58.20
Anop stei	19.88	3.26	0.20	9.76	67.96
Ocym spB	6.55	3.05	0.95	9.13	77.09
Phei spB	4.33	1.39	0.50	4.17	81.26
Mon notu	2.54	1.19	1.05	3.57	84.83
Tetr set	2.53	1.14	0.92	3.42	88.25
Tetr ser	2.31	0.94	0.72	2.81	91.06

Appendix 8.5. SIMPER analyses based on ant absence/presence data, displaying similarities measures within land uses and dissimilarity measures between land uses.

Group Commercial: Average similarity: 53.91

Species	Av.Abund	Av.S	Sim/SD	Contrib%	Cum%
Mon rufu	1.00	5.38	9.86	9.99	9.99
Ocym spB	0.94	4.73	2.71	8.77	18.75
Mon fasti	0.89	4.17	1.86	7.74	26.49
Phei spC	0.83	3.64	1.45	6.75	33.25
Ocym spC	0.72	2.79	1.01	5.17	38.42
Anop spB	0.72	2.75	1.00	5.10	43.52
Tetr spC	0.67	2.23	0.86	4.13	47.65
Anop spA	0.67	2.22	0.86	4.11	51.76
Mera spi	0.67	2.15	0.86	4.00	55.76
Phei spD	0.61	1.90	0.74	3.52	59.28
Mon spB	0.61	1.90	0.74	3.52	62.80
Mon notu	0.61	1.89	0.74	3.51	66.31
Anop stei	0.61	1.87	0.74	3.47	69.78
Phei spA	0.61	1.86	0.74	3.45	73.23
Tetr set	0.61	1.81	0.74	3.35	76.58
Mera spC	0.56	1.53	0.64	2.84	79.41
Camp spC	0.50	1.26	0.55	2.33	81.75
Lepi spA	0.50	1.26	0.55	2.33	84.07
Ocym spD	0.44	1.05	0.47	1.94	86.01
Camp spD	0.44	0.99	0.47	1.84	87.86
Phei spB	0.44	0.99	0.47	1.83	89.68
Ocym spA	0.44	0.98	0.47	1.82	91.50

Group Tribal - Average similarity: 59.49

Species	Av.Abund	Av.S	Sim/SD	Contrib%	Cum%
Mon fasti	1.00	4.27	9.67	7.17	7.17
Mon rufu	1.00	4.27	9.67	7.17	14.35
Mon spB	1.17	4.27	9.67	7.17	21.52
Phei spB	0.89	3.29	1.86	5.53	27.05
Phei spD	0.89	3.29	1.86	5.53	32.58
Tetr bau	0.89	3.26	1.86	5.48	38.06
Camp ful	0.83	3.02	1.45	5.08	43.14
Phei spC	0.83	2.99	1.45	5.02	48.17
Tetr spC	0.83	2.90	1.45	4.88	53.05
Card spA	0.83	2.89	1.45	4.86	57.91
Crem spA	0.78	2.52	1.19	4.24	62.14
Ocym spB	0.72	2.23	1.00	3.74	65.89
Myrm spA	0.67	1.94	0.86	3.27	69.16
Anop spA	0.67	1.77	0.86	2.98	72.14

APPENDIX 8.5 (continue . . .)

Species	Av.Abund	Av.S	Sim/SD	Contrib%	Cum%
Ocym spD	0.61	1.52	0.74	2.56	74.70
Tetr set	0.61	1.44	0.74	2.42	77.12
Plec man	0.56	1.28	0.64	2.15	79.27
Mera spB	0.56	1.21	0.64	2.04	81.31
Camp spB	0.56	1.19	0.64	2.01	83.32
Lepi spA	0.50	1.05	0.55	1.77	85.09
Phei spA	0.50	1.04	0.55	1.75	86.84
Tetr ser	0.50	0.95	0.55	1.60	88.44
Camp spC	0.50	0.95	0.55	1.60	90.04

Group Reserve - Average similarity: 59.79

Species	Av.Abund	Av.S	Sim/SD	Contrib%	Cum%
Mon fasti	1.00	4.91	5.36	8.21	8.21
Mon notu	1.00	4.91	5.36	8.21	16.43
Mon rufu	0.94	4.15	2.65	6.94	23.37
Ocym spB	0.94	4.15	2.65	6.94	30.31
Tetr set	0.89	3.92	1.76	6.56	36.87
Tetr ser	0.83	3.13	1.44	5.23	42.10
Ocym spD	0.83	3.10	1.45	5.19	47.29
Tetr spC	0.78	2.80	1.18	4.68	51.97
Phei spC	0.78	2.72	1.19	4.56	56.53
Myrm spA	0.72	2.24	1.01	3.74	60.27
Mon spB	0.67	2.06	0.84	3.44	63.71
Camp spC	0.67	2.01	0.86	3.35	67.06
Ocym spA	0.67	2.00	0.84	3.35	70.41
Ocym spC	0.67	2.00	0.86	3.34	73.75
Phei spB	0.67	1.97	0.86	3.29	77.04
Anop spB	0.67	1.95	0.86	3.25	80.29
Opt bert	0.61	1.67	0.74	2.79	83.08
Lepi spA	0.61	1.64	0.74	2.74	85.82
Camp ful	0.56	1.40	0.63	2.33	88.15
Phei spA	0.56	1.33	0.64	2.23	90.38

APPENDIX 8.5 (continue . . .)

