UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

The vegetation of Omusati and Oshana Regions, central-northern Namibia

by

FRANSISKA NDIITEELA KANGOMBE

Submitted in partial fulfillment of the requirements for the degree

MAGISTER SCIENTIAE

in the Department of Plant ScienceFaculty of Natural and Agricultural Sciences

University of Pretoria

December 2010

Supervisor: Prof. Dr. G.J. Bredenkamp

Co-supervisor: Mr. B.J. Strohbach

© University of Pretoria

ABSTRACT

The vegetation of Omusati and Oshana Regions, central-northern Namibia

by

FRANSISKA NDIITEELA KANGOMBE

Supervisor: Prof. Dr. G.J. Bredenkamp

Submitted in partial fulfillment of the requirements for the degree

MAGISTER SCIENTIAE

in the Department of Plant Science, Faculty of Natural and Agricultural Sciences

University of Pretoria

December 2010

Central-northern Namibia is home to an approximate 43% of the country's population, a large proportion of which still depends directly on natural resources for their livelihoods. The main land use in this area is agro-silvo-pastoralism i.e. a combination of subsistence farming and silvi-culture. The few phytosociological and biodiversity data available in Namibia are not substantial to motivate environmental management and sustainable utilization of the country's natural wealth. The Vegetation Survey Project of Namibia coupled with the BIOTA southern Africa Project therefore share a common goal of re-classifying Namibian vegetation by building on the Preliminary Vegetation Map of Namibia of 1971 and the Homogenous Framing Areas Report of 1979.

The vegetation of Omusati and Oshana regions which are situated in the Mopanne Savanna in central-northern Namibia was classified and described by subjecting 415 relevés to multivariate analysis i.e. classification and ordination. The geographical distribution of these community types was established by supervised classification of satellite data of the study area. Data collected in this study will be used for hypothesis generation of further ecological investigations while the map can be used for planning and conservation of vegetation resources in the area.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABREVIATIONS AND ACRONYMS

BIOTA : Biological Diversity Transect Analysis

MAWF : Ministry of Agriculture, Water and Forestry

MET : Ministry of Environment and Tourism

WIND : National Herbarium of Namibia

LANDSAT : Land Remote-Sensing Satellite System

MSS : Landsat Multispectral Scanner

TM : Thematic Mapper

GPS : Global positioning system

GIS : Geographic Information Systems

TWINSPAN : Two-Way Indicator Species Analysis

DCA : Detrended Correspondence Analysis

PCA : Principal Components Analysis

RA : Reciprocal Averaging

ILU : Indigenous Land Unit

ITCZ : Inter-tropical Convergence Zone

TZ : Temperate Zone

SHPZ : Subtropical High Pressure Zone

SOFTWARES

JUICE: A Windows application for editing, classifying and analyzing large phytosociological tables

TurboVeg for Windows : A program designed for capture and storage of vegetation data (relevés)

PC-ORD : A Windows program for multivariate analysis of ecological data entered in spreadsheets

ERDAS : Earth Resources Data Analysis Systems, a raster geoprocessing software for GIS, remote sensing, and photogrammetry

IDRISI : A GIS and image processing software package

ArcGIS : A name given to a group of geographic information system software product lines produced by ESRI

CHAPTER 1. INTRODUCTION

1.1 Thematic Background

Vegetation refers to groups of plants growing together forming species populations at local scales, of which groups of species polulations growing together form plant communities (Kent and Coker 2003). It is the most obvious physical representation of an ecosystem in many terrestrial habitats of the world and is solely responsible for primary production of such systems (Kent and Coker 2003, Krebs 1994, Barbour *et al.* 1987). However, the importance of vegetation spreads beyond primary production and other functions at ecosystem level. Vegetation can prevent soil erosion through protective cover of the land and modifies the local climate through transpiration and other processes. It also provides habitats within which other organisms live, grow, reproduce and die (Bredenkamp and Brown 2002, Krebs 1994). Plants are therefore fundamental as initiators of energy flow in various ecosystems, as a part of biodiversity as well as to humans as providers of various goods and services.

Despite the obvious significance of plants, scientific knowledge on basic vegetation data appears to be surprisingly low. At present the vegetation maps for Namibia have very little baseline data. The maps tend to be biased towards the dominant and desirable species therefore excluding other species from analysis. Some of these species that get exclused may be rare, sensitive and of ecological importance such as indicator species (Strohbach and Petersen 2007, Strohbach 2002).

Kent and Coker (2003) defined plant communities as distinct assemblages of plant species repeating themselves over space such that whenever a more or less obvious spatial change occurs in the vegetation, a different community may be distinguished. This definition of a plant community will be adapted in this thesis. Plant communities are usually the main patterns visible from a landscape view of natural vegetation, although major distinctions can be made on the basis of structural differences of the vegetation (Bredenkamp and Brown 2002). The existence of populations and communities represent a lengthy and gradual process of evolution, as determined by climate and soil factors. The unique flora composition that is observed in the vegetation of various ecological regions can therefore be explained by the unique geological history predominantly the climate and substrate conditions (Bredenkamp and Brown 2002, Bredenkamp *et al.* 2001).

1.2 The study of plant communities

Phytosociology is a division of botanical science, concerned with (methods of) recognizing and defining plant communities (Kent and Coker 2003, Barbour *et al.* 1987). Plant communities are important because they form the basis of vegetation mapping and vegetation dynamics investigations, and may as well be studied as habitats for animals and other organisms. They also enable us to study and understand the relationships between plant species distribution patterns and environmental controls such that the knowledge of species can be used to infer about environmental or substrate conditions (Kent and Coker 2003). Plant communities often form the basis of environmental planning, management and conservation.

Despite the obvious significance of plant communities in both ecological sense and in terms of application to environmental management and conservation, the concept or boundaries of a plant community remain unclear and/or subjective. Two major and contrasting views of the plant community have dominated the ecological literature where plant community ecology is concerned.

The Clements' view of the plant community (also known as the organismic concept) considers plant communities as clearly recognizable and definable entities, which repeats themselves over space (Kent and Coker 2003). The plant community is viewed as a super-organism, which could not function without all its organs i.e. species that define it. This view stresses the dependence of species that define a given community on each other. The basic method of vegetation mapping in which a survey of species abundances should be made on pre-determined quadratic areas to allow community classification is based on this idea. The conventional succession theory is supported in this view such that any climax vegetation will return to its climax state after a disturbance (Kent and Coker 2003, Mueller-Dombois and Ellenberg 1974). Plant communities to be studied here will also be based on this concept.

On the other hand the Gleason's view of the plant community regards plant communities to be all plant species distributed as a continuum such that these species respond individually to variation in environmental factors as well as to other factors, which vary continuously in spatial and temporal scales. This produces a unique combination of plant species found at any given point on the globe meaning that the vegetation is distributed along environmental gradients as a continuum. This approach makes it rather impossible to classify vegetation into groups or distinct communities, which further makes vegetation mapping of such communities difficult. In terms of vegetation dynamics, individual species will respond to a disturbance rather than responding as a 'community', hence the individualistic concept (Kent and Coker 2003, Mueller-Dombois and Ellenberg 1974).

Vegetation data is usually required in order to study plant communities and derive scientific conclusions relevant to solving ecological problems (Kent and Coker 2003). All methods for recognizing and defining plant communities are regarded methods of classification. In community ecology, classification is defined as the assignment of entities of a vegetation data set (i.e. relevés or species) to groups based on a given similarity index. These groups are imposed on the data, regardless of the level of homogeneity (Kent and Coker 2003, Gauch 1986). Although this was a manual operation in former times, the invention of computers has allowed for faster and more accurate classifications. Todate, various computer softwares exist, that are equipped with numerical methods based on mathematics and statistics for classification purposes (Kent and Coker 2003).

Various schools of Phytosociology exist and are based on the different views of a plant community. The four major schools include The Zurich-Montpellier School, The Uppsala School, The Raunkiaer (Danish) School and the 'Hybrid schools' (Kent and Coker 2003). The Zurich-Montpellier School, established by Professor Braun-Blanquet in 1928 is based on Clements' view of a plant community. This school of Phytosociology has gained considerable popularity in vegetation science because it provides methods for classification of vegetation types. These methods, commonly termed Braun-Blanquet classification methods sort floristic data by similarities to assemble a hierarchy of plant communities in a phytosociological table. Furthermore, the methods are based on several concepts and assumptions: - relevé homogeneity, minimal area the concept of an association (Kent and Coker 2003, Werger 1974).

The Braun-Blanquet classification system has crowned the association as the most basic or fundamental unit of vegetation i.e. a plant community. An association is thus a plant community type obtained by grouping similar relevés together using species composition as the main criterion. The different hierarchical levels of vegetation units used by the Braun-

Blanquet classification system are presented in Figure 1. Higher and lower levels of classification can be recognized within the overall floristic association system depending on the amount of variation between units. Two or more associations that have major species in common and whose differences are only explained by fine detail may be combined to form an alliance. Similarly, alliances can be pooled to give orders at a higher level; and orders into classes. At lower levels, an association can be sub-divided into sub-associations, which can further be divided into variants and so forth.

This classification system allows the entire hierarchy of the vegetation units in a region to be described and their relationships to be demonstrated and understood. The allocation of names to vegetation units is based on the concept of syntaxonomy, a set guidelines for naming of communities and other hierarchies under the Braun Blanquet system, following the international code of botanical nomenclature. The nomenclature system of the Zurich-Montpellier method uses names of characterizing species and suffixes to denote a community type (Kent and Coker 2003, Werger 1974) and was used for naming the community types identified in this study.

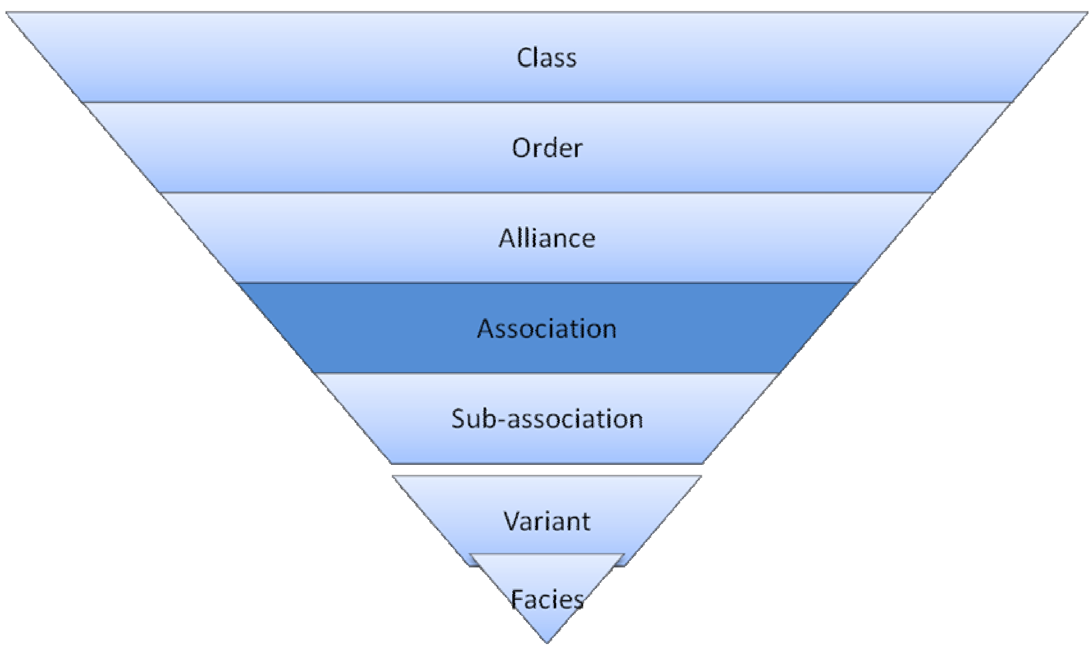


Figure 1 The hierarchical classification units of the Braun-Blanquet system

Adapted from Kent and Coker (2003)

1.3 The BIOTA southern Africa Project

The loss of biodiversity on both local and global scales has been attributed to the rapid increase in development (particularly infrastructural development) and the ever-increasing human population (Strohbach 2002). Human-induced factors that are believed to have negatively impacted global biodiversity and are of global concern include alien invasive species, habitat fragmentation, bush encroachment and genetically modified organisms (Hunter 1996). Changes in biodiversity directly influence the species composition, which in turn alters and often reduces opportunities for land use, as systems become increasingly less productive or generally degraded in the long-term (Strohbach 2002).

The Biological Diversity Transect Analysis (BIOTA) Africa is a cooperative, interdisciplinary and integrative research project with contributions. Initiated in 1999, the project is focused on the monitoring of changes in biodiversity, taking into consideration ecosystematic, biological and socio-economic processes in attempt to achieve its overall aim of sustainable use and biodiversity conservation through scientific research (Jürgens *et al.* 2010). As a main aim of the project, thorough knowledge of the dynamics of biodiversity is primarily sought after to enable conceptualization of sustainable management guidelines for rangelands (Jürgens *et al.* 2010, Strohbach 2002).

The BIOTA southern Africa Project concentrates its scientific investigations in Namibia and South Africa. It comprises a transect that runs from the Cape region in South Africa to the Kavango Region in north-eastern Namibia with 35 carefully selected, permanently marked and standardized long-term monitoring sites i.e. biodiversity observatories (Figure 2). The BIOTA observatories have been strategically placed along a major climatic gradient (on the transect) from the winter rainfall zone at Cape Town, South Africa to a summer rainfall zone in Kavango, Namibia, covering six main biomes of the region. Such placement of observatories allows for investigation of interactions of biodiversity over a spectrum of climatic and soil edaphic conditions (Jürgens *et al.* 2010). In Namibia, two transect extensions have been made (1) from the Mile 46/Mutompo observatories in the north-east through Ogongo and Omanoo go Ndjamba observatories in the central-north to the furthest point in the north-west and (2) from the Sandveld Research Station in the east to the Kleinberg observatory in the west, across the central part of the country (Figure 2) (Jürgens *et* *al*. 2010). In this thesis, the Omano go Ndjamba observatory will be referred to as Omano observatory.

Figure 2. The BIOTA southern Africa transects and placement of biodiversity observatories

(Source: Jürgens *et al*. 2010)

A BIOTA observatory encompasses an area of 1 km^2 (1000 m x 1000 m) with boundaries oriented along cardinal directions. This 1 km^2 area is divived into 100 1-hectare plots of 100 m x 100 m. All corner points of the 1-hectare plots are geo-referenced with a differential GPS and are numbered from 00 to 99 starting in the north-western corner and running from west to east and southwards through the observatory (Jurgens *et al*. 2010). The plots are further then ranked, considering different habitat types, using a stratified sampling design to develop a ranking method based on the d'Hondt divisor rules procedure. This is done to ensure representative randomized sampling. Vegetation sampling is done in the 20 m x 50 m and 10 m x 10 m plots, constructed within the highly ranked 1-hectare plots. The heactare plots represent the largest replicated sampling unit within the BIOTA observatory system (Jurgens *et al*. 2010). A diagrammatic overview of the design of BIOTA observatories is shown in Figure 3.

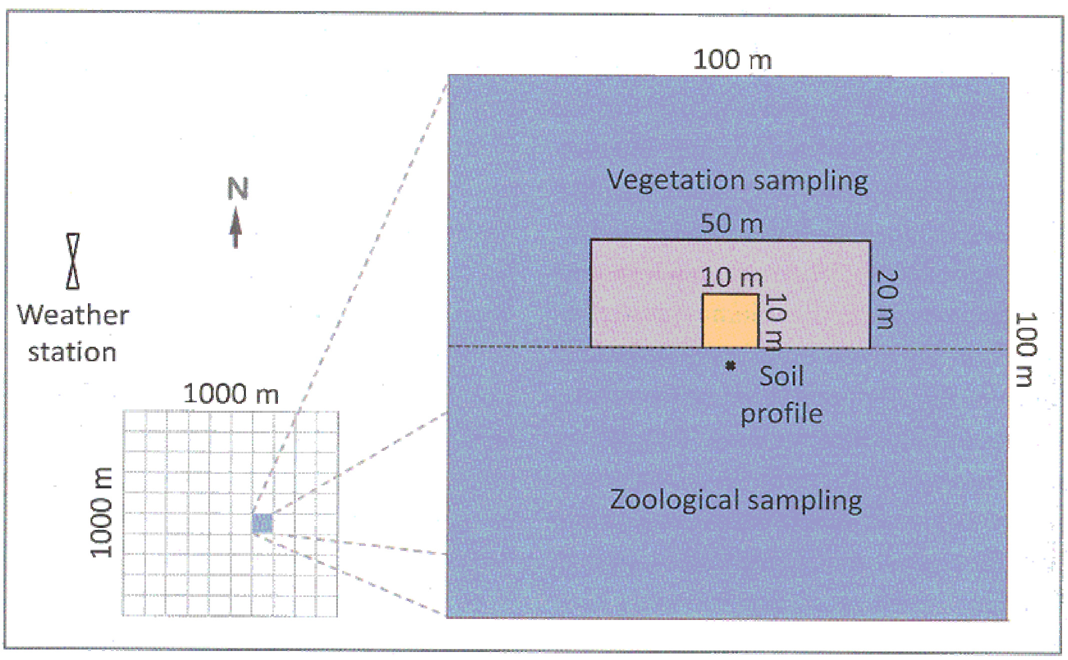


Figure 3. A schematic layout of a BIOTA observatory in southern Africa and arrangement of different sampling areas within a hectare plot

(Source: Jürgens *et al*. 2010)

The main focus of vegetation studies carried out under the BIOTA project is the documentation, classification and mapping of vegetation along the transect with the aid of remote sensing techniques. In Namibia, this is done in conjunction with the Vegetation Survey Project of the Ministry of Agriculture, Water and Forestry. The collective aim of these projects is to survey the vegetation of Namibia and create a database with relevé data which can be used for future reference (Strohbach 2002). Long-term accumulation of these data can be used to study the dynamics of the vegetation and other biodiversity aspects along the transect.

For a country whose economy relies heavily on agricultural production, Namibia should cautiously invest in biodiversity research and monitoring. It is therefore important to undertake investigations that can improve current knowledge and understanding of the underlying mechanisms of biodiversity changes for improved guidelines on land management practices.

1.4 Literature Review

Limited phytosociological studies have been carried out in Namibia to date (Strohbach and Petersen 2007, Burke and Strohbach 2000) and only little data exists on Namibia's biodiversity and effects of land utilization on the functioning of plant communities (Strohbach 2002, Burke and Strohbach 2000). At present, the vegetation maps that are available in Namibia are from Giess (1971), most of which lack the required information for land management and monitoring methods. This presents land use planners and managers with a major challenge regarding informed decision making for sustainable land utilization (Burke and Strohbach 2000), even more so under changing climates.

Although climate change is an inevitable occurrence, human activities have contributed towards the acceleration rates of this change and global change at large (Stringer *et al*. 2009). With reference to the fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), analysis of long-term climatic data reveal increasing temperature trends for southern Africa, with maximum warming trends occurring in the north-eastern parts of the region. Furthermore, the extent of arid and semi-arid areas is expected to expand between 5% and 8% under a range of future climatic scenarios (Schmiedel and Jürgens 2010, Stringer *et al*. 2009). In terms of rainfall, a drying trend is evident over the larger portion of the sub-region since 1901. The observed decline in annual rainfall is principally caused by a decrease in the winter rainfall zones as long-term analysis of average summer rainfall did not significantly change over that period. However, for Namibia the data might indicate a tendency towards a drier climate during the last 25 years (Schmiedel and Jürgens 2010).

In Namibia, desertification is one of the major environmental problems, thus investigations of the underlying causes of land degradation are highly prioritized. However, the processes that cause desertification are complex and operate on an ecosystem level. Investigation of such processes thus depends on vegetation description and analysis of the affected areas. It is only when existing plant communities have been identified and their relation to prevalent environmental factors and grazing pressures that processes of land degradation can be studied and understood (Burke and Strohbach 2000). At the same time, the impacts of climate change, drought and desertification are closely interlinked and these aspects should as well be incorporated in such investigations.

Many regional and local plant surveys in Namibia merely produce checklists and attempts to explain the vegetation in relation to its environment are seldom made. A few of the studies have been carried out during intensive field observations and produced descriptive accounts of the vegetation as well as useful management recommendations (Burke and Strohbach 2000). Despite the limitations of many of these studies, they are not entirely insignificant and could hold some baseline information and clues that can be used for further research. The preliminary work done on vegetation descriptions and mapping by Giess (1971), forms an important basis for detailed vegetation studies and hypothesis generation (Burke and Strohbach 2000).

A review paper on the synopsis of vegetation studies in Namibia by Burke and Strohbach (2000) reveals that minimal vegetation research is undertaken in central- northern Namibia. Besides the national phytosociological studies of Giess (1971) who broadly described the study area as a Mopanne savanna, only general vegetation surveys by Claasen and Page (1978) in former Owambo and by Hines and Burke (1997) in Kabbe and Okatjali areas of southern Oshana region are noted. Vegetation data available on central-northern Namibia covers parts of Oshikoto Region and only a few data from Omusati and Oshana Regions. According to du Plessis (2001), much of the phytosociological data available on the Mopaneveld in Namibia is concentrated in Kaokoland and northern Damaraland, in the administrative region of Kunene as well as in Etosha National Park.

The phytosociological synthesis of the Mopaneveld (the vegetation zone in which this study was conducted) in southern Africa by du Plessis (2001) allowed for the description of the vegetation into vegetation types and major plant communities at regional scale. Nevertheless there remains a need for increased scientific sampling of the mopaneveld in southern Africa to enable more accurate mapping and understanding of the vegetation dynamics of this rather extensive vegetation type. Du Plessis (2001) further noted that the inclusion of data from the Cuvelai area (i.e. Central-northern Namibia) in northern Namibia at this scale could not separate the Cuvelai units. Local scale studies of the Mopaneveld in this area were therefore strongly recommended for detailed stratification of this vegetation.

Verlinden and Dayot (2005) undertook a study in central-northern Namibia that focused on comparing indigenous land units (ILUs) with conventional vegetation analysis to improve understanding of the vegetation in the area by the scientific community. Their data were collected using the basic methods of participatory GIS. This study found that the ILUs were classified based on several criteria, mainly soil aspects, vegetation characteristics and landform. Landform was particularly important for identification of the main drainage areas e.g. *Omulonga*, *Elamba* and *Oshana* (Verlinden and Dayot 2005). This serves to suggest that vegetation was not considered an important indicator at such sites. The wide range of criteria used for local land units classification (of which vegetation parameters are only partial) makes it difficult to consistently describe the vegetation following such procedures.

The study nonetheless produced an indigenous land units map for Ogongo Agricultural College and the surrounds. The map recognizes 10 indigenous land units; seven of which are naturally occurring and three are exclusively man-made. These have been identified in the local language to be *Ehenene*, *Ehenge*, *Ekango*, *Olushwa*, *Olutha*, *Omuthitu*, and *Oshanas* with the man-made units as Canal, Excavations and Waterworks respectively (Verlinden and Dayot 2005). In terms of vegetation, a broad description of these units was done based on the dominant plant species and a combination of scientific and local knowledge of indicator species. The findings of this study therefore seemed to be more dependent on indigenous knowledge of land units rather than on vegetation survey data.

In another study by Ndeinoma (2001) a management plan was developed in attempt to apply community-based natural resource management (inclusive of the surrounding communities) of forestry resources in Ogongo Agricultural College. The college is recognized as one of the few community forests, and a protected area remaining in central-northern Namibia. This study found that most natural resources inside the protected area e.g. wood and grazing resources were already being over-utilized. Consequently, it was suggested that these resources could not be released for further use by the surrounding communities. Moreover, the natural resources may require sustainable management implementation if animal and crop production were to continue on a sustainable basis.

1.5 Background on Namibia

Namibia is a southern African country covering an area of about 823, 680 km^2, positioned between 17º and 29º South and 11º and 26º East (Barnard 1998, MET 2002, Mendelssohn *et al*. 2002). A broad geological classification recognizes two major geological zones in Namibia. The first one is located in the western part of the country and is evident from the great diversity of rock formations, most of which are exposed in a rugged landscape of valleys, escarpments, mountains and large open plains. The second zone is in the east, where sands and other recent deposits cover most of the surface and where the landscapes are much more uniform than in the west (Mendelssohn *et al*. 2002).

In its location, the country is exposed to air movements driven by three major climate systems or belts: the Inter-tropical Convergence Zone (ITCZ), the Subtropical High Pressure Zone (SHPZ), and the Temperate Zone (TZ). These systems collectively determine the country's rainfall 'income'. There is particularly a continuous fight back mechanism between the ITCZ and the SHPZ because the former brings in moist air from the north while the latter pushes back the moist air with dry, cold air. The relative dominance of the SHPZ yields the semi-arid to hyper-arid climate, which is experienced for the most part of the year in Namibia (Mendelssohn *et al*. 2002).

Rainfall in Namibia is generally low and highly variable with the intensity of these properties increasing from east to west and north to south. In the western parts, rainfall ranges from 25-50 mm increasing to between 250-300 mm in the central highlands while it ranges from 400 mm to 600 mm in the far north east where records may rise to 700 mm in a good rainy year (MET 2002). Figure 3 shows the distribution of rainfall in Namibia, along with the vegetation types in the country.

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

1.5.1 The vegetation

The vegetation in Namibia is strongly influenced by rainfall to an extend that it is seen to be tallest and most lush in the north-east, becoming more sparse and short towards the west and south. This is not merely a rainfall gradient as other factors such as soil types and other landscapes parameters affect the vegetation (Mendelssohn *et al*. 2002, Barnard 1998). Although there's no national scientific based vegetation map yet, the vegetation has been preliminarily been classified into three main vegetation zones: deserts (46), savannas (37%) and woodlands (17%). Following this rather crude classification, fourteen more detailed vegetation types have been recognized and are represented in Figure 4.

The broad-leaved tree and shrub savannas grow largely on deep Kalahari sandveld, plant life being dominated by several species of tall trees. On the other hand, the *Acacia* tree and shrub savanna is characterized by large, open expanses of grasslands with sparsely distributed *Acacia* trees. The trees are tallest in areas with deep sand in the east, and becoming shorter or shrubby towards the west where soils are shallower and the landscape becomes hilly and rocky (Mendelssohn *et al*. 2002).

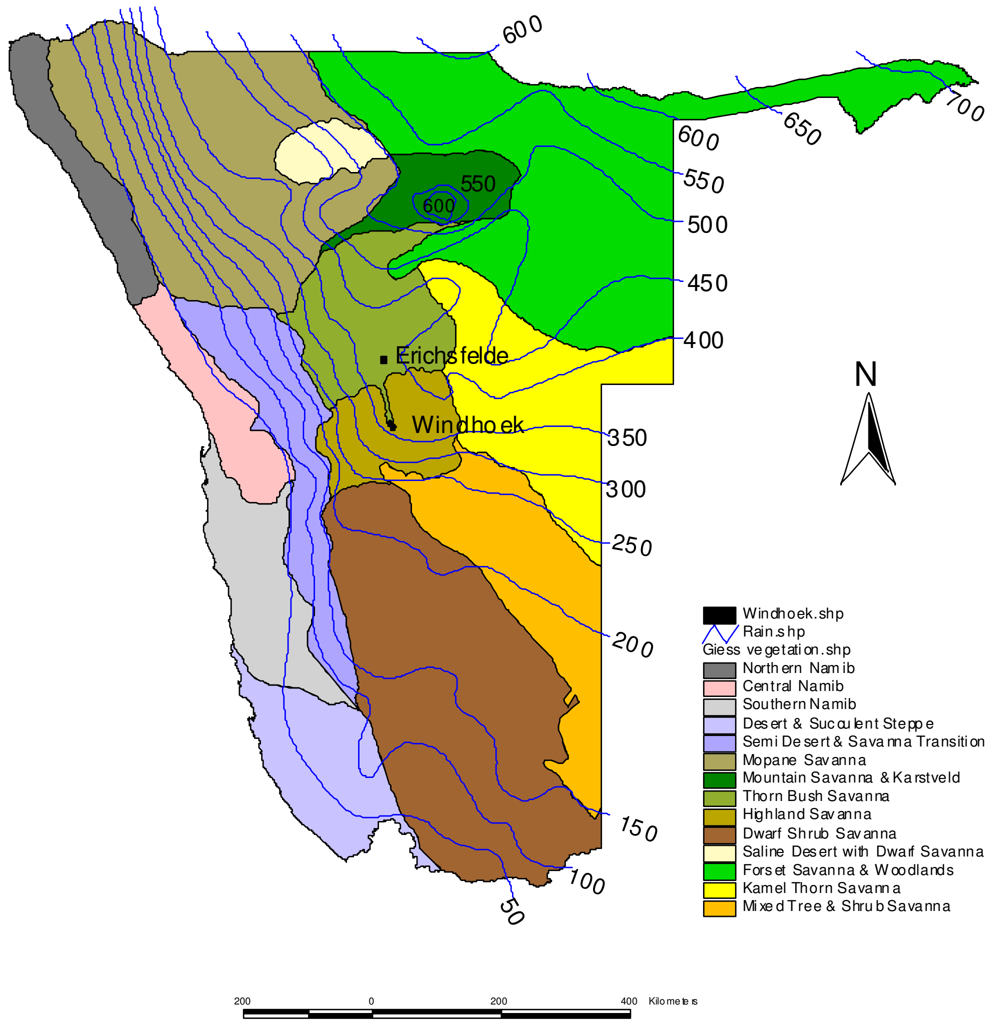


Figure 4 The preliminary vegetation map of Namibia (Giess 1971), over-layed with rainfall isohyets

(Source: NARIS 2001).

1.5.2 Natural resources and land use

In Namibia, agriculture and mining make up the main land use activities at national level although marine fisheries resources are also important for the country's economy. Current and past land use patterns are determined by the country's political history, ecology and climate (MET 2002, Mendelssohn *et al*. 2002, Barnard 1998). Being an arid country with infertile soils, Namibia's agriculture is typical of dry land farming throughout the world, with a big emphasis on livestock production. Most farmers keep cattle, sheep, goats, game animals or a combination thereof (MET 2002).

A great proportion of the population in the country directly depend on natural resources for survival. About 71% of the population live in rural areas where they largely practice subsistence farming. About 13.8% of the land has been proclaimed as state-controlled protected conservation areas (MET 2002, Mendelssohn *et al*. 2002). Arable land on Namibia comprises less than 2% of the land surface due to low rainfall. About 3 000 km^2 of the land is used for crop cultivation with sorghum, pearl millet and maize as the main or staple crops (Mendelssohn *et al*. 2002). Commercial farmers (less than 1% of the population) own about 44% of the land. An economic unit for commercial livestock unit may vary from 3 000 to 20 000 hectares in size. Commercial farming is dominated by livestock, particularly cattle and sheep, most of which is produced for meat for the supply of both local and international (South Africa and the European Union) markets (MET 2002).

1.6 Background on central-northern Namibia

1.6.1 Location and physical environment

The central-northern part of Namibia (formerly known as Owamboland or Owambo) comprises four administrative regions: Ohangwena, Omusati, Oshana, and Oshikoto (Mendelssohn *et al.* 2000). It borders Angola in the north, Kavango Region in the east, Kunene Region in the west and Etosha National Park in the south. Following the post independence (1990) subdivision of Owambo into administrative regions, the terms central-northern Namibia or north-central Namibia are currently used to refer to this area. This area is hereafter reffered to as central-northern Namibia.

Central-northern Namibia forms part of the extensive Kalahari sand basin (Strohbach *et al.* 2002) and covers about 5.2 million hectares of land (Hangula *et al.* 1998). The central part of the region is intersected by a network of shallow water courses locally known as *oshanas* which comprise the Cuvelai Delta. The *oshanas* are usually recharged by flood waters that flow from the Angolan highlands where annual rainfalls may exceed 700 mm. The oshanas also receive and keep water from heavy rainfalls that are occasionally experienced in this part of the country (Mendelssohn *et al.* 2000, Seely & Marsh 1992).

The flood waters from the northern Cuvelai, south of Evale (Angola) through to Lake Oponono and Ekuma channel into Etosha pan. Along with the life supporting water, the *oshanas* also transport salts which increase the salinity of the soil especially to the south hence an unsuitable area for subsistence farming (Mendelssohn *et al.* 2000). From Onoolongo, north of Etosha extends the *ombuga* flat grassland about 50 km wide with numerous salt water pans. These pans also receive water during rainy seasons from local run off or flood water. The southern part of central-northern Namibia is uniquely characterized by west-eastern oriented sand dunes and shallow water courses called *omiramba* (Erkkila & Sisskonen 1992).

1.6.2 Geology

Namibia has a unique and ancient geological history with spectacular rock formations that have come as a result of a series of tectonic activities (Mendelsohn *et al*. 2002), and the Owambo basin is no exclusion.

The Owambo basin (also misleadingly referred to as Etosha basin) is the northwestern outlier of the large, southern African, interior depo-centre of the Kalahari basin. The sedimentation history of this basin, started as early as during the Permo/Carboniferous glaciation (Buch & Rose 1996). Located between 14°E and 18° E and between the northern border of Namibia to 19°15'S, the basin lies on an old continental base of granites, gneisses and volcanic rocks (Mendelsohn *et al*. 2000, Miller 1997). It is floored by mid-Proterozoic crustal rocks of the Congo Craton and contains possibly as much as 8000 m of sedimentary rocks of the Nosib, Otavi and Mulden Groups of the late-Proterozoic Damara Sequence, 360 m of Karoo rocks and a blanket of semi-consolidated to unconsolidated Cretaceous to Recent Kalahari Sequence sediments up to 600 m thick (Miller 1997).

The Pan-African Damara Sequence rests on a gnessic and granitic basement containing mid-Protezoric cover rocks that are intruded by granites. The Damara Sequence rocks of Owambo basin were deposited on the stable northern platform of the Damara Oregon during phases of intra-continental rifting, spreading and continental collision, between 600 – 900 million years ago (ma) (Miller 1997). The collision of continental fragments formed a rim of dolomites and limestones around the edge of Owambo Basin. This rim is represented to the south of the basin by the hills around Tsumeb, Otavi and Grootfontein; to the west by the hills of Kamanjab and to the north-west by the hills of Kaokoveld, Ruacana and south-western Omusati (Mendelsohn *et al*. 2000).

This tectonic event was followed by an extended period of continental erosion, between 330 and 550 million years ago and thereafter followed a new deposition period called the Karoo Sequence. The Karoo Sequence events occurred during the glaciations period, also known as the Dwyka glacial period (Mendelsohn *et al*. 2000, Buch & Rose 1996). In Namibia, the glaciers cut deep valleys from the western edge of Owambo basin through the Kunene to the Atlantic Ocean. This period was followed by warmer conditions that melted the glaciers and ice sheets which eventually caused the shallow seas to dry up (Mendelsohn *et al*. 2000).

By about 130-150 ma, much of Gondwaland became covered in dunes and wind-blown sand in which case these sand deposits remain buried below the surface in central-northern Namibia. During the period of about 70 ma, the coupled effect of erosion and continental drift created a broad marginal plain known to us today as the Namib Desert. It was during the same period that a broad depression (the Kalahari basin) formed in the centre of the southern African subcontinent of which Owambo basin now forms a small western lobe of this great Kalahari basin (Mendelsohn *et al*. 2000).