Groups Commercial & Tribal - Average dissimilarity: 51.45

	Group Commercial	**Group Tribal**				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Card spA	0.00	0.83	1.97	*2.15	3.83	3.83
Ocym spC	0.72	0.11	1.62	*1.41	3.14	6.98
Camp ful	0.28	0.83	1.57	*1.33	3.06	10.04
Crem spA	0.22	0.78	1.55	*1.35	3.01	13.04
Myrm spA	0.22	0.67	1.43	1.19	2.78	15.83
Anop stei	0.61	0.11	1.38	1.17	2.69	18.52
Anop spB	0.72	0.33	1.38	1.14	2.69	21.21
Mon spB	0.61	1.17	1.32	0.67	2.57	23.78
Plec man	0.11	0.56	1.31	1.08	2.54	26.32
Tetr bau	0.44	0.89	1.29	1.08	2.52	28.83
Phei spB	0.44	0.89	1.29	1.08	2.51	31.34
Mon notu	0.61	0.33	1.27	1.06	2.47	33.82
Mera spi	0.67	0.39	1.26	1.06	2.45	36.27
Camp spB	0.22	0.56	1.25	1.05	2.42	38.70
Mera spC	0.56	0.28	1.24	1.04	2.41	41.11
Mera spB	0.28	0.56	1.24	1.04	2.41	43.52
Ocym spD	0.44	0.61	1.21	1.01	2.36	45.88
Lepi spA	0.50	0.50	1.19	0.99	2.32	48.20
Camp spC	0.50	0.50	1.19	0.99	2.32	50.51
Phei spA	0.61	0.50	1.19	0.99	2.31	52.82
Tetr sim	0.28	0.50	1.17	0.99	2.28	55.10
Tetr ser	0.06	0.50	1.16	0.99	2.26	57.35
Tetr set	0.61	0.61	1.15	0.94	2.24	59.59
Camp spD	0.44	0.33	1.15	0.95	2.23	61.82
Ocym spA	0.44	0.28	1.13	0.94	2.20	64.02
Anop spA	0.67	0.67	1.08	0.89	2.10	66.12
Tetr spD	0.22	0.39	1.02	0.88	1.98	68.10
Phei spD	0.61	0.89	1.00	0.83	1.94	70.04
Tetr spC	0.67	0.83	0.95	0.79	1.84	71.88
Opt bert	0.28	0.28	0.93	0.81	1.81	73.70
Tetr spE	0.33	0.11	0.86	0.76	1.67	75.37
Plag spA	0.11	0.33	0.86	0.76	1.67	77.03
Lepi spi	0.00	0.33	0.80	0.70	1.55	78.58
Ocym spB	0.94	0.72	0.71	0.65	1.37	79.95
Tet V111	0.28	0.06	0.69	0.65	1.35	81.30
Phei spC	0.83	0.83	0.66	0.61	1.28	82.58
Lepi spB	0.17	0.17	0.65	0.61	1.26	83.84
Tet spA	0.22	0.00	0.54	0.53	1.05	84.89
Sp.XII	0.00	0.22	0.50	0.53	0.98	85.87
Tap spA	0.00	0.22	0.49	0.53	0.96	86.83
Tetr wei	0.06	0.17	0.49	0.50	0.95	87.78
Tetr spH	0.00	0.22	0.49	0.53	0.95	88.73
Ocym wei	0.17	0.06	0.47	0.50	0.92	89.65
Tet.n.se	0.06	0.17	0.45	0.50	0.88	90.53

APPENDIX 8.5 (continue . . .)

Groups Commercial & Reserve - Average dissimilarity: 47.03

	Group Commercial	**Group Reserve**				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Tetr ser	0.06	0.83	1.97	*1.91	4.20	4.20
Myrm spA	0.22	0.72	1.54	*1.25	3.27	7.47
Phei spD	0.61	0.17	1.47	1.12	3.12	10.59
Mera spi	0.67	0.33	1.41	1.09	3.00	13.59
Opt bert	0.28	0.61	1.40	1.08	2.97	16.56
Anop stei	0.61	0.28	1.39	1.07	2.96	19.52
Anop spA	0.67	0.39	1.38	1.04	2.93	22.45
Mera spC	0.56	0.17	1.37	1.05	2.91	25.36
Ocym spD	0.44	0.83	1.35	1.04	2.88	28.24
Camp ful	0.28	0.56	1.34	1.03	2.85	31.09
Ocym spA	0.44	0.67	1.33	1.01	2.83	33.92
Phei spB	0.44	0.67	1.33	1.01	2.82	36.74
Camp spC	0.50	0.67	1.29	0.97	2.74	39.48
Lepi spA	0.50	0.61	1.29	0.97	2.74	42.21
Tetr bau	0.44	0.50	1.28	0.97	2.71	44.93
Phei spA	0.61	0.56	1.27	0.95	2.70	47.63
Camp spD	0.44	0.39	1.25	0.95	2.66	50.29
Mon spB	0.61	0.67	1.20	0.91	2.55	52.84
Mera spB	0.28	0.44	1.20	0.94	2.55	55.39
Anop spB	0.72	0.67	1.13	0.84	2.40	57.79
Ocym spC	0.72	0.67	1.12	0.84	2.37	60.17
Tetr set	0.61	0.89	1.10	0.82	2.34	62.51
Tetr spC	0.67	0.78	1.08	0.81	2.30	64.81
Mon notu	0.61	1.00	1.02	0.78	2.16	66.97
Tetr spE	0.33	0.11	0.92	0.75	1.97	68.94
Crem spA	0.22	0.22	0.88	0.71	1.88	70.82
Plec man	0.11	0.33	0.88	0.76	1.87	72.69
Phei spC	0.83	0.78	0.87	0.66	1.84	74.53
Tet V111	0.28	0.17	0.86	0.73	1.83	76.36
Camp spB	0.22	0.22	0.84	0.71	1.78	78.15
Lepi spB	0.17	0.22	0.78	0.67	1.65	79.80
Tetr sim	0.28	0.00	0.75	0.61	1.60	81.40
Tet spA	0.22	0.11	0.74	0.62	1.56	82.96
Ocym wei	0.17	0.17	0.73	0.60	1.56	84.52
Tetr spD	0.22	0.06	0.65	0.56	1.39	85.91
Camp sp E	0.06	0.22	0.60	0.58	1.28	87.20
Mon spA	0.17	0.11	0.57	0.56	1.22	88.42
Anoc spA	0.06	0.17	0.49	0.50	1.03	89.45
Camp spA	0.11	0.11	0.48	0.49	1.02	90.47

APPENDIX 8.5 (continue . . .)

Groups Tribal & Reserve - Average dissimilarity: 47.89

	Group Tribal	Group Reserve				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Phei spD	0.89	0.17	1.72	*1.69	3.60	3.60
Card spA	0.83	0.17	1.66	*1.54	3.46	7.06
Mon notu	0.33	1.00	1.51	1.37	3.16	10.22
Crem spA	0.78	0.22	1.50	1.33	3.14	13.36
Ocym spC	0.11	0.67	1.41	1.28	2.94	16.30
Ocym spA	0.28	0.67	1.29	1.13	2.70	19.00
Anop spB	0.33	0.67	1.26	1.10	2.62	21.63
Opt bert	0.28	0.61	1.24	1.08	2.59	24.22
Anop spA	0.67	0.39	1.22	1.05	2.56	26.78
Plec man	0.56	0.33	1.20	1.01	2.50	29.28
Camp spB	0.56	0.22	1.20	1.04	2.50	31.78
Tetr bau	0.89	0.50	1.19	0.98	2.49	34.27
Tetr ser	0.50	0.83	1.16	0.98	2.42	36.69
Mera spB	0.56	0.44	1.16	0.99	2.41	39.10
Camp spC	0.50	0.67	1.15	0.98	2.40	41.51
Mon spB	1.17	0.67	1.15	0.61	2.40	43.91
Phei spA	0.50	0.56	1.14	0.97	2.39	46.29
Lepi spA	0.50	0.61	1.14	0.97	2.38	48.67
Tetr sim	0.50	0.00	1.10	0.98	2.30	50.97
Camp ful	0.83	0.56	1.07	0.90	2.23	53.20
Mera spi	0.39	0.33	1.06	0.91	2.22	55.42
Camp spD	0.33	0.39	1.03	0.91	2.16	57.58
Ocym spD	0.61	0.83	0.99	0.84	2.07	59.65
Myrm spA	0.67	0.72	0.99	0.83	2.07	61.72
Tetr set	0.61	0.89	0.98	0.82	2.05	63.77
Tetr spD	0.39	0.06	0.91	0.80	1.90	65.66
Phei spB	0.89	0.67	0.89	0.75	1.86	67.52
Lepi spi	0.33	0.06	0.80	0.73	1.68	69.20
Mera spC	0.28	0.17	0.78	0.72	1.64	70.84
Anop stei	0.11	0.28	0.78	0.68	1.62	72.47
Plag spA	0.33	0.06	0.77	0.73	1.60	74.07
Phei spC	0.83	0.78	0.75	0.66	1.56	75.63
Tetr spC	0.83	0.78	0.75	0.66	1.56	77.19
Ocym spB	0.72	0.94	0.70	0.64	1.46	78.65
Lepi spB	0.17	0.22	0.68	0.67	1.41	80.06
Camp sp E	0.11	0.22	0.62	0.62	1.28	81.35
Ocym wei	0.06	0.17	0.50	0.49	1.04	82.39
Sp. XII	0.22	0.00	0.48	0.53	1.01	83.40
Tap spA	0.22	0.00	0.47	0.53	0.99	84.39
Tetr spH	0.22	0.00	0.47	0.53	0.98	85.37
Tetr wei	0.17	0.06	0.46	0.50	0.97	86.33
Mon spE	0.17	0.06	0.46	0.50	0.97	87.30
Tet.n.se	0.17	0.06	0.43	0.50	0.90	88.20
Tet V111	0.06	0.17	0.43	0.50	0.90	89.10
Tetr spE	0.11	0.11	0.43	0.49	0.89	89.99
Anoc spA	0.06	0.17	0.42	0.50	0.89	90.88

Appendix 8.6. Margalef's species richness, Shannon diversity, total abundance, number of species and Pielou's evenness.

Sub-replicate	Antdiv	Antabun	AntSpec	Antrich	Anteven
B1	2.683	134	18	4.589	0.9283
B2	2.797	180	19	4.566	0.9498
B3	2.692	329	18	4.069	0.9314
B4	2.712	665	21	4.498	0.8907
B5	2.743	1649	28	5.665	0.8231
B6	2.616	806	20	4.251	0.8731
Sc1	2.577	295	17	3.951	0.9096
Sc2	2.762	191	20	4.858	0.922
Sc3	2.639	185	17	4.159	0.9315
Sc4	2.457	264	15	3.573	0.9071
Sc5	2.216	1162	19	4.162	0.7526
Sc6	2.529	144	16	4.107	0.9122
O1	2.352	255	15	3.668	0.8686
O2	2.765	343	20	4.522	0.9228
O3	2.429	290	16	3.819	0.8761
O4	2.725	376	18	3.995	0.9427
O5	2.703	316	19	4.4	0.9179
O6	2.791	816	22	4.555	0.9028
A1	2.758	435	25	4.919	0.8923
A2	3.075	372	27	5.887	0.933
A3	2.964	164	22	5.272	0.9615
A4	2.795	764	26	5.638	0.8579
A5	2.968	195	23	5.417	0.9466
A6	2.898	217	21	4.909	0.9518
S1	3.025	306	26	5.848	0.9285
S2	2.958	242	23	5.297	0.9434
S3	2.939	320	25	5.689	0.9131
S4	3.04	371	28	6.229	0.9123
S5	3.063	280	27	6.14	0.9292
S6	2.977	484	28	6.099	0.8935
T1	2.679	236	18	4.26	0.9268
T2	2.799	693	24	5.185	0.8807
T3	2.687	567	20	4.375	0.8969
T4	3.014	622	27	5.654	0.9146
T5	2.755	176	18	4.351	0.9531
T6	2.517	391	18	4.14	0.8707
MS1	2.917	310	22	4.937	0.9435
MS2	2.893	473	23	4.992	0.9226
MS3	2.83	993	26	5.408	0.8687
MG1	2.56	1558	23	4.716	0.8163
MG2	2.983	267	24	5.464	0.9386
MG3	2.921	303	23	5.207	0.9315
Ms1	2.971	252	24	5.548	0.9347
Ms2	2.704	249	19	4.483	0.9184
Ms3	2.519	102	14	3.703	0.9546
Mg1	2.777	324	21	4.799	0.912
Mg2	2.804	979	28	5.93	0.8415
Mg3	2.681	219	19	4.577	0.9106
mS1	2.798	185	20	4.835	0.9385
mS2	0.7121	20475	8	1.365	0.3425
mS3	2.773	882	26	5.581	0.8511
gS1	2.281	1154	18	3.888	0.7938
gS2	3.022	164	23	5.487	0.9637
gS3	1.588	4548	16	3.215	0.5729

Appendix 8.7. IndVal values for ant species (absolute ant abundances) for typological level 1 across all land uses, with IndVal values > 70% for species, indicated in **bold**.