Today, the ancient rocks of the Owambo basin are covered by a thick layer of Continental Cretaceous to Recent aeolian sands and lacustrine clays of the Kalahari Sequence (Miller 1997). Additionally, the Cuvelai delta as is seen today was also formed and shaped by varying regimes of flooding, slow-flowing water and wind-blown sand deposits from the east. These recurring processes led to the formation of the shallow water channels, commonly known as *oshanas* (Strohbach 2000).

1.6.3 Soils

Almost all the soils in central-northern Namibia have been deposited by wind and water. The soils are typical of arid regions with low fertility due minimal organic matter that is returned to the soil (Mendelssohn *et al*, 2000). A large proportion of the soils in this area are broadly categorized as Arenosols or sandy soils (Mendelssohn *et al*. 2002, Erkkila & Siiskonen 1992).

The deep Kalahari sands are found in the eastern and western parts, while clayey sodic sands dominate in the oshanas with sodic sands occurring on the surrounding higher grounds. Sands and loams occur largely to the south, north, east and west of the Cuvelai delta, where wind and water have repeatedly reworked the soil to create a mixture of deposits (Mendelsohn 2000). Clayey sodic sands and sodic sands of the Cuvelai comprise high sodium content of these soils is due to cycles of recurring floods and water evaporation. A coarse classification of soils of central-northern Namibia is shown in Figure 5. The sands and loams of the central and northern part of the Cuvelai have much lower salinity and provide fairly good soils for cropping (Mendelssohn *et al*. 2000, Strohbach 2000). Despite being poor in humus and plant available nutrients (Erkkila & Siiskonen 1992), soils in central-northern Namibia have a fairly high suitability for crop cultivation, relative to other soil types in other parts of the country (Mendelssohn *et al*. 2002). It is therefore not surprising that the study area is densely packed with crop fields.

Preliminary findings of a detailed soil profile survey at Ogongo and Omano BIOTA observatories have revealed a dominance of regosols (signaling low influence of soil forming processes) and cambisols although leptosols, fluvisols and arenosols were also found to a lesser extent at these sites. A common feature of the soils here is the formation of a desert pavement on soil surface, comprising of fine to coarse gravel. This is a sign of wind erosion of the silty substrates ([1]Prof. Gröngröft, pers. comm.)

Generally, rocks do not occur in central-northern Namibia, but precipitated calcareous concretes have been encountered at some sites.

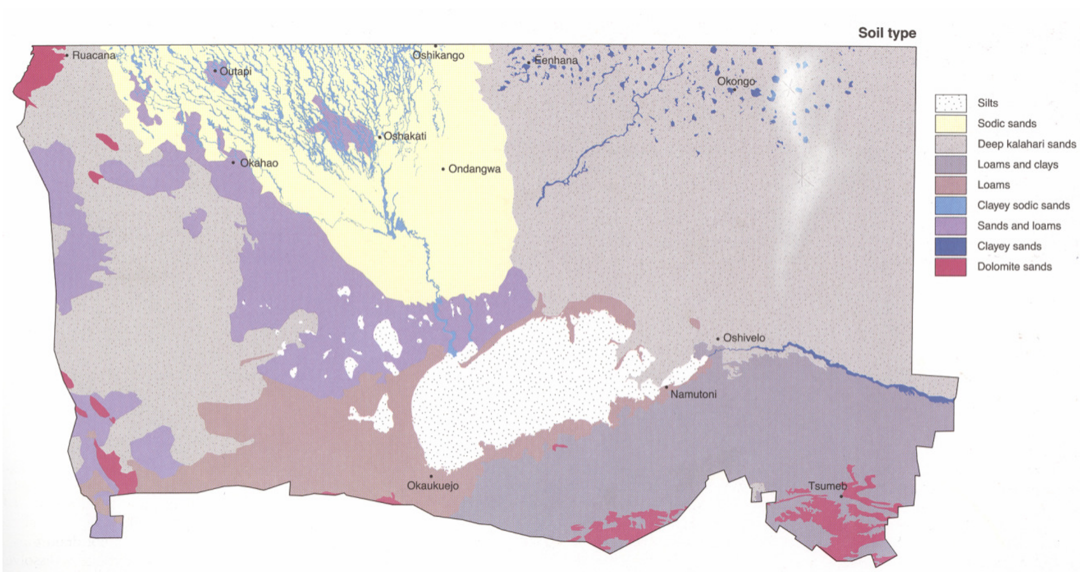


Figure 5. An overview of soil types in central-northern Namibia

(Source: Mendelssohn *et al*. 2000)

[1] Prof. Dr. Alexander Gröngröft, Institute of Soil Science, University of Hamburg, Hamburg.

1.6.4 Climate

In general, the climate in central-northern Namibia can be described as semi-arid, with rainfall restricted to the summer months (November to April) when temperature is also highest. The annual average rainfall varies from 550-600 millimeters per year in the wettest areas in the north-east and around Tsumeb, to 250-300 millimeters per pear in the drier south-western parts around Etosha (Mendelssohn *et al*. 2000). Rainfall is highly variable in amount and temporal distribution. High rainfall is experienced during wet years (e.g. in 1997) but dry years also occur, such as the 1992/3 when much lower rainfall was experienced. Wet and dry periods are therefore a normal climatic feature of this environment which has been persistent for millions of years (Mendelssohn *et al*. 2000).

It is estimated that about 83% of all rainwater evaporates soon after it has fallen while percolation rate is also very high (Hangula *et al.* 1998). This suggests poor water holding capacity of the soils in the area and consequent reduction in the water available to plants. Seasonality of rainfall is an important driving force of biological and cultural processes in semi-arid environments. Mean monthly humidity at midday ranges from 50% in March to 17% in September. This marks the extreme effect of evapo-transpiration hence the amount of water that is available for plant growth (Seely and Marsh 1992).

The temperature of central-northern Namibia varies greatly as it has hot summers and mild winters. In summer, the heat is often subdued by the rains but temperatures may rise well above 37.5 ^{o}C (Hangula *et al*. 1998). In winter, the night temperature may drop to freezing point with the day temperature rising to 27 ^{o}C or more (Erkkila and Siiskonen 1992). The *oshanas*, which receive water rain and surface flowing water, dry out by July at the latest as the winter season sets in. The area then experiences at least four months of no rainfall and the lack of water often causes severe difficulties to rural communities, animals and plants (Seely and Marsh 1992).

1.6.5 The people

There are no data available on the number of hunter-gatherers who formerly occupied central-northern Namibia before the arrival of the agro-pastoralists. Based on research carried in Angola and Zambia, it has been estimated that the first agriculturists occupied northern Namibia at least 2000 years ago. Owambo speaking agro-pastoralists were probably present in northern Namibia and southern Angola by the 17th century. The population of central-northern Namibia was estimated to be 90 000 people in 1920. About seventy years later the national census of 1992 revealed that the population had increased to 630 000 people (Seely and Marsh 1992). The availability of water in the semi-arid region of the Cuvelai Delta has attracted human settlement hence densely populated mainly by people who depend on the land for farming and on other natural resources available in the area (du Plessis 2001).

In 2001 the national census revealed that about 780 149 people live in this part of the country, making up about 43% of the total population. The population density was recorded to be 12.1 people per square kilometer. This makes central-northern Namibia to be the most populous region in the country. Approximately 48% of the population is less than fifteen years of age, suggesting a rapid population increase (Government of the Republic of Namibia 2003). The continuous increasing number of people in the area has put the environment within which they live under severe pressure (Mendelssohn 2000).

1.6.6 Land use

Three main farming types are recognized in central-northern Namibia.

The first farming type is subsistence farming, which is practiced by the majority of the people and involves agricultural production, aimed principally for household consumption and to a lesser extent for income generation. Each household has to fence off their *ekove* or *uuyanda*, an area (about two to five hectares) allocated to them by the traditional authority, which encloses the homestead, a cropfield and a 'home-use' grazing area. Closely packed mopane branches are the preferred traditional fencing material (Erkkila 2001, Mendelssohn 2000, Seely and Marsh 1992). The term homestead used here refers to the traditional household, which in the study area usually refers to a round fenced off area enclosing several huts. The huts are also usually made of wood, clay and thatched roof.

This farming type constitutes the main land use, agro-silvo-pastoralism, which is based primarily on pearl millet *Pennisetum glaucum* as a crop component (locally known as *Omahangu*), livestock and a multipurpose use of indigenous plants. Agro-silvo-pastoralism has been shown to have greater benefits at community level than focusing on a single resource. Despite being subjected to decades of war, droughts and plagues, this system has

allowed the people to deal with these crises rather successfully. However this land use system is said to be currently under stress, mainly because environmental problems as well as human influences threaten the sustainability of the system (Kreike 1995, Seely and Marsh 1992), hence a need to evaluate currently existing traditional knowledge of natural resource management to develop strategies suited for current conditions.
The second farming type is the large-scale subsistence farming constitutes large farms, either leased at nominal rates in the Mangetti area or established informally by fencing off large tracts of traditional grazing land. The third farming option is that of privately owned commercial farms in the Tsumeb area (Mendelsohn *et al*. 2000).

An additional land use type practiced to a smaller extent, and a fairly new concept in central-northern Namibia is community forestry initiatives. Community forests are areas within the communal lands of Namibia that are managed on a sustainable way by local communities in order to protect forest and tree resources and to improve livelihoods. The community forest programmes have been deliberately modeled in the context of community-based natural resource management initiatives, with a focus on managing wood and non-wood plant resources (MAWF 2009). At present, four community forests occur in the study area, one of which is gazetted, under section 15(3) of the Forest Act, 2001 (Act No. 12 of 2001) of the Government of the Republic of Namibia, while the remaining are emerging (Table 1).

Table 1 : An inventory of Community forests in Oshana and Omusati Regions

(MAWF 2009)

Name of community forest	**Administrative Region**	**Status**	**Size (ha)**
Uukolonkadhi	Omusati	Gazzeted	111, 700
Uukwaludhi	Omusati	Emerging	143, 700
Ongandjera	Omusati	Emerging	502, 600
Oshikushiithilonde	Oshana	Emerging	87, 836

1.7 Using remote sensing in vegetation mapping

Remote sensing is the practice of deriving information about the earth's land and water surfaces by means of images acquired from an overhead perspective, using electromagnetic radiation, in one or more regions of the electromagnetic spectrum, as reflected from the earth's surface (Campbell 2002, Figure 6). Gathering of such data involves a variety of techniques used by instruments that are mounted on satellites, aircrafts as well as on the ground. The data can be stored (and made available) chemically i.e. as photographs or electronically. As a data collecting tool, remote sensing has the capability to provide synoptic views over very large areas in a relatively short period of time. Remote sensing provides an image at a specific point in time thus can be used to monitor changes over time (Treweek and Wardsworth 1999, Campbell 2002). The date of a satellite image is very important for analysis because one has to refer to events that have taken place during that time.

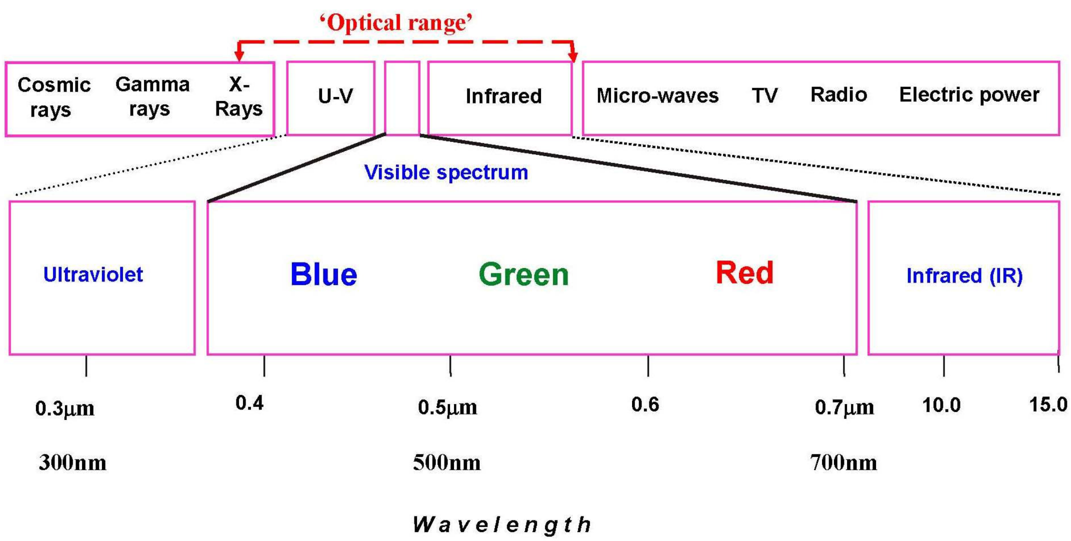


Figure 6: The electromagnetic spectrum showing the different wavelengths

(Source: Campbell 2002)

The structural adaptations of plants to perform photosynthesis and their interaction with the electromagnetic energy produce spectral appearances of vegetation, which can be recorded with remote sensing instruments (Jensen 2000). The incident electromagnetic energy interacts with pigments, water and intercellular spaces within the plant leaf. It is therefore possible to measure the amount incident energy reflected by the leaf, absorbed by the leaf and transmitted through the leaf (Jensen 2000). Remote sensing of chlorophyll absorption within vegetation represents a fundamental biophysical variable that is useful in many biogeographical investigations. The health state of vegetation as influenced by photosynthesis, determines how a leaf and its associated plant canopy will appear radiometrically on remotely sensed images (Jensen 2000).

Chlorophyll molecules in a typical green plant (pigments) have evolved to absorb wavelengths of light in the visible region of the spectrum (0.35-0.70 µm) and they absorb blue and red light. Different pigments are active at different health states of vegetation and have different absorption bands. For photosynthesis, chlorophyll *a* and *b* are most important. Chlorophyll *a* absorbs wavelengths of 0.43 and 0.66 µm and chlorophyll *b* at wavelengths of 0.45 and 0.65 µm (Figure 6). A high absorption of pigments at the above-mentioned wavelengths may suggest high levels of photosynthetic activity in the vegetation. The effect is that vegetation that is photosynthetically active appears reddish on a false colour satellite image (4:5:3; R:G:B band combination). Although other pigments present in plants may have similar absorption properties, chloropyll *a* and *b* tend to dominate and mask the effects of such pigments (Jensen 2000).

Conversely, when a plant undergoes senescence or some degree of stress, the chlorophyll production declines to low levels and/or may be terminated completely, thus allowing carotenes, xanthophylls and other pigments to take over, causing the plant, (usually the leaves) to appear yellow, suggesting drier vegetation. Under stress conditions, some trees may produce large amounts of anthocyanin causing bright red coloration in the leaves (Jensen 2000, Verbyla 1995).

Water in plants absorbs incident energy between the absorption bands with increasing strength at longer wavelengths. Water has high absorption capacity of middle-infrared energy, thus greater turgidity of the leaves causes lower middle-infrared reflectance (Jensen 2000, Verbyla 1995). This provides a possibility to use remotely sensed images to infer about the moisture content of the vegetation.

LANDSAT-5-TM is one of the numerous land observation satellites, which collects data every 18 days at particular locations along, various paths around the globe. It utilizes two sensor systems, Landsat Multispectral Scanner (MSS) and Landsat Thematic Mapper (TM) for its data collection (Verbyla 1995). These data may include topography, vegetation, urban development, agriculture and other geographic features (Wadsworth and Treweek 1999). The satellite uses 8 band combinations or sections of the electromagnetic spectrum i.e. blue, green, red, and infrared, near infrared 1, near infrared 2, pan chromatic and the thermal band. These are also referred to as the 1-8 bands in numerical terms respectively. For the purpose of vegetation studies the first 6 bands are commonly used (Campbell 2002, Jensen 2000).

The 4:5:3 band combination in Red: Green: Blue is regarded as the best band combination to discriminate vegetation status (Jensen 2005). The red and blue light is absorbed by the plants for carbon fixation hence an indication of photosynthetic activity. The infrared and near infrared are absorbed by water which can be used to predict the moisture content of the vegetation (Jensen 2000). LANDSAT TM band 3 (0.63 – 0.69 μm) also known as the red chlorophyll absorption band is an important band for vegetation discrimination. It is to a great extent controlled by chlorophylls a and b as well as by other leaf pigments such as carotenoids and xanthophylls. Band 4 (0.76 – 0.90 μm) is sensitive to canopy cover of vegetation biomass and is mainly controlled by cellular structures. Finally, band 5 (1.55 – 1.73 μm) is more responsive to the moisture content of the vegetation and may therefore be used to infer about the health status of the vegetation under study (Campbell 2002, Strohbach 2002).

Thematic maps are highly generalized abstractions of reality, particularly in terms of their spatial resolution, boundary delineation and classification detail. Therefore maps that are produced from remote sensed data are based on units that can be spectrally separated. Existing remote sensing techniques are highly effective in detecting structural types, percentage cover and stress symptoms in vegetation but have a reduced or low ability to discriminate different species assemblages like plant communities. Although vegetation indices such as NDVI are effective in the assessment of plant production or drought stress, these cannot be used to delimit vegetation on a much finer scale than the biome level (Strohbach 2002).

Despite these flaws, using remotely sensed data together with field data provides a possibility to map vegetation in a vast country like Namibia that is also faced with constraints of time, budget and human resources. The use of satellite imagery classification represents an accurate and cost-effective alternative of vegetation mapping, particularly for large scale coverage.

1.7.1 Types of image classification

In the context on remote sensing, classification refers to a procedure where data cells (pixels) are assigned to one of a broad group of landcover classes, using the similarity of spectral reflectances as a criterion. Two main approaches of image classifications are recognized i.e. unsupervised and supervised classifications (Eastman 2006, Campbell 2002).

Unsupervised multi-spectral classification is a technique for computer-assisted interpretation of remotely sensed imagery, done by statistical clustering of typical patterns in the reflectance data. The process is purely independent of investigator bias and allows for identification, delineation and mapping of natural classes or clusters without prior knowledge of their identity. It is therefore useful for making of base maps, thus provides an opportunity for planning field sampling methods e.g. pre-determine the number and location of samples for each representative class (Campbell 2002).

On the other hand, supervised multispectral classification is a technique or a process of using the statistical properties of samples of known identity (training areas) to classify pixels of unknown identity, i.e. land cover classes with similar spectral properties (Campbell 2002). The training sites are sensibly selected (using imaging software e.g. IDRISI or ERDAS) on the basis of field samples, whose exact location can be superimposed onto a digital image. These training sites also include a pre-set minimum number of pixels around the sampling point, which should be closely related to the field sample as possible (Strohbach 2002).

CHAPTER 2. PROBLEM STATEMENT

Central-northern Namibia is home to an approximate 43% of the country's population (Government of the Republic of Namibia 2003). A large proportion of these people still depend directly on natural resources for their livelihoods and have adopted agro-silvo-pastoralism as the main land use. The little phytosociological and biodiversity data available on Namibia are not substantial to motivate environmental management and sustainable utilization of the country's natural wealth.

Plant communities are fundamental units of ecosystems and should form the basis for environmental management plans and/or guidelines. This stresses the importance of obtaining a thorough inventory of the plant communities (i.e. species and their associated habitats), which can serve as a foundation for science based development. Furthermore, conclusions and recommendations drawn from plant community analyses may provide opportunities of ecological restoration and rehabilitation of degraded natural vegetation (Bredenkamp and Brown 2002).

Plant communities are therefore not only important for ecological investigations but also in applied environmental sciences. For example, in the area studied here, an inventory of plant community types could contribute to the much needed efforts to review local land use. In addition, the major urban centres in the area such as Outapi, Okahao and Tsandi are expanding at fast rates, which is usually accompanied by a load of development projects such as the construction of infrastructures e.g. power lines, roads, rails, housing and business centres. Such projects are often harmful to the environment and biodiversity at large and it is therefore important to ensure that the respective land users and town planners make informed decisions.

Accordingly, this study was aimed at inventorying, describing and mapping of the vegetation of Omusati and Oshana Regions, to improve our understanding of the functioning of plant communities and develop a scientific basis for effective environmental planning, management and sustainable land use for the area.

The study was initiated following recommendations of a similar study conducted in a smaller geographical area of Ogongo Agricultural College and surrounds in Omusati Region. Efforts to map the vegetation Ogongo Agricultural College and surrounds by Kangombe (2007) proved difficult due to bias in the data related more to climate variability and land use types and intensities, which introduced a risk of mapping vegetation types together with vegetation states.

The sensitivity of this savanna ecosystem to rainfall, particularly the herbal layer and differences in the intensity of land use at various locations of the study area means that relevés sampled in different years and/or from differing land use regimes, but belonging to one community type may have different species composition. This variation may cause these relevés to be assigned to different groups in a classification which can lead to a description of vegetation states instead of vegetation types during a phytosociological investigation. In order to thoroughly describe such vegetation, ample data is required to cover for the variation while knowledge of the area is indispensable. It is for this reason that a detailed phytosociological survey was required for a more accurate representation and description of community types in the Cuvelai delta of central-northern Namibia.

Consequently, more phytosociological data was collected in the two aforementioned regions between 2006 and 2009 to cover temporal and spatial variation in the area.

2.1 Land use types and intensities

Two major land uses were observed in the area sampled by Kangombe (2007). The first one is the protected area of Ogongo Agricultural College where rotational grazing, supplementation and other modern farm management strategies are applied. The second land use type is communal farming where traditional farming strategies such as continuous grazing of open pastures are predominant. Moreover, on the communal areas, the area surrounding a given homestead is often fenced off as a reserve for private grazing leaving limited land in the surrounding for open access grazing. This further introduces another dimension to land use regime in the study area. Vegetation data used in the study was collected regardless of land use type and intensity, which might have influenced the findings results of that study (Kangombe 2007). This raised the need for further inventory of the vegetation in the area.

2.2 Climate variability

In terms of climate variability, Namibia's climate varies greatly between years and being an arid to semi arid country, it is regarded the driest in sub-Saharan Africa (Mendelssohn *et al*. 2002). This means that the country may experience years of good rainfall, poor rainfall and moderate or 'normal' rainfalls, in no particular order. As an example, the year 2006 was a relatively wet year while 2007 was a relatively dry year (personal observation). The wet/dry year pattern is explained in section 1.6.4. Due to this high variation in temporal and spatial climatic parameters (especially rainfall), it was recommended to analyze the influence of rainfall on vegetation between years, to enable more accurate description of plant communities.

CHAPTER 3. AIMS OF THE STUDY

This study was carried out as part of the BIOTA southern Africa project under the sub-projects vegetation mapping (B4) and vegetation monitoring (B3). The aim of this study was to describe and map the vegetation of Omusati and Oshana Regions of Central-northern Namibia, using vegetation survey data and satellite imagery.

3.1 Research Objectives

The specific objectives of the study are:-

- To describe the vegetation of Omusati and Oshana Regions, as to study patterns and understand hierarchical relationships

- To produce a detailed vegetation map of the study area

- To compare the information depicted by the satellite image of the study area with the resulting map to assess the suitability of this satellite information as an indicator of vegetation cover, vegetation structure, and vegetation health status.

- To contribute to the baseline data base of Namibia's flora and biodiversity

- To quantify and map the extent of land degradation in the study area

3.2 Research Questions

The key questions identified for this study are as follows:-

- Can the Braun-Blanquet methods be used to describe and map the vegetation Omusati and Oshana Regions?

- Can the different colours on the false colour satellite image of Omusati and Oshana Regions be used to distinguish between different plant communities?

- What is the extent of land degradation in the study area?

3.3 Study Approach

Vegetation mapping involves a lengthy process of gathering (and processing) different types of data to assemble into a vegetation map. The flow chart below (Figure 7) illustrates the various steps followed in this study to map the vegetation of Oshana and Omusati regions in central-northern Namibia.

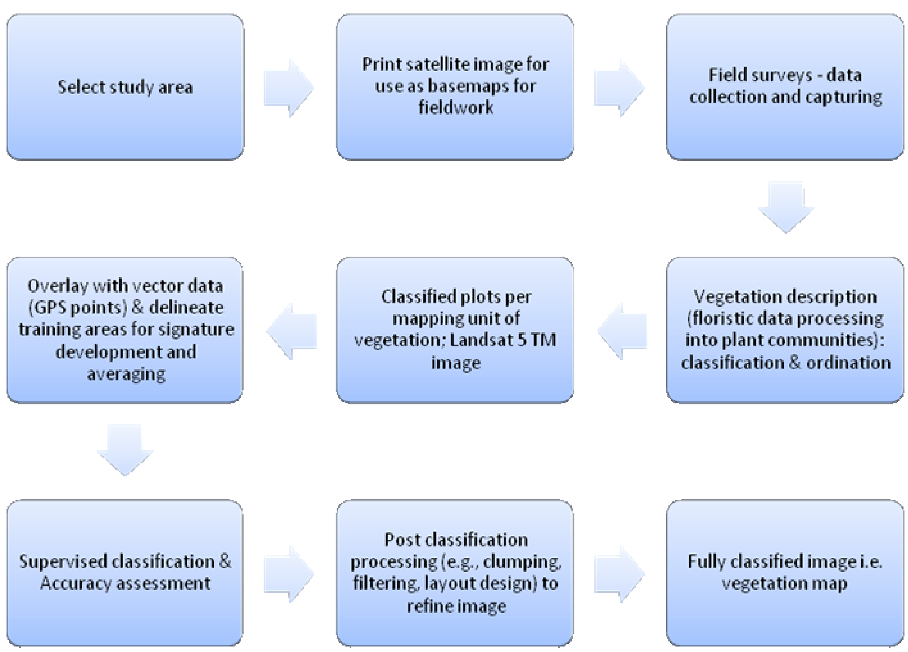


Figure 7. A conceptual diagram of the study approach of this research

CHAPTER 4. METHODS

4.1 Study Site: Omusati and Oshana Regions

Omusati and Oshana are two administrative regions of central-northern Namibia, geographically adjacent to each other and situated in the heart of the extensive Cuvelai Drainage Basin. While both regions border Etosha National Park to the south, Omusati borders Kunene region to the west, and Oshana borders Oshikoto to the south-east and Ohangwena to the north and north-east (Figure 8). Following the Giess (1971) classification of vegetation zones in Namibia, the study area belongs to the Mopane savanna - an extensive vegetation type within the savannas of southern Africa (du Plessis 2001). In Namibia, this vegetation type is found in the north-western part of the country and is characterized by a well-known economically and ecologically important tree species *Colophospermum mopane*, the mopane shrub/tree (du Plessis 2001, Giess 1998).

In addition, the study area makes part of the east-west extension of the BIOTA transect (Figure 2), where monitoring sites of Ogongo and Omano observatories, have been established. The former observatory is situated inside Ogongo Agricultural College, a protected area and the latter on the communal farming areas within more or less the same latitudinal boundaries, for comparative research studies (Jürgens *et al*. 2010).

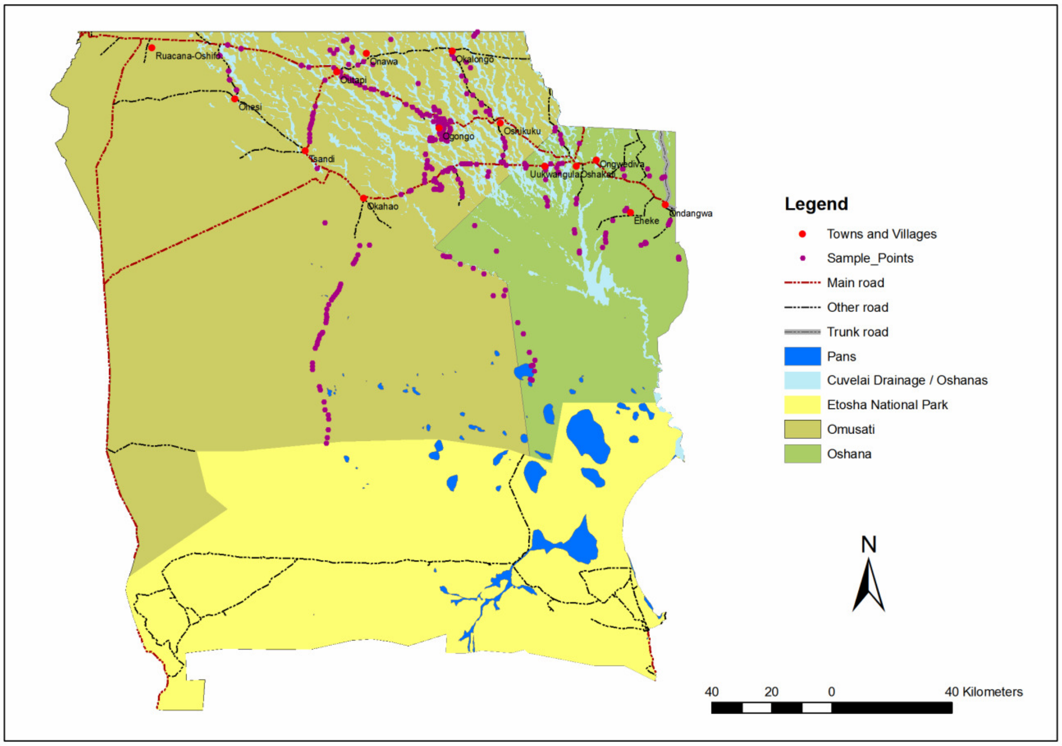


Figure 8. The location of the study area and distribution of sample plots.

Note: The seasonally flooded oshanas, which dominate the central part of the area.

4.2 Data collection

Vegetation data was collected during the rainy season from February to April (occasionally May, depending on floods) for the period of 2006-2009. In addition, vegetation monitoring data was also collected during the same time period, from the biodiversity observatories of Ogongo and Omano. The data was collected following the Braun-Blanquet sampling methods as adapted to the Vegetation Survey of Namibia project. In arid environments like Namibia, vegetation data collection best done during the peak of the growing season, which in the study area is generally between January and April. Flowers and fruits are produced during this time while annuals and ephemerals will only grow during this time when sufficient moisture is available. Sampling during this time therefore increases the probability to encounter the true species composition than it would be during the dry season when annuals for instance, mainly only occur as seeds.

A merged false colour satellite image (Landsat 5 TM Path 180 Row 72 and 73 dated 02 July 2000) was used as a base map for field surveys. As one of the pre-requisites to Braun-

Blanquet sampling methodology, homogenous vegetation needed to be selected at different sites and a set of relevés were sampled from it. However, it was difficult to find the required homogeneity within the study area due to the high variation in the landscape and vegetation over small distances mainly due to *oshanas* dissecting the savanna vegetation (Figure 8). Extensive crop cultivation and fencing tendencies also made it challenging to sample natural vegetation in the area.

Following the standardized methods for the Namibia Vegetation Survey (Strohbach 2001), at each location, a sample plot of 20 m X 50 m in size (1000 m^2), as stipulated in Figure 9, was laid out on estimation at each location then assigned a unique number. However, the observatory plots have been specifically measured out and permanently marked using metal droppers (Jürgens *et al*. 2010). A species composition inventory of all plant species present in the sample plot was established as the investigator walked through it. The investigator then walked to the centre point of the north facing edge of the sample plot from which a representative view of the plant community could be obtained. A cover abundance value was then assigned to each species expressed as a percentage of the sample plot taking note of the different height classes for woody species and growth forms for the herbaceous layer. The percentage cover scale used was 0.1% to 100%. A total score was calculated for each relevé by addition of the cover of each species encountered in that relevé. A simple diagrammatic model of this sampling technique is presented in Figure 9.

This method enabled both the physiognomic and floristic characteristics of the vegetation to be recorded at each relevé. A total of 415 relevés were compiled during this study over the four-year period. The spatial distribution of these relevés is given in Figure 8 as sample plots. In addition, vegetation monitoring plots of Ogongo and Omano observatories were survered every year for the 2006-2009 period, following the same procedure.

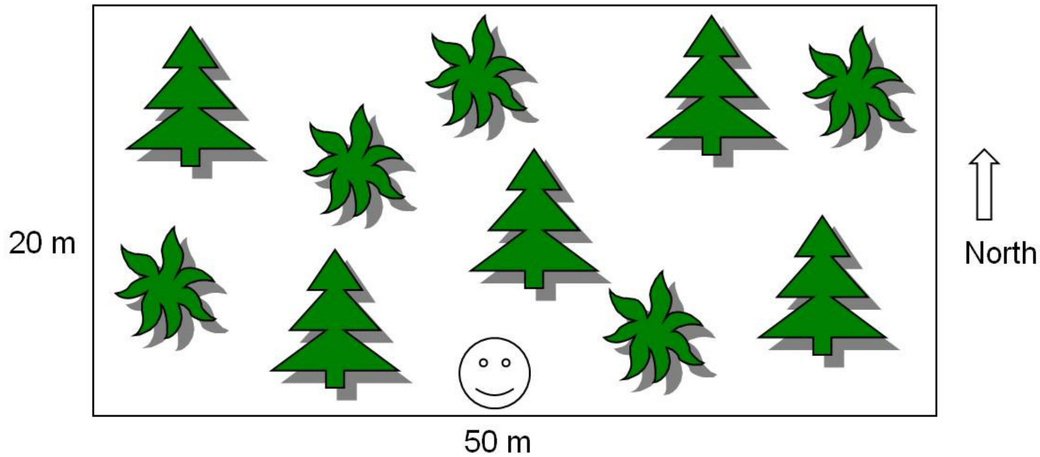


Figure 9 A simple model of the Braun-Blanquet sampling methodology

All unknown plant species were given a provisional name, collected and pressed following the standard pressing procedures and collector field notes to enable identification at the National Herbarium of Namibia (WIND). In addition, a representative specimen of each species encountered in the study area was collected for the confirmation of the field identification. The correct scientific name of the species was used for incorporation of this vegetation data into a TurboVeg database. Alongside these vegetation data, habitat description data such as the global positioning system (GPS) information, the exact locality, slope, landscape type, edaphic features and disturbances were all recorded for each relevé. Appendix I shows all habitat data that were recorded in the study.

4.3 Data analysis

A TurboVeg database was created for capturing the habitatat description and vegetation data. All data (vegetation and habitat description data) were captured into this database.

4.3.1 Multivariate statistics (classification and ordination)

The data were exported from the TurboVeg database into JUICE, a windows classification program where the data were classified by modified TWINSPAN (Chytrý 2002).

In vegetation ecology, numerical classification represents a method that groups a set of individual vegetation samples into groups based on their floristic composition. The Two-Way Indicator Species Analysis (TWINSPAN) Hill is currently the most widely used technique for polythetic divisive classification. It is based on the progressive refinement of a single ordination axis from reciprocal averaging or canonical analysis (Kent and Coker 2003, Chytrý 2002).

Classification uses the calculation of species constancy i.e is the number of relevés that a given species occurs, to identify differential species. Differential species are species of medium to low constancy that display a tendency of occurring together in a set of relevés, thus potentially characterizing that set of relevés into a group. Sequential sorting of relevés on the basis of species composition, distribution and abundance, allows similar relevés and species to be placed next to each other thus defining different community types (Kent and Coker 2003, Chytrý 2002).

During analysis (classification), a combined synoptic table was constructed to facilitate the recognition and definition of plant communities represented in the data set. Vegetation associations could therefore be defined taking into account the following: (a) species occurring in 60% or more of the relevés in that association, not considering the cover, (b) common species which occur with high cover and (c) subjectively based on investigator's fieldnotes and knowledge. Characteristic species were also verified by considering their fidelity values. The concept of fidelity was developed to test a species loyalty to a given set of relevés that forms a vegetation unit. It's important to note that a species of high constancy may not necessarily have the highest degree of fidelity. The Braun-Blanquet system recognizes 5 different levels of fidelity (Appendix II).