Species	Inval %
Anoc spA	9.26
Anop spA	57.41
Anop spB	57.41
Anop spC	1.85
Anop stei	33.33
Camp ful	55.56
Camp spB	33.33
Camp spC	55.56
Camp spD	38.89
Camp spA	7.41
Camp sp E	12.96
Camp may	3.7
Card spA	33.33
Crem spA	40.74
Crem spI	1.85
Dor helv	1.85
Lepi spA	53.7
Lepi spB	18.52
Lepi spi	12.96
Lepi spC	1.85
Mera spi	46.3
Mera spB	42.59
Mera spC	33.33
Mera spD	1.85
Mes.n.cap	5.56
Mon fasti	**96.3**
Mon notu	64.81
Mon rufu	**98.15**
Mon spA	9.26
Mon spB	**75.93**
Mon spC	1.85
Mon spE	7.41
Myrm spA	53.7
Myrm spB	1.85
Ocym spA	46.3
Ocym spB	**87.04**
Ocym spC	50
Ocym spD	62.96
Ocym spE	1.85
Ocym wei	12.96
Opt bert	38.89
Pac spA	5.56
Pac sha	1.85
Pac spC	3.7
Phei spA	55.56
Phei spB	66.67
Phei spC	**81.48**
Phei spD	55.56
Plag spA	16.67
Plec man	33.33
Sp. XII	7.41
Tap spA	7.41
Tetr bau	61.11
Tech spA	1.85
Tetr ser	46.3
Tetr set	**70.37**
Tet spA	11.11
Tetr sim	25.93
Tetr spC	**75.93**
Tetr spD	22.22
Tetr spE	18.52
Tetr spG	3.7
Tetr spH	7.41
Tet.n.se	9.26
Tetr spIII	1.85
Tetr spV	5.56
Tet V111	16.67
Tetr wei	9.26
Tet spXVI	1.85
Tet sp2	1.85
Tet sp3	5.56
Tet sp4	3.7
Tetrpo A	1.85

Appendix 8.8. Key environmental variables indicated as important in explaining ant species compositional patterns, employing the ant matrix (absolute abundances) as predictor in the BVSTEP test.

Bush numbers	Bush TE	Soil	Environment (Land use and rangeland condition)	Annual spc	Annual ecological	Annual grazing	Annual lifeform	Production kg/ha
$\rho = 0.285$	**$\rho = 0.22$**	**$\rho = 0.189$**	**$\rho = 0.308$**	**$\rho = 0.348$**	**$\rho = 0.222$**	**$\rho = 0.207$**	**$\rho = 0.17$**	**$\rho = 0.207$**
	$\rho = 0.208$	**$\rho = 0.175$**		**$\rho = 0.339$**				**$\rho = 0.199$**
Ac eri	***Ac eri***	**P Bray 1**	**Commercial**	***ANT PUB***	**INCR I**	**DE**	**WEAKPER**	***ANT PUB***
Ac hae	***Bos alb***	**Coarse sand**	**Tribal**	***BRAC NIG***	**INCR II**	**LD**	**ANNUAL**	***BRAC NIG***
Ac heb	***Dic cin***	**Med sand**		***ERA LEH***	**INCR III**	**UD**		***E MUT***
Bos alb	***Ehr rig***	**Fine sand**		***ARI STI***				***SCHM KAL***
Dic cin	***Gre fla***	**Silt**		***ERA PAL***				***TRI AND***
Ehr rig	***Ter ser***			***MEL REP***				***URU BRA***
Gre fla				***SCHM KAL***				
Rhi bre								
Ter ser								
CCA ordination: additional /marginal species indicated in *italics*								
Gym bux	*Gym bux*			*ARIST CON*				*ERA PAL*
	Ac lue							*ARIST CON*
	Ac mel							*STIP UNI*
								SCHM PAP

1. Yellow highlighted block are the best BVSTEP stepwise fit for variables
2. Green highligthed are "marginal" variables indicatedby the BVSTEP procedure

Appendix 8.9. Environmental variables in order of importance in explaining the species-environment variance for the species-integrated key environmental relations, as indicated by the Monte Carlo test.

Monte Carlo permutation test		
Variable	**P**	**F**
Tribal	0.002	5.1
Acerio	0.002	3.98
Commercial	0.002	2.78
Fine sand	0.006	2.67
Silt	0.006	2.23
ERA LEHsp	0.012	1.99
SCHM KALsp	0.032	1.85
Med sand	0.022	2.1
Com*Good	0.034	1.86
Ac heb	0.042	1.81
LD	0.036	1.67
EM UT	0.06	1.7
ANT PUBsp	0.26	1.16
STIP UNI	0.214	1.19
P Bray 1	0.244	1.16
SCHM KAL	0.288	1.15
ERA RIG	0.168	1.29
ERA PALsp	0.33	1.1
Tri*Poor	0.128	1.41
Good	0.266	1.16
Ca	0.24	1.18
TAND	0.316	1.13
Ter ser	0.168	1.31
Dic cin	0.24	1.2
ANT PUB	0.388	1.1
UD	0.338	1.11
Annual	0.288	1.1
Gym bux	0.18	1.36
Rhi bre	0.136	1.4
Incr I	0.34	1.1
ERA PAL	0.344	1.07
K	0.576	0.89
ARI STI	0.516	0.87
ARIST CONSsp	0.454	0.96
ARIST CON	0.5	0.96
MEL REPsp	0.598	0.81
URU BRA	0.538	0.83
Incr III	0.374	1.12
Weakper	0.532	0.94
ARI STIsp	0.204	1.26
DE	0.484	0.95
Gre fla	0.352	1.08
Bos alb	0.402	1.04
SCHM PAP	0.414	1.02
Ac hae	0.668	0.73
BRAC NIGsp	0.718	0.65

Appendix 8.10. Key ant species associated with key environmental variables, as were indicated by the BVSTEP test (ρ - correlation coefficient).

Bush numbers	**Bush-TE**	**Soil**	**Annual species composition**	**Annual ecological**	**Annual grazing**	**Annual lifeform**	**Land use**	**Production kgspc**
ρ= 0.262	**ρ = 0.207**	**ρ = 0.397**	**ρ = 0.372**	**ρ= 0.12**	**ρ = 0.17**	**ρ= 0.139**	**ρ = 0.373**	**ρ = 0.481**
NA	**NA**	**NA**	***ρ= 0.363-0.37**	**NA**	**NA**	***ρ= 0.116**	**NA**	***ρ = 0.48**
Ac hae	*Ac heb*	P Bray 1	*ANT PUB**	DECREASER	DE	WEAKPER	Tribal	*ARIST CON*
Ac kar	*Ac mel*	Na	*BRAC NIG*	INCR 1	LD	ANNUAL		*ANT PUB*
Ac tor	*Bos alb*	NO3-N	*ERA PAL*		BP	BP*		*BRAC NIG*
Bos alb	*Gre fla*	Coarse sand	*ARIST CON*					*CENGLAU*
Gre fla	*Lyc hir*	Med sand	*URU BRA*					*DERI*
Lyc hir		Fine sand	*TRA BER**					*EBIC**
Rhi bre		Clay						*EMUT*
								ERA PAL
								ERA TRI
								*PAN MAX**
								PER PAT
								SCHM KAL
								SCHM PAP
								STIP UNI
								*TRA BER**
								*TRA KOEL**
								URU BRA

* Second-best BVSTEP fit (ρ coefficient for stepwise procedure), thus "marginal" variables included in the analysis

Appendix 9.1. Dry material yield (DM kg/ha) and ha/LSU for each survey site (sub-replicate)

COMMERCIAL			TRIBAL			RESERVE		
Site	**DM kg/ha**	**ha/LSU**	**Site**	**DM kg/ha**	**ha/LSU**	**Site**	**DM kg/ha**	**ha/LSU**
B1	1237.42	8.85	A1	79.23	138.21	MS1	461.51	23.73
B2	260.39	42.05	A2	332.41	32.94	MS2	22.81	479.96
B3	184.13	59.47	A3	403.04	27.17	MS3	476.11	23.00
BBP	1323.54	8.27	ABP	1432.89	7.64	MSBP	8.39	1305.72
B4	1006.37	10.88	A4	854.64	12.81	MG1	1448.45	7.56
B5	1399.60	7.82	A5	1214.08	9.02	MG2	1353.56	8.09
B6	652.51	16.78	A6	622.74	17.58	MG3	873.80	12.53
BBG	1242.05	8.82	ABG	866.34	12.64	MGBG	937.78	11.68
Sc1	59.04	185.47	S1	144.98	75.53	Ms1	384.25	28.50
Sc2	39.71	275.76	S2	42.60	257.03	Ms2	477.37	22.94
Sc3	141.43	77.42	S3	2053.17	5.33	Ms3	382.85	28.60
ScBP	155.27	70.52	SBP	919.36	11.91	MsBP	757.51	14.46
Sc4	100.91	108.51	S4	1725.56	6.35	Mg1	657.86	16.64
Sc5	713.11	15.36	S5	1986.53	5.51	Mg2	1338.46	8.18
Sc6	318.41	34.39	S6	2926.03	3.74	Mg3	961.29	11.39
ScBG	849.37	12.89	SBG	2315.71	4.73	MgBG	1310.43	8.36
O1	148.78	73.60	T1	75.76	144.54	mS1	1003.90	10.91
O2	200.36	54.65	T2	19.14	572.23	mS2	81.37	134.57
O3	66.53	164.58	T3	18.33	597.27	mS3	912.09	12.01
OBP	231.42	47.32	TBP	50.83	215.43	msBP	13.74	797.00
O4	289.33	37.85	T4	135.73	80.68	gS1	3452.46	3.17
O5	293.37	37.32	T5	148.93	73.53	gS2	2561.71	4.27
O6	1052.40	10.40	T6	326.63	33.52	gS3	462.46	23.68
OBG	330.45	33.14	TBG	1200.57	9.12	gSBG	1987.04	5.51

"Good" rangeland condition sites are underlined

Appendix 9.2. Mean dry materield yield (DM kg/ha) and ha/LSU for each land use type

	DM kg/ha	ha/LSU		DM kg/ha	ha/LSU		DM kg/ha	ha/LSU
Commercial: General			**Tribal: General**			**Reserve: General**		
Mean	512.33	**58.42**	Mean	828.97	98.10	Mean	**930.30**	125.10
Standard Error	94.44	13.50	Standard Error	174.00	33.71	Standard Error	168.62	63.39
Minimum	39.71	7.82	Minimum	18.33	3.74	Minimum	8.39	3.17
Maximum	1399.60	275.76	Maximum	2926.03	597.27	Maximum	3452.46	1305.72
Commercial: Good			**Tribal: Good**			**Reserve: Good**		
Mean	687.32	27.85	Mean	1193.62	22.44	Mean	**1445.44**	**10.09**
Standard Error	123.07	8.08	Standard Error	256.47	7.74	Minimum	462.46	3.17
Minimum	100.91	7.82	Minimum	135.73	3.74	Maximum	3452.46	23.68
Maximum	1399.60	108.51	Maximum	2926.03	80.68	Standard Error	246.35	1.65
Commercial: Poor			**Tribal: Poor**			**Reserve: Poor**		
Mean	337.34	**89.00**	Mean	**464.31**	173.77	Mean	415.16	240.11
Standard Error	128.76	22.95	Standard Error	191.44	60.43	Standard Error	99.79	119.99
Minimum	39.71	8.27	Minimum	18.33	5.33	Minimum	8.39	10.91
Maximum	1323.54	275.76	Maximum	2053.17	597.27	Maximum	1003.90	1305.72
Commercial: Benchmark Good			**Tribal: Benchmark Good**			**Reserve: Benchmark Good**		
Mean	807.29	18.28	Mean	**1460.87**	8.83	Mean	1411.75	**8.51**
Standard Error	263.99	7.52	Standard Error	438.18	2.29	Standard Error	307.10	1.78
Minimum	330.45	8.82	Minimum	866.34	4.73	Minimum	937.78	5.51
Maximum	1242.05	33.14	Maximum	2315.71	12.64	Maximum	1987.04	11.68
Commercial: Benchmark Poor			**Tribal: Benchmark Poor**			**Reserve: Benchmark Poor**		
Mean	570.08	**42.04**	Mean	**801.03**	78.33	Mean	259.88	705.72
Standard Error	377.37	18.16	Standard Error	403.33	68.56	Standard Error	248.82	375.54
Minimum	155.27	8.27	Minimum	50.83	7.64	Minimum	8.39	14.46
Maximum	1323.54	70.52	Maximum	1432.89	215.43	Maximum	757.51	1305.72