Diagnostic species have been defined as those species with fidelity value higher than the 'lower' fidelity threshold, while constant species are those with relative frequency higher than the 'lower' frequency threshold (Kent and Coker 2003). A species can therefore be both diagnostic and constant, but the diagnostic species list is given first priority. Dominant species are defined as those species that have cover values higher than the threshold cover (Kent and Coker 2003).

To confirm the resulting groups of the TWINSPAN classification and to infer the underlying gradients in the data, indirect gradient analysis of data was performed by Detrended Correspondence Analysis (DCA) ordination, using the ordination program PC-ORD 5.0. The plots 9233 and 9235 were singled out as outliers in this dataset, and were consequently omitted from further ordination analyses. Although several ordination techniques exist, the DCA was chosen because it allowed better interpretation of ordination diagrams against reciprocal averaging (RA) and also due the heterogeneous nature of the data. Next to Principal Components Analysis (PCA), DCA is strongly recommended in literature as an effective and robust ordination technique (Gauch 1986, Kent and Coker 2003). The former is designed to ordinate data that exhibit very little variability.

The resulting classification groups from JUICE together with the header data were exported into the imaging software ERDAS, with which the mapping was performed.

4.3.2 Basic Statistics

In addition to the multivariate analysis, some basic statistical analyses were also performed on the data collected in this study. Average vegetation cover per defined layer of vegetation as well as overall average coverage was computed at alliance, association and sub-association syntaxonomic levels.

Floristic data of twenty selected monitoring plots from Ogongo and Omano observatories were analysed (average cover calculations) for changes in vegetation over the four-year period, alongside rainfall data obtained from Ondangwa Meteorological Station. Selection of these data was restricted to plots belonging to the *Eragrostis trichophora - Colophospermum mopane* shrublands alliance and a relevé reference for all four years. This is because consistent monitoring data could not be collected from other vegetation alliances, either due to inadequate representation on the selected monitoring sites or floofing events experienced during the duration of the study. The observatory plots analysed in this regard are given in Appendix VI. Efforts of the BIOTA southern Africa project to set-up a weather station at Ogongo observatory could not yield fruitful results during the duration of this study, due to unforseen technical complexities of the equipment. A fire occurrence at the site during August/September 2008 also caused gaps in weather data records at this station.

4.4 Vegetation Mapping

Plant communities are useful spatial units for environmental planning. Mapping of ecosystems requires classification of available, relevant data to derive homogenous map units with predictable characteristics. This is often done with combined datasets of various characteristics factor such as climate, geology and vegetation. Digital maps produced from such datasets provide a spatial representation of ecosystem classifications and can be used to depict habitats, wildlife and other ecological resources in a standardized and directly comparable fashion. Combining data from different sources such as satellite imagery, aerial photographs, field survey data and radar images also greatly enhances the value and accuracy of ecosystem maps, more than using a single data source (Treweek and Wardsworth 1999).

One of the primary objectives of this study is to map the vegetation of Omusati and Oshana Regions of central-northern Namibia. Mapping was done using the image processing software ERDAS 9.3 (Earth Resources Data Analysis Systems), with satellite images and field vegetation data as the main ingredients. Mapping was done at association level, but the sub-association level was also taken into consideration for associations that were further classified to that level. The reason for this is that in most cases, the additional division of an association to sub-associations was related to land-use differences; hence this was an attempt to differentiate between vegetation states and community types.

A merged LANDSAT-7-TM image from the scenes of the Path 180 Row 072 and Path 180 Row 073 satellite images, both dated 30 April 2009, was used for mapping the vegetation of the study area. Being regarded the best bands for vegetation analysis, bands 4, 5 and 3, in Red, Green and Blue (RGB) combination, also known as a false colour image was used for this mapping process. The mapping was done as part of a remote sensing training course through the Department of Geography at the Julius-Maximillian University in Würzburg, southern Germany during September 2009. It is however essential to acknowledge the time-consuming and labour-intensitve steps involved at the different stages of data preparation (for both field and satellite data) required before a map can be obtained by supervised classification. These steps (as summarized in Figure 7, Section 3.3) include acquisition of raster information or satellite images, conversion into suitable formats (including projections and statistics), field data collection, preparation of vector data, demarcation of areas of interest for signature development, supervised classification and accuracy assessment, to mention a few.

During the mapping process in this study, a subset of the study area was made from the merged composite satellite image. The vegetation data was split into two portions of 70% for mapping and 30% for accuracy assessment respective to each association or vegetation unit, as recommended in the literature (Jensen 2000, Campbell 2002). The vector data was prepared in such a way that relevés belonging to the same association shared a common group number. This number was used as a guideline to delineate training sites or areas of interest for each sample plot on the satellite image to form individual signatures.

On the subset image, in the aforementioned band combination, polygons were demarcated so as to re-construct more or less the individual sample plots surveyed, which represent one of the defined community types. A polygon pulls together similar pixels and groups it with its associated signature if plotted together in the signature mean plot of the signature editor. For each association, signatures were averaged and merged according to spectral reflectance curves thus excluding outliers from the final analysis. Using the averaged and merged signatures the different vegetation units were mapped following a maximum likelihood supervised classification. This method of supervised classification assumes a normal distribution of survey points. For each pixel, a probability of belonging to its defined unit is computed and the pixel is assigned it to the group with the highest probability of belongingness (Campbell 2002).

The output classification or raw vegetation map was then post processed in a two-step method of clumping and elimination, to improve visual interpretation of the map by the users. The map was then subjected to accuracy assessment; a lengthy statistical process that allows quantification of the map's accuracy hence its efficacy. Finally, the map was exported for final visual refinement in ArcGIS, to produce the final vegetation map (Figure 34).

4.4.1 Accuracy Assessment

It is unfortunate but spatial thematic information contains error, and scientists working with such data should be able to recognize possible sources of error and minimize it as much as possible (Jensen 2005). Some possible sources of error in remotely sensed data include miscalibrated remote sensing equipment, unfavourable weather conditions such as fog, high relative humidity and other physical properties e.g. smog. The accuracy of maps derived from remotely sensed images is therefore naturally questionable by prospective users, regarding the information contained in such maps. This emphasizes the need to subject such maps to a thorough accuracy assessment before they can become useful in scientific investigations and policy decisions (Campbell 2002, Jensen 2005).

Accuracy is a measure of the correctness or the agreement between a standard assumed to be correct and a classified image of unknown quality. An image classification that corresponds closely with the standard is said to be "accurate". In a statistical context, high accuracy is associated with low bias as well as low variability in estimates. Precision on the other hand, defines the amount of detail contained in a map. It is important to differentiate between accuracy and precision because the two measures influence one another. For example, one can increase accuracy by decreasing precision i.e. by being coarse with the classification, therefore as detail increases so does the opportunity for error (Campbell 2002).

Two main methods of accuracy assessment exist. One such method is the qualitative confidence-building assessment, which involves visual inspection of the thematic map to the overall area frame by knowledgeable individuals to identify any gross errors (Campbell 2002). This kind of accuracy assessment was applied by Kangombe (2007) on the remotely sensed data based map produced for Ogongo Agricultural College and surrounds. The second method is the statistical measurement of accuracy, which is further sub-divided into model-based inference and design-based inference. The latter, although expensive, is a robust technique as it provides unbiased map accuracy statistics using consistent estimators. It is based on statistical principles that infer the statistical characteristics of a finite population based on the sampling frame. It measures statistical parameters e.g. producer's accuracy, user's accuracy and overall accuracy and Kappa co-efficient of agreement (Campbell 2002). Design-based inference was applied in this study to evaluate the correctness of the maps.

The application of design-based inference requires the division of training data into two portions, one for supervised classification (70% of training data) and the other for validation (30% of training data) to assess the accuracy of the classification. The standard form for reporting design-based inference is the error matrix, also referred to as the confusion matrix, because it identifies both the overall errors for each category and misclassifications (due to confusion between groups) by category (Campbell 2002, Jensen 2005).

The error matrix is used to evaluate the accuracy of the classification of remotely sensed data with reference to the number of classes classified. The columns of the matrix represent the ground reference data while the rows signify the classification of generated from the remotely sensed data. The total number of samples classified is shown in the column and row total while a grand total appears in the diagonal corner of these sections. The intersection of rows and columns and rows summarize the number of samples (i.e. pixels, clusters of pixels or polygons) given to a particular class relative to the actual category that is defined in the field. The diagonal of the matrix summarizes those pixels or polygons that were classified correctly. All other entries denote errors as deviations from the wrong and or correct category thus an account of the amount of confusion between classes (Jensen 2005).

In addition to the error matrix, a summary accuracy table showing accuracy totals (producer's and user's accuracy) and other statistical information per classified unit is usually an output of accuracy assessment. Producer's accuracy is a statistical measure of omission of error and refers to the relative correctness of map, against input or training data i.e. the probability that a reference pixel is correctly classified because the producer is usually interested in how well a given area can be classified. User's accuracy refers to the probability that a pixel classified on a map, actually represents that category or the confidence with which a consumer can use the map. Kappa analysis is a discrete multivariate technique of use in accuracy assessment. It is a measure of agreement between the remotely sensed-derived classification map and the reference data as indicated by the major diagonal in the matrix and the chance agreement (Jensen 2005).

Campbell (2002) has however, noted a third possible method of assessing the accuracy of a map derived from remotely sensed information, which is done by comparing it to another map i.e. reference map, derived from a different source of information. This reference map is assumed to be accurate, hence forms the standard for comparison. This method of accuracy assessment could not be applied in this study due to the lack of suitable data required for this process.

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

CHAPTER 5. RESULTS

5.1 Results Overview

A total of 415 relevés were sampled from which 495 species, spread out across 78 families and 274 genera, were recorded in the entire study area.

Taxonomically, the area is principally dominated by the families Fabaceae and Poaceae, both of which recorded 33 genera, followed by Asteraceae with 17 genera and Amaranthaceae for which 11 genera were recorded. The families Cyperaceae and Apocynaceae were also well represented by 10 genera each, while Rubiaceae, Hyacinthaceae, Euphorbiaceae all recorded 8 genera each (Table 2). A full species list of all species encountered in the study area is given in Appendix III.

Table 2. A taxonomic account of plant species recorded in Omusati and Oshana Regions, indicating the number of genera per family and number species per genus.

Family (Number of Genera)	**Genus (Number of Species)**
Acanthaceae (7)	*Barleria* (1), *Blepharis* (5), *Justicia* (1), *Monechma* (2), *Petalidium* (1), *Ruellia* (1), *Justicia* (1)
Aizoaceae (1)	*Sesuvium* (1)
Alismataceae (1)	*Burnatia* (1)
Amaranthaceae (11)	*Achyranthes* (1), *Aerva* (1), *Alternanthera* (1), *Amaranthus* (1), *Celosia* (1), *Cyathula* (1), *Gomphrena* (1), *Kyphocarpa* (1), *Pupalia* (1), *Sericorema* (1), *Hermbstaedtia* (3)
Amaryllidaceae (3)	*Boophane* (1), *Crinum* (2), *Nerine* (1)
Anacardiaceae (3)	*Ozoroa* (1), *Rhus* (1), *Sclerocarya* (1)
Anthericaceae (1)	*Chlorophytum* (1)
Apocynaceae (10)	*Caralluma* (1), *Ceropegia* (2), *Fockea* (1), *Gomphocarpus* (1), *Larryleachia* (1), *Marsdenia* (1), *Orbeopsis* (1), *Orthanthera* (1), *Strophanthus* (1), *Tavaresia* (1)
Aponogetonaceae (1)	*Aponogeton* (1)
Arecaceae (1)	*Hyphaene* (1)

Family (Number of Genera)	**Genus (Number of Species)**
Asclepiadaceae (5)	*Hoodia* (1), *Microloma* (1), *Pergularia* (1), *Sarcostemma* (1), *Stapelia* (1)
Asparagaceae (1)	*Asparagus* (6)
Asphodelaceae (2)	*Aloe* (3), *Trachyandra* (2)
Asteraceae (17)	*Acanthospermum* (1), *Bidens* (1), *Calostephane* (1), *Dicoma* (2), *Emilia* (1), *Erlangea* (1), *Felicia* (1), *Geigeria* (4), *Helichrysum* (1), *Hirpicium* (3), *Kleinia* (1), *Leucosphaera* (1), *Litogyne* (1), *Pechuel-Loeschea* (1), *Pulicaria* (1), *Sphaeranthus* (1), *Vernonia* (1)
Bignoniaceae (3)	*Catophractes* (1), *Heliotropium* (5), *Rhigozum* (1)
Bombacaceae (1)	*Adansonia* (1)
Boraginaceae (1)	*Ehretia* (1)
Burseraceae (1)	*Commiphora* (5)
Capparaceae (3)	*Boscia* (1), *Cleome* (5), *Maerua* (1)
Caryophyllaceae (2)	*Pollichia* (1), *Polycarpaea* (1)
Celastraceae (2)	*Maytenus* (1), *Salacia* (1)
Chenopodiaceae (1)	*Chenopodium* (1)
Colchiacaceae (2)	*Camptorrhiza* (1), *Gloriosa* (1)
Combretaceae (2)	*Combretum* (7), *Terminalia* (2)
Commelinaceae (1)	*Commelina* (5)
Convolvulaceae (6)	*Evolvulus* (1), *Ipomoea* (9), *Jacquemontia* (1), *Merremia* (1), *Seddera* (1), *Xenostegia* (1)
Cucurbitaceae (6)	*Acanthosicyos* (1), *Citrullus* (1), *Corallocarpus* (1), *Dactyliandra* (1), *Zehneria* (1), *Momordica* (1),
Cyperaceae (10)	*Bulbostylis* (1), *Courtoisina* (1), *Cyperus* (10), *Eleocharis* (1), *Fimbristylis* (1), *Mariscus* (3), *Monandrus* (1), *Pycreus* (1), *Schoenoplectus* (3), *Kyllinga* (4)
Dichapetalaceae (1)	*Dichapetalum* (1)
Dracaenaceae (1)	*Sansevieria* (1)
Ebenaceae (2)	*Diospyros* (2), *Euclea* (1)

Family (Number of Genera)	Genus (Number of Species)
Eriospermaceae (1)	*Eriospermum* (3)
Euphorbiaceae (8)	*Acalypha* (1), *Chamaesyce* (1), *Croton* (1), *Erythrococca* (1), *Euphorbia* (3), *Phyllanthus* (5), *Schinziophyton* (1), *Tragia* (2)
Fabaceae (33)	*Acacia* (14), *Albizia* (1), *Aeschynomene* (1), *Baphia* (1), *Bauhinia* (1), *Burkea* (1), *Colophospermum* (1), *Crotalaria* (7), *Dichrostachys* (1), *Erythrophleum* (1), *Hypericum* (1), *Indigastrum* (2), *Indigofera* (11), *Lonchocarpus* (1), *Lotononis* (1), *Microcharis* (1), *Mundulea* (1), *Neorautanenia* (1), *Neptunia* (1), *Otoptera* (1), *Peltophorum* (1), *Pterocarpus* (1), *Requienia* (1), *Rhynchosia* (4), *Senna* (1), *Sesbania* (1), *Stylosanthes* (1), *Tephrosia* (4), *Trifolium* (1), *Vigna* (2), *Zornia* (2), *Chamaecrista* (2), *Elephantorrhiza* (3)
Flacourtiaceae (1)	*Dovyalis* (1)
Gentianaceae (1)	*Sebaea* (1)
Geraniaceae (1)	*Monsonia* (2)
Gisekiaceae (1)	*Gisekia* (1)
Hyacinthaceae (8)	*Drimia* (1), *Elytrophorus* (1), *Ledebouria* (1), *Lindneria* (1), *Ornithogalum* (1), *Scilla* (1), *Urginea* (1), *Dipcadi* (2)
Hydrocharitaceae (1)	*Ottelia* (1)
Iridaceae (2)	*Ferraria* (1), *Lapeirousia* (2)
Lamiaceae (6)	*Acrotome* (2), *Becium* (1), *Endostemon* (1), *Hemizygia* (1), *Ocimum* (1), *Clerodendrum* (1),
Loranthaceae (1)	*Tapinanthus* (2)
Lythraceae (2)	*Ammannia* (1), *Nesaea* (1)
Malvaceae (6)	*Abutilon* (1), *Gossypium* (1), *Heteropogon* (1), *Hibiscus* (9), *Pavonia* (2), *Sida* (2),
Marsileaceae (1)	*Marsilea* (1)
Menyanthaceae (1)	*Nymphoides* (1)

Family (Number of Genera)	**Genus (Number of Species)**
Mesembryanthemaceae (1)	*Phyllobolus* (1)
Molluginaceae (2)	*Limeum* (3), *Mollugo* (2)
Moraceae (1)	*Ficus* (2)
Myristicaceae (1)	*Pycnanthus* (1)
Nyctaginaceae (1)	*Commicarpus* (1)
Nymphaeaceae (1)	*Nymphaea* (1)
Ochnaceae (1)	*Ochna* (1)
Olacaceae (1)	*Ximenia* (2)
Ophioglossaceae (1)	*Ophioglossum* (1)
Orobanchaceae (2)	*Buchnera* (1), Cycnium (1)
Pedaliaceae (5)	*Dicerocaryum* (1), *Harpagophytum* (2), *Pterodiscus* (1), *Sesamothamnus* (1), *Sesamum* (3)
Periplocaceae (1)	*Raphionacme* (2)
Phytolaccaceae (1)	*Lophiocarpus* (1)
Poaceae (33)	*Anthephora* (2), *Aristida* (8), *Brachiaria* (4), *Cenchrus* (1), *Chloris* (1), *Cynodon* (1), *Dactyloctenium* (1), *Digitaria* (3), *Echinochloa* (3), *Enneapogon* (2), *Eragrostis* (13), *Leptochloa* (1), *Megaloprotachne* (1), *Melinis* (2), *Microchloa* (1), *Monelytrum* (1), *Odyssea* (1), *Oryzidium* (1), *Panicum* (4), *Pennisetum* (1), *Perotis* (2), *Pogonarthria* (1), *Schizachyrium* (1), *Schmidtia* (2), *Setaria* (3), *Sporobolus* (6), *Stipagrostis* (1), *Tragus* (2), *Tricholaena* (1), *Trichoneura* (1), *Triraphis* (1), *Urochloa* (1), *Willkommia* (2)
Polygalaceae (2)	*Polygala* (2), *Securidaca* (1)
Polygonaceae (1)	*Oxygonum* (1)
Portulacaceae (2)	*Portulaca* (3), *Talinum* (1)
Rhamnaceae (3)	*Berchemia* (1), *Helinus* (1), *Ziziphus* (1)
Rubiaceae (8)	*Gardenia* (1), *Kohautia* (3), *Pavetta* (1), *Psydrax* (1), *Spermacoce* (1), *Vangueria* (1), *Achyranthes* (1), *Kohautia*

Family (Number of Genera)	**Genus (Number of Species)**
Salvadoraceae (1)	*Salvadora* (1)
Scrophulariaceae (4)	*Anticharis* (1), *Aptosimum* (3), *Polycarena* (1), *Striga* (1)
Solanaceae (4)	*Datura* (2), *Lycium* (1), *Lycopersicon* (1), *Solanum* (5)
Sterculiaceae (4)	*Hermannia* (4), *Melhania* (1), *Pterygota* (1), *Waltheria* (1)
Tecophilaeaceae (1)	*Walleria* (1)
Tiliaceae (3)	*Corchorus* (1), *Grewia* (5), *Triumfetta* (1)
Vahliaceae (1)	*Vahlia* (1)
Velloziaceae (1)	*Xerophyta* (1)
Verbenaceae (1)	*Lantana* (1)
Violaceae (1)	*Hybanthus* (1)
Vitaceae (1)	*Cyphostemma* (2)
Zygophyllaceae (1)	*Tribulus* (2)

The species richness in the study area is boosted by the herbaceous component of the grass layer which constitutes 68% of the species while grasses and the woody component each contribute 16% to the overall species richness (Figure 10). However, the average cover for herbs was often too low to significantly define community types.

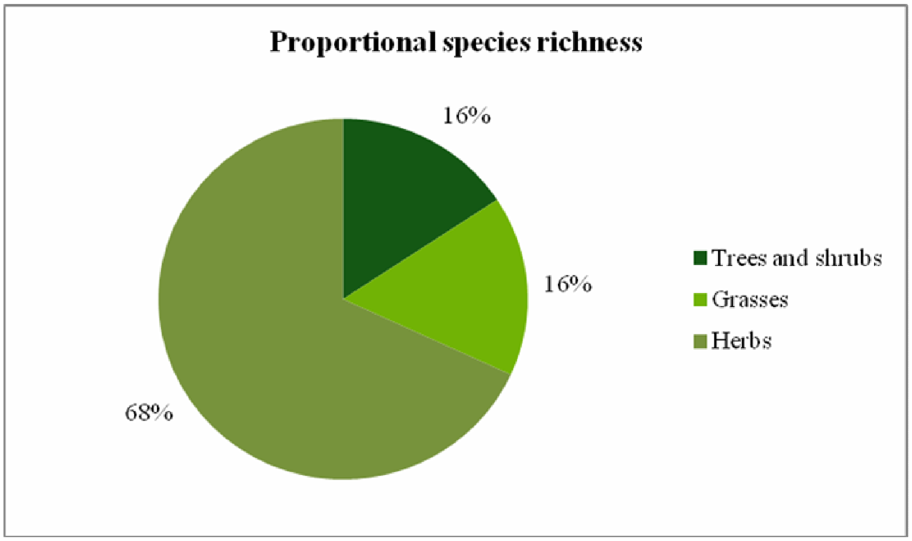


Figure 10. Pie chart showing the proportional contribution of each defined layer of vegetation to the species richness of Omusati and Oshana Regions.

Classification of floristic data yielded five vegetation alliances, ten associations and nine sub-associations. These vegetation units were described based on their species composition and distribution and mapped with the aid of satellite imagery. Detailed descriptions of the units are given in section 5.2. The Braun-Blanquet phytosociological table is shown in Appendix IV while the vegetation map produced for these units is to be seen in Appendix V. Pie charts showing the average percentage cover per defined layer of vegetation as well as photographic examples for the different associations described in this study are presented in Figures 16-33.

Phytosociological analysis of the data revealed soil types to be an influential environmental factor of vegetation in Omusati and Oshana regions, as a soil moisture gradient was inferred (Figure 11). This gradient is strongly evident on the first axis, where relevés (and associated species) typical of water-logged soils are found on the hydric side of the gradient while relevés of dry sandy soils are on the xeric side of the gradient (Figure 11a). The percentage cover of the woody layer component, which generally increases as soils become drier and sandier, at both alliance and association level (Figures 12 and 13), also supports the soil types hypothesis. Woody plant establishment in the study area is likely influenced by the rooting depth of the soils which is shallow in the clayey sodic sands of wetlands (*oshanas*) as they are often void of topsoils; and moderately deep to deep in the sandy to loamy soils on higher terraces, where shrubland vegetation becomes established.

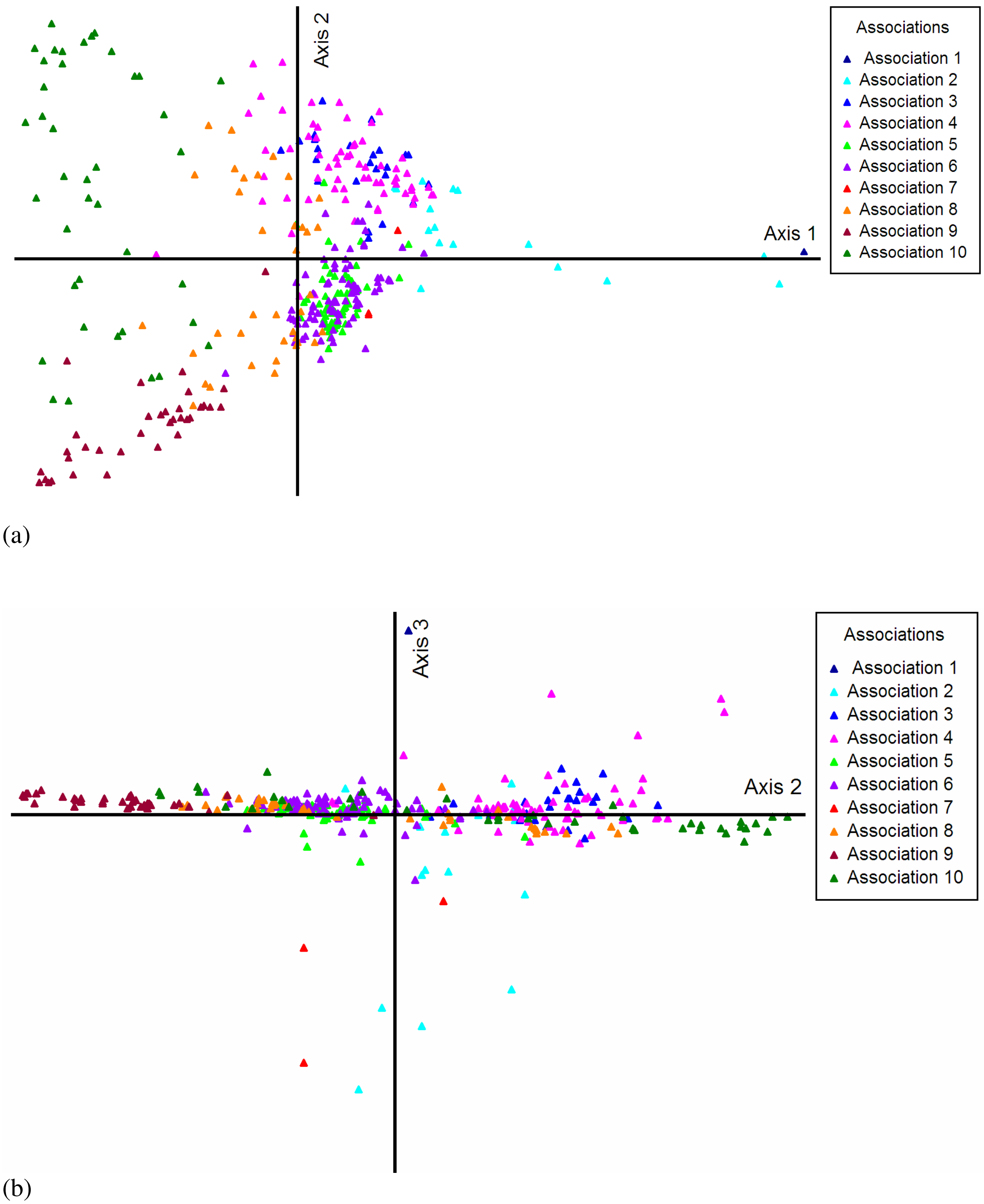


Figure 11. The Detrended Correspondence Analysis ordination diagram of 413 relevés surveyed between 2006 and 2009 in Omusati and Oshana Regions, central-northern Namibia.

Further vegetation data analysis at alliance level has shown that all the vegetation properties assessed in this study per defined layer of vegetation (i.e. percentage vegetation cover and species richness) have their peak in the transitional vegetation type *Colophospermum mopane - Terminalia prunioides* shrublands, Alliance 4 (Figure 12). Evidence derived from the phytosociological table (Appendix IV), shows a mixture of species from and beyond the two adjacent vegetation types in this zone. Although the Kalahari vegetation alliance *Terminalia sericea - Combretum* spp. typically recorded the highest species richness (29 species) on average, the two fringe vegetation alliances *Hyphaene petersiana - Acacia arenaria* shrublands and *Colophospermum mopane – Terminalia prunioides* shrublands also recorded relatively high average number of species of 26 and 27, respectively (Figure 14). For the wetlands alliance however, parameters may have been inaccurately estimated as only a few relevés were surveyed.

The average percentage cover per vegetation stratum for the different plant community types or associations defined in this study is shown in Figure 13. Generally trees are scarce in the study area with the highest average cover recording a rather low value of less than 4 %. This means that the structural composition of the area is limited to shrublands or bushlands, plains and grasslands. The highest average vegetation cover (80%) was recorded in *Colophospermum mopane - Terminalia sericea* shrublands association (Association 9) owing to the highest shrub cover record (30%) and a second highest cover (46%) in the herbaceous layer of this group. The *Eragrostis rotifer - Eragrostis cilianensis oshanas* association (Association 2) recorded the highest average percentage cover for the grass layer as it is structurally a grassland and is nearly exclusively herbaceous (Figure 13).

There was little difference in the species richness at both alliance and association level with Alliance 5 and Association 3 recording the highest species diversity at 29 and 31 species per 1000 m^2 respectively (Figures 14 and 15).

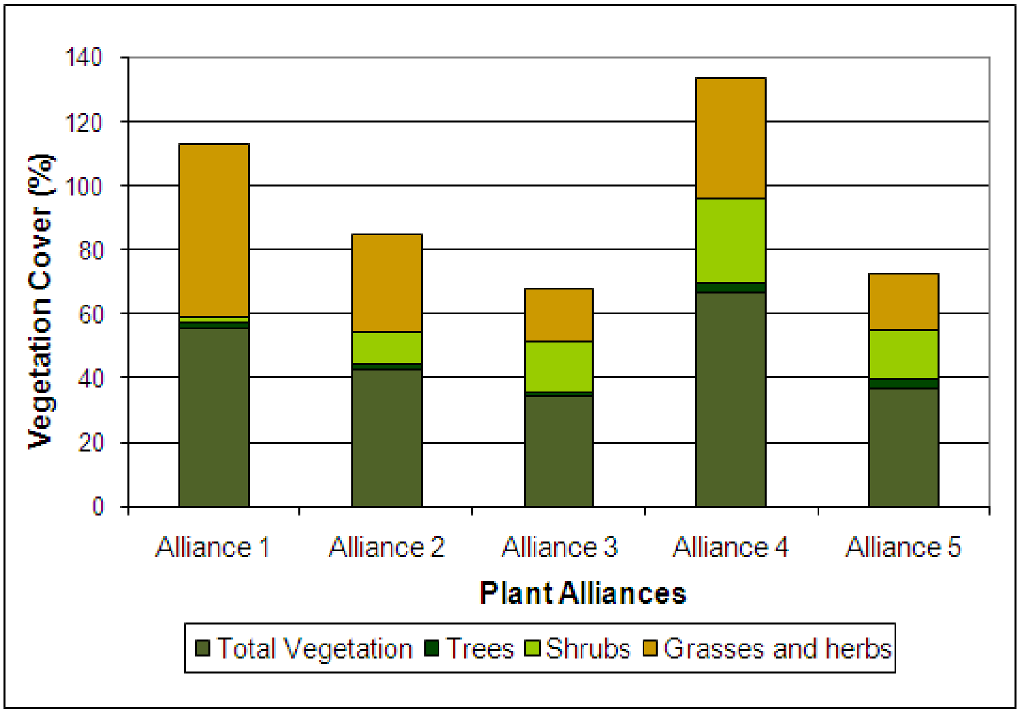


Figure 12. The average percentage cover of vegetation at alliance level per specified growth form for Omusati and Oshana Regions

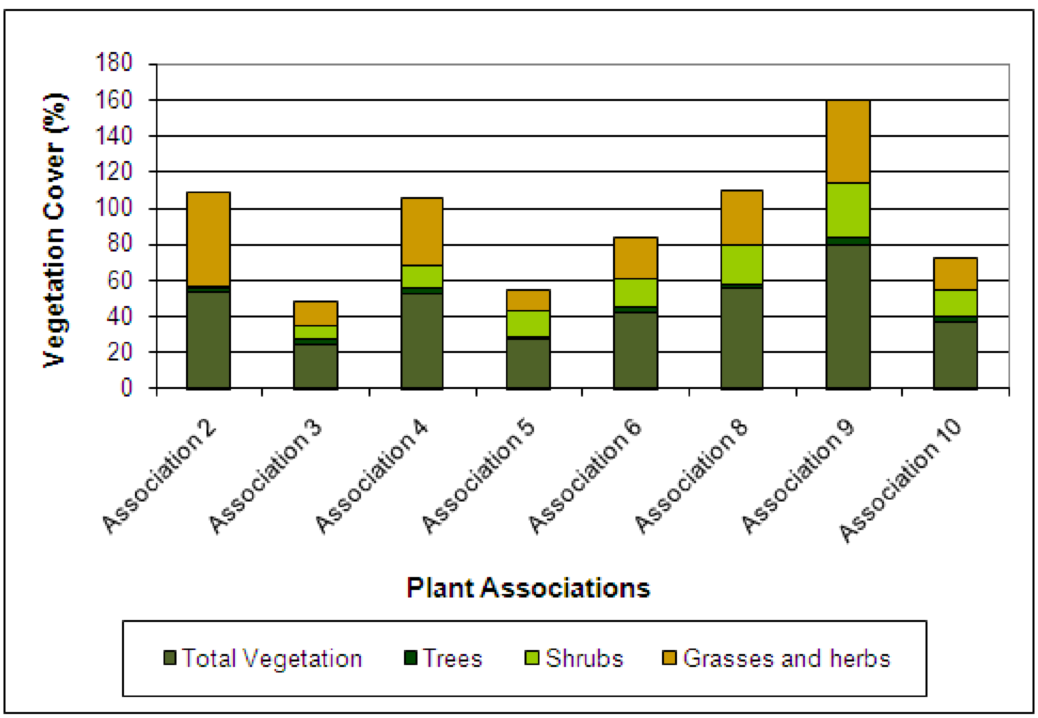


Figure 13. The average percentage cover of vegetation at association level per specified growth form for Omusati and Oshana Regions

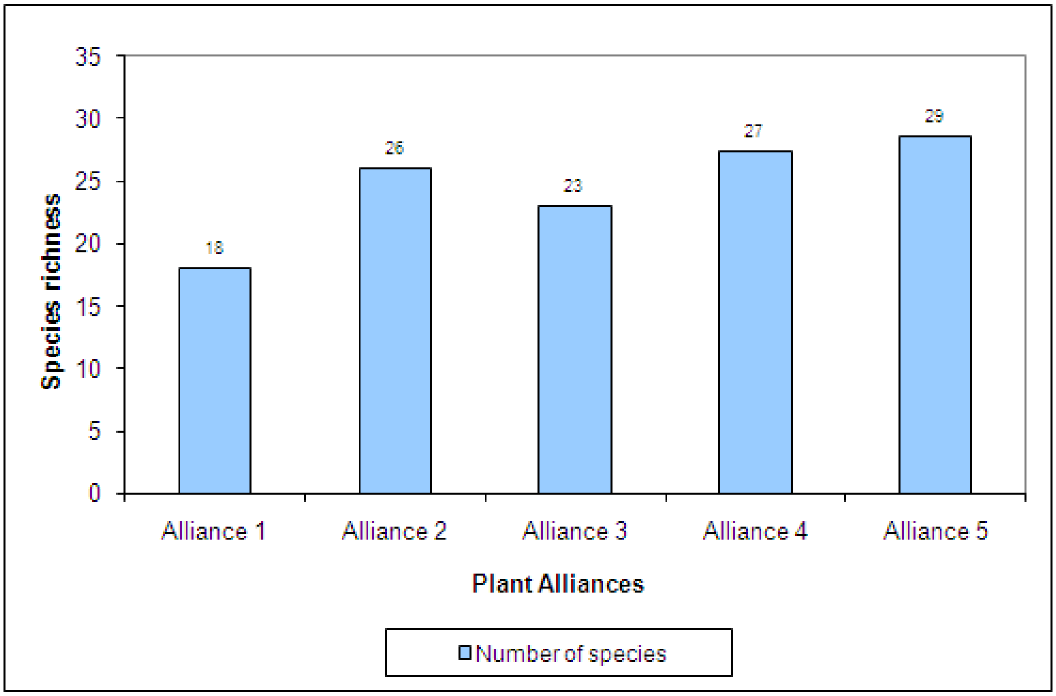


Figure 14. The average species richness per relevé (1000m^2) for plant alliances of Omusati and Oshana Regions

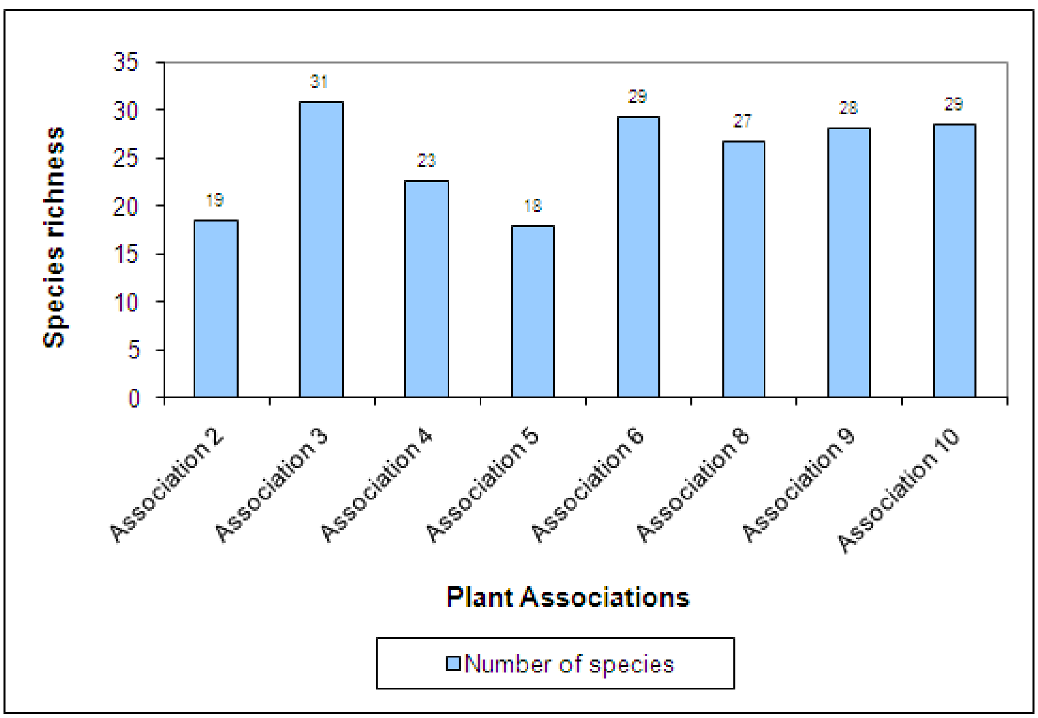


Figure 15. The average species richness per relevé (1000m^2) for plant associations of Omusati and Oshana Regions

5.2 Vegetation description

Classification of floristic data allowed for stratification of vegetation of the study area into five vegetation alliances, ten associations and nine sub-associations. These vegetation units were described based on their species composition and distribution and mapped with the aid of satellite imagery. The phytosociological table and percentage frequency synoptic table (Appendix IV) highlight diagnostic species of the various plant communities described in this study.