APPENDIX 10.1

The development of a tool to improve rangeland and degradation management within the semi-arid western rangelands of Southern Africa, using remote sensing and GIS

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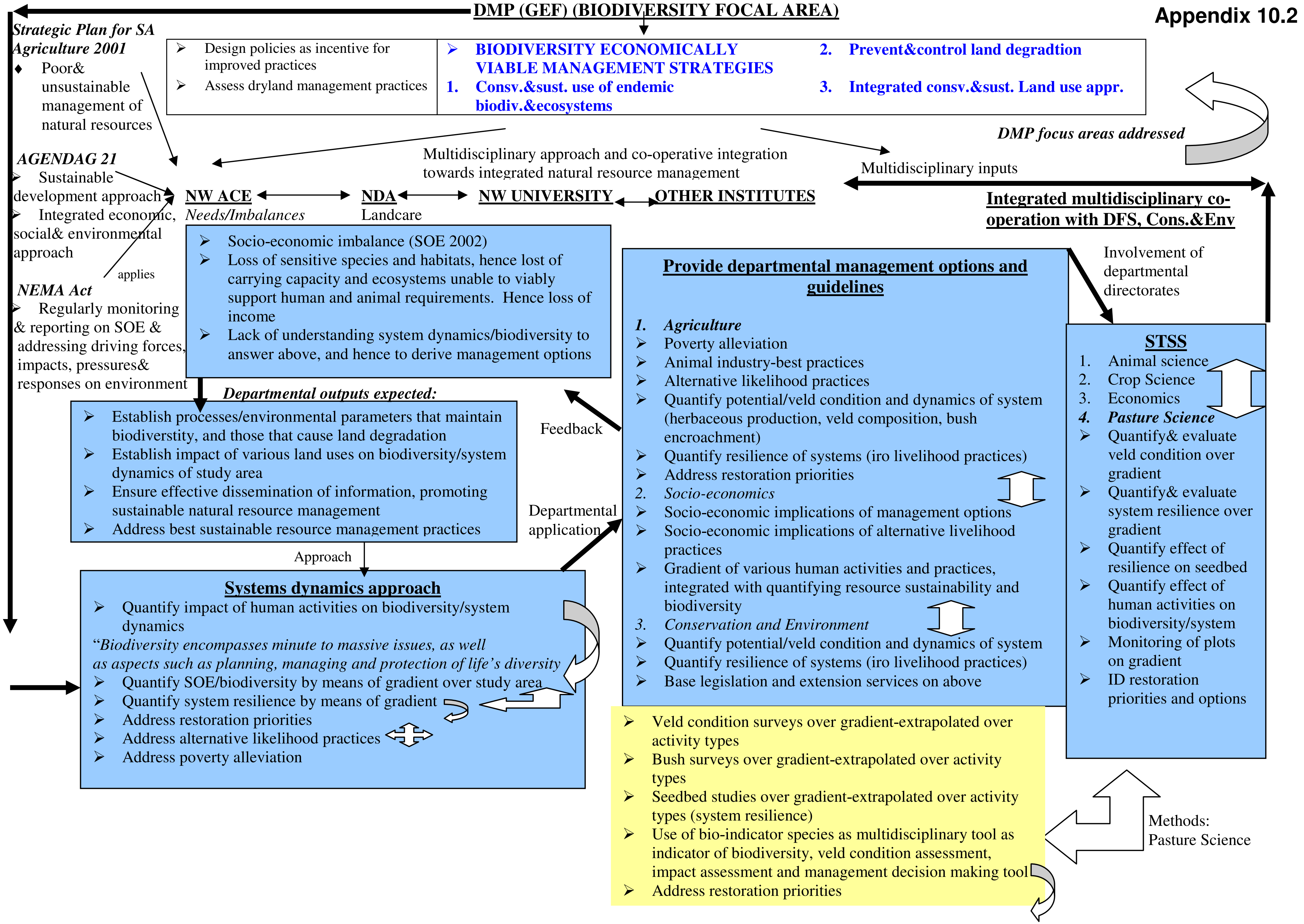
Appropriate policies and technical interventions can be applied only if the fundamental ecosystem dynamics are clearly understood as guidelines for development policies, otherwise inventions might prove to be “development experiments” that might result in unfortunate implications for both the ecosystems and people. Hence, in order to manage rangelands, it is essential to understand how they function and what the potential impacts of the different management strategies are. In order to address policy decisions within selected areas of the NW Province from household level up to provincial scale as how to identify, prevent and/or adapt to desertification and land degradation, it is crucial to work through the causal links of dryland land degradation at different temporal and spatial scales. Hence, a framework needs to be developed to identify when different systems are at different risk of desertification and land degradation. To allow effective rangeland and degradation management and monitoring, there is a need for spatial data on the status of natural resources. 72 “Field laboratory” sites for monitoring biodiversity and land degradation, representing a degradation gradient (relative poor and relative good rangeland condition extremes) within each of 3 tribal-, 3 commercial- and 3 conservation areas within the Molopo semi-arid rangelands of the NW Province, forms part of this study, with additional sites along the larger degradation gradient to be included. GIS and remote imagery as an adaptive management tool towards rangeland biodiversity and degradation management and monitoring, are employed. This project will develop multi-temporal spatial data that will distinguish between climatic and landscape variability, management impacts and land use types. The information in the system could be used to report on rangeland condition, grazing capacity, rangeland and soil degradation, biodiversity, fire mapping and drought monitoring, woody density-, composition, -structure and bush encroachment. The MODIS derived grazing capacity product will be verified and refined using available field data and a new field dataset based on the methodology used for the MODIS derived grazing capacity product. A methodology will be developed to create a percentage tree cover dataset based on available SPOT 5 imagery as well as SPOT 4 and LANDSAT data, which will serve as pilot study areas for the remainder of the North West Province. The continuous tree cover layer will be used to identify bush encroached areas. A primary production model for the North West Province using local climatological and MODIS Vegetation Indices data will be developed. Current soil loss prediction models and mapping methods used in detailed land use planning will be reviewed, and spatially predicted soil loss factor values will be verified through field observation. A map on seasonal fires and fire scars in the Molopo District of the North West Province, using MODIS 8-day fire products together with Band 2 MODIS surface reflectance images before and after the fire data, will be compiled, to map the effect of fire on rangeland condition; herbaceous composition and grazing capacity; woody composition, structural form and density; and on diversity patterns. Finally, a web-based information system, for reporting, planning and decision making at farm, district and provincial level will be developed.

Appendix 10.2



DMP (GEF) (BIODIVERSITY FOCAL AREA)

Strategic Plan for SA Agriculture 2001

- ♦ Poor& unsustainable management of natural resources

- ➢ Design policies as incentive for improved practices
- ➢ Assess dryland management practices

- ➢ **BIODIVERSITY ECONOMICALLY VIABLE MANAGEMENT STRATEGIES**

1. **Consv.&sust. use of endemic biodiv.&ecosystems**
2. **Prevent&control land degradtion**
3. **Integrated consv.&sust. Land use appr.**

DMP focus areas addressed

AGENDAG 21

- ➢ Sustainable development approach
- ➢ Integrated economic, social& environmental approach

applies

NEMA Act

- ➢ Regularly monitoring & reporting on SOE & addressing driving forces, impacts, pressures& responses on environment

Multidisciplinary approach and co-operative integration towards integrated natural resource management

Multidisciplinary inputs

NW ACE *Needs/Imbalances*

NDA Landcare

NW UNIVERSITY

OTHER INSTITUTES

Integrated multidisciplinary co-operation with DFS, Cons.&Env

- ➢ Socio-economic imbalance (SOE 2002)
- ➢ Loss of sensitive species and habitats, hence lost of carrying capacity and ecosystems unable to viably support human and animal requirements. Hence loss of income
- ➢ Lack of understanding system dynamics/biodiversity to answer above, and hence to derive management options

Departmental outputs expected:

- ➢ Establish processes/environmental parameters that maintain biodiverstity, and those that cause land degradation
- ➢ Establish impact of various land uses on biodiversity/system dynamics of study area
- ➢ Ensure effective dissemination of information, promoting sustainable natural resource management
- ➢ Address best sustainable resource management practices

Feedback

Departmental application

Approach

Systems dynamics approach

- ➢ Quantify impact of human activities on biodiversity/system dynamics

"*Biodiversity encompasses minute to massive issues, as well as aspects such as planning, managing and protection of life's diversity*

- ➢ Quantify SOE/biodiversity by means of gradient over study area
- ➢ Quantify system resilience by means of gradient
- ➢ Address restoration priorities
- ➢ Address alternative likelihood practices
- ➢ Address poverty alleviation

Provide departmental management options and guidelines

1. ***Agriculture***
- ➢ Poverty alleviation
- ➢ Animal industry-best practices
- ➢ Alternative likelihood practices
- ➢ Quantify potential/veld condition and dynamics of system (herbaceous production, veld composition, bush encroachment)
- ➢ Quantify resilience of systems (iro livelihood practices)
- ➢ Address restoration priorities

2. *Socio-economics*
- ➢ Socio-economic implications of management options
- ➢ Socio-economic implications of alternative livelihood practices
- ➢ Gradient of various human activities and practices, integrated with quantifying resource sustainability and biodiversity

3. *Conservation and Environment*
- ➢ Quantify potential/veld condition and dynamics of system
- ➢ Quantify resilience of systems (iro livelihood practices)
- ➢ Base legislation and extension services on above

Involvement of departmental directorates

STSS

1. Animal science
2. Crop Science
3. Economics
4. ***Pasture Science***
- ➢ Quantify& evaluate veld condition over gradient
- ➢ Quantify& evaluate system resilience over gradient
- ➢ Quantify effect of resilience on seedbed
- ➢ Quantify effect of human activities on biodiversity/system
- ➢ Monitoring of plots on gradient
- ➢ ID restoration priorities and options

- ➢ Veld condition surveys over gradient-extrapolated over activity types
- ➢ Bush surveys over gradient-extrapolated over activity types
- ➢ Seedbed studies over gradient-extrapolated over activity types (system resilience)
- ➢ Use of bio-indicator species as multidisciplinary tool as indicator of biodiversity, veld condition assessment, impact assessment and management decision making tool
- ➢ Address restoration priorities

Methods:
Pasture Science

Appendix 10.3. Brochures compiled in English and Tswana for rangeland monitoring workshops in the Tribal areas of the Molopo semi-arid rangelands, thus targeting the local communities as well as the agricultural extension officers