5.2.1 *Leptochloa fusca* - *Nymphaea nouchali* wetlands vegetation alliance

The wetlands vegetation structurally occurs as open grasslands with few scattered trees and/or shrubs, often *Acacia* species or *Hyphaene petersiana*. The vegetation class is characterized by the wetland species *Leptochloa fusca* and *Nymphaea nouchali*. It is found on the hydric end of the soil moisture gradient on clayey soil types, which are often seasonally waterlogged and inundated, allowing only species tolerant and/or typical of such habitats to grow here.

Soils here are dark grey coloured and fine grained, with varying but relatively high clay content. The soils generally have very little or no topsoil, while the subsoil is typically characterized by a 'hard pan' in the form of prismatic structures that are possibly bonded together by salt. These soils also expand and shrink as the wetlands dry up, due to the water-logging effect, allowing wind-blown sands to penetrate deeper horizons (Prof. Gröngröft, pers. comm.). Trees and shrubs are rare to absent in this vegetation type, probably due to unfavourable rooting depth of these soils.

5.2.1.1 *Nymphaea nouchali* - *Oryzidium barnabadii* pond association (Association 1)

This pond association could not be thoroughly described and mapped due to insufficient sample size (n = 1), which is related to the technical challenges involved in sampling wetland vegetation. Water in the ponds of the Cuvelai Drainage Basin can reach depths of upto 2-3 m at the peak of the rainy season and would require an aquatic vehicle for thorough sampling. This particular pond on the Ogongo observatory was estimated to be about 2 m deep. However, it is worth noting that the pond was characterized by a unique set of species. The species *Nymphaea nouchali* and *Leptochloa fusca* were found in association with *Oryzidium barnabadii*, *Schoenoplectus corymbosus* and *Neptunia oleracea* to form an exclusive herbaceous community type (Figure 16). Other species occurring in the pond include a deep-water tolerant grass species *Echinochloa stagnina* and sedge *Pycreus chrysanthus*.

Figure 16. Example *Nymphaea nouchali* - *Oryzidium barnabadii* pond association

5.2.1.2 *Eragrostis rotifer* - *Eragrostis cilianensis* oshanas association (Association 2)

The association is formed on the widely distributed intersected network of water courses (*oshanas*) of the Cuvelai Delta. Strucurally, this community type occurs as open grasslands of variable widths and lengths of upto several kilometers, occasionally patched with trees and/or shrubs. It is typically characterized by a strong occurrence of water loving grasses *Eragrostis rotifer*, *E. cilianensis, Panicum trichonode*, *Brachiaria dura* and *Leptochloa fusca* and sedges e.g. *Pycreus chrysanthus* and *Cyperus procerus*.

It constitutes a fairly high (70%) perennial grass versus annual grass (14%) cover while shrubs of *Hyphaene petersiana* and some *Acacia* species e.g. *A. hebeclada* occur patchily in these open grasslands (Figure 17 - 18). The *Eragrostis rotifer - Eragrostis cilianensis* oshanas plant community type is therefore traditionally recognized as an important grazing resource as livestock are specifically herded in these habitats. Furthermore, the community type forms an important fishing zone for locals, and more so during flood-years when fish is seasonally abundant, whereas the micro-habitats in this community type are fundamental breeding grounds for water birds, locally known as *oonkwikwiti*.

This association was sub-divided into two sub-associations or sub-communities (shallow and deep oshanas) due to the unique set of species that are found at different depths during the rainy season.

Figure 17. Example of *Eragrostis rotifer* - *Eragrostis cilianensis* oshanas association

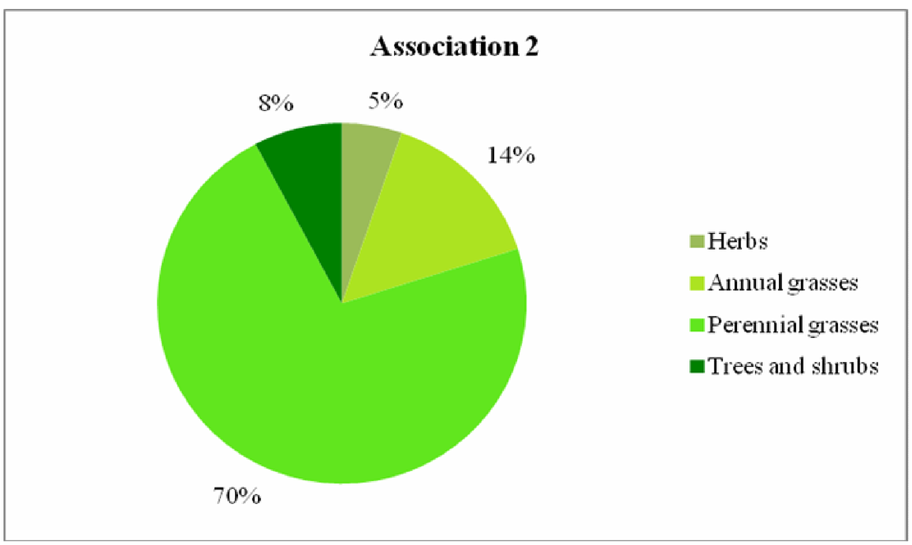


Figure 18. Pie chart showing the average percentage cover per defined layer of vegetation for association 2

5.2.1.2.1 *Panicum trichonode* - *Aponogeton junceus* deep oshanas sub-association

This sub-association is defined by several bulb forming species i.e. *Aponogeton junceus*, *Crinum rautanenii* and *Ledebouria cooperi* the hydrophyte *Marsilea* species as well as the common water lily *Nymphaea nouchali*, which is locally recognized as an excellent indicator of deep water. This community type recorded a relatively high average vegetation cover (63%) and is pre-dominated by the herbaceous component which recorded an average cover of 62% while the shrub layer only covered up to 1% on average. No trees were recorded in this community type.

5.2.1.2.2 *Eragrostis cilianensis* – *Willkommia sarmentosa* shallow oshanas sub-association

Occurring more as grassland with a few scattered trees and/or shrubs than a wetland, the vegetation type is typified by species such as *Schoenoplectus roylei*, *Asparagus cooperi*, *Elytrophorus globularis* and *Justicia exigua*. However, the occurrence of typical wetland species such as *Eragrostis rotifer*, *Eragrostis cilianensis*, *Willkommia sarmentosa*, and *Leptochloa fusca* suggest otherwise. *Colophospermum mopane* trees and shrubs and its associated grass species in this landscape *Eragrostis trichophora* were also recorded in this sub-association. The average vegetation cover recorded for various layers in this association is 3%, 3% and 44% for trees, shrubs and the herb layer respectively, totaling to an average vegetation cover of 46%.

5.2.2 *Hyphaene petersiana* - *Acacia arenaria* shrublands vegetation alliance

This vegetation type occurs as fringe vegetation between the seasonally waterlogged soils of the wetlands or *oshanas* and the relatively dry sand soils of the mopane shrublands. It also occurs as an open shrubland or as grassland with scattered stands of woody plants, particularly towards the south of the study area as the salt content increases. This vegetation has a very patchy distribution, particularly in the central part of study area where it is limited to the borders of *oshanas* where shallow, often leached white sands that collect to form little islands. This community type is defined by *Hyphaene petersiana*, *Acacia arenaria*, *Acacia hebeclada* and *Acacia luederitzii* shrubs as the main components of the woody layer. Also occurring notably in this vegetation is the bitterbush species *Pechuel-Loeschea leubnitziae* and two main grass species *Sporobolus ioclados* and *Cynodon dactylon*.

5.2.2.1 *Hyphaene petersiana* - *Acacia hebeclada* shrublands association (Association 3)

This community type is defined by *Hyphaene petersiana, Acacia hebeclada* subsp. *tristis* and *Acacia arenaria* as the main components of the woody layer, all of which have been observed to favour habitats on the shore of the *oshanas*. *A. arenaria* typically grows on shallow sand hills which are found to be bordering the *oshanas* particularly in central-northern Namibia (personal observation). Additionally, *H. petersiana* in central-northern Namibia, has been reported to show a habitat preference of *oshana* margins (i.e. areas with a shallower water table) rather than the sandy plains between the *oshanas* but it generally avoids the *oshana* itself (Strohbach *et al*. 2002).

The herb layer of this association is characterized by *Sporobolus coromandelianus*, *Aptosimum decumbens*, *Gomphrena celosioides*, and *Indigofera torulosa,* all typical species of shallow sandy plains of central-northern Namibia. The presence of species such as *Marsilea vera, Fimbristylis microcarya, Echinochloa colona* and *Nesaea* species, indicates moist conditions, or close proximity of wetlands. The highest average species richness of 31 species per 1000 m^2 for this study was noted in this transitional community type. Trees and shrubs (15%) and perennial grasses (14%) co-dominate this vegetation, while annual grasses cover about 8% on average (Figure 19 - 20). The community type is also used locally for livestock grazing as the soils are not suitable for crop production.

Figure 19. Example of *Hyphaene petersiana* - *Acacia hebeclada* shrublands association. Notice the bitter bush *Pechuel-Loeschea leubnitziae*, an indicator of land degradation.

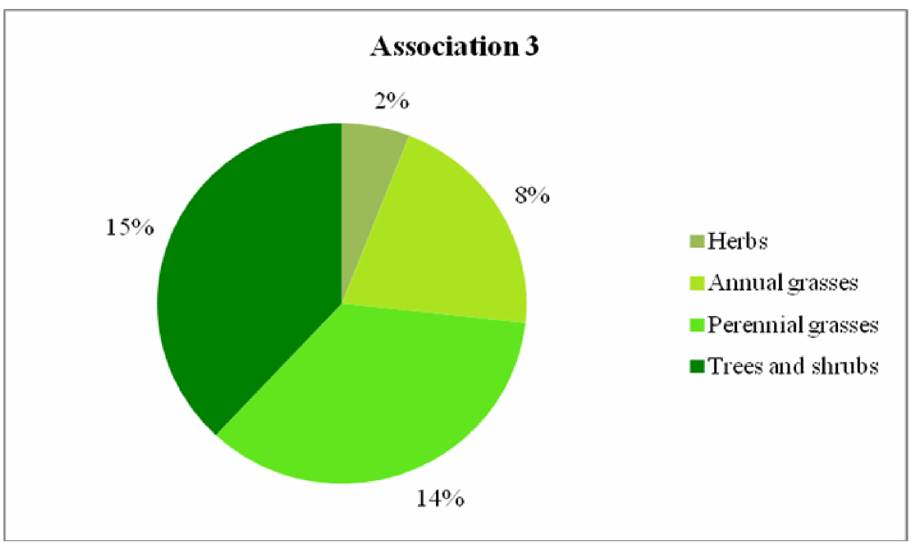


Figure 20. Pie chart showing the average percentage cover per defined layer of vegetation for association 3

5.2.2.2 *Odyssea paucinervis* - *Hirpicium gorterioides* saline grasslands association (Association 4)

This association mainly represents the saline grasslands of the southern part of central-northern Namibia. As with the *Hyphaene petersiana* - *Acacia hebeclada* shrublands association, the species *Hyphaene petersiana*, *Pechuel-Loeschea leubnitziae*, *Acacia arenaria*, *Acacia hebeclada* spp *tristis*, and *Acacia luederitzii* dominate the woody layer but tend to be scattered in the open grasslands of this vegetation. The grass layer is dominated by a variety of herbaceous species such as *Hirpicium gorterioides Eragrostis trichophora, Anthephora schinzii, Bulbostylis hispidula, Sporobolus ioclados* and *Monandrus squarrosa*, *Microchloa caffra* and *Cynodon dactylon*. Having a proportionally high perennial grass cover of 80%, the phanerophytes cover (30%) and annual grass cover (26%) is yet again out-competed in this community (Figure 21 – 22).

The strong occurrence of the halophytic grass species *Odyssea paucinervis*, which is an indicator of saline soils (Müller 2007), suggests poor soil quality for these grasslands due to high salt content, making soils harder, hence preventing woody plants establishment. Despite its low grazing value due to its low biomass production (Müller 2007), the dense basal cover of the tufted perennial grass species *Microchloa caffra* plays a vital role in reducing erosion as a protective cover of the soil as is that of the rhizomatous, stoloniferous, mat-forming perennial grass *Cynodon dactylon*. The economically important species *Harpagophytum zeyheri*, (due to its high medicinal properties) commonly known as Devil's claw is shared between this community type and the *Colophospermum mopane – Terminalia sericea* shrublands association, hence could be used here as an indicator of sandy soils, which get deposited by flowing waters of the Cuvelai Drainage System. Furthermore, the *Odyssea paucinervis - Hirpicium gorterioides* saline grasslands community forms part of the Ombuga flats, an area that was historically used for transhumance (Mendelssohn 2000), hence useful as a source of grazing resources for livestock.

The association has been sub-divided into two sub-associations, based on variation in land-use intensity.

Figure 21. Example of *Odyssea paucinervis* - *Hirpicium gorterioides* saline grasslands association

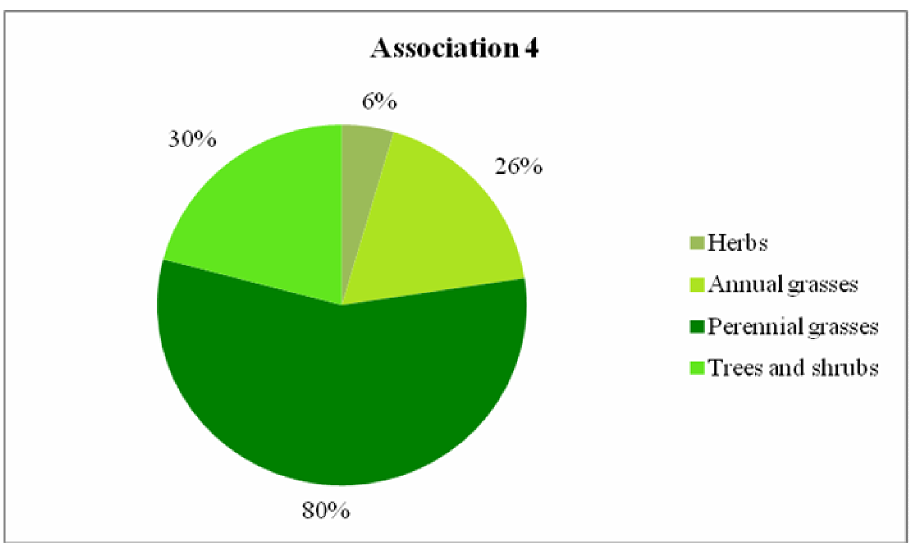


Figure 22. Pie chart showing the average percentage cover per defined layer of vegetation for association 4

5.2.2.2.1 *Sporobolus* sp. – *Limeum sulcatum* saline grassland sub-association

This sub-community is exclusively typified by herbaceous species *Kyllinga alba*, *Cleome rubella*, *Ophioglossum polyphyllum*, *Eriospermum rautanenii*, *Tephrosia dregeana* and *Emilia ambifaria*. Together with grasses such as *Sporobolus spicatus*, *Eragrostis trichophora*, *Willkommia sarmentosa*, *Anthephora schinzii*, *Odyssea paucinervis* and a scatter of shrubs, often belonging to the genus *Acacia*, they characterize an open saline grassland. An average cover of 7%, and 35% were recorded for the shrub and herb layers respectively, summing up to an overall average vegetation cover of 44%. No trees were recorded in this sub-association.

5.2.2.2.2 *Acacia luederitzii* – *Crotalaria pisicarpa* saline grassland sub-association

The second sub-association of the saline grasslands differs from the other by a unique set of differential species: - *Sclerocarya birrea*, *Microchloa caffra*, *Cynodon dactylon*, *Cyperus schinzii*, *Kyllinga alata*, *Trachyandra arvensis*, *Indigofera flavicans*, *Eragrostis viscosa*, *Dicoma tomentosa*, *Dicoma schinzii*, and *Orthanthera jasminiflora*. However the high abundance of *Sida cordifolia*, *Geigeria ornativa* and *Acanthospermum hispidum*, all of which are common indicators of degradation and/or disturbed areas also supports the land use intensities division. Similarly, a low tree (2%), and shrub (13%) cover, and a high grass layer cover (38%), further justifies the open grassland nature of this sub-association.

5.2.3 *Eragrostis trichophora* - *Colophospermum mopane* shrublands vegetation alliance

This is the largest vegetation alliance in this study with a sample size of 180 relevés (43% of the data) and is randomly distributed in the area. This is not surprising because the study area is situated in the mopane savanna vegetation zone of Namibia. Structurally, it occurs as a typical bushveld with a co-dominance of shrubs (15%) and grass layer (17%). Soils in this vegetation class comprise the loose grey Aeolian sands that are common in the study area, and typically comprise about 15-30 cm topsoil and a 'hard pan' in the lower horizon (Prof. Gröngröft, pers. comm.) which might prevent deeper penetration of soil by roots of woody plants. However, *C. mopane* is abundant here as it is well adapted to grow in these soils given its shallow rooting system.

This vegetation type is characterized by the strong co-occurrence of the economically and ecologically important tree species *Colophospermum mopane*, and the sub-climax perennial grass species *Eragrostis trichophora*, which recorded a 98% and 92% frequency rates respectively, at alliance level. It is divided into four associations and two sub-associations. As per ordination diagrams (Figures 11), this alliance is situated in the middle of the soil type gradient where it is found occurring on Aeolian sands with two transitional vegetation alliances on either side. Other constant species in this vegetation class include the grass species *Pogonarthria fleckii*, *Anthephora schinzii*, *Brachiaria xantholeuca*, *Willkommia sarmentosa* and herbs such as *Bulbostylis hispidula*, *Kohautia azurea*, *Mollugo cerviana* and *Portulaca hereroensis*.

5.2.3.1 *Eragrostis viscosa* - *Colophospermum mopane* wet shrublands association (Association 5)

The species *Eragrostis viscosa* and *Mariscus albomarginatus* are noted to be the only diagnostic species of this shrubland plant community. The strong co-occurrence of the moist-loving species *Eragrostis viscosa* and *Mariscus albomarginatus* as well as the occurrence of other water-loving species such as *Eragrostis rotifer*, coined the reference to this unit as a 'wet' mopane shrubland. This community type is further characterized by several constant species including *Anthephora schinzii, Bulbostylis hispidula, Colophospermum mopane, Eragrostis trichophora, Gisekia africana, Kohautia azurea, Mollugo cerviana, Pogonarthria fleckii, Portulaca hereroensis* and *Willkommia sarmentosa.*

The association is also often flooded during good rainy years, particularly at the peak of the rainy season, which often affects the development of the herbaceous component (Figure 23). Proportionally, the phanerophyte cover is higher than the grass layer, while perennial grasses dominate over annual grasses in this vegetation (Figures 24). Although the *Acacia nilotica* - *Colophospermum mopane* dry shrublands association is more sought-after for crop cultivation than its hydric sister community *Eragrostis viscosa* - *Colophospermum mopane* wet shrublands association, the latter is also at risk of replacement by crop fields as the demand for cropland in rural central-northern Namibia is ever on the rise with increasing population pressures.

This association was sub-divided into two sub-associations based on differences in land-use intensity, with *Pechuel-Loeschea leubnitziae* - *Geigeria acaulis* sub-association being a degraded variant of *Eragrostis viscosa* - *Colophospermum mopane* wet shrublands sub-association.

Figure 23. Example of *Eragrostis viscosa* - *Colophospermum mopane* wet shrublands association

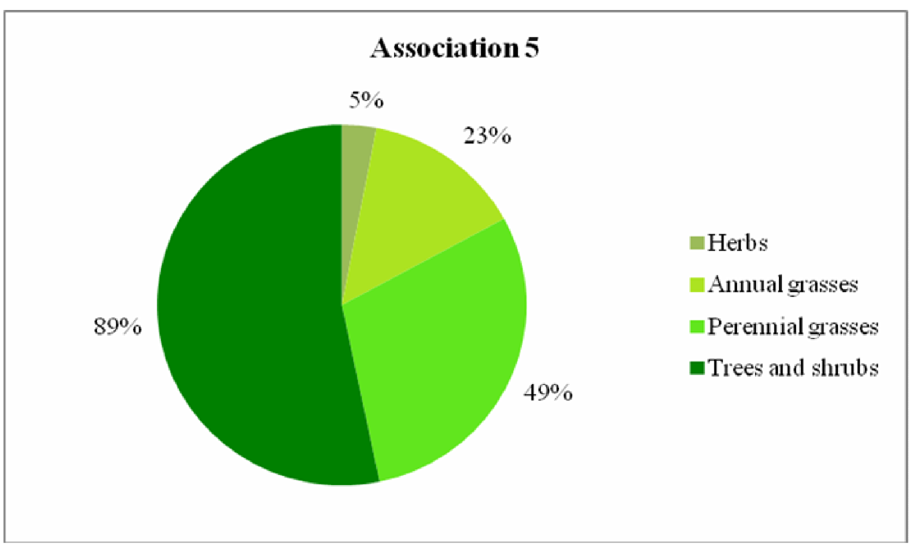


Figure 24. Pie chart showing the average percentage cover per defined layer of vegetation for association 5

5.2.3.1.1 *Pechuel-Loeschea leubnitziae* - *Geigeria acaulis* sub-association

Being a degraded variant of *Eragrostis viscosa* - *Colophospermum mopane* wet shrublands sub-association, this sub-community is defined by two land degradation indicator species *Pechuel-Loeschea leubnitziae* and *Geigeria acaulis*. This wet mopane sub-association is further characterized by species of moist habitats such as *Gomphrena celosioides*, *Asparagus virgatus* and *Vahlia capensis*, and species that are typical of plains such as *Acacia arenaria*, *Helichrysum candolleanum*, *Vernonia poskeana* and *Microchloa caffra*. This suggests that this habitat is a blend of substrates from nearby habitats, while the presence of species such as *Phyllanthus pentandrus* and *Kleinia longiflora* is an indication of sandy soils. Trees are rare (1%) in this community type, but the shrub layer was recorded to have an average vegetation cover of about 17% while a 15% was recorded for the herb layer.

5.2.3.1.2 *Eragrostis viscosa* - *Colophospermum mopane* wet shrublands sub-association

This second sub-association is defined by the relative absence of the species that define the first association, henceforth lacking any exclusive, selective and preferential fidelity species. Initially thought to be a land-use related problem, further investigations revealed that the division between the two sub-associations is derived from annual variability, as explained by the wet/dry year concept (see section 1.6.4). Nearly 50% of the relevés in this unit have been sampled in 2007, which was generally a dry year (Figure 36), while only 25% of relevés were sampled in the same year in the previous sub-association. The shrub layer recorded an average cover of 13%, and the herb layer 7%, giving an average vegetation cover of 21%.

5.2.3.2 *Acacia nilotica - Colophospermum mopane* dry shrublands association (Association 6)

The diagnostic species *Acacia fleckii, Acacia nilotica*, *Commiphora glandulosa* and *Colophospermum mopane* form the main component of the woody layer in this association. These are complemented in the herbal layer by a rich array of diagnostic grass species *Chloris virgata*, *Aristida rhiniochloa*, *Aristida stipoides*, *Urochloa brachyura*, *Sporobolus ioclados*, *Enneapogon cenchroides*, *Pogonarthria fleckii*, *Stipagrostis uniplumis*, *Dactyloctenium aegyptium*, *Tragus racemosus* and diagnostic herbs species *Acalypha segetalis, Aloe esculenta, Commelina benghalensis, Portulaca hereroensis, Corchorus tridens, Crotalaria pisicarpa, Sesuvium sesuvioides*, *Limeum myosotis*, *Hibiscus sidiformis, Indigofera charlieriana, Ipomoea coptica* and *Achyranthes aspera* var. *aspera* as well as sedges such as *Monandrus squarrosus* and *Cyperus fulgens*.

Colophospermum mopane recorded a 100% frequency with the highest average cover of up to 60%. Although the annual grasses *Brachiaria xantholeuca* and the indicator of dry and/or seasonally waterlogged soils *Anthephora schinzii* occur throughout the *Colophospermum mopane* - *Eragrostis trichophora* shrublands vegetation alliance, their abundance is highest in this association. A fairly well balanced trees & shrubs (41%), perennial grass (35%) and annual grass cover (30%) ratio is recorded for this shrubland vegetation (Figure 26). An indicator of calcrete, the annual grass species *Enneapogon cenchroides* strongly occurs in this community as it is seen growing selectively on higher terraces (*iituntu*) in this landscape (Figure 25). The dark loamy soils of this community type form first priority for crop field establishment as they are locally known for high fertility and nutrient content.

Interestingly however, a relatively strong occurrence of moist loving species such as *Eragrostis rotifer*, *E. cilianensis*, *Leptochloa fusca* & *Commelina subulata* could be clearly noted. This is due to the small depressions that form in between the Mopane shrublands within this vegetation type, where water temporarily collects, supporting the establishment of these species. These depressions are locally known and recognized as ‘olutha’, an indigenous land unit that has been reported and mapped by Verlinden & Dayot (2005).

Two sub-communities are recognized within this association based purely on species composition and distribution at that level.

Figure 25. Example of *Acacia nilotica* - *Colophospermum mopane* dry shrublands community type in better (above) and poor (below) states.

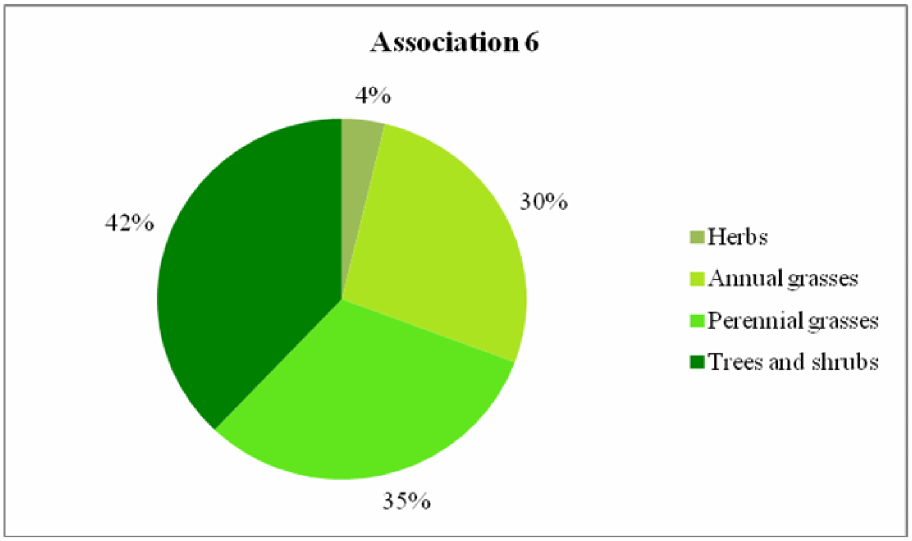


Figure 26. Pie chart showing the average percentage cover per defined layer of vegetation for association 6

5.2.3.2.1 *Enneapogon cenchroides* - *Colophospermum mopane* dry shrublands sub-association

Being a characteristic species in this community type, *C. mopane* defines the woody layer in association with *Commiphora glandulosa* and *Acacia fleckii* and *Acacia nilotica.* This unit represents a well-drained mopane savanna as evident from the high abundance of the herb species *Hibiscus sidiformis*, *Corchorus tridens*, *Aloe esculenta* and *Commelina benghalensis* which tend to favour such habitats. Typifying grass species in the herbal layer include *Aristida rhiniochloa*, *Stipagrostis uniplumis* and the lime and/or calcrete indicator *Enneapogon cenchroides*. The total average vegetation cover for this sub-association was 36% where the shrub layer and the grass layer seem to co-dominate covering both with 17% while trees only recorded 3% cover on average.

5.2.3.2.2 *Sporobolus ioclados* - *Colophospermum mopane* dry shrublands sub-association

This community type also lacks diagnostic species and is therefore only differentiated by the absence of the set of species that typify the *Colophospermum mopane* - *Enneapogon cenchroides* shrublands sub-association. An average vegetation cover of 45% was recorded for this community type of which 25% comprised the grass layer, 16% for the shrub layer and 3% for the tree layer.

5.2.3.3 *Pennisetum glaucum* crop fields association (Association 7)

The *Pennisetum glaucum* crop fields (Figure 27) are not a natural vegetation type but rather anthropogenic vegetation, and are discussed here due to their prominent occurrence in the landscape resulting from extensive subsistence farming that is practiced in the communal areas of central-northern Namibia. This association is characterized by the staple crop *Pennisetum glaucum* (as well as other crops e.g. *Citrullus lanatus, Vigna species*), where it is found in association with species that are associated with disturbed sites such as *Cleome gynandra*, *Amaranthus thunbergii* and *Hermbstaedtia argenteiformis*.

The herbaceous species *C. gynandra* and *A. thunbergii* are usually not weeded out of the fields because they are locally used as edible leafy vegetables thus constituting an important component of the local diet. These are therefore intercropped in these fields among other indigenous species used for the same purpose such as *Corchorus tridens* and *Sesuvium sesuvioides*. Cropfields are carefully selected and established on the dark grey Aeolian sandy soils that support the mopane shrublands, especially the *Acacia nilotica* - *Colophospermum mopane* dry mopane shrublands, also evident from the similarity in species composition between these vegetation units. This practice poses a direct threat of transformation of mopane shrublands into cropland.

Figure 27. Example of *Pennisetum glaucum* crop fields association

5.2.4 *Terminalia prunioides* - *Colophospermum mopane* shrublands vegetation alliance

This vegetation type occurs as a transition between the deep Kalahari sand vegetation and the relatively shallow dark sands of the mopane savanna. As a result, it comprises species from and beyond adjacent vegetation types. Soils also appear to be a mixture of the deep Kalahari sands and the grey Aeolian sands but sand deposits are definitely deeper than in the mopane shrublands. Patches of calcrete-enriched soils have been encountered at some sites, as also indicated by species such as *Catophractes alexandri* and *Enneapogon cenchroides*. The vegetation structurally occurs as a bushveld but with more high shrubs (2-5m) than the common low shrubs (1-2m) of central north. Geographically, this vegetation type is found more abundantly south of Okahao Constituency where human settlements are fewer than in the densely populated central parts of the study area, where it forms part of the western Kalahari vegetation sensu Mendehlson *et al*. (2002).

This alliance of vegetation is defined by the diagnostic species *Terminalia prunioides*, *Asparagus nelsii* and *Mundulea sericea* and numerous preferential species such as *Colophospermum mopane*, *Eragrostis dinteri*, *Schmidtia kalihariensis*, *Commiphora glandulosa*, *Pechuel-Loeschea leubnitziae*, *Vernonia poskeana*, *Dicoma tomentosa*, *Acrotome inflata*, *Melinis repens* subsp. *grandiflora*, and *Kohautia aspera*. The set of differential species of the *Colophospermum mopane – Enneapogon cenchroides* community type i.e. *Enneapogon cenchroides*, *Acacia fleckii*, *Aristida rhiniochloa*, *Stipagrostis uniplumis* and *Pogonarthria fleckii*, also occur here strongly, which supports the idea that there is some similarity between these two habitats. The vegetation type was divided into two associations.

5.2.4.1 *Aristida adscensionis - Colophospermum mopane* shrublands association (Association 8)

This is a relatively loose group, with no distinct diagnostic species, although *Aristida adscensionis* and *Zornia milneana* were found to be selectively favouring this habitat. This vegetation type also portrays a fair cover balance between phanerophytes (22%), perennial grasses (18%) and annual grasses (22%) (Figure 28 - 29). Spatially, the vegetation is more prominent in the south-central to south western parts of the study site (Figure 34) where fewer settelements have been observed and is currently used for livestock grazing purposes.

The community is associated with the ecotone between the deep Kalahari sand vegetation and the relatively shallow sandy soils of mopane shrublands vegetation forming a mosaic. The *Aristida adscensionis* - *Colophospermum mopane* shrublands community behaves more like a transition zone or habitat boundary for species that are typical of adjacent vegetation types. Species such as *Eragrostis viscosa*, *Brachiaria xantholeuca, Anthephora schinzii*, *Monandrus squarrosus*, *Ipomoea coptica*, *Cyperus schinzii, Sesuvium sesuvioides,* and *Kohautia azurea* of preceding communities tend to find their niche limitations in this zone. Similarly, the species *Catophractes alexandri, Rhigozum brevispinosum*, *Grewia flava*, *Eragrostis dinteri* and *Calostephane marlothiana* of the adjacent *Terminalia sericea* - *Colophospermum mopane* shrublands community display the same pattern from the opposite direction (Appendix IV).

Figure 28. Example of *Aristida adscensionis* - *Colophospermum mopane* shrublands association

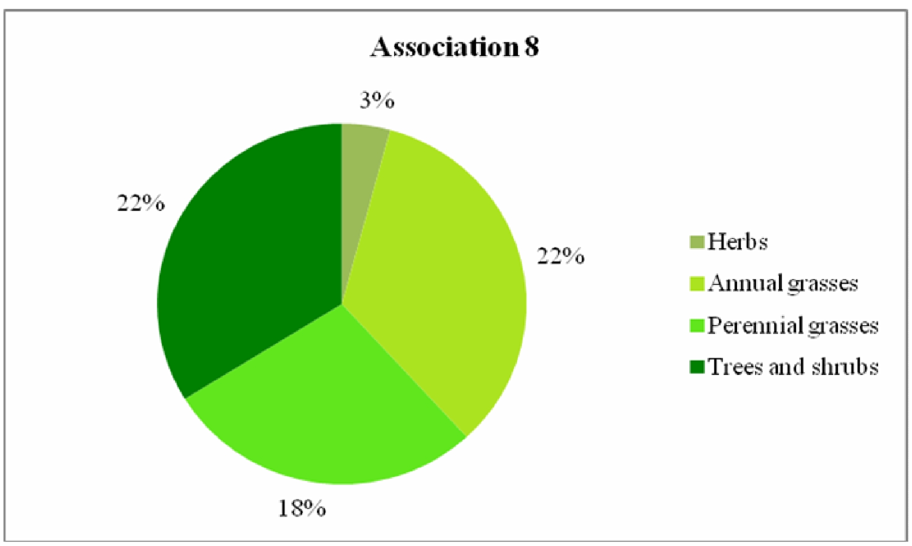


Figure 29. Pie chart showing the average percentage cover per defined layer of vegetation for association 8

5.2.4.2 *Terminalia sericea* - *Colophospermum mopane* shrublands association (Association 9)

This community type is the true Kalahari – Mopane mosaic, and recorded the highest average vegetation cover of 80% in the study area, as well as the highest cover for trees (4%) and shrubs 30% whereas the grass layer recored an average value 46% for both grasses and herbs (Figure 12). Proportionally, a good cover of trees and shrubs (28%) is retained while annual grasses (65%) dominate over perennial grasses (21%), indicating poor veld conditions and probable sensitivity of this community type to over-utilization (Figure 30 - 31). The site is currently used for communal livestock grazing. Few settlements and no signs of crop cultivation were observed on site during the data collection phase.

The woody layer of this association is well defined by numerous selective species e.g. *Catophractes alexandri, Terminalia prunioides, Elephantorrhiza schinziana, Acacia mellifera* subsp. *detinens*, *Dichrostachys cinerea, Albizia anthelmintica, Acacia senegal, Rhigozum brevispinosum, Commiphora africana, Grewia flava, Acacia ataxacantha* and *Ozoroa schinzii*. Preferential woody species occurring here include *Acacia luederitzii*, *Terminalia sericea* and *Acacia erioloba*. The herb layer also has numerous distinct selective species of *Clerodendrum ternatum*, *Sesamum triphyllum*, *Eragrostis dinteri*, *Heliotropium zeylanicum*, *Calostephane marlothiana*, *Anthephora pubescens*, *Trichoneura grandiglumis*, *Otoptera burchelii*, *Harpagophytum procumbens* and preferential species e.g. *Melinis repens* spp. *grandiflora*, *Acanthosicyos naudinianus*, *Tephrosia purpurea*, *Xenostegia tridentata*, *Indigofera daleoides*, *Hemizygia bracteosa and Rhynchosia venulosa* most of which are typical sand loving species.

Figure 30. Example of *Terminalia sericea* - *Colophospermum mopane* shrublands association

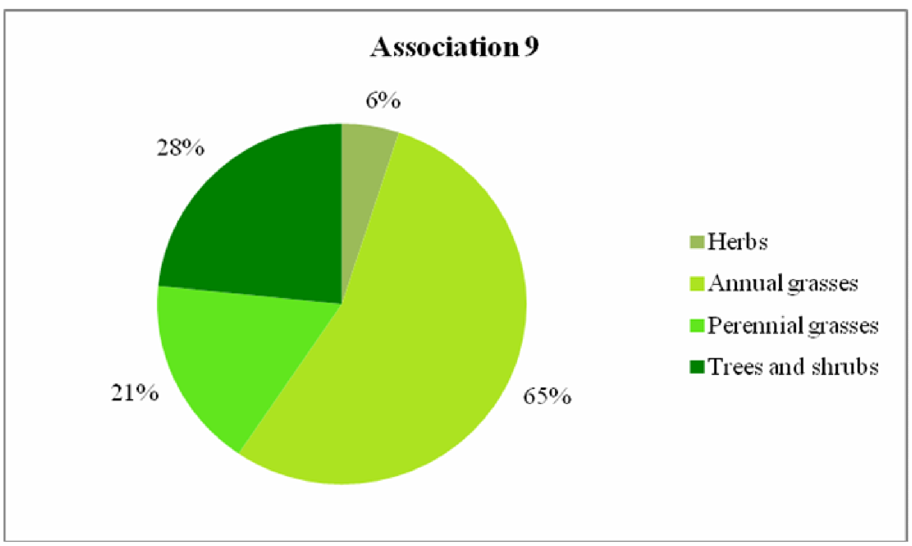


Figure 31. Pie chart showing the average percentage cover per defined layer of vegetation for association 9

5.2.5 *Combretum collinum* - *Terminalia sericea* shrublands vegetation alliance

The vegetation alliance is typified by deep Kalahari sand species and structurally occurs as open shrublands. Soils here are those of deep red and brown Kalahari sands origin with low nutrient content and little water retaining capacity. The vegetation unit is therefore positioned on the dry end of the soil moisture gradient because the sand acts as a sponge, which sucks the water into deeper horizons, leaving soil surfaces generally dry. These soils have relatively deep rooting depths, probably the deepest in this area thus trees and shrubs can tap water from the deep soil horizons, hence a relatively high woody layer ratio (Figure 12). At alliance level, the highest number of species of 29 species per 1000 m^2 was encountered in this vegetation group.

Only one association could be recognized in this alliance, which was further sub-divided into two sub-associations in relation to land-use intensity.

5.2.5.1 *Combretum collinum* - *Terminalia sericea* shrublands association (Association 10)

The *Combretum collinum* - *Terminalia sericea* shrublands community displays an open shrubland structure, with a well-develped woody layer covering about 23% on average and a co-dominance from perennial grass and annual grass cover of 15% each (Figure 32). The woody layer of this association is characterized by diagnostic species such as the phanerophytes *Vangueria infausta*, *Commiphora angolensis* and *Grewia flavescens* while the herbaceous layer is defined by typical deep sand species such as *Orthanthera jasminiflora*, *Dicerocaryum eriocarpum*, *Ipomoea hackeliana*, *Eragrostis trichophora*, *Phyllanthus omahekensis*, *Sida cordifolia, Tribulus zeyheri*, *Hermannia modesta, Indigofera charlieriana* and *Indigofera flavicans*, all of which have diagnostic character for this vegetation unit. The woody species *Terminalia sericea* should ideally be depict preferential fidelity patterns but its vigour is affected by its high utilization potential as a source of wood in the study area.

Despite their occurrence in other community types, the species *Pechuel-Loeschea leubnitziae* and *Schmidtia kalihariensis*, are recognized as diagnostic in this community and occur here in relative high abundance. This is yet another indication of land degradation in this ecosystem as high grazing value perennial grasses such as *Schmidtia pappophroides* is replaced by its inferior annual *S. kalihariensis* while the woody species are taken over by species of poor palatability such as *Pechuel-Loeschea leubnitziae*. Constant species in this association include *Bulbostylis hispidula, Combretum collinum, Eragrostis lehmanniana, Gisekia africana, Limeum myosotis* and *Tephrosia lupinifolia*.

The *Combretum collinum* - *Terminalia sericea* shrublands community type has a rather patchy distribution in the study area hence only occurs on sites where the sand deposits are deep enough to support such vegetation. Moreover, this community type seems to be more sensitive to utilization (particularly overgrazing) and external influential factors such as rainfall relative to other associations. The herbaceous layer was observed to respond strongly to rainfall with very low average cover to nearly absent during dry years (personal observation) as demonstrated in Figure 33. The soils are commonly known to be of poor quality for cropping hence the community type is more functional as a grazing resource and used for silvi-culture.

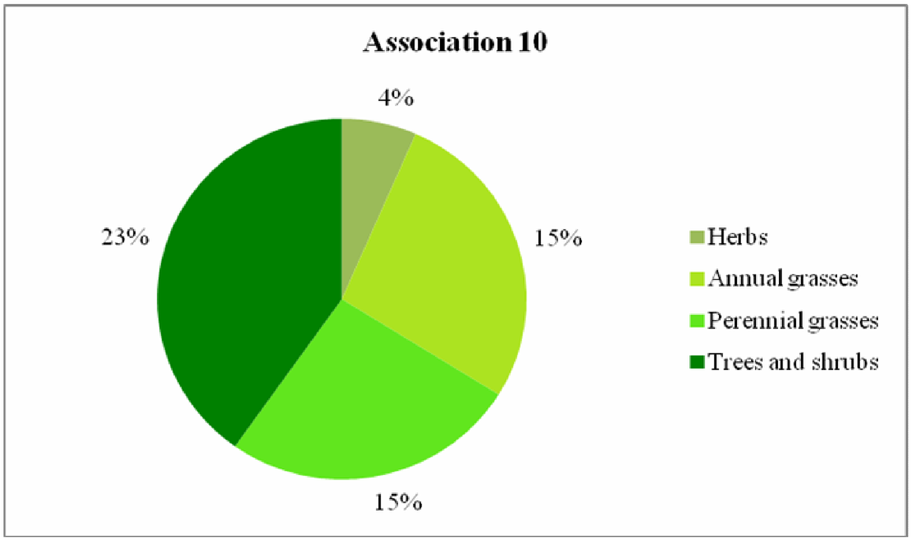


Figure 32. Pie chart showing the average percentage cover per defined layer of vegetation for association 10

Figure 33. Example of *Combretum collinum – Terminalia sericea* community type in better (above) and poor (below) states.

5.2.5.1.1 *Crotalaria podocarpa* - *Combretum collinum* shrublands sub-association

The set of diagnostic species found in this community type is entirely herbaceous and comprises species such as *Sesamum pedalioides*, *Hibiscus rhabdotospermus*, *Hibiscus calyphyllus*, *Tephrosia burchellii*, *Ipomoea hochstetteri*, *Crotalaria podocarpa*, *Tribulus zeyheri* and *Hermannia* species. Other species that are not exclusive to this sub-community but occurring here with fairly high abundances include *Commiphora angolensis*, *Bidens biternata*, *Acacia nilotica*, *Acacia erioloba*, *Hyphaene petersiana*, *Stipagrostis uniplumis* and *Crotalaria pisicarpa.* The woody layer has recorded an with average cover of 11% for shrubs and a usually low tree cover of only 2%, while the herb layer covers about 20% on average.

5.2.5.1.2 *Eragrostis lehmanniana* - *Combretum collinum* shrublands sub-association

The woody layer is well defined by the typical Kalahari sand species *Combretum collinum*, *Terminalia sericea*, *Commiphora angolensis*, *Acacia erioloba* and *Lycium eenii* while the herbal layer is classified by *Megaloprotachne albescens*, *Spermacoce senensis*, *Zornia glochidiata*, *Crotalaria platysepala*, *Gomphocarpus tomentosus* and *Cyphostemma congestum* all of which are diagnostic species for this sub-association. The silverbush *Mundulea sericea*, *Sida cordifolia* (indicator of degradation), *Dicoma schinzii* and *Eragrostis lehmanniana* occur in other communities but have shown high vigour here, hence preferential to this particular community type. A co-dominance of the shrub and herb layers is observed with both covering 16% on average while the tree layer remains at a low average cover of 3%.

5.3 Vegetation mapping

The accuracy assessment scores of the vegetation map produced in this study are represented in Table 3, while the confusion matrix is displayed in Table 4. A high overall accuracy of 81.94% and Kappa statistic of 0.77 for the vegetation map is boasted for this study although individual accuracies of several units remains variable (Table 3).

In the confusion matrix (Table 4), units that were misclassified and confused with others are revealed. For example, the *Colophospermum mopane - Eragrostis viscosa* shrublands sub-association was often confused with *Colophospermum mopane – Sporobolus ioclados shrublands* sub-association while the *Pechuel-Loeschea – Geigeria ornativa* shrublands sub-association, *Combretum collinum – Eragrostis lehmanniana* shrublands sub-association (degraded) and *Sporobolus sp. – Limeum sulcatum grasslands* sub-association were often confused with crop fields. The two degraded units *Acacia luederitzii – Crotalaria pisicarpa* grasslands sub-association (degraded) and *Combretum collinum – Eragrostis lehmanniana* shrublands sub-association (degraded) were also confused with each other. Confusion of the various units with each other is a result of similarity in spectral reflectances of the surfaces in these units. In many instances, the confusion in this study can be attributed to degradation of the different community types.

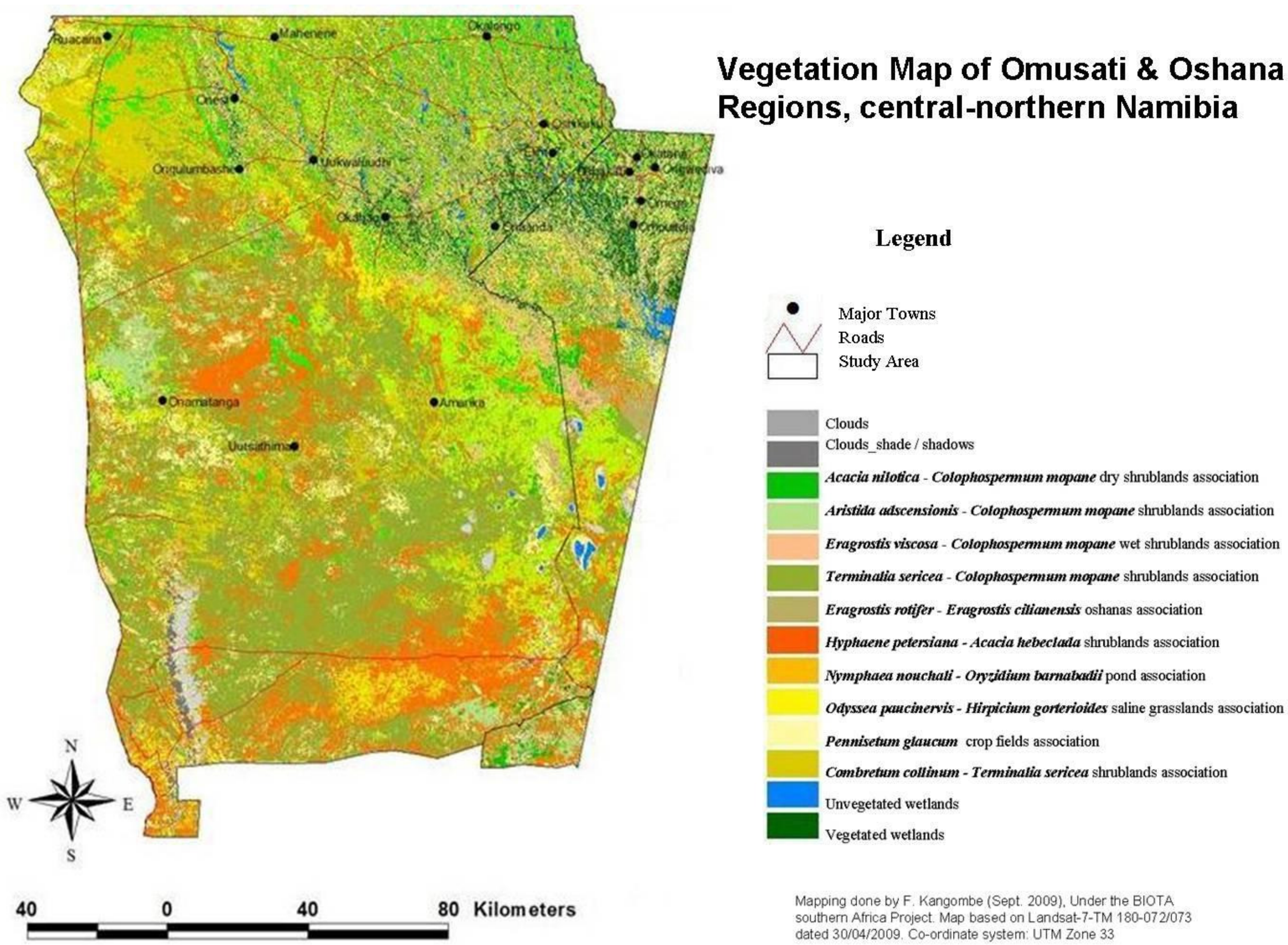


Figure 34. The vegetation map of Omusati and Oshana Regions, showing the different vegetation plant communities of the study area

Table 3. The accuracy assessment scores of the mapped community types of Omusati and Oshana Regions

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Combretum collinum – Crotalaria podocarpa shrublands sub-association	38	34	22	57.89%	64.71%
Combretum collinum – Eragrostis lehmanniana shrublands sub-association (Degraded)	57	101	15	26.32%	14.85%
Panicum trichonode - Aponogeton junceus deep oshanas sub-association	20	21	12	60.00%	57.14%
Eragrostis cilianensis – Willkommia sarmentosa shallow oshanas sub-association	30	42	6	20.00%	14.29%
Pechuel-Loeschea – Geigeria ornativa shrublands sub-association	56	71	3	5.36%	4.23%
Colophospermum mopane - Eragrostis viscosa shrublands sub-association	91	136	54	59.34%	39.71%
Sporobolus sp. – Limeum sulcatum grasslands sub-association	35	118	14	40.00%	11.86%
Acacia luederitzii – Crotalaria pisicarpa grasslands sub-association (Degraded)	92	124	90	97.83%	72.58%
Colophospermum mopane – Enneapogon cenchroides shrublands sub-association	78	198	67	85.90%	33.84%
Nymphaea nouchali - Oryzidium barnabadii pond association	9	3	3	33.33%	100.00%
Colophospermum mopane – Sporobolus ioclados shrublands sub-association	67	39	5	7.46%	12.82%
Colophospermum mopane - Aristida adscensionis shrublands association	53	56	26	49.06%	46.43%
Clouds	310	310	310	100.00%	100.00%
Clouds_shadow	37	37	37	100.00%	100.00%
Vegetated wetlands	138	138	138	100.00%	100.00%
Un-vegetated wetlands	1387	1387	1387	100.00%	100.00%
Pennisetum glaucum cropfields	1001	771	748	74.73%	97.02%
Colophospermum mopane – Terminalia sericea shrublands association	177	88	85	48.02%	96.59%
Hyphaene petersiana - Acacia hebeclada shrublands association	39	41	22	56.41%	53.66%
				59.03%	
Totals	3715	3715	3044		
Overall Classification Accuracy = 81.94%					
Overall Kappa Statistics = 0.7715					

Table 4. Confusion matrix of the vegetation map derived from LandSat TM data of Omusati and Oshana Regions

Classified Data \ Reference Data	*Combretum collinum – Crotalaria podocarpa* shrublands sub-association	*Combretum collinum – Eragrostis lehmanniana* shrublands sub-association (Degr)	*Panicum trichonode - Aponogeton junceus* deep oshanas sub-association	*Eragrostis cilianensis – Willkommia sarmentosa* shallow oshanas sub-association	*Pechuel-Loeschea – Geigeria ornativa* shrublands sub-association	*Colophospermum mopane - Eragrostis viscosa* shrublands sub-association	*Sporobolus sp. – Limeum sulcatum* grasslands sub-association	*Acacia luederitzii – Crotalaria pisicarpa* grasslands sub-association (Degr)	*Colophospermum mopane – Enneapogon cenchroides* shrublands sub-association	*Oryzidium barnabadii - Schoenoplectus corymbosus* pond association	*Colophospermum mopane – Sporobolus ioclados* shrublands sub-association	*Colophospermum mopane - Aristida adscensionis* shrublands association	Clouds	Clouds_shadow	Vegetated wetlands	Un-vegetated wetlands	*Pennisetum glaucum* cropfields	*Colophospermum mopane – Terminalia sericea* shrublands association	*Hyphaene petersiana - Acacia hebeclada* shrublands association	**Row Total**
Classified Data																				
Combretum collinum – Crotalaria podocarpa shrublands sub-association	**22**	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	3	8	0	**34**
Combretum collinum – Eragrostis lehmanniana shrublands sub-association (Degraded)	0	**15**	0	0	0	0	0	2	0	0	0	0	0	0	0	0	84	0	0	**101**
Panicum trichonode - Aponogeton junceus deep oshanas sub-association	0	0	**12**	0	3	0	0	0	0	5	0	0	0	0	0	0	1	0	0	**21**
Eragrostis cilianensis – Willkommia sarmentosa shallow oshanas sub-association	6	1	6	**6**	2	0	5	0	0	0	10	1	0	0	0	0	5	0	0	**42**
Pechuel-Loeschea – Geigeria ornativa shrublands sub-association	3	0	0	5	**3**	0	0	0	2	0	0	0	0	0	0	0	25	24	9	**71**
Colophospermum mopane - Eragrostis viscosa shrublands sub-association	0	6	0	0	7	**54**	2	0	2	0	30	10	0	0	0	0	23	0	2	**136**
Sporobolus sp. – Limeum sulcatum grasslands sub-association	0	0	0	9	7	0	**14**	0	3	1	1	15	0	0	0	0	52	16	0	**118**

Acacia luederitzii – Crotalaria pisicarpa grasslands sub-association (Degraded)	0	25	0	7	0	1	1	**90**	0	0	0	0	0	0	0	0	0	0	0	**124**
Colophospermum mopane – Enneapogon cenchroides shrublands sub-association	4	0	0	0	27	10	13	0	**67**	0	21	1	0	0	0	0	27	28	0	**198**
Oryzidium barnabadii - Schoenoplectus corymbosus pond association	0	0	0	0	0	0	0	0	0	**3**	0	0	0	0	0	0	0	0	0	**3**
Colophospermum mopane – Sporobolus ioclados shrublands sub-association	0	1	0	1	0	20	0	0	4	0	**5**	0	0	0	0	0	8	0	0	**39**
Colophospermum mopane - Aristida adscensionis shrublands association	0	0	0	0	2	6	0	0	0	0	0	**26**	0	0	0	0	22	0	0	**56**
Clouds	0	0	0	0	0	0	0	0	0	0	0	0	**310**	0	0	0	0	0	0	**310**
Clouds_shadow	0	0	0	0	0	0	0	0	0	0	0	0	0	**37**	0	0	0	0	0	**37**
Vegetated wetlands	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**138**	0	0	0	0	**138**
Un-vegetated wetlands	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1387**	0	0	0	**1387**
Pennisetum glaucum cropfields	3	9	0	0	4	0	0	0	0	0	0	0	0	0	0	0	**748**	1	6	**771**
Colophospermum mopane – Terminalia sericea shrublands association	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**85**	0	**88**
Hyphaene petersiana - Acacia hebeclada shrublands association	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	2	15	**22**	**41**
Column Total	**38**	**57**	**20**	**30**	**56**	**91**	**35**	**92**	**78**	**9**	**67**	**53**	**310**	**37**	**138**	**1387**	**1001**	**177**	**39**	**3715**

5.4 Vegetation monitoring

Analysis of the four-year monitoring data has revealed trends and impacts of rainfall on vegetation in the study area (Figures 35-39). Generally, vegetation cover is lowest in 2007 and correspondingly, the mean annual rainfall is also lowest in 2007 (Figures 35 and 36 respectively). A higher perennial grass cover to annual grass trend is eminent (Figure 35) but an inverse 1:2 species richness ratio is noted for perennial to annual grasses respectively (Figure 37). The grass layer of the mopane shrublands in central-northern Namibia tends to respond strongly to rainfall. As an example, while 2007 was notably a bad rain year and 2009 an exceptionally good rain year (Figure 36), the herbaceous layer of the monitored plots was similarly low and fairly high respective to the rainfall trends (Figures 35, 38 and 39). Although herb species recorded the highest and more than twice as many mean number of species than other growth forms combined (Figure 37), their average cover was always lowest (Figure 35). This generally implies a low species diversity in this ecosystem with a few species that are dominant in terms of populations and/or size.

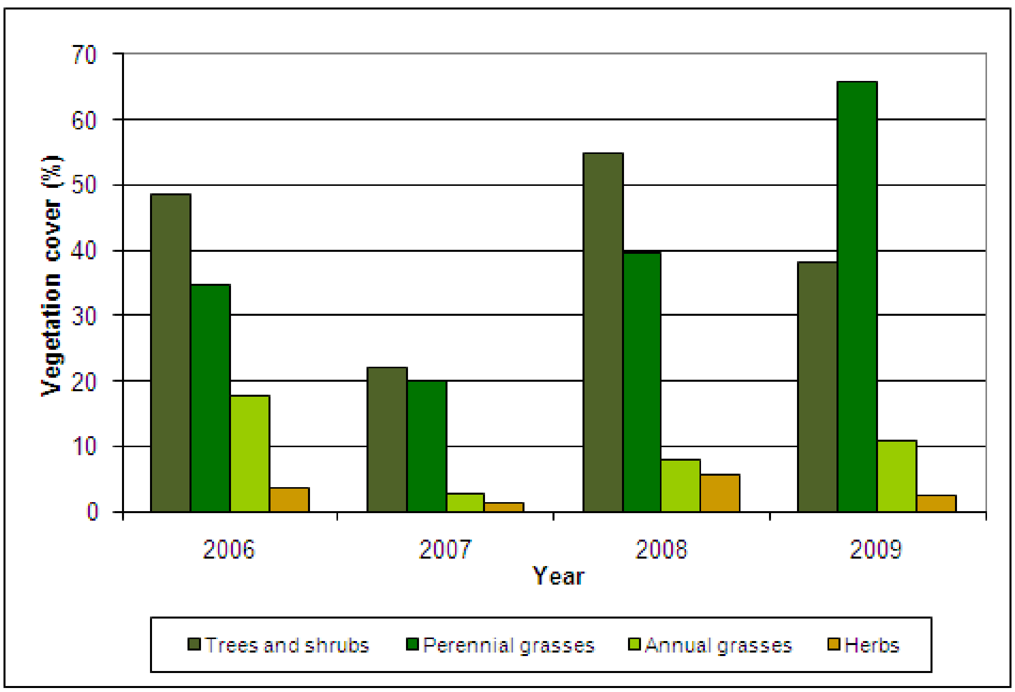


Figure 35. Changes in vegetation cover on Ogongo and Omano observatories between 2006 and 2009 (n = 20).

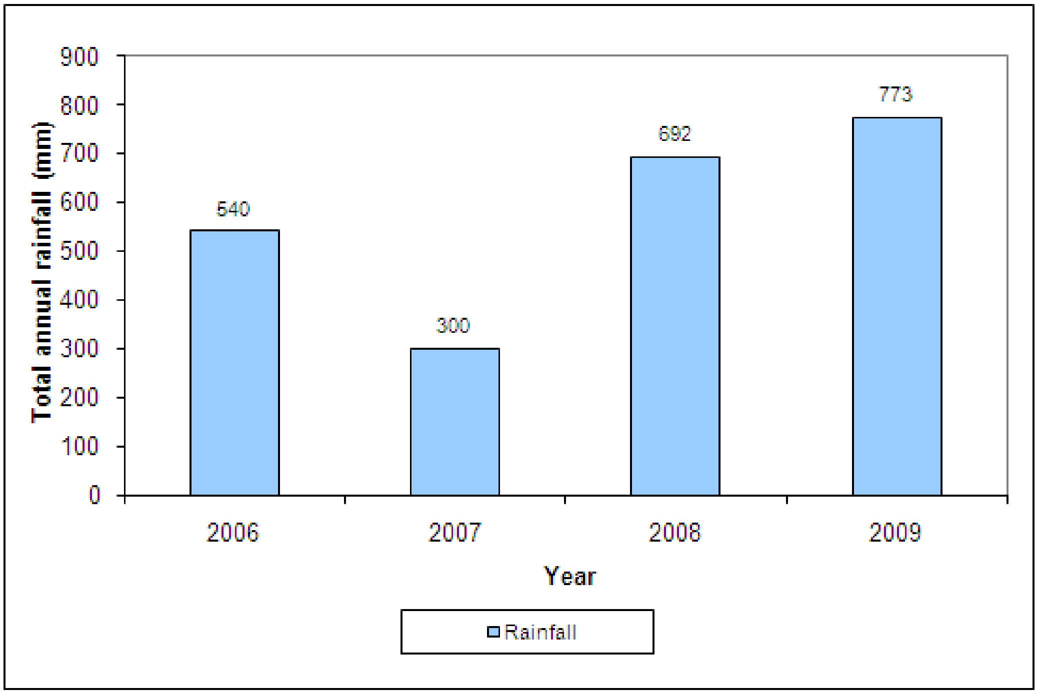


Figure 36. Total annual rainfall in central-northern Namibia between 2006 and 2009

(Source: Meteorological Services of Namibia, Ondangwa Station).

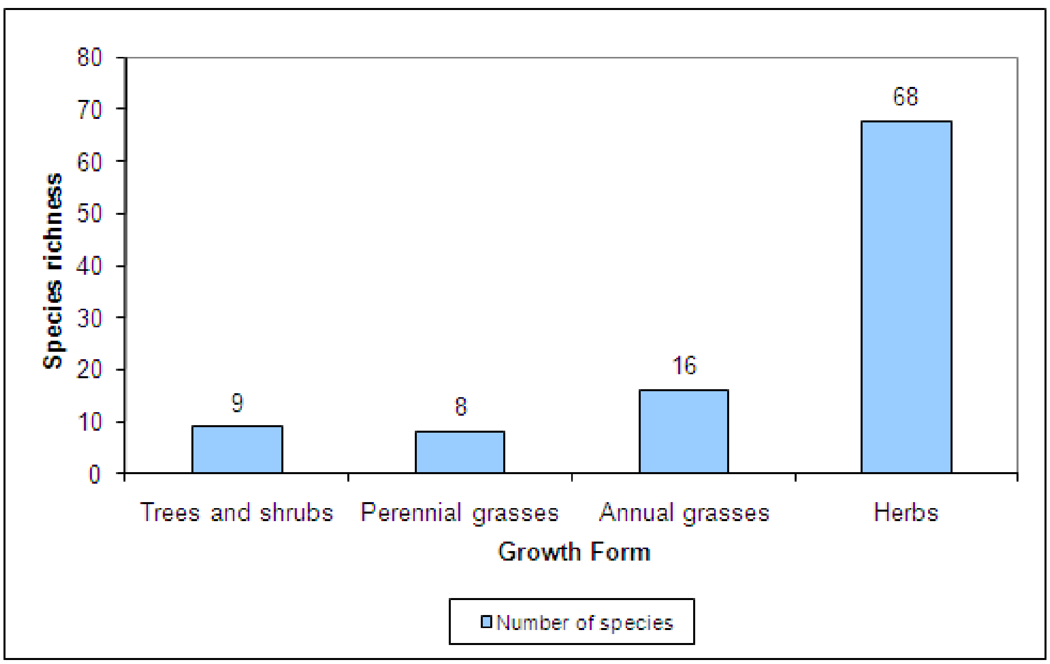


Figure 37. The mean number of species occurring in Ogongo and Omano observatories per layer of vegetation. (The average calculated from 2006-2009 records, n = 20).

Figure 38. An example of the effects of annual rainfall variability on vegetation in Ogongo observatory. Plot OG1-22, during 2007 (above) and 2009 (below).

Figure 39. An example of the effects of annual rainfall variability on Omano goNdjamba observatory. Plot OG2-04, during 2007 (above) and 2009 (below). Notice the dominant pioneer grass species *Aristida stipoides* in the foreground.

CHAPTER 6. DISCUSSION

6.1 Phytosocilogical methods

The sampling methods (Braun-Blanquet) and multivariate analysis techniques (classification and ordination) applied in this study allowed for vegetation to be stratified and its patterns to be studied and understood. The Braun-Blanquet method has been criticized among others for being over-simplified and representing a weak methodology on to a much complex real world (Gauch 1986). This on the other hand could be viewed as an advantage by optimistic ecologists as it prodives an opportunity to simplify the complexity for improved understanding of vegetation.

Although phytosociology is widely reported to be partially an art, and a subjective method to study vegetation (Werger 1974, Gauch 1986, McCune and Grace 2002, Kent and Coker 2003), modern fidelity measures, cocktail methods, objective numerical classification (Chytrý 2002) as well as the existence of fairly robust ordination techniques make up for this flaw. Furthermore, vegetation stratification using phytosociological approaches does not change the underlying ecology of any given vegetation. Detailed criticism of these methods is however beyond the scope of this thesis.

6.2 The ordinations

All ordination techniques are not without one or other error and many have been criticized in community ecology, particularly those of indirect gradient analysis. One such major criticism is the arch effect, associated with Correspondence Analysis (CA) and Reciprocal Averaging (RA), and even the apparent superior ordination technique of Non-metric multidimensional scaling (NMDS) (McCune and Grace 2002, Kent and Coker 2003, Gauch 1986). In CA and RA, points at the ends of the first axis are compressed, relative to those in the middle which produces an arch effect in the data thus interfering with appropriate interpretation of ordination diagrams. DCA solves this problem by segmentation and rescaling (by expanding segments at the ends of axis and contracting those in the middle of axis) in a process called detrending, thus removing the arch effect. Despite its limitations, DCA remains a powerful method of indirect gradient analysis and is computationally efficient (Kent and Coker 2003, Gauch 1986).

An absence of information regarding habitat preferences and ecological specificity of species in the study area makes it difficult to make confident inferences of ordination gradients. However, investigator's knowledge of the study area and field observations of species during the duration of the study could make for suppositions of gradients in the ordinated data.

Figure 11 shows a two-dimensional samples ordination derived from DCA of floristic data collected in this study, where the triangles represent relevés surveyed. The distances between the triangles are approximately proportional to the dissimilarities between the relevés. In ordination, the eigenvalue is a reflection of the amount of variation explained by a particular axis, relative to the total variation in the data (Kent and Coker 2003, McCune and Grace 2002).

The first axis in the ordination diagram (Figure 11a) is thought to reveal a soil type gradient with relevés (and species) of deep, well-drained sand soils on the xeric end of the gradient while relevés of the poorly drained, seasonally flooded shallow soils of the Cuvelai drainage basin (*oshanas*) are found on the hydric end of this gradient. Although soil moisture values were not determined in this study, the gradient on axis 1 is deemed to be related to soil moisture properties e.g. water holding capacity of the soils. This gradient is of moderate strength and only partially explains the variation in the data, as reflected in the eigenvalue of 0.59. A second gradient is evident on the second axis of the diagram, carrying with it about 0.46 eigenvalue worth of variation in the dataset (Figure 11b). However, no meaningful ecological or environmental explanation could be deduced by the use of this floristic data alone, particularly as deep sand soils relevés are spread all across this second gradient (Figure 11b).