Best land use practices

For improved livelihoods

Tiriso e e siameng ya lefatshe

Tokafatso ya matshelo

Global Environment Facility

LANDCARE SOUTH AFRICA

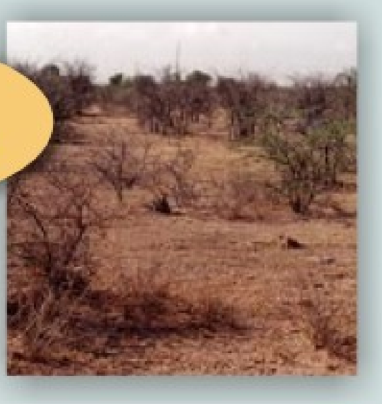
NORTH WEST PROVINCE

No care = **Poor/incorrect or zero management, poor knowledge**

- **Decreased agricultural production**
- **Destruction of natural resource**
- **Decreased veld potential**
- **Poverty**

Result in:

1. Bush encroachment



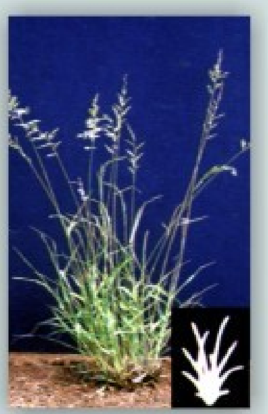
2. Loss of herbaceous production: not enough food for animals

3. Bare patches, increased water run-off, lost of topsoil (soil erosion)

4. Poor animal production

5. Smaller grass tufts comprised of unpalatable, non-nutritious species

Small unpalatable tufts



Larger palatable tufts

How do I manage natural resources?

LandCare = knowledge of veld processes and active participation

- ☑ Increased agricultural production
- ☑ Improved veld potential
- ☑ Poverty alleviation

Directives for LandCare:

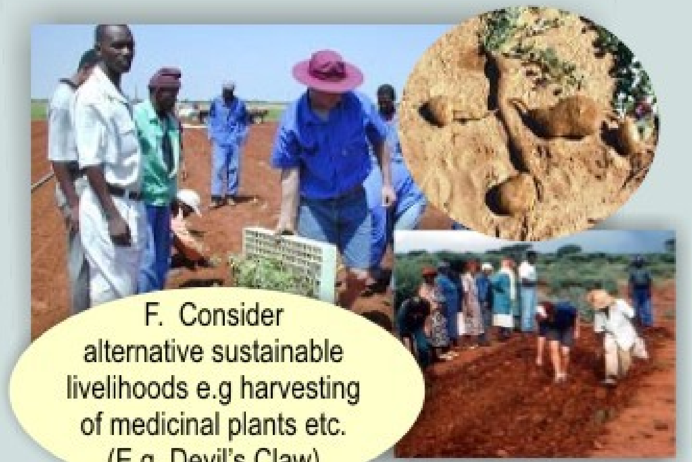
A. Knowledge regarding veld condition and veld management:present status of veld resistance against soil erosion & its potential to produce forage for sustained livestock production

B. Less animals (correct stocking rate for specific veld): bigger tufts, better cover, less water run-off & better animal production

C. Use resource potential optimally by stocking & managing with correct animal type for that resource

D. Apply resting for veld to ensure growth and vigor of grass, and increase in grass production, resilience and animal production

E. Manage against localised overstocking and trampling around water points



F. Consider alternative sustainable livelihoods e.g harvesting of medicinal plants etc. (E.g. Devil's Claw)

Get help from the local Extension officer and other experts!!

For more information contact:
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Best land use practices

For improved livelihoods

Tiriso e e siameng ya lefatshe go

Tokafatsa matshelo

Global Environment Facility

LANDCARE SOUTH AFRICA

DMP

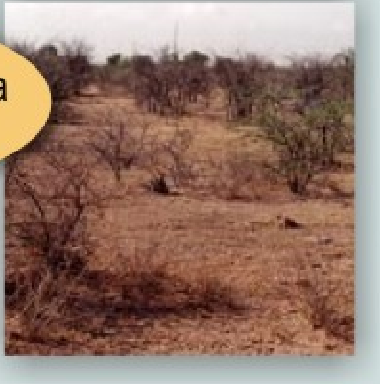
NORTH WEST PROVINCE

No care = **Tsamaiso e e bokoa kgotsa e e seng teng gotlhelele, go tlhoka kitso.**

- **Phokotsego ya ntsho dikuno ya temothuo.**
- **Tshenyego ya metswedi ya tlhago le bokgoni jwa naga.**
- **Lehuma.**

Ditlamorago:

1. Go kitlana ga sekgwa.



2. Tatlhego ya phulo: le go tlhokega ga yona go tlamela leruo.

3. Dibataola, koketsego ya tatlhegelo ya metsi le kgogolego ya mmu.

4. Ntsho ya leruo e e bokoa.

5. Dirite tse dinnye tse di senang tatso le dikotla.

Dirite tse di kgolo tse di nang le tatso le dikotla.

Ke tsamaisa jang metswedi ya tlhago?

LandCare = kitso ya tsamaiso ya naga le go tsaya karolo ka botlalo kgotsa mafolofolo.

- ☑ Ntsho dikuno ya temothuo e e oketsegileng.
- ☑ Bokgoni jwa naga go ntsha dikuno tse di kwa godimo.
- ☑ Go koba lehuma.

Dikaelo tsa LandCare

A. Kitso mabapi le: tsamaiso le maemo a phulo: kemo kgatlhanong le kgogolego ya mmu bokgoni jwa naga go ntsha dijo tsa leruo go netefatsa ntsho leruo e e ya leruri.

B. Palo ya leruo e e kwa tlase le go lekanyetsa naga eo, dirite tse dikgolo, phokotsego ya dibataola, tatlhego ya metsi e e potlana, ntsho leruo e e botoka.

C. Tiriso ya metswedi ka botlalo le go tsamaisa phulo sentle go ya ka leruo le le tshwanetseng naga eo.

D. Ikhutsise phulo ya gago go neteftsa kgolo e e itumedisang ya tlhaga le go tokafatsa ga yone.

E. Thibela phudiso e e kwa godimo le kgatakako gaufi le le lefelo la metsi.

F. Seka seka mokgwa wa go itlamela, sekai go jala Sengaparele.

Golagana le balemisi go fetlhelela tshedimositso le baitsanape ba bangwe!!

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