To illustrate the inferred soil moisture gradient, basic soil properties are considered, focusing on the two main soil type extremes for the study area. Clay soils hold a lot of water due to increased inter-particile space, even during dry periods but the water is unavailable to plants. The soils are often water-logged due to very low infiltration capacity and are hard when dry hence associated with very shallow rooting depths, forming not only a barrier for root penetration but also reduced uptake of water and oxygen by roots (Prof. Gröngröft, pers. comm., Mr. Strohbach, pers.comm.). This explains the minimal encounter of trees and shrubs in the wetlands habitats during this study.

Contrary to clayey soils, sandy soils have a reduced water-holding capacity due to high infiltration characteristic of these soils, which allows water to seep through to deep soil horizons. Moreover, sandy soils are loose and soft, allowing ample rooting space for root growth. Woody plants can therefore tap water from the deep soil horizons for their growth and development as well as that of ther plants through the hydraulic lift system ([2]Prof. Gröngröft, pers. comm., [3]Mr. Strohbach, pers.comm.). An added distinction between these two soil types is that clayey soils have higher nutrient content than sandy soils, which further explains why some local farmers collect such soils from the *oshanas* to make their cropfields more fertile for cropping ([4]Mrs. Frans. pers.comm.).

Soil type as influenced by different soil properties e.g. texture and water-holding capacity, is therefore an important environmental factor, determining the species composition of vegetation types and specifically species distributions in the study area.

While habitat data were collected at some sites, these data were not sufficient to make meaningful analyses alongside the vegetation data.

[2] Prof. Dr. Alexander Gröngröft, Institute of Soil Science, University of Hamburg, Hamburg.

[3] Mr. Ben. Strohbach, Chief Agricultural Researcher, National Botanical Research Institute, Windhoek.

[4] Mrs. Martha Frans, Communal farmer, Omano go Ndjamba Village, Omusati Region.

6.3 Vegetation description: patterns and relationships

Considering the Mopaneveld in southern Africa as a vegetation class, the Mopane savanna vegetation *sensu* Giess (1971), of Omusati and Oshana regions could be summarized into five alliances which were further divided to ten associations and nine sub-associations. All vegetation units were defined on the basis of their floristic composition taking into consideration the diagnostic and constant species as guided by their fidelity values. The high frequency of occurrence (62%) of the tree species *Colophospermum mopane* in the surveyed relevés confirms that the study area is situated in the Mopane savanna, with *C. mopane* as a dominant woody species. However, it is important to acknowledge that the landscape is naturally dynamic, with three major vegetation types and two transitional vegetation types.

As part of the broad and relatively flat plain of central-northern Namibia, the vegetation of Omusati and Oshana Regions has a unique appearance probably due to a unique combination of substate (and climatic) conditions in this area. At landscape level, the *Eragrostis trichophora* - *Colophospermum mopane* shrublands vegetation alliance (Alliance 3) appears to be heavily dissected by the shallow water courses (*oshanas*) of the Cuvelai delta, which creates specialized habitats for aquatic plants (e.g. the water lily *Nymphaea nouchali*) at different water depths. The wetlands communities have been classed under the *Leptochloa fusca* - *Nymphaea nouchali* wetlands vegetation alliance (Alliance 1).

The transitional shallow sand plains of the *Hyphaene petersiana* - *Acacia arenaria* shrublands vegetation alliance (Alliance 2) form on the borders of the *oshanas*, while islands of deep Kalahari sand or the *Combretum collinum* - *Terminalia sericea* shrublands vegetation alliance (Alliance 5) vegetation are patchily distributed throughout the study area, occurring only in areas where sand deposits are deep enough to support this type of vegetation. The Mopane – Kalahari transition or *Terminalia prunioides* - *Colophospermum mopane* shrublands vegetation alliance (Alliance 4) is established on sites where the soils of Alliance 3 and Alliance 5 have been mixed by geochemical cycles to form a mosaic, as reflected in the species composition of this particular vegetation type.

Given that the water flowing through the *oshanas* is naturally destined for Etosha Pan or other smaller pans towards the south of central-northern Namibia, the salt content of the soil generally increases with the distance from north to southern parts of the Cuvelai Drainage Basin (Strohbach 2000). Similarly, the tree/shrub cover decreases with increasing soil salinity (associated with shallow rooting depths) and the vegetation takes on the form of a grassland with a high abundance of the halophytic (salt-loving) grass *Odyssea paucinervis*. Shallow saline soils limit the growth and development of trees.

The plant community types described in this study represent fundamental ecosystem units, which should form the basic ecological units for land use planning, environmental management and conservation. This is enormously important for this system because it is generally under stressful land use intensities of agro-silvo-pastoralism. The presence of an inventory of plant communities may provide guidelines for improved management of plant resources in the area. In this respect, Ogongo Agricultural College as a protected area could play a crucial role in demonstrating appropriate farming practices such as rotational grazing. Moreover, a plant community inventory is important for environmental impact assessments, a relevant planning step for areas targeted for development.

Pond vegetation surveyed in this study is strikingly unique from all vegetation and explained the first polythetic and/or dichotomic division of TWINSPAN of the entire dataset, implying that only specialized species occur and can grow in this azonal habitat.

At the alliance syntaxonomic level (Figures 12-15), *Colophospermum mopane – Terminalia prunioides* shrublands and *Hyphaene petersiana - Acacia arenaria* shrublands represent ecotone vegetation while the remaining three alliances are though to represent more “pure vegetation”. In this study, the transitional vegetation alliances have recorded high vegetation cover as well as species richness, and shared a common floristic composition with adjacent vegetation types. The high species richness can be explained by the probable multi-available niches, due to combined properties of two (or more) habitats with which the ecotone is associated.

Although some ecologists may choose to ignore transitional vegetation zones in phytosociological investigations, it is important to equally consider them during stratification of vegetation (Kent & Coker 2003, du Plessis 2001), because they represent essential ecotones between major plant communities. Ecotone habitats or tension zones as referred to by Krebs (1994) usually overlap with the distributional limits of many species, a pattern that has been demonstrated in this study, particularly by species occurring in the *Aristida adscensionis - Colophospermum mopane* shrublands association (Appendix IV). Ecotone vegetation could therefore be used to deduce clues about relationships between pure plant communities, species movements and species habitat selection as well as distribution margins.

Some species in these tension zones may be involved in the modification of the environment by facilitation, thus encouraging growth and establishment of other species. It is anticipated that competition (and predation) for ecological resources will be high in this vegetation zone. Animal diversity is also expected to be high because species rich vegetation is associated with more habitats and niches for animals (Krebs 1994). Similarly, the low species richness observed in the wetlands vegetation units can be explained by unfavourable conditions (e.g. water-logging) for plant growth and development such that only species tolerant of such habitats become established there. Transitional community types seemed to be associated with generalist species while well-defined community types were more associated with specialist species.

The *Hyphaene petersiana – Acacia arenaria* shrublands alliance is also an important vegetation unit for grazing as is the *Leptochloa fusca - Nymphaea nouchali* wetlands alliance. This is mainly because the soils of these vegetation units are not favoured for cropping activities. Another important feature of this vegetation is the occurrence of two important tree species of high commercial potential; *H. petersiana* for the basketry industry and the common fruit tree *Sclerocarya birrea* (marula). In central-northern Namibia, *H. petersiana* populations are threatened by unsustainable harvesting of young shoots, browsing and tapping of the phloem sap to make palm wine (*omalunga*), a practice which is prohibited due to its destructive nature but which is continuously observed in some remote areas (Strohbach 2002, Seely and Marsh 1992). On the other hand the species *S. birrea* is currently being researched extensively for its multi-purpose oil producing potential, both as a food and cosmetic oil ([5]Carr, pers. comm.). Appropriate management is therefore required for this vegetation as it has a limited spatial extent.

The co-dominance of shrubs and grasses in the shrublands community types defined in this study (Figures 12 – 13) could be viewed as a form of competition between the two structural layers. This could be more so as the tree species *C. mopane* which dominates much of this vegetation is known to be a shallow rooter. A large proportion of its roots are concentrated in the shallow soil horizon

[5] Mr. Steve Carr, Senior Agricultural Researcher, National Botanical Research Institute, Windhoek

where it actively competes with the herbaceous stratum of the vegetation (de Klerk 2004, du Plessis 2001).

A sharp overall average tree to shrub ratio of 2% : 15% noted in this study suggests a shrubland structured vegetation than a tree savanna. Although earlier researchers (Giess 1971, Erkkila and Siiskonen 1992) have described the Mopaneveld of central-northern Namibia as an open tree savanna, shrublands presently dominate much of this vegetation type in this area. These shrublands are not believed to be "natural" shrublands but rather degraded woodlands that have suffered deforestation (Strohbach 2000).

Long-term exposure of the ecosystems to multi-disturbances from human activities (e.g. cropping and browsing by livestock) and natural disasters (e.g. droughts) may preclude the development of shrubs into trees. Continuous subjection of *C. mopane* shrubs to browsing, keeps them at browsing height, hence no vertical growth (Lubbe *et al*. 2009). As a result, the vegetation develops into shrublands rather than a proper tree savanna.

The general scarcity of trees in the landscape is attributed to their high utilization as a source of wood in the area. The mopane savanna vegetation is important to rural communities of central-northern Namibia who have long used the species *C. mopane* for various purposes. The wood is popularly harvested for construction poles and for firewood. The bark fibres are made into ropes and used for tying kraal fences and hut frames together while the heartwood is used to make pestles for pounding grains of the staple crops (du Plessis 2001, Erkkila 2001, Seely and Marsh 1992). *Terminalia sericea* is also used in a similar manner in areas where it occurs, making it a much sought after species as well. Extensive harvesting of trees (& shrubs) for various purposes has contributed greatly to deforestation that has been heavily experienced in many parts of central-northern Namibia, still evident todate (Figure 40).

Figure 40. Visible signs of deforestation in the study area

Despite the existence of other woody species such as *H. petersiana* and several *Acacia* spp., in the study area *C. mopane* remains sought after for these conventional needs hence may suffer exclusive pressure of over-utilization. Although *C. mopane* is a vigorous coppicing species, continued harvesting will lead to the reduction of the species (Strohbach 2000). An additional important use of the mopane tree is the provision of habitat for its associated mopane worms, which are the larvae of the mopane emperor moth, *Imbrasia belina*. Mopane worms are an important source of protein for the human diet in rural areas (du Plessis 2001), a recognized local and international delicacy as well as a major source of income for rural poor who largely collect the worms for sale, particularly in Namibia.

The extent to which vegetation is used in the region is a clear indication of the direct dependency of local people on natural resources for survival. Such high socio-economic valuation of the various vegetation types in the study area should therefore prompt the relevant authorities and all stakeholders to invest in pertinent research to furnish appropriate management recommendations and improve people's livelihoods.

6.3.1Comparison to other vegetation surveys

The description of the *Nymphaea nouchali – Oryzidium barnabardii* pond association in this study corresponds to the perennial swamps of *Oryzidium barnabardii*, *Echinochloa* sp. and *Sesbania* sp. as given by Hines and Burke (1997). The vegetation units described under the *Hyphaene petersiana – Acacia arenaria* shrublands alliance of this study are similar to the associations of *Hyphaene ventricosa – Sclerocarya birrea* high open/sparse woodland, *Cynodon dactylon* short closed grasslands, *Sporobolus – Brachiaria – Eragrostis* tall closed grasslands and *Odyssea – Schmidtia* short closed grasslands defined by Hines and Burke (1997).

The *Colophospermum mopane - Eragrostis trichophora* shrublands defined in this study, corresponds to the *Eragrostis viscosa – Colophospermum mopane*, plant community described by du Plessis (2001). Additionally, the two sister communities *Leucosphaera bainesii - Colophospermum mopane* and the *Lonchocarpus nelsii - Colophospermum mopane* defined by du Plessis (2001) match up to the *Colophospermum mopane – Terminalia prunioides* shrublands alliance, all of which are associated with calcareous soils. Given the difficulties outlined in du Plessis (2001) in describing the plant communities of the Mopaneveld in central-northern Namibia, the plant associations described in this study could be more detailed than those specified by du Plessis (2001).

6.4 Vegetation mapping

Mapping vegetation units in a digitized format using GIS applications provides comprehensive spatial information which can be useful for land use planning and appropriate management of natural resources (Hines and Burke 1997). The vegetation map (Figure 34) shows the geographical extent of the different vegetation units identified in this study. The landscape patterns of the different vegetation units can be seen from the map. The seasonally flooded oshanas dissect the central portion of the landscape in central-northern Namibia, forming the Cuvelai Delta as they flow towards the south and disappear into Ekuma River, other small pans; and eventually into Etosha pan.

The transitional nature of *Hyphaene petersiana – Acacia arenaria* shrublands is also depicted on the vegetation map (Figure 34) where it is found occuring between the *Leptochloa fusca - Nymphaea nouchali* wetlands and *Colophospermum mopane - Eragrostis trichophora* shrublands. The *Odyssea paucinervis – Hirpicium gorterioides* saline grasslands association is more prominent in the southern parts of the study area as soil salinity increases with decreasing distance to Etosha pan, the ultimate destination for the Cuvelai waters.

A remarkable contrast is noted on the density of *Colophospermum mopane – Eragrostis trichophora* shrublands, with higher densities inside Ogongo Agricultural College and much lower densities on the surrounding communal farming areas where the shrublands are replaced by cropfields (Figure 34). These shrublands (ideally) make the main vegetation type in the central parts of the study area, but have been greatly reduced due to expansion of human populations in the area, who intensively depend on crop cultivation agriculture. Central-northern Namibia has also been heavily settled by the people, owing to water, fish and other natural resources provided by the *oshanas*.

The vegetation map (Figure 34) also shows units of the *Colophospermum mopane - Terminalia prunioides* shrublands vegetation alliance as they occurs more prominently in the south-western parts where human settlements are relatively fewer and less dense. The *Combretum collinum - Terminalia sericea* shrublands vegetation is shown with a patchy distribution and occupies only small portions of the study site where it occurs as islands of deep Kalahari sand, although larger patches are also seen in the south-west. This vegetation type is more typical of the eastern parts of central-northern Namibia where it forms part of the extensive deep Kalahari sand belt that stretches into Kavango Region.

6.3.1 Accuracy assessment of vegetation map

A statistical accuracy assessment was performed on the vegetation map produced in this study (Figure 34) following the design-based inference method, in order to evaluate the correctness of the map. The accuracy assessment scores and confusion matrix resulting from the accuracy assessment are shown in Tables 3 and 4.

The overall Kappa statistic for the map produced in this study is 0.7715 (Table 3), which means that there is about 77% agreement between the remotely sensed data and the phytosociological classification of the data into community types, hence a 0.77 probability of correctness. However, the overall accuracy of the map, which is calculated by dividing total reference pixels by total correct pixels, yielded an accuracy of 81.94%. Literature (Campbell 2002, Jensen 2005) recommends that a map of 60% accuracy is fairly usable, hence the map produced in this study could be used for different purposes by different users e.g. for environmental planning and management. It is also recommended that if two groups are often confused with each other in the confusion matrix then they should be merged, to increase the accuracy.

However, as per Table 3, some classes could not be well mapped, indicating poor accuracies while others showed high accuracy figures. It is important to closely observe the various forms of accuracy and to consider this at categorical level as well. Although an overall classification accuracy of over 80% may seem attractive, this should not be over-interpreted as an overall measure of correctness and usefulness for all units represented on the map. As an example from this study, although a producer's accuracy of 97.83% was computed for the *Acacia luederitzii – Crotalaria pisicarpa* grasslands sub-association (degraded), user interested in this community type will find that is only 72.58% of the areas mapped to belong to this mapping unit actually belongs to that unit.

In the confusion matrix (Table 4), similar mapping units relative to species composition and vegetation structure, particularly belonging to one association, where often confused with each other. One such example is the *Colophospermum mopane* - *Sporobolus ioclados* shrublands sub-association and *Colophospermum mopane* - *Eragrostis viscosa* shrublands sub-association. These two sub-associations along with *Pechuel-Loeschea* - *Geigeria ornativa* shrublands sub-association were also confused with cropfields, further confirming that this community type is favoured for cropping. The *Acacia luederitzii* - *Crotalaria pisicarpa* grasslands sub-association (degraded) was often confused with *Combretum collinum* - *Eragrostis lehmanniana* shrublands sub-association (degraded), of which the former unit was heavily confused with cropfields. It is not surprising that two degraded states of different community types are confused with each other as their spectral reflectance is possibly influenced by the degree of exposed soil. The confusion of *Sporobolus* sp. - *Limeum sulcatum* grasslands sub-association with cropfields could be related to degradation but probably to similarity in vegetation structure and density, as both units are predominated by herbaceous components.

Although remote sensing professionals often advice to include as much detail as possible when creating maps, it is evident from the confusion matrix of this study that a suitable level of detail needs to be identified well in advance to avoid reduced accuracy, especially at categorical level. For this study, vegetation mapping should have been restricted to association level of vegetation units. At sub-association levels and beyond, fine scale variation in vegetation (which in this area is often related to land use intensities) is not important for mapping of vegetation types. However, for the purpose of studying land use effects on vegetation, differences and similarities could be evaluated on the identical vegetation types under various land use intensities. The risk of mapping vegetation states as separate vegetation types was therefore dealt with in this study by investigating the level of variation between the classified vegetation units guided mainly by indicator species.

Mapping an area that has a dynamic landscape and under multiple disturbances with coarse resolution satellite data (e.g. LandSat TM/ETM) is challenging for reasons related to heterogeneity in spectral reflectance. The pond vegetation and small depressions (*olutha*) for example could not be thoroughly mapped out, possibly because they are too small for detection by the low resolution satellite data used for mapping in this study. The resolution for Landsat satellite images is 30 m x 30 m, hence any features smaller than this size may not be picked up by these remote sensors (Jensen 2005). For accurate mapping of such small units, participatory GIS techniques used by Verlinden & Dayot (2005) may be more appropriate. The use of high resolution remotely sensed could also provide an accurate alternative for this purpose but acquisition of such information is often costly. Nonetheless, the summarization of the vegetation data in the fashion presented here has made it possible to differentiate broadly between vegetation types and vegetation states.

6.4 Vegetation dynamics in central-northern Namibia due to natural fluctuations

The concept of plant succession or sequential changes in species composition has been for many years an important framework of vegetation ecology (Mueller-Dombois & Ellenberg, 1974). The theory was developed to study regular and predictable patterns of vegetation change in order to enable vegetation ecologists to speculate the history and future of a given site. There are also important implications in these concepts for the management of the vegetation for human use and conservation purposes. Concepts of vegetation change can as well be used to study its interactions with the biotic and abiotic factors with reference to both ecological and evolutionary time (Burrows, 1990).

The most sufficient, preferred and practical way to illustrate vegetation change is by using permanent monitoring plots, containing marked or mapped individuals, which are evaluated at time intervals over a period of years. The relative potential longevity of species present and the rate of change will determine how frequent such observations need to be done (Barbour *et al.*1987;

Burrow, 1990). The BIOTA observatories have been designed as a standardized tool for spatially-precise biodiversity monitoring at different spatial scales (Figure 2). They are devised to reflect the land use and landscape type but comprise smaller plots to cover for different habitat types and beta-diversity within the landscape (Jurgens *et al*. 2010).

Conventional perceptions have tended to view the dynamics of all systems including savannas to be dependent on or based on the traditional succession theory. The theory assumes that each system reaches a stage of stability (the climax) at some point as succession progresses (Illius and O'Connor 2002, Briske *et al*. 2003, Mueller-Dombois and Ellenberg 1974). This is also known as the state of equilibrium. The basic idea is that, after a disturbance, the vegetation is bound to come back to the climax when conditions are favourable again and the disturbance does not persist.

However, it has long been noticed that this concept is only largely applicable to forests and other biomes in the tropical environment where conditions tend to be relatively stable. As a result, a more habitat-dependant approach, the non-equilibrium concept, has been introduced and is now being used to explain dynamics of different systems (Bredenkamp 2006, Behnke & Scoones 1993, Westoby *et al*. 1989). The non-equilibrium concept is contra to the equilibrium concept because it acknowledges that different ecosystems may be controlled by significantly different factors, hence not liable to the application of the conventional succession theory. For example, stable equilibria are not achievable in many arid and semi-arid ecosystems though long-term persistence is a possible effect. In these systems, vegetation change is determined more by external control factors (abiotic factors), hence independent of the effects of the biotic components of the system (Bredenkamp 2006).

It is further explained that equilibrium and non-equilibrium ecosystems are not distinguished on the basis of unique processes within the system but by the assessment of system dynamics at different spatial and temporal scales. It is not always possible to identify a system at equilibrium or non-equilibrium because things may change with changing scales of time and space. This implies then that a given ecosystem can display both equilibrium and non-equilibrium dynamics under varying conditions. This school of thought therefore argues that ecosystems are distributed along a continuum from equilibrium to non-equilibrium states (Bredenkamp 2006, Briske *et al*. 2003, Illius and O'Connor 2002).

In terms of rangeland ecology, equilibrium grazing systems are likely to be found in systems with relatively unvarying or stable environmental conditions e.g. tropical forests. It is expected that consumption by herbivores will not control plant biomass because the animal population is regulated by environmental factors controlling plant biomass and the availability of feed ultimately regulates the growth of the herbivore population. Non-equilibrium grazing systems tend to differ in that the physical conditions supporting plant growth are highly variable and consumption by herbivores cannot significantly impact plant biomass because the animal population in itself should also withstand the same abiotic effects which control the vegetation (Behnke & Scoones 1993, Westoby *et al*. 1989).

In a critical review, Bredenkamp (2006) argued that some evidence exists, suggesting that the semi-arid to arid savannas of southern Africa represent various positions on an equilibrium - non-equilibrium vegetation dynamics gradient. With precipitation being the primary determinant of this gradient (since rainfall is the main determining factor of savanna dynamics), the moister savannas are ideally found to be positioned towards the equilibrium side of the gradient and drier savannas on the non-equilibrium side of it. This analysis however implies that savannas are generally non-equilibrial systems.

The non-equilibrium concept is thus largely applicable to savannas, particularly in southern Africa where they essentially fit the definition of event-driven ecosystems (Bredenkamp 2006). After the occurrence of an event such as fire, drought, overgrazing or a huge rainfall event (which could cause a flood), the system will not necessarily return to its climax or original state. This is probably part of the reason why restoration programmes in many arid and semi-arid ecosystems tend to fail. Vegetation cannot be expected to recover through the withdrawal of livestock alone given that external factors are more important in determining system dynamics ([6]Prof. Bredenkamp, pers. comm.).

As an outcome of the review, Bredenkamp (2006) has identified six savanna types. These are presented here from the most mesic to the most xeric, as presumably also positioned on the equilibrium- non-equilibrium continuum:-

- Moist broad-leaved savanna on sandy, nutrient poor soils (>600 mm rainfall)

[6] Prof. Dr. George Bredenkamp, Department of Science, University of Hamburg, Hamburg..

- Moist microphyllous savanna on clayey, nutrient rich soils (>600 mm rainfall)
- Dry broad-leaved savanna on sandy, nutrient poor soils (>300-600 mm rainfall)
- Dry microphyllous savanna on clayey, nutrient rich soils (>300-600 mm rainfall)
- Arid microphyllous savanna on very dry, nutrient rich sandy soils (>200-300 mm rainfall)
- Arid broad-leaved savannas on arid, nutirnet rich, clay soils (>200-300 mm rainfall) (e.g. Mopane savanna)

Following the aforementioned vegetation dynamics classification of southern African savannas, the vegetation of Omusati and Oshana Regions fits in well as an arid broad-leaved savanna on arid, nutrient rich, and clay soils (<300 mm rainfall). This places it on the arid side of the equilibrium – non-equilibrium continuum, implying that ecosystem dynamics are determined more by external physical factors rather than by the biotic components of the system.

Analysis of four-year monitoring plot data from Ogongo and Omano observatories has yielded evidence that supports this hypothesis, with rainfall as an important influential abiotic factor affecting vegetation in the area (Figures 35 to 37). Generally, vegetation cover is lowest in 2007 and correspondingly, the mean annual rainfall is also lowest in 2007 (Figures 35 & 37 respectively). Furthermore, the herbal layer of these mopane shrublands has shown patterns of drastic response, particularly in terms of species composition, to the erratic rainfalls experienced in the area, as shown in Figures 38 to 39. Unpredictable rainfalls coupled with high land use intensities are thought to cause a diversity of vegetation states in various plant communities.

Although a higher perennial grass cover than annual grass trend is evident in the monitoring data (Figure 35), only a few perennial grass species were encountered over the years and just a few contribute to the overall cover reported here. *Eragrostis trichophora,* is one of the few remaining resilient perennial grasses in this ecosystem, surviving high grazing pressures that and occurs as the single most abundant perennial grass followed by *Willkommia sarmentosa* and *Eragrostis rotifer*. Other perennial grass species such *Diplachne fusca* and *Sporobolus ioclados* occur in moderate abundance while *Eragrostis lehmanniana, Stipagrostis uniplumis* and *Schmidtia pappophoroides* are seldom encountered. On the contrary, a high species density of annual grasses such as *Brachiaria xantholeuca, Anthephora schinzii, Chloris virgata, Pogonarthria fleckii, Eragrostis porosa* and *Aristida stipoides* was encountered. These are all unimportant grazing grasses which do not contribute greatly to vegetation cover. Disadvantages of annual grass dominated veld are discussed in detail in section 6.5.2.

Although findings of these surveys could be more explained by seasonal variation or phenology, they present an important illustration of the vegetation's response to varying erratic rainfalls, especially in the herbaceous stratum of this system. Moreover, all four regions of central-northern Namibia have experienced consecutive floods in 2006/7, 2007/8 and 2008/9 seasons, which resulted in massive reduction of crop yields (MAWF 2009). Floods are a possible natural disaster that might influence the vegetation dynamics in the area and may occur more frequently in central-northern Namibia as well as in other parts of southern African region, given the rapidly changing climates.

The low average species richness observed for perennial grasses and relatively high species richness for annual grasses (Figure 37) is attributable to over-utilization of the veld. The relatively low woody cover in 2007 could be attributed to limited establishment of seedlings, particularly of *Colophospermum mopane*, which was observed in other years. It is assumed here that seedlings will become established in good rain years but their survival may be highly influenced by browsing and amounts of rainfall in the following rainy season.

As an alternative explanation the observed low woody cover trend in 2007 (Figure 35) could also be a result of observer bias, as there were different observers for the permanently marked relevés in 2006 and 2007. This maybe more so because it was also noted during the field surveys that the woody vegetation cover may have been under-estimated in 2007 by the respective observer, who then chose to be consistent to ensure comparability of results. This is one of the shortcomings of the Braun-Blanquet approach which compromises consistency and repeatability in the estimation of abundances or vegetation cover.

6.5 Impacts of land use in central-northern Namibia

The old nomadic lifestyle of African pastoralists, including the Oshiwambo speakers of northern Namibia and southern Angola, provided an opportunity for plant resources to regenerate and ecosystems could return to favourable states before the area would become settled again. The sustainability of this system was dependant on traditional methods of natural resource management. In former times, rotational grazing was practiced in areas that are traditionally set aside for dry season grazing in search for water and better pastures when water in the oshanas has dried up and grazing is depleted in the central Cuvelai. Young men and boys would move herds of cattle to specific grazing areas e.g. the Ombuga Flats (south of Oshakati), Andoni Plains (southern Oshikoto Region), and Oshimpolo veld (now in Angola) (Seely and Marsh 1992).

Today, a more sedentary lifestyle is observed in central-northern Namibia, where agro-silvo-pastoralism has sustained human life for many years (Seely and Marsh 1992). This has in turn put the environment under severe pressure and natural resources have become depleted with this sedentary lifestyle and growing human populations. Modern technology has made possible the construction of canals and pipelines, making water available all year round in central-northern Namibia, and leaving the people with no incentives to practice rotational grazing. Ultimately, grazing pressures on the land were increased which might have contributed to land degradation in the region, which is more evident near waterpoints (Seely and Marsh 1992). Seasonal cattle movement is an important traditional range management strategy, well adapted for systems like this one as major biotic components i.e. large herbivores and plants can cope with impacts of low and sporadic rainfalls. The plant component is given a rest period from browsing, grazing and trampling (Seely and Marsh 1992, Mendelsohn *et al*. 2000).

The shift from nomadic to sedentary lifestyle is not the only factor that has fueled overgrazing in central-northern Namibia. Wealthier farmers have now privatized parts of these traditional grazing areas by fencing off large tracts of land for their cattle (Mendelsohn *et al*. 2000). Moreover, many small-scale subsistence farmers have also taken action by fencing off of open grazing pastures near their homesteads. Grasses such as *Eragrostis rotifer* and *Panicum trichonode* are also harvested for thatching, while in desperate situations any grass maybe illegally harvested from the oshanas by some locals for livestock fodder during the dry season. All these practices may enhance land degradation in the area.

The scarcity of grazing in central-northern Namibia cannot be over-emphasized as cattle movements into neighbouring Angola to the north and Kavango Region to the east have been reported (Kangombe 2007). Cattle and other livestock have been reported to browse on the unpalatable palm shrubs (*Hyphaene petersiana*), especially seedlings and younger plants when the availability of fodder is limited (Strohbach *et al*. 2002). Farmers residing near towns collect cardboard and other paper refuse to feed their livestock during extreme grazing conditions (Kangombe 2007; Mendelsohn *et al*. 2000). This is an indication of the extent to which the grazing resources have been depleted in the area. Serious intervention is therefore required to rescue the rangeland potential in the study area.

6.5.1 Land use on Ogongo and Omano observatories

Three major land use types are observed on Ogongo and Omano observatories: - modern farming in Ogongo Agricultural College, communal fencing and the open access grazing system. Because of these different management practices, relevés belonging to one vegetation type often have different species composition which may cause them to be grouped differently during classification. This impact made it difficult to map vegetation in the area as one vegetation type occurs in several vegetation states. Vegetation description and mapping therefore required expert knowledge in the area and thorough investigation.

The worst management strategy is the open access option because it is basically an area for open access grazing, grass harvesting, wood harvesting and other local land use practices. Over-utilization and unsustainable harvesting of resources is common due to a lack of ownership. The Ogongo Agricultural College and the Communal Fencing management options often produce similar results and relevés from either may actually be classed together in a numerical classification, indicating similarity. In addition, personal observations have recorded biological crusting of the surface on sites of both management options. Communal farming is therefore not necessarily a bad farming system as it is often labeled to be, because impacts depend on the applied management strategies.

6.5.2 Grazing

While a wide range of interacting environmental factors e.g. rainfall and soil nutrient content determine dynamics of savanna ecosystems (Scholes and Walker 1997, Scholes and Walker 1993, Skarpe 1992), the structure of most savannas, particularly African ones, is believed to be due to the impact of fire and large herbivores (Skarpe 1992). In former times, a decline in food and water during the dry season in natural dry savanna systems prompted animal migration in search for these essentials. Such migration reduces herbivore pressure on the vegetation and gives it a chance to regenerate (Milton and Hoffman 1994). However, continuous livestock grazing in dry savannas has adverse effects on plants that grow and/or persist into the dry period, i.e. perennials (Scholes and Walker 1997, Skarpe 1992).

Although no exact figures of stocking densities could be obtained for comparison in this study, some inferences can be made about the condition of the range in the area. The very few sub-climax grass species such as *Eragrostis trichophora*, *Willkommia sarmentosa*, *Stipagrostis uniplumis* and *Sporobolus ioclados* encountered amongst numerous annual grass species suggest low rangeland quality in the area. Important annual grasses encountered in the study area include *Schmidtia kalihariensis*, *Melinis repens* subsp. *grandiflora*, *Enneapogon cenchroides* and *Urochloa brachyura* as they are more readily taken by livestock. However, a high abundance of the poorly utilized pioneer species *Aristida stipoides*, *Aristida rhiniochloa* and *Aristida adscensionis* indicates degradation because these species are known to increase considerably under conditions of disturbance (Lubbe *et al*. 2009).

In the some parts of the study area however, perennial grass species such as the desirable *Stipagrostis uniplumis*, and *Eragrostis lehmanniana*, and the mat forming *Microchloa caffra*, and *Monelytrum luederitzianum* become abundant at some sites, particularly further away from the central parts of the study area towards Etosha National Park. In addition, a few stands of the valuable palatable species *Anthephora pubescens* were occasionally encountered south of Okahao in the *Terminalia sericea* - *Colophospermum mopane* shrublands association, where human impacts seem relatively minimal, compared to the populous central parts of study area. This climax species is rare in most areas of central north and its occurrence in moderate to high abundance indicates a veld in good condition (Müller 1985). Its encounter here suggests that the area still has active seed banks of such valuable perennial species, which may become established in the veld with appropriate management.

Monitoring plots on the two observatories reveal a relatively high perennial grass and low annul grass cover. This pattern is explainable by reference to the survival strategies of the two life forms. Perennial grasses usually invest in a dense root system (and more leaf mass production) for optimal extraction of moisture out of a limited soil space, and eventually long-term survival. These grasses can survive throughout the dry seasons and may still produce some leaf mass, hence protecting the soil and providing some fodder (Strohbach 2000, Tainton 2000, Tainton 1999).

Despite a fair perennial grass cover, few perennial grass species were encountered, with twice as many annual grass species recorded in the area on average. In fact, there's only about three important perennial grass species that grow in fairly high abundance, *Eragrostis trichophora* being the most important (frequency of occurrence, 80%), followed by *Eragrostis rotifer* and *Willkommia sarmentosa*. Other important perennial grasses include *Sporobolus ioclados* and *Leptochloa fusca*, while species such as *Schmidtia pappophoroides*, *Eragrostis pallens*, *Digitaria seriata* and *Anthephora pubescens* never occur in considerable abundances to define community types.

In terms of veld condition it should not be perceived that the veld is in good condition based on this very coarse indicator of the perennial to annual grass ratio. Veld condition is assessed by considering aspects of palatability, species diversity, successional status and accessibility that collectively determine grazing value (Tainton 2000, Tainton 1999), and which have not been assessed here. The very low species richness of perennial grasses on the observatories (Figure 37) implies that these species suffer continuous grazing pressures by livestock. One such perennial species is *E. trichophora*, which is the single most important grazable species in the area. Preferentially grazed species loose competitive power compared to less grazed ones and subsequently decrease (Skarpe 1992).

Perennial grasses are important competitors for the woody layer, hence could play an important role in preventing woody plant establishment, and ultimately bush thickening. However continuous heavy grazing of the perennial grasses reduces their vigour particularly if coupled with periods of drought, thus enhancing bush encroachment (de Klerk 2004, Strohbach 2000). This is why opportunistic management is advised for event-driven systems, such as this one to give the grass component this crucial chance to survive and revive its vigour.

A general high species richness (and abundance) of annual grasses is an indication of degradation and low rangeland value. This is of great concern because annual grasses invest very little resources into leaf mass production and root systems, hence easily uprooted during grazing. Annual grasses are opportunistic, and their main survival strategy is to produce many seeds within a short time

(Strohbach 2000, Tainton 1999). Additionally, theses grasses are an unreliable veld resource as they may not germinate well in poor rain seasons, leaving the veld with insufficient resources to support livestock and the soil void of protective cover thus at risk of wind- and water erosion during the dry periods and at the onset of the following rainy season (Strohbach 2000).

The response of annual grasses to rainfall in the study area has been well demonstrated (Figures 35 to 36). Examples of annual grass species that occur with a high cover in Ogongo and Omano observatories include *Pogonarthria fleckii*, *Anthephora schinzii*, *Brachiaria xantholeuca*, *Eragrostis viscosa*, *Chloris virgata*, *Eragrostis cylindriflora*, *Aristida stipoides*, *Aristida rhiniochloa* and *Eragrostis porosa*, all of which are of low grazing value *sensu* Müller (1985).

6.5.3 Cropping

From the vegetation map produced in this study (Figure 34) as well as from the descriptions of the community types, it is evidently clear that the *Colophospermum mopane – Eragrostis trichophora* shrublands are more prominent inside the protected area of Ogongo Agricultural College and become increasingly replaced by crop fields on the surrounding communal farming areas. This further supports the idea that soils of this vegetation unit are favoured for crop production.

Extensive crop cultivation as practiced in central-northern Namibia poses a major threat to vegetation and biodiversity in general. According to one of the communal farmers, the wild plant resources have become scarce in the area while some might have gone extinct ([7]Mr. Katshuna, pers. comm. 2006) as a result of land clearing for crop fields. Concerns over the conversion of natural vegetation to agricultural fields and grazing land in central-northern Namibia have been expressed by several authors (Erkkila and Siiskonen 1992, Seely and Marsh 1998, du Plessis 2001, Mendelssohn *et al*. 2000, Strohbach 2000).

6.5.4 Land Degradation

Land Degradation has been defined as the loss of biological productivity of the land (Katjiua and Ward 2007, Zeidler *et al*. 2002) while desertification is defined as land degradation in dry land areas (Giannini *et al*. 2008, Klintenberg *et al*. 2007), such as Namibia which is regarded an arid- to semi-arid country. The most obvious changes attributable to land degradation in rangelands are

[7] Mr. Katshuna, Communal farmer, Omano go Ndjamba Village, Omusati Region.

such as the transformation of an open savanna to a bush thickened one, perennial to annual grasslands, palatable to unpalatable vegetation systems (Zeidler *et al*. 2002). In this study, land degradation was inferred by the use of indicator species, perennial to annual grass ratio, vegetation response to rainfall and biological soil crust. In this respect, many of the sites surveyed, particularly the north to central portions of the study area, which are also densely populated, were assessed to be under one or other form of degradation state. Photographic examples of some existing vegetation states in the area are shown in Figures 25 and 33.

The hypothesis of degradation is supported by the high abundance grass species *Enneapogon cenchroides*, *Pogonarthria fleckii*, *Aristida rhiniochloa*, *Eragrostis porosa*, *Tragus racemosus*, *T. berteronianus* and *A. adscensionis*. These species have been classified as Increaser IV species in Namibia (Strohbach 2000). Increaser IV species are rare in a veld that is in good condition but will increase in abundance if the veld is heavily overgrazed over the long term (Tainton 1999). In addition, the aromatic bitterbush species *Pechuel-Loeschea leubnitziae* which is strongly associated with disturbed sites and often used as an indicator of reduced land productivity and over-grazing (Burke 2000, Strohbach 2000, Seely & Marsh 1992), occurs in high abundance on an array of vegetation types within the study area. The species is known to invade cleared and trampled areas e.g. roadsides and waterpoints. Despite its perennial growth form, the shrublet is unpalatable and has been reported to taint the taste of milk and meat for desperate livestock that browse on it under very extreme conditions (Strohbach 2000).

Other observed signs of land degradation in the area include loss of vegetation cover, loss of palatable species and/or changes in species composition, soil erosion, reduction in crop yields, deforestation and to a lesser extent bush encroachment. Habitat fragmentation and vegetation transformation are not the only ecosystem challenges facing the degraded lands of central-northern Namibia. Several alien invasive species such as *Prosopis* species and *Jatropha curcas* that are planted for shade, as well as *Ricinis communis,* planted for medicinal and cosmetic use, and *Datura ferox* which is planted around the homestead to ward off snakes (due to its aromatic smell); have all been encountered in these region. Potential alien invasion by these species is of particular concern, given the patterns and pathways of invasive species.

Land degradation in the study area could partly be attributed to heavy grazing in the study area where cattle and small stock production equally constitutes an important component of subsistence farming as cropping. However, continued overgrazing and trampling greatly reduces the potential of the grass layer to protect the soil thus its ability to form biological soil crusting. The impact is much felt in low rainfall years when the grass cover is low, leaving the topsoil at high erosion risk from wind and water e.g. Figure 33. Efforts to rehabilitate such a veld may therefore require more than a mere removal of livestock as numerous factors (e.g. climatic conditions, other land use related influences) other than heavy grazing could be influencing ecosystem dynamics in this system.

It is important to acknowledge the awareness and perceptions of local resource users in central north to degrading lands. Informal interviews with some farmers, conducted during the field surveys revealed that the people are degrading the land because they do not have alternative means of survival. It also became apparent that many farmers are willing to improve this situation. Some committed farmers have even tried to sow and propagate the palatable and valuable sub-climax grass species *Stipagrostis uniplumis* on their farms in attempt to improve grazing conditions for their livestock. Interventions should strive to deepen people's the understanding of causes and processes of degradation as well as to suggest alternate means of livelihoods and ways to combat further degradation and restore degraded lands.

Although land degradation mapping was one of objectives of this study, this proved to be a challenging exercise for several reasons. Mapping of degradation trends requires benchmark sites (temporal or spatial data) for comparison, preferably for every vegetation type defined. The lack of historical or long term monitoring data made it impossible to compare current status of the vegetation to that of the past, hence a major challenge in validating land degradation trends. In the study area, benchmark sites where difficult to find for every community type described, as most surveyed sites were observed to be in one or other state of degradation. Additionally, a suitable method for land degradation assessment and mapping could not be obtained in good time. Nonetheless, a few land use related differences could be noted between vegetation units. Quantification and mapping of land degradation remains important for communal areas in these regions, if the problem is to be dealt with.

CHAPTER 7. CONCLUSIONS

The vegetation of Omusati and Oshana regions could be stratified into five alliances, ten plant communities and nine sub-communities which were defined by their floristic composition. The mosaic of vegetation and the high variation which became apparent by indirect gradient analysis of floristic data is a reflection of the diversity of habitats. A soil type related gradient (axis 1) was inferred and soil type is shown to be a key determinant of the spatial pattern of vegetation in the study area. While the Braun-Blanquet classification system is argued to be a subjective process, it still represents a competent method to study plant community ecology, and an efficient means of mapping vegetation, particularly over large areas. The subjectivity of this method is complimented by the objective classification and ordination techniques and its application does not alter the underlying ecology of any given vegetation.

The associations defined in this study are summarized below:-

- *Nymphaea nouchali* - *Oryzidium barnabadii* pond association
- *Eragrostis rotifer* - *Eragrostis cilianensis* oshanas association
- *Hyphaene petersiana* - *Acacia hebeclada* shrublands association
- *Odyssea paucinervis* - *Hirpicium gorterioides* saline grasslands association
- *Eragrostis viscosa* - *Colophospermum mopane* wet shrublands association
- *Acacia nilotica* - *Colophospermum mopane* dry shrublands association
- *Pennisetum glaucum* crop fields association
- *Aristida adscensionis* - *Colophospermum mopane* shrublands association
- *Terminalia sericea* - *Colophospermum mopane* shrublands association
- *Combretum collinum* - *Terminalia sericea* shrublands association

The various vegetation units were mapped with the aid of satellite imagery and land-use related differences could as well be investigated and mapped. The magnitude and different levels of land use intensity has caused fragmentation and transformation of natural vegetation, making it more difficult to map the vegetation, in this already diverse landscape. Remote sensing and GIS have proved to be useful tools in vegetation mapping and land use change. Regrettably, the actual extent of land degradation could not be quantified and mapped.

Phytosociological investigations allow for vegetation units to be described and their patterns understood as well as environmental determinants of vegetation. Important rare and sensitive species can be identified and conserved accordingly. Changes in species composition can be monitored with long-term data. Moreover, such studies allow for hypotheses generation of more specific research while speculations about vegetation dynamics can as well be made to a small extent.

The high degree of spatial and temporal variability in rainfall in the study area makes this an event driven system which requires opportunistic management. The short-term monitoring data collected and analyzed in this study provide supporting evidence of the theory of non-equilibrium systems for the study area but not be over-interpreted. Long-term data is therefore required for thorough understanding of ecosystem dynamics and other ecological processes. Habitat information or physical environmental parameters such as soils, topography and climate are also equally important and can aid enormously in interpretation of vegetation data as well as add value to such research work. Botanical researchers may require basic training and assistance with the collection of such data.

The high abundance of perennial grass cover is an indication of persistence from these grasses despite the heavy grazing. However, over-utilization of this resource will likely reduce their vigour and have an overall negative impact on ecosystem resilience and rangeland potential. Several land degradation indicators have been noted in this study, suggesting the need for further research and intervention in some parts of the study area. Increasing replacement of the Mopane shrublands by cropfields pose a major threat to persistence this vegetation type and overall biodiversity in the area.

The conventional practice of transhumance in central-northern Namibia which was done seasonally as the oshanas dried up, sustained the land use of agro-silvo-pastoralism under relatively low human populations. Permanent access to water to date coupled with increased human populations has significantly intensified the pressure on the land resulting in negative impacts on ecosystems e.g. land degradation.

This study contributed towards building a national baseline vegetation database for Namibia and to the overall biodiversity records of the country. Furthermore, the data collected in this study is of inevitably high value, particularly the monitoring data as these can be used as basis for future investigations within and beyond the scope multivariate community ecology. The data should therefore be systematically documented and archived for future reference material.

CHAPTER 8. RECOMMENDATIONS

This thesis represents findings of exploratory research undertaken in two administrative regions of central-northern Namibia, Oshana and Omusati. It should therefore be viewed as a baseline ecological study, from which detailed research experiments can be designed. Further research is required to improve our understanding of determinants of system dynamics and vegetation pattern of this dry savanna ecosystem, more so because savannas are highly dynamic ecosystems on all temporal and spatial scales. For this purpose, long-term monitoring data is necessary and hereby strongly recommended.

An absolute priority is detailed investigation of livestock impacts & over tilling, on vegetation for appropriate land use management. Carrying capacities of different vegetation units need to be determined for suitable rangeland management strategies to be implemented. The ratio between perennial and annual grasses in a veld is a very crude indicator of veld condition and already, a bias in the species richness between the two growth forms of grasses is reported here. The potential of the range in central-northern Namibia needs to be reviewed, against the extent of land degradation to find appropriate ways of improving the veld condition. Different sites could be selected and assessed for the presence of active seed banks, as well as re-establishment of valuable perennial grasses. Opportunities for restoration and rehabilitation of degraded lands should be initiated and explored through applied ecological research. Optimal livestock production and sustainable land use should be the ultimate goal. Ogongo Agricultural College as a training institution could be used as a facility for trial research of some of these activities.

With regard to agro-silvo-pastoralism as a main land use system, it is obviously difficult to change traditional farming practices over the short-term. People could be encouraged to return to the old time traditional grazing practices of transhumance, an informal form of rotational grazing. This may however be difficult to achieve, especially given changes in the land tenure system over the years, particularly post independence. It could be useful to search alternative sources of income or ways to improve the livelihoods of the rural poor in the area. The government could introduce laws on the limits of livestock numbers, although this could also be difficult to achieve as livestock keeping in the region is mainly for prestige or wealth, manure, and to a lesser extent for meat and income generation.

Alternative innovative measures are required to change the attitudes of the main resource users, if conditions are to be improved and pressure on land reduced. Perhaps what people really need is a powerful understanding of the underlying ecosystem dynamics, because unless a common perception of the actual problem is reached, any law enforcement is likely to fail. Conservation, restoration and rehabilitation strategies should strive to change perceptions of the public and encourage attitudes of working together to save this environment. A little education is more likely to go a long way as most farmers in these regions are aware of problems associated with land use, while others are even willing to contribute their efforts towards solving these problems.

Customary laws and environmental laws should be reviewed to release the pressure on the land, particularly with regard to the various fencing and any other inappropriate land use practices. Because controversy exists between nature conservationists and land users, care must be taken as this issue is dealt with for the benefit of the environment, particularly in Namibia where the study area is located in a politically sensitive zone.

The introduction of community forestry initiatives by the Namibian Government through the Ministry of Agriculture, Water and Forestry is a positive intervention as local people can actively participate in the establishment of community forestry reserves for the benefit of present and future generations. This programme should be extended and strengthened, while similar initiatives could as well be explored.

SUMMARY

The vegetation of Omusati and Oshana Regions, central-northern Namibia

by

FRANSISKA NDIITEELA KANGOMBE

Supervisor: Prof. Dr. G.J. Bredenkamp

Submitted in partial fulfillment of the requirements for the degree

MAGISTER SCIENTIAE

in the

Department of Plant Science, Faculty of Natural and Agricultural Sciences

University of Pretoria

December 2010

One of the major challenges hindering effective environmental planning, management and sustainable land use in Namibia is the lack of adequate ecological data. Vegetation is regarded a key indicator for the state and change of biodiversity, thus an inventory of plant communities occurring in a given area forms an essential basis. The main objectives of this study, as part of the Biological Diversity Transect Analysis Africa (BIOTA) Project, were to systematically document, stratify, and describe the vegetation of Omusati and Oshana Regions with emphasis on land use types and intensities. This baseline study is particularly important for an area that is under varying intensities of land use, as this affects vegetation change over the long-term. Moreover, the study aids to identify underlying environmental gradients, contributing to our understanding of the distribution, composition and patterns of vegetation as well as functioning of plant communities in the area.

A total of 495 species were recorded across 415 relevés that were randomly surveyed over the two regions during February to April for the period of 2006-2009, following the Braun-Blanquet

methods. Classification of floristic data using TWINSPAN in JUICE summarized the data into five recognizable vegetation alliances, ten associations and nine sub-associations.

The following plant associations were identified and described for the vegetation of Omusati and Oshana Regions :-

- *Nymphaea nouchali* - *Oryzidium barnabadii* pond association
- *Eragrostis rotifer* - *Eragrostis cilianensis* oshanas association
- *Hyphaene petersiana* - *Acacia hebeclada* shrublands association
- *Odyssea paucinervis* - *Hirpicium gorterioides* saline grasslands association
- *Eragrostis viscosa* - *Colophospermum mopane* wet shrublands association
- *Acacia nilotica* - *Colophospermum mopane* dry shrublands association
- *Pennisetum glaucum* crop fields association
- *Aristida adscensionis* - *Colophospermum mopane* shrublands association
- *Terminalia sericea* - *Colophospermum mopane* shrublands association
- *Combretum collinum* - *Terminalia sericea* shrublands association

Complimentary subjection of floristic data to indirect gradient analysis using DCA in PC-ORD suggested soil type to be a major environmental gradient of vegetation patterns and plant species distribution in the area. A merged satellite image from LandSat 5 TM, Path 180 Row 72/73, dated 20090430, was used for supervised classification i.e. mapping of plant associations, yielding an accuracy assessment of 82%. A clear replacement trend of Mopane shrublands by crop fields on communal farming areas is noted. Factors influencing vegetation pattern and dynamics as well as impacts of land use on environment are discussed.

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

CHAPTER 9. REFERENCES

BARBOUR, M.G., BURK, J.H. & PITTS, W.D. 1987. *Terrestrial Plant Ecology*. Benjamin/Cummings Publishers, California.

BARBARD, P. (ed). 1998. *Biological Diversity in Namibia: A country study*. Ministry of Environment and Tourism, Windhoek.

BEHNKE, R.H., SCOONES, I. & KERVEN, C. 1993. *Range ecology at disequilibrium: new models of natural variability and pastoral adaptation in African savannas*. Overseas Development Institute, London.

BREDENKAMP, G.J, 2006. Vegetation types and dynamics in African savannas. Reinhold-Tuxen Gesellschaft.

BREDENKAMP, G.J. & BROWN, L.R. 2002. *Vegetation: A reliable tool for environmental planning*. Urban Greenfile.

BREDENKAMP, G.J., BROWN, L.R., GROBLER, C. & CUSTERS, M. 2001. Vegetation: More than just a species list. *International Association for Impact Assessment South Africa (IAIASA) Newsletter*, November Issue.

BRISKE, D.D., FUHLENDORF, S.D. & SMEINS, F.E. 2003. Vegetation Dynamics on Rangelands: A Critique on the current paradigms. *Journal of Applied Ecology* **40**(4): 601-614.

BURKE, A. 2000. Plant diversity of a man-made wetland – The Olushandja Dam in north central Namibia. *Dinteria* **26**: 25-44.

BURKE, A. & STROHBACH, B.J. 2000. Review: Vegetation studies in Namibia. *Dinteria* **26**: 1-24.

BUCH, M.W. & D. ROSE, D. 1996. Mineralogy and geochemistry of the sediments of the Etosha Pan Region in northern Namibia: a reconstruction of the depositional environment *Journal of Earth Science* **22**(3): 355 – 378.

BURROWS, C.J. 1990. *Processes of vegetation change*. Chapman & Hall Publishers, London.

CAMPBELL, J.B.2002. *Introduction to remote rensing*. Third Edition. The Guilford Press, New York.

CHYTRÝ, M., TICHÝ, L., HOLT, J. & BOTTÁ-DUKKÁT, Z. 2002. Determination of diagnostic species with statistical fidelity measures. Journal of Vegetation Science **13**: 79-90.

DE KLERK, J.N. 2000. *Bush encroachment in Namibia*. Ministry of Environment and Tourism, Windhoek.

DU PLESSIS, F. 2001. A phytosociological synthesis of Mopaneveld. *M.Sc. Thesis*. Department of Botany, University of Pretoria, Pretoria.

EASTMAN, J. R. 2006. *IDRISI Andes: Guide to GIS and Image Processing*. Clark University. USA

ERKKILA, A. 2001. *Living on the land: Change in forest cover in central-northern Namibia 1943-1996*, Gummerus Publishers, Jyvaskyla, Finland.

ERKKILA, A. & SIISKONEN, H.1992. *Forestry in Namibia*. University of Joensuu, Finland.

GAUCH, H.G. 1986. *Multivariate analysis in community ecology*. Cambridge University Press, Cambridge.

GIANNINI, A., BIASUTTI, M. & VERSTRAETE, M.M. 2008. Climate model-based review of drought in the Sahel: Desertification, the re-greening and climate change. *Global and Planetary Change* **64**: 119 – 128.

GIESS, W. 1971. A preliminary Vegetation Map of South West Africa. *Dinteria*. 4: 5-114

GIESS, W. 1998. A preliminary Vegetation Map of Namibia. 3rd Revised Edition. *Dinteria* **4**:1-112.

GOVERNMENT OF THE REPUBLIC OF NAMIBIA, National Planning Commission, Central Bureau of Statistics. 2003. *National Report: Population and housing census 2001*. Windhoek.

HANGULA, L., ANGULA, M.N., MAFWILA, S.K. & SHAPI, M.K. 1998. *Economy, ecology, aesthetics: A study of indigenous tree use in former Owamboland*, University of Namibia: Multidisciplinary Research Centre, Windhoek.

HINES, C. & BURKE, A. 1997. Vegetation survey of NOLIDEP pilot communities. Prepared for the Northern Regions Livestock Development Project, Ministry of Agriculture, Water and Rural Development, Republic of Namibia. Windhoek.

HUNTER, M.L. 1996. *Fundamentals of Conservation Biology*. Blackwell Science Publishes, USA.

JENSEN, J.R. 2000. *Remote sensing of Vegetation*. Pearson Prentice-Hall Publishers, U.S.A.

JENSEN, J.R. 2005. *Introductory Digital Image Processing: A Remote sensing Perspective*. Third Edition. Pearson Prentice-Hall Publishers, U.S.A.

JÜRGENS, N., HAARMEYER, D.H., LUTHER-MOSEBACH, J., DENGLER, J., FINCKH, M. & SCHMIEDEL, U. (eds.). 2010. *Biodiversity in southern Africa **1**: Patterns at local scale: The BIOTA Observatories*. Klaus Hess Publishers, Göttingen & Windhoek.

KANGOMBE, F.N. 2007. Traditional non-wood uses of plants in central-northern

Namibia. Unpublished presentation, South African Association of Botanists Confrerence, Cape Town

KANGOMBE, F.N. 2007. Vegetation description of Ogongo Agricultural College and surrounds with the aid of satellite imagery. *Bsc. (Hons.) Dissertation*. Department of Plant Science, University of Pretoria, Pretoria.

KENT, M. AND COKER, P. 2003. *Vegetation Description and Analysis: A practical approach*. John Wiley & Sons Publishers, Chichester.

KLINTENBERG, P., M. SEELY, M. & C. CHRISTIANSSON, C. 2007. Local and national perceptions of environmental change in central-northern Namibia: Do they correspond? *Journal of Arid Environments* **69**: 506 – 525.

KREBS, C.J. 1994. *Ecology: The experimental analysis of distribution and abundance*. Fourth Edition. Harper Collins College Publishers. New York.

KREIKE, E.H.P.M. 1995. *The Ovambo agro-silvopastoral system: Traditional land use and indigenous natural resource management in central-northern Namibia*, Forestry publication No.4, Directorate of Forestry, Windhoek.

LUBBE, L., KATITI, A. & VAN ROOYEN, B. 2009. Rangeland survey in the southern grazing areas of Omusati and Oshana. Ministry of Agriculture, Water and Forestry. Windhoek.

MANNHEIMER, C. & CURTIS, B. (eds). 2009. *Le Roux & Müller's Field Guide to the Trees and Shrubs of Namibia*. Macmillan Education Namibia, Windhoek.

McCUNE, B. & GRACE, J.B. 2002. *Analysis of Ecological Communities*. MjM Software Designs, Oregon, USA.

MENDELSOHN, J., JARVIS, A., ROBERTS, C. AND ROBERTSON, T. 2002. *Atlas of Namibia: A portrait of the land and its people*. David Philip Publishers, Cape Town.

MENDEHLSON, J. E.L., OBEID, S. & ROBERTS, C. 2000. *A profile of central-northern Namibia*, Directorate of Environmental Affairs and Gamsberg Macmillan Publishers, Windhoek.

MILLER, R. mcG. 1997. The Owambo Basin of Northern Namibia. *Sedimentary Basins of the* World **3**: 237-268.

MILTON, S.J. & HOFFMAN, M.T. 1994. The application of state-and-transition models to rangeland research and management in arid succulent and semi-arid grassy Karoo, South Africa. *African Journal of Range and Forage Science* **11**: 18 - 26.

MINISTRY OF AGRICULTURE, WATER & FORESTRY. July 2009. *Crop prospects and food security situation report*. Windhoek.

MINISTRY OF ENVIRONMENT AND TOURISM. 2002. *Namibia: Initial National Communication to the United Nations Framework Convention on Climate Change*. Windhoek.

MUELLER-DOMBOIS, D. AND ELLENBERG, H. 1974. *Aims and methods of vegetation ecology*. John Wiley and Sons, New York.

MÜLLER, M.A.N. 2007. *Grasses of Namibia*. Revised Edition. Ministry of Agriculture, Water and Forestry. Windhoek.

NDEINOMA, A. 2001. Community-based management and utilization of natural resources at Ogongo State Forest. *B. Sc. (Hons.) Dissertation*. University of Stellenbosch. Cape Town.

ILLIUS, A.W. & O'CONNOR T.G. 2002. On non-equilibrium concepts in arid and semi-arid grazing systems. *Journal of Biogeography* **29**: 1595-1618.

SCHMIEDEL, U. & JÜRGENS, N. 2010. *Biodiversity in southern Africa* **2**: *Patterns and* *processes at regional scale.* Klaus Hess Publishers, Göttingen & Windhoek.

SCHOLES, R.J. & WALKER, B.H. 1993. *An African Savanna*. Cambridge University Press, Cambridge.

SCHOLES, R.J. & WALKER, B.H. 1997. Tree-grass interactions in Savannas. *Annual Review of Ecology and Systematics* **28**: 517-544.

SEELY, M., DIRKX, E., HAGER, C., KLINTENBERG, P., ROBERTS, C. & VON OERTZEN, D. 2008. Advances in desertification and climate change research: Are they accessible for application to enhance adaptive capacity? *Global and Planetary Change* **64**: 236-243.

SEELY, M. & MARSH, A. 1992. *Oshanas: sustaining people, environment and development in Central Owambo, Namibia*. Desert Research Foundation of Namibia and SIDA, Windhoek.

SKARPE, C. 1992. Dynamics of savanna ecosystems. *Journal of Vegetation Science* **3**: 293 - 300.

STRINGER, L. C., DYER, J. C., REED, M. S., DOUGILL, A. J., TWYMAN, C. & MKWAMBISI, D. 2009. Adaptation to climate change, drought and desertification: local insights to enhance policy in southern Africa. *Environmental Science & Policy* **12**: 748-765.

STROHBACH, B.J. 2000. *Veld degradation & bush encroachment*. Farmer's Day at Exelsior, Otjiwarongo, Osire and Kalkveld, Namibia.

STROHBACH, B.J. 2000. *Veld Degradation in Namibia*. 75th Anniversary Congress of the Namibian Scientific Society. Windhoek, Namibia.

STROHBACH, B.J. 2000. Vegetation degradation trends on the northern Oshikoto Region: The *Colophospermum mopane* shrublands. *Dinteria*. **26**: 63-75

STROHBACH, B.J. & AUSTERMÜHLE R. 2002. *Long-term compositional* *change of the Thornbush Savanna in Namibia: An example from a cattle farm in central Namibia*. Unpublished presentation, International Association for Vegetation Science Symposium, Porte Alegre, Brazil.

STROHBACH, B., COLE, D. & SEELY, M. 2002. *Environmental Impact Assessment on commercialization of the basketry industry depending on Makalani palm leaves as a resource of in central-northern Namibia*, Sigma One corporation and Desert Research Foundation of Namibia, Windhoek.

STROHBACH, B.J. & PETERSEN, A. 2007. Vegetation of the central Kavango woodlands in Namibia: An example from the Mile 46 Livestock Development Centre. *South African Journal of Botany* **73**: 391-401.

STROHBACH, M.M. 2002. Vegetation description and mapping along a strip transect in Central Namibia with the aid of satellite imagery. *M. Sc. Dissertation*. Department of Botany, University of Pretoria, Pretoria.

TAINTON, N.M. (ed.) 2000. *Pasture management in South Africa.* University of Natal Press, Pietermaritzburg.

TAINTON, N.M. (ed.) 1999. *Veld management in South Africa.* University of Natal Press, Pietermaritzburg.

TREWEEK, J. & WADSWORTH, R. 1999. *Geographical Information Systems for Ecology*. Addison Wesley Longman Publishers, Singapore.

VERBYLA, D.L. 1995. *Satellite remote sensing of natural resources*. CRC Press, USA.

VERLINDEN, A. & DAYOT. B. 2005. A comparison between indigenous environmental knowledge and a conventional vegetation analysis in north central Namibia. *Journal of Arid Environments* **62**: 143-175.

VERLINDEN, A., SEELY, M.K., & HILLYER, A. 2006. Settlement, trees and termites in Central North Namibia: A case of indigenous resource management. *Journal of Arid Environments* **66**: 307-335

VORSTER, M. 1982. The development of the ecological index method for assessing veld condition in the Karoo. *Proceedings of Grassland Society of South Africa* **17**: 84-89

KATJIUA. M. & WARD, D. 2007. Pastoralists' perceptions and realities of vegetation change and browse consumption in the northern Kalahari, Namibia. *Journal of Arid Environments* **69**: 716 – 730.

WERGER, M. J. A. 1974. On concepts and techniques applied in the Zurich-Montepellier method of vegetation survey. *Bothalia* **11**(3): 309-323.

WESTOBY, M., WALKER, B.H. & NOY-MEIR, I. 1989. Range management on the basis of a model which does not seek to establish equilibrium. *Journal of Arid Environments* **17**: 235 - 239.

WESTOBY, M., WALKER, B.H. & NOY-MEIR, I. 1989. Opportunistic management for rangelands not at equilibrium. *Journal of Range Management* **37**:262-264.

ZEIDLER, J., HANRAHAN, S. & SCHOLES M. 2002. Land use intensity affects range condition in arid to semi-arid Namibia. *Journal of Arid Environments* **52**: 389-403.

Personal Communications

Mr. Ben. Strohbach, Chief Agricultural Researcher, National Botanical Research Institute, Windhoek

Mr. Steve Carr, Senior Agricultural Researcher, National Botanical Research Institute, Windhoek

Prof. Dr. Alexander Gröngröft, Institute of Soil Science, University of Hamburg, Hamburg.

Prof. Dr. George Bredenkamp, Department of Plant Science, University of Pretoria, Pretoria.

Mr. Katshuna, Communal farmer, Omano go Ndjamba Village, Omusati Region

Mrs. Martha Frans, Communal farmer, Omano go Ndjamba Village, Omusati Region

Appendix

Appendix I: The standardized forms used for raw data collection during vegetation surveys in Namibia

Habitat Description

Observer:	Number:	Computer No:
Landscape:	Date:	Altitude:
Locality:	Region:	GPS reading: ° ' " S
	District:	° ' " E
	Owner:	Accuracy of GPS: (Schwarzeneck)
		Estimate from 1:50 000 map / General estimate

Landscape: **Local Topography:**

Level land						
LP	Plain	<8%	<100m/km	LPP	Plain	
				LPS	Sand drift plain	Covered by >50 % sand (unconsolidated)
				LPI	Interdunal street	
				LPD	Low dunefield	Plains with low dunes like hummock dunes
				LPF	Flood plain	Temporarry water logged, especially along river systems
				LPO	Oshana	Shallow channels of the Cuvelai delta
				LPM	Omuramba	Shallow, broad drainage lines of the erosion plains
LL	Plateau	<8%	<100m/km	LLP	Plateau	
LD	Depression	<8%	<100m/km	LDP	Pan	Seasonally water filled
LF	Low gradient footslope	<8%	<100m/km	LFF	Low gradient footslope	
LV	Valley floor	<8%	<100m/km	LVR	Dry river bed	
				LVBD	Dry river embankment	
				LVB	Perennial river embankment	
Sloping land						
SM	Medium gradient mountain	15-30 %	>600m/2km	SMM	Medium gradient mountain	
				SMF	Medium gradient footslope	
				SML	Medium gradient plateau	
SH	Medium gradient hill	8-30 %	>50 m/slope unit	SHH	Medium gradient hill	
SE	Medium gradient escarpment zone	15-30 %	<600m/2km	SER	River terrace	Especially along the Okavango and Omurambas in the Kalahari sand plateau
				SDP	Pan terrace / rim	
SR	Ridges	8-30 %	>50 m/slope unit	SRR	Rocky ridges	
				SRDF	Fossil dunes: foot	
				SRDS	Fossil dunes: slope	
				SRDC	Fossil dunes: crest	
				SRAS	Active dunes: slip face	
				SRAW	Active dunes: windward face	
SU	Mountainous highland	8-30 %	>600m/2km	SUU	Mountainous highland	
SP	Dissected plain	8-30 %	Variable	SPP	Dissected plain	
				SPA	Alluvial fan	
				SWC	Water courses and small rivers	
Steep land						
TM	High gradient mountain	>30 %	>600m/2km	TMM	High gradient mountain	
				TMF	High gradient footslope	
				TMB	Inselbergs, bornhardts	
TH	High gradient hill	>30 %	<600m/2km	THH	High gradient hill	
				THR	Rocky outcrops like dolerite koppies	
TE	High gradient escarpment zone	>30 %	>600m/2km	TEE	Escarpment	
				TET	Tallus slope	
TV	High gradient valleys	>30 %	Variable	TVC	Canyon slope	
				TWC	Steep water courses and ravines	
Land with composite landforms						
CV	Valley	>8 %	Variable	Other:		
CL	Narrow plateau	>8 %	Variable			
CD	Major depression	>8 %	Variable			

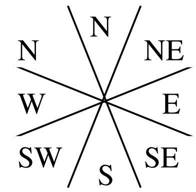
Slope:

Flat	Gently undulating	Undulating	Rolling	Moderately steep	Steep	Very steep
0 - 1°	1 - 3°	3 - 6°	6 - 9°	9 - 17°	17 - 30°	> 30°
(0-2%)	(2-5%)	(5-10%)	(10-15%)	(15-30%)	(30-60%)	(>60 %)

Stoniness: Cover & Size:

None	Gravel 0.2-2 cm	Pebbles 2-6 cm	Medium 6-20 cm	Large 20-60 cm	Rock >60 cm
0-2 %					
2-5 %					
5-15 %					
15-40 %					
40-80 %					
>80 %					

Aspect:



Lithology:

Acidic igneous rock	IA1	Granite	Clastic sediments	SC1	Conglomerate, Breccia
	IA2	Grano-diorite		SC2	Sandstone, greywacke, arkose
	IA3	Quartz-doprite		SC3	Siltstone, mudstone, claystone
	IA4	Rhyolite		SC4	Shale
Intermediate igneous rock	II1	Andesite, trachyte, phonolite	Organic sediments	SO1	Limestone and other carbonate rocks
	II2	Diorite-syenite		SO2	Marl and other mixtures
Basic igneous rock	IB1	Gabbro		SO3	Coals, bitumen and related rocks
	IB2	Basalt	Evaporites	SE1	Anhydrite, gypsum
	IB3	Dolerite		SE2	Halite
Ultrabasic igneous rock	IU1	Peridotite	Unconsolidated material	UF	Fluvial
	IU2	Pyroxenite		UL	Lacustrine
	IU3	Ilmenite, magnetite, ironstone, serpentine		UM UC	Marine Colluvial
Acidic metamorphic rock	MA1	Quartzite		UE	Eolian
	MA2	Gneiss, magmatite		UG	Glacial
Basic metamorphic rock	MB1	Slate, phylite (peltic rocks)		UP UO	Pyroclastic Organic
	MB2	Schist		UCa	Calcrete
	MB3	Gneiss rich in ferro-magnesian minerals	Other:		
	MB4	Metamorphic limestone (marble)			

Erosion:

None	Wind erosion	Wind deposition	Shifting sand	Sheet erosion	Rill erosion	Gully erosion	Deposition by water
Slight							
moderate							
Severe							
Extreme							

Surface Crusting:

None	Weak (soft or slightly hard, <0.5 cm thick)	Moderate (soft or slightly hard, >0.5 cm thick, or hard <0.5 cm)	Strong (hard crust >0.5 cm)	Clay bubbles (Schaumböden) present

Rooting Depth:

Very shallow < 30 cm	Shallow 30 – 50 cm	Moderately deep 50 – 100 cm	Deep 100 – 150 cm	Very deep > 150 cm

Disturbances:

None	Herbicides	Selective clearing	Mechanical clearing
Fire	Bush encroachment	Severe overgrazing	Deforestation
Other:			
Notes:			

Stratigraphy (Geology):
AEZ:
Growing Period Zone:
Soil Type:
Photos:

Vegetation Data

Observer:	Number:	Computer No:	
Landscape:	Date:	Altitude:	
Locality:	Region:	GPS reading: ° ‘ “ S	
	District:	° ‘ “ E	
	Owner:	Accuracy of GPS: (Schwarzeneck)	
		Estimate from 1:50 000 map	General estimate

Vegetation structure:

	Total	Trees	Shrubs >1m	Trees and shrubs	Shrubs <1m	Grasses	Herbs
Average height							
Total cover							
Vegetation structure:							
Th: High tree >20m Tt: Tall tree 10 – 20m Ts: Small tree 5 –1 0m Tl: Low tree 2- 5m Sh: High shrub 2 –5 m St: Tall shrub 1 – 2m Ss: Small shrub 0.5 – 1 m Sl: Low shrub <50cm							

Species composition:

Coll. No	Species	Abundance by growth form									
		T1		T2	T3	S1		S2		Hl	
		Th	Tt	Ts	Tl	Sh	St	Ss	Sl	G	H
	Total cover:										

Coll. No	Species	Abundance by growth form									
		T1		T2	T3	S1		S2		Hl	
		Th	Tt	Ts	Tl	Sh	St	Ss	Sl	G	H
	Total cover:										

Appendix II: The various degrees of fidelity, used for the selection of differential species. Adapted from Kent & Coker (2003).

Fidelity level	**Species types**	**Definition**
Fidelity 5	Exclusive species	Completely or almost completely confined to one community
Fidelity 4	Selective species	Found most frequently in a certain community but also rarely occurring in other communities
Fidelity 3	Preferential species	Present in several communities more or less abundantly, but predominant in one certain community, and there with a great deal of vigour
Fidelity 2	Indifferent species	Without a definite affinity for any particular community
Fidelity 1	Accidentals	Rare species, accidental intruders from another community or relics of a preceding community

Appendix III: A species list of all species encountered in Omusati and Oshana Regions during the survey period of 2006-2009, indicating frequency of occurrence and average non-zero covers per species across the 415 relevés.

Species name	Frequency	Average non-zero cover
Abutilon austro-africanum Hochr.	2	0.3
Acacia arenaria Schinz	61	4.69
Acacia ataxacantha DC.	10	1.3
Acacia erioloba E.Mey.	33	2.45
Acacia fleckii Schinz	27	1.94
Acacia hebeclada DC.	36	1.33
Acacia hebeclada DC. ssp. hebeclada	8	3.63
Acacia hebeclada DC. ssp. tristis A.Schreib.	15	3.83
Acacia kirkii Oliv.	4	1.38
Acacia luederitzii Engl.	30	3.95
Acacia mellifera (Vahl) Benth.	11	1.09
Acacia nebrownii Burtt Davy	3	6.5
Acacia nilotica (L.) Willd. ex Delile	113	1.89
Acacia senegal (L.) Willd.	20	1.33
Acacia tortilis (Forssk.) Hayne	2	3
Acalypha segetalis Müll.Arg.	8	0.3
Acanthosicyos naudinianus (Sond.) C.Jeffrey	32	1.61
Acanthospermum hispidum DC.	35	0.61
Achyranthes aspera L. var. aspera	43	0.54
Acrotome angustifolia G.Taylor	2	0.5
Acrotome inflata Benth.	74	0.95
Adansonia digitata L.	3	17.33
Aerva leucura Moq.	1	0.5
Aeschynomene indica L.	14	1.91
Albizia anthelmintica (A.Rich.) Brongn.	17	1.38
Aloe littoralis Baker	12	1.38
Aloe species	8	1.09
Aloe zebrina Baker	4	1.63
Alternanthera pungens Humb.	3	0.5
Amaranthus species	1	0.5
Amaranthus thunbergii Moq.	19	0.34
Ammannia baccifera L.	2	0.3
Anthephora pubescens Nees	10	1.4
Anthephora schinzii Hack.	197	2.22
Anticharis scoparia (E.Mey. ex Benth.) Hiern ex Schinz	2	0.5

Species name	Frequency	Average non-zero cover
Aponogeton junceus Lehm. ex Schltdl.	16	0.94
Aptosimum arenarium Engl.	10	0.8
Aptosimum decumbens Schinz	4	0.53
Aptosimum glandulosum E.Weber & Schinz	2	1.5
Aristida adscensionis L.	48	1.45
Aristida congesta Roem. & Schult.	29	0.58
Aristida effusa Henrard	1	0.5
Aristida meridionalis Henrard	5	0.44
Aristida pilgeri Henrard	4	0.63
Aristida rhiniochloa Hochst.	48	1.86
Aristida stipitata Hack.	13	0.94
Aristida stipoides Lam.	154	1.73
Asparagus bechuanicus Baker	13	0.35
Asparagus cooperi Baker	5	0.42
Asparagus exuvialis Burch.	12	0.3
Asparagus nelsii Schinz	69	0.76
Asparagus suaveolens Burch.	9	0.58
Asparagus virgatus Baker	9	0.62
Barleria lancifolia T.Anderson	1	0.5
Bauhinia petersiana Bolle	3	1.67
Becium filamentosum (Forssk.) Chiov.	1	1
Berchemia discolor (Klotzsch) Hemsl.	6	4.92
Bidens biternata (Lour.) Merr. & Sherff	15	0.39
Blepharis diversispina (Nees) C.B.Clarke	1	2
Blepharis fleckii P.G.Mey.	2	0.1
Blepharis integrifolia (L.f.) E.Mey. ex Schinz var. integrifolia	15	0.37
Blepharis leendertziae Oberm.	3	0.5
Blepharis obmitrata C.B.Clarke	4	0.3
Boophane disticha (L.f.) Herb.	4	0.3
Boscia albitrunca (Burch.) Gilg & Gilg-Ben.	4	1
Brachiaria deflexa (Schumach.) C.E.Hubb. ex Robyns	11	0.44
Brachiaria dura Stapf	2	10
Brachiaria nigropedata (Ficalho & Hiern) Stapf	2	0.3
Brachiaria xantholeuca (Schinz) Stapf	159	1.01
Buchnera hispida Buch.-Ham. ex D.Don	6	1.18
Bulbostylis hispidula (Vahl) R.W.Haines	237	0.76
Burkea africana Hook.	2	2
Burnatia enneandra P.Micheli	4	0.53
Calostephane marlothiana O.Hoffm.	24	0.96
Camptorrhiza strumosa (Baker) Oberm.	2	0.3
Caralluma peschii Nel	2	0.1

Species name	Frequency	Average non-zero cover
Catophractes alexandri D.Don	17	5.56
Celosia species	1	0.5
Cenchrus ciliaris L.	3	2
Ceropegia lugardae N.E.Br.	1	0.1
Ceropegia nilotica Kotschy	2	0.1
Ceropegia species	2	0.5
Chamaecrista absus (L.) Irwin & Barneby	17	0.53
Chamaecrista biensis (Steyaert) Lock	2	0.55
Chamaesyce inaequilatera (Sond.) Soják	122	0.42
Chenopodium olukondae (Murr) Murr	2	0.1
Chloris virgata Sw.	120	1.2
Chlorophytum calyptrocarpum (Baker) Kativu	2	0.5
Citrullus lanatus (Thunb.) Matsum. & Nakai	22	0.6
Cleome gynandra L.	12	0.3
Cleome hirta (Klotzsch) Oliv.	7	0.51
Cleome macrophylla (Klotzsch) Briq.	1	0.1
Cleome monophylla L.	7	0.46
Cleome rubella Burch.	44	0.48
Clerodendrum species	2	1
Clerodendrum ternatum Schinz	12	0.93
Colophospermum mopane (J.Kirk ex Benth.) J.Kirk ex J.Léonard	256	14.24
Combretum apiculatum Sond.	4	0.75
Combretum collinum Fresen.	40	9.54
Combretum imberbe Wawra	13	1.73
Combretum tenuipetiolatum Wickens	1	1
Commelina africana L.	5	0.42
Commelina benghalensis L.	71	0.49
Commelina forskaolii Vahl	9	0.32
Commelina livingstonii C.B.Clarke	1	0.1
Commelina species	4	0.2
Commelina subulata Roth	58	0.64
Commicarpus fallacissimus (Heimerl) Heimerl ex Oberm.	2	0.1
Commiphora africana (A.Rich.) Engl.	10	0.65
Commiphora angolensis Engl.	29	1.61
Commiphora glandulosa Schinz	55	1.4
Commiphora mollis (Oliv.) Engl.	2	1
Commiphora tenuipetiolata Engl.	3	0.83
Corallocarpus welwitschii (Naudin) Hook.f. ex Welw.	1	0.5
Corchorus tridens L.	39	0.35
Courtoisina cyperoides	3	0.23

Species name	Frequency	Average non-zero cover
Crinum macowanii Baker	2	0.75
Crinum rautanenianum Schinz	7	0.93
Crotalaria barkae Schweinf.	1	0.5
Crotalaria barnabassii Dinter ex Baker f.	1	0.1
Crotalaria flavicarinata Baker f.	1	0.5
Crotalaria pisicarpa Welw. ex Baker	59	0.98
Crotalaria platysepala Harv.	4	0.1
Crotalaria podocarpa DC.	22	0.4
Crotalaria species	1	0.5
Crotalaria sphaerocarpa Perr. ex DC.	11	0.32
Croton gratissimus Burch.	7	3.5
Cyathula lanceolata Schinz	2	1
Cycnium tubulosum (L.f.) Engl.	1	0.5
Cynodon dactylon (L.) Pers.	44	2.74
Cyperus amabilis Vahl	17	0.45
Cyperus compressus L.	30	0.5
Cyperus cuspidatus Kunth	4	0.4
Cyperus difformis L.	8	0.69
Cyperus digitatus Roxb.	1	2
Cyperus esculentus L.	4	0.63
Cyperus fulgens C.B.Clarke	47	0.55
Cyperus margaritaceus Vahl	3	0.37
Cyperus procerus Rottb.	5	4.82
Cyperus schinzii Boeck.	104	0.71
Cyphostemma congestum (Baker) Desc. ex Wild & R.B.Drumm.	19	0.47
Cyphostemma sandersonii (Harv.) Desc.	1	0.1
Dactyliandra welwitschii Hook.f.	1	0.1
Dactyloctenium aegyptium (L.) Willd.	100	0.89
Datura ferox L.	1	0.5
Datura inoxia Mill.	1	0.1
Dicerocaryum eriocarpum (Decne.) Abels	21	0.89
Dichapetalum tomentosum Engl.	2	0.3
Dichrostachys cinerea (L.) Wight & Arn.	49	3.04
Dicoma schinzii O.Hoffm.	64	0.68
Dicoma tomentosa Cass.	113	0.58
Digitaria gayana (Kunth) Stapf	3	0.67
Digitaria milanjiana (Rendle) Stapf	9	1.9
Digitaria seriata Stapf	3	0.87
Digitaria species	1	0.5
Diospyros lycioides Desf.	1	1
Diospyros mespiliformis Hochst. ex A.DC.	6	1.83

Species name	Frequency	Average non-zero cover
Dipcadi glaucum (Ker Gawl.) Baker	2	0.3
Dipcadi marlothii Engl.	2	0.1
Diplachne fusca (L.) P.Beauv. ex Roem. & Schult.	31	4.98
Dovyalis caffra (Hook.f. & Harv.) Hook.f.	2	0.3
Drimia species	1	0.5
Echinochloa colona (L.) Link	13	1.04
Echinochloa crus-galli (L.) P.Beauv.	6	2.33
Echinochloa stagnina (Retz.) P.Beauv.	2	10.25
Ehretia rigida (Thunb.) Druce	1	1
Eleocharis acutangula (Roxb.) Schult.	1	0.1
Eleocharis species	1	2
Elephantorrhiza elephantina (Burch.) Skeels	1	2
Elephantorrhiza schinziana Dinter	13	2.92
Elephantorrhiza suffruticosa Schinz	3	1.67
Elytrophorus globularis Hack.	4	0.75
Emilia ambifaria (S.Moore) C.Jeffrey	45	0.8
Endostemon tenuiflorus (Benth.) M.Ashby	5	0.42
Enneapogon cenchroides (Roem. & Schult.) C.E.Hubb.	65	1.37
Enneapogon desvauxii P.Beauv.	2	15
Eragrostis annulata Rendle ex Scott-Elliot	1	1
Eragrostis cilianensis (All.) F.T.Hubb.	47	3.38
Eragrostis cylindriflora Hochst.	3	0.67
Eragrostis dinteri Stapf	33	6.8
Eragrostis leersiiformis Launert	6	5.33
Eragrostis lehmanniana Nees	36	1.1
Eragrostis pallens Hack.	1	0.5
Eragrostis pilgeriana Dinter ex Pilg.	13	0.58
Eragrostis porosa Nees	30	3.95
Eragrostis rotifer Rendle	64	4.67
Eragrostis superba Peyr.	22	0.5
Eragrostis trichophora Coss. & Durieu	332	5.71
Eragrostis viscosa (Retz.) Trin.	150	1.62
Eriospermum abyssinicum Baker	1	0.5
Eriospermum bakerianum Schinz	16	1.28
Eriospermum rautanenii Schinz	11	0.65
Eriospermum species	1	0.1
Erythrococca menyharthii (Pax) Prain	5	0.8
Euclea divinorum Hiern	3	2
Euphorbia crotonoides Boiss.	1	0.5
Euphorbia forskalii J.Gay in Webb & Berthel.	3	0.5
Euphorbia monteiri Hook.f.	2	1.25

Species name	Frequency	Average non-zero cover
Evolvulus alsinoides (L.) L.	29	0.43
Felicia alba Grau	22	0.71
Ferraria glutinosa (Baker) Rendle	2	0.3
Ficus capreifolia Delile	2	0.35
Ficus sycomorus L.	3	3.67
Fimbristylis microcarya F.Muell.	11	0.91
Fockea multiflora K.Schum.	7	0.27
Gardenia volkensii K.Schum. ssp. spatulifolia (Stapf & Hutch.) Verdc.	3	0.37
Geigeria acaulis (Sch.Bip.) Benth. & Hook.f. ex Oliv. & Hiern	61	0.98
Geigeria alata (Hochst. & Steud.) Benth. & Hook.f. ex Oliv. & Hiern	1	0.5
Geigeria ornativa O.Hoffm.	106	0.75
Geigeria pectidea (DC.) Harv.	5	0.9
Gisekia africana (Lour.) Kuntze	236	0.56
Gloriosa superba L.	8	0.51
Gomphocarpus tomentosus Burch.	7	0.59
Gomphrena celosioides Mart.	66	0.53
Gossypium herbaceum L. ssp. africanum (Watt) Vollesen	1	1
Grewia avellana Hiern	1	0.1
Grewia falcistipula K.Schum.	2	0.5
Grewia flava DC.	21	1.05
Grewia flavescens Juss.	38	0.69
Grewia species	1	0.5
Grewia tenax (Forssk.) Fiori	1	0.5
Harpagophytum procumbens (Burch.) DC. ex Meisn.	6	0.43
Harpagophytum zeyheri Decne.	10	1.47
Helichrysum candolleanum H.Buek	74	0.74
Helinus spartioides (Engl.) Schinz ex Engl.	5	0.42
Heliotropium ciliatum Kaplan	2	0.75
Heliotropium marifolium Retz.	4	0.5
Heliotropium ovalifolium Forssk.	4	0.1
Heliotropium species	12	0.51
Heliotropium strigosum Willd.	4	0.88
Heliotropium zeylanicum (Burm.f.) Lam.	27	1.58
Hemizygia bracteosa (Benth.) Briq.	8	0.7
Hermannia guerkeana K.Schum.	3	0.37
Hermannia modesta (Ehrenb.) Mast.	72	0.42
Hermannia species	8	1.23
Hermannia tomentosa (Turcz.) Schinz ex Engl.	16	0.78
Hermbstaedtia argenteiformis Schinz	6	0.77
Hermbstaedtia odorata (Burch.) T.Cooke	7	1.09

Species name	Frequency	Average non-zero cover
Hermbstaedtia scabra Schinz	2	0.3
Hermbstaedtia species	1	0.1
Heteropogon contortus (L.) Roem. & Schult.	1	0.5
Hibiscus caesius Garcke	2	0.5
Hibiscus calyphyllus Cav.	8	0.45
Hibiscus castroi Baker f. & Exell	1	0.5
Hibiscus elliottiae Harv.	2	0.3
Hibiscus mastersianus Hiern	10	0.51
Hibiscus meeusei Exell	6	0.52
Hibiscus micranthus L.f.	6	0.37
Hibiscus rhabdotospermus Garcke	11	0.44
Hibiscus sidiformis Baill.	54	0.38
Hibiscus species	3	0.5
Hirpicium echinus Less.	12	0.43
Hirpicium gazanioides (Harv.) Roessler	2	0.75
Hirpicium gorterioides (Oliv. & Hiern) Roessler	108	1.65
Hirpicium species	14	0.71
Hoodia parviflora N.E.Br.	3	0.5
Hybanthus densifolius Engl.	1	0.5
Hypericum lalandii Choisy	4	0.3
Hyphaene petersiana Klotzsch	62	3.72
Indigastrum costatum (Guill. & Perr.) Schrire	6	0.85
Indigastrum parviflorm (B.Heyne ex Wight & Arn.) Schrire	6	0.37
Indigofera annua Milne-Redh.	2	0.3
Indigofera astragalina DC.	4	0.5
Indigofera charlieriana Schinz	132	0.46
Indigofera cryptantha Benth. ex Harv.	6	0.6
Indigofera daleoides Benth. ex Harv.	23	0.94
Indigofera flabellata Harv.	2	0.5
Indigofera flavicans Baker	60	0.87
Indigofera hololeuca Benth. ex Harv.	1	0.1
Indigofera holubii N.E.Br.	3	0.37
Indigofera schinzii N.E.Br.	1	0.5
Indigofera species	14	0.39
Indigofera torulosa E.Mey.	27	0.83
Ipomoea adenioides Schinz	1	0.5
Ipomoea bolusiana Schinz	13	0.35
Ipomoea coptica (L.) Roth ex Roem. & Schult.	90	0.5
Ipomoea hackeliana (Schinz) Hallier f.	19	0.44
Ipomoea hochstetteri House	10	0.26
Ipomoea magnusiana Schinz	10	0.35

Species name	Frequency	Average non-zero cover
Ipomoea sinensis (Desr.) Choisy	11	0.52
Jacquemontia tamnifolia (L.) Griseb.	4	0.3
Justicia exigua S.Moore	28	0.72
Justicia heterocarpa T.Anderson	1	0.1
Kleinia longiflora DC.	27	1.73
Kohautia aspera (B.Heyne ex Roth) Bremek.	121	0.51
Kohautia azurea (Dinter & K.Krause) Bremek.	177	0.76
Kohautia caespitosa Schnizl.	10	0.7
Kyllinga alata Nees	73	0.85
Kyllinga alba Nees	26	0.71
Kyllinga albiceps (Ridl.) Rendle	5	1
Kyllinga intricata Cherm.	10	0.39
Kyphocarpa angustifolia (Moq.) Lopr.	17	0.43
Lantana angolensis Moldenke	7	0.44
Lapeirousia littoralis Baker ssp. caudata (Schinz) Goldblatt	3	0.53
Lapeirousia rivularis Wanntorp	2	0.5
Lapeirousia species	3	0.5
Larryleachia dinteri (A.Berger) Plowes	1	0.5
Ledebouria cooperi (Hook.f.) Jessop	3	1.03
Leucosphaera bainesii (Hook.f.) Gilg	6	3.17
Limeum fenestratum (Fenzl) Heimerl	13	0.5
Limeum myosotis H.Walter	150	0.63
Limeum sulcatum (Klotzsch) Hutch.	23	0.61
Lindneria clavata (Mast.) Speta	2	0.5
Litogyne gariepina (DC.) Anderb.	4	3.38
Lonchocarpus nelsii (Schinz) Heering & Grimme	6	1.25
Lophiocarpus tenuissimus Hook.f.	12	0.43
Lotononis brachyantha Harms	15	0.37
Lycium eenii S.Moore	4	0.75
Lycopersicon esculentum Mill.	1	0.1
Maerua schinzii Pax	2	0.5
Mariscus albomarginatus C.B.Clarke	50	0.52
Mariscus confusus Vorster	1	0.5
Mariscus hamulosus (M.Bieb.) Hooper	2	0.1
Marsdenia sylvestris (Retz.) P.I.Forst.	4	0.5
Marsilea species	18	1.01
Marsilea vera Launert	10	0.76
Maytenus senegalensis (Lam.) Exell	6	1.33
Megaloprotachne albescens C.E.Hubb.	11	4.78
Melhania acuminata Mast.	5	0.5
Melinis nerviglumis (Franch.) Zizka	3	1.83

Species name	Frequency	Average non-zero cover
Melinis repens (Willd.) Zizka ssp. grandiflora (Hochst.) Zizka	31	1.62
Melinis repens (Willd.) Zizka ssp. repens	2	0.75
Merremia palmata Hallier f.	1	0.5
Microcharis disjuncta (J.B.Gillett) Schrire var. disjuncta	2	0.1
Microchloa caffra Nees	39	3.23
Microloma species	2	0.1
Mollugo cerviana (L.) Ser. ex DC.	143	0.46
Mollugo nudicaulis Lam.	6	0.3
Momordica balsamina L.	4	0.5
Momordica species	1	0.5
Monandrus squarrosus (L.) Vorster	130	0.8
Monechma genistifolium (Engl.) C.B.Clarke	5	3.2
Monechma spartioides (T.Anderson) C.B.Clarke	1	0.5
Monelytrum luederitzianum Hack.	9	3.56
Monsonia angustifolia E.Mey. ex A.Rich.	5	0.1
Monsonia senegalensis Guill. & Perr.	2	0.5
Mundulea sericea (Willd.) A.Chev.	18	5.89
Neorautanenia amboensis Schinz	2	0.75
Neptunia oleracea Lour.	1	2
Nerine laticoma (Ker Gawl.) T.Durand & Schinz	5	0.42
Nerine species	3	1.33
Nesaea species	13	0.48
Nymphaea nouchali Burm.f.	14	3.82
Nymphoides rautanenii (N.E.Br.) A.Raynal	2	20
Nymphoides species	2	0.75
Ochna pulchra Hook.	2	0.75
Ocimum americanum L.	20	0.74
Odyssea paucinervis (Nees) Stapf	58	3.4
Ophioglossum polyphyllum A.Braun	11	1.73
Orbeopsis lutea (N.E.Br.) L.C.Leach	7	0.34
Ornithogalum species	2	0.1
Orthanthera jasminiflora (Decne.) Schinz	37	1.22
Oryzidium barnardii C.E.Hubb. & Schweick.	1	20
Otoptera burchellii DC.	13	0.88
Ottelia exserta (Ridl.) Dandy	1	0.5
Oxygonum alatum Burch.	70	0.66
Ozoroa schinzii (Engl.) R.& A.Fern.	10	1.5
Panicum gilvum Launert	8	0.46
Panicum maximum Jacq.	1	2
Panicum species	2	1
Panicum trichonode Launert & Renvoize	21	4.46

Species name	Frequency	Average non-zero cover
Pavetta zeyheri Sond.	3	0.83
Pavonia burchellii (DC.) R.A.Dyer	4	0.4
Pavonia clathrata Mast.	2	0.5
Pechuel-Loeschea leubnitziae (Kuntze) O.Hoffm.	146	3.85
Peltophorum africanum Sond.	2	1.5
Pennisetum glaucum (L.) R.Br.	3	33.33
Pergularia daemia (Forssk.) Chiov.	11	0.64
Perotis patens Gand.	3	0.37
Petalidium engleranum (Schinz) C.B.Clarke	2	1.5
Phyllanthus maderaspatensis L.	1	0.1
Phyllanthus mendesii J.F.Brunel ex Radcl.-Sm.	1	0.1
Phyllanthus niruri L.	26	0.42
Phyllanthus omahekensis Dinter & Pax	26	0.63
Phyllanthus pentandrus Schumach. & Thonn.	25	0.34
Phyllobolus congestus (L.Bolus) Gerbaulet	1	0.5
Pogonarthria fleckii (Hack.) Hack.	254	2.61
Pogonarthria squarrosa (Roem. & Schult.) Pilg.	1	0.1
Pollichia campestris Aiton	2	0.3
Polycarpaea corymbosa (L.) Lam.	8	0.63
Polygala albida Schinz	1	0.5
Polygala erioptera DC.	4	0.4
Portulaca hereroensis Schinz	103	0.48
Portulaca kermesina N.E.Br.	10	0.42
Portulaca oleracea L.	2	0.5
Portulaca species	12	0.54
Psydrax livida (Hiern) Bridson	1	0.5
Pterodiscus aurantiacus Welw.	43	0.3
Pterygota augouardii Pellegr.	1	0.5
Pulicaria scabra (Thunb.) Druce	1	0.1
Pupalia lappacea (L.) A.Juss.	3	0.5
Pycnanthus marchalianus Ghesq.	2	0.3
Pycreus chrysanthus (Boeck.) C.B.Clarke	7	13.64
Raphionacme lanceolata Schinz	2	0.1
Raphionacme species	5	0.18
Raphionacme velutina Schltr.	11	0.21
Requienia sphaerosperma DC.	1	0.5
Rhigozum brevispinosum Kuntze	31	2.97
Rhus tenuinervis Engl.	5	1.5
Rhynchosia minima (L.) DC. var. minima	1	0.5
Rhynchosia sublobata (Schumach.) Meikle	1	1
Rhynchosia totta (Thunb.) DC.	1	0.5

Species name	Frequency	Average non-zero cover
Rhynchosia venulosa (Hiern) K.Schum.	11	0.55
Ruellia species	1	0.5
Salvadora persica L.	2	0.5
Sansevieria pearsonii N.E.Br.	2	1.25
Sarcostemma viminale (L.) R.Br.	2	0.3
Schinziophyton rautanenii (Schinz) Radcl.-Sm.	1	8
Schizachyrium exile (Hochst.) Pilg.	1	1
Schmidtia kalihariensis Stent	118	6.65
Schmidtia pappophoroides Steud.	31	1.55
Schoenoplectus corymbosus (Roth ex Roem. & Schult.) J.Raynal	1	5
Schoenoplectus muricinux (C.B.Clarke) J.Raynal	1	1
Schoenoplectus roylei (Nees) Ovcz. & Czukav.	12	1.25
Scilla nervosa (Burch.) Jessop	2	0.5
Sclerocarya birrea (A.Rich.) Hochst.	12	2.25
Sebaea exigua (Oliv.) Schinz	4	0.3
Seddera suffruticosa (Schinz) Hallier f.	8	0.58
Senna italica Mill.	14	0.61
Sericorema sericea (Schinz) Lopr.	2	1.55
Sesamothamnus guerichii (Engl.) E.A.Bruce	2	18.5
Sesamum alatum Thonn.	5	0.42
Sesamum pedalioides Welw. ex Hiern	10	0.26
Sesamum species	4	0.4
Sesamum triphyllum Welw. ex Asch.	42	0.44
Sesbania sesban (L.) Merr.	5	0.5
Sesuvium sesuvioides (Fenzl) Verdc.	107	0.47
Setaria sagittifolia (A.Rich.) Walp.	2	0.3
Setaria verticillata (L.) P.Beauv.	9	0.5
Sida cordifolia L.	47	1.98
Sida ovata Forssk.	13	0.52
Solanum catombelense Peyr.	6	0.5
Solanum delagoense Dunal	21	0.45
Solanum incanum L.	1	0.5
Solanum multiglandulosum Bitter	11	5.43
Solanum rigescens Jacq.	21	0.62
Solanum species	3	0.5
Spermacoce senensis (Klotzsch) Hiern	19	0.48
Sphaeranthus peduncularis DC.	9	0.83
Sporobolus conrathii Chiov.	2	0.5
Sporobolus coromandelianus (Retz.) Kunth	40	0.63
Sporobolus ioclados (Trin.) Nees	80	1.63

Species name	Frequency	Average non-zero cover
Sporobolus nebulosus Hack.	3	17
Sporobolus rangei Pilg.	2	2
Sporobolus species	9	3.72
Sporobolus spicatus (Vahl) Kunth	3	0.67
Stapelia species	14	0.39
Stipagrostis uniplumis (Licht.) De Winter	70	3.03
Striga bilabiata (Thunb.) Kuntze	2	0.5
Strophanthus amboensis (Schinz) Engl. & Pax	4	0.4
Stylosanthes fruticosa (Retz.) Alston	2	0.5
Talinum caffrum (Thunb.) Eckl. & Zeyh.	1	0.1
Talinum species	3	0.1
Tapinanthus guerichii (Engl.) Danser	2	0.5
Tapinanthus oleifolius (J.C.Wendl.) Danser	14	0.54
Tavaresia barklyi (Dyer) N.E.Br.	17	0.45
Tephrosia burchellii Burtt Davy	8	0.41
Tephrosia dregeana E.Mey.	24	0.52
Tephrosia lupinifolia DC.	31	0.48
Tephrosia purpurea (L.) Pers.	24	0.53
Terminalia prunioides M.A.Lawson	32	2.55
Terminalia sericea Burch. ex DC.	27	4.43
Trachyandra arvensis (Schinz) Oberm.	23	1.47
Trachyandra laxa (N.E.Br.) Oberm.	10	0.43
Tragia okanyua Pax	3	0.5
Tragia pogostemonoides Radcl.-Sm.	1	1
Tragus berteronianus Schult.	22	0.85
Tragus racemosus (L.) All.	93	0.86
Tragus species	1	0.5
Tribulus terrestris L.	30	0.59
Tribulus zeyheri Sond.	21	0.5
Tricholaena monachne (Trin.) Stapf & C.E.Hubb.	3	0.37
Trichoneura grandiglumis (Nees) Ekman	7	2.14
Trifolium tembense Fresen.	1	0.5
Triraphis schinzii Hack.	1	1
Triraphis species	1	0.5
Urginea altissima (L.f.) Baker	1	0.5
Urochloa brachyura (Hack.) Stapf	100	0.82
Vahlia capensis (L.f.) Thunb.	23	0.63
Vangueria infausta Burch.	17	1.82
Vernonia poskeana Vatke & Hildebr. ssp. botswanica G.V.Pope	67	0.71
Vigna oblongifolia A.Rich.	6	0.37
Vigna species	2	0.55

Species name	Frequency	Average non-zero cover
Walleria nutans J.Kirk	4	0.65
Waltheria indica L.	2	0.3
Willkommia newtonii Hack.	1	0.5
Willkommia sarmentosa Hack.	203	3.31
Xenostegia tridentata (L.) D.F.Austin & Staples	25	0.49
Xerophyta humilis (Baker) T.Durand & Schinz	4	0.5
Ximenia americana L.	9	0.72
Ximenia caffra Sond.	3	0.67
Zehneria marlothii (Cogn.) R.& A.Fern.	3	0.37
Ziziphus mucronata Willd.	13	1.12
Zornia glochidiata DC.	23	0.43
Zornia milneana Mohlenbr.	20	0.54

Appendix IV

Appendix IV (a): The Percentage Frequecny Synoptic Table for all associations (10) described in this study. The values indicate the percentage abundance of species in each association i.e. the number of times (expressed as a percentage) a species has been encountered in the releves assigned to that association. Important frequency values have been highlighted.

For ease of comparison and interpreatation, species have been listed alphabetically.

Percentage synoptic table

Community type		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
No. of relevés		**1**	**19**	**28**	**66**	**97**	**80**	**3**	**39**	**35**	**47**
Abutilon austro-africanum	*Abu*	.	.	.	.	.	1	.	3	.	.
Acacia arenaria	*Aca*	.	5	54	38	9	9	.	10	.	.
Acacia ataxacantha	*Aca*	.	.	.	.	.	1	.	.	20	4
Acacia erioloba	*Aca*	.	.	.	2	.	1	.	3	37	36
Acacia fleckii	*Aca*	.	.	.	.	.	13	.	15	20	9
Acacia hebeclada	*Aca*	.	21	50	15	.	3	.	5	.	9
Acacia hebeclada s. hebeclada	*Aca*	.	.	4	8	.	.	.	5	.	.
Acacia hebeclada s. tristis	*Aca*	.	.	14	14	1	.	.	.	.	2
Acacia kirkii	*Aca*	.	.	4	.	.	3	.	.	3	.
Acacia luederitzii	*Aca*	.	.	.	17	1	4	.	13	29	.
Acacia mellifera	*Aca*	.	.	.	2	.	.	.	3	26	.
Acacia nebrownii	*Aca*	.	.	.	.	.	.	.	3	6	.
Acacia nilotica	*Aca*	.	37	50	9	19	54	.	41	.	19
Acacia senegal	*Aca*	.	.	4	2	2	8	.	8	17	2
Acacia tortilis	*Aca*	.	.	.	3	.	.	.	.	.	.
Acalypha segetalis	*Aca*	.	.	.	.	.	10	.	.	.	.
Acanthosicyos naudinianus	*Aca*	.	.	4	2	.	.	.	3	51	23
Acanthospermum hispidum	*Aca*	.	5	14	15	2	5	.	13	6	15
Achyranthes aspera	*Ach*	.	5	14	2	2	34	.	13	.	6
Acrotome angustifolia	*Acr*	.	.	.	2	.	.	.	3	.	.
Acrotome inflata	*Acr*	.	5	11	23	3	14	.	38	51	17
Adansonia digitata	*Ada*	.	.	4	.	1	1	.	.	.	.
Aerva leucura	*Aer*	.	.	.	.	.	1	.	.	.	.
Aeschynomene indica	*Aes*	100	26	.	2	.	9	.	.	.	.
Albizia anthelmintica	*Alb*	.	.	4	3	2	1	.	8	23	.
Aloe littoralis	*Alo*	.	.	.	2	1	8	.	10	.	.
Aloe species	*Alo*	.	.	.	.	.	8	.	5	.	.
Aloe zebrina	*Alo*	.	.	.	.	3	.	.	3	.	.
Alternanthera pungens	*Alt*	.	.	11	.	.	.	.	.	.	.
Amaranthus species	*Ama*	.	.	.	2	.	.	.	.	.	.
Amaranthus thunbergii	*Ama*	.	.	14	.	6	6	100	3	.	.
Ammannia baccifera	*Amm*	.	.	4	.	1	.	.	.	.	.
Anthephora pubescens	*Ant*	.	.	.	2	.	1	.	.	23	.
Anthephora schinzii	*Ant*	.	42	25	58	57	78	.	54	3	11
Anticharis scoparia	*Ant*	.	.	.	.	2	.	.	.	.	.
Aponogeton junceus	*Apo*	.	47	14	.	1	3	.	.	.	.
Aptosimum arenarium	*Apt*	.	.	4	.	1	.	.	5	17	.
Aptosimum decumbens	*Apt*	.	.	11	.	.	1	.	.	.	.
Aptosimum glandulosum	*Apt*	.	.	.	.	.	.	.	5	.	.
Aristida adscensionis	*Ari*	.	11	29	3	5	14	.	44	6	2
Aristida congesta	*Ari*	.	.	14	.	19	1	.	5	3	6
Aristida effusa	*Ari*	.	.	.	.	.	.	.	3	.	.

Aristida meridionalis	*Ari*	.	.	.	.	2	.	.	.	9	.
Aristida pilgeri	*Ari*	.	.	.	.	.	4	.	3	.	.
Aristida rhiniochloa	*Ari*	.	.	.	2	.	33	.	28	23	4
Aristida stipitata	*Ari*	.	.	.	8	.	4	.	8	.	4
Aristida stipoides	*Ari*	.	21	11	55	23	61	.	46	9	40
Asparagus bechuanicus	*Asp*	.	.	7	.	2	10	.	3	.	.
Asparagus cooperi	*Asp*	.	21	.	2	.	.	.	.	.	.
Asparagus exuvialis	*Asp*	.	.	.	2	7	3	.	.	.	4
Asparagus nelsii	*Asp*	.	.	.	9	8	14	.	31	51	30
Asparagus suaveolens	*Asp*	.	16	.	.	1	6	.	.	.	.
Asparagus virgatus	*Asp*	.	.	.	.	7	1	.	.	3	.
Barleria lancifolia	*Bar*	.	.	.	.	.	.	.	.	3	.
Bauhinia petersiana	*Bau*	.	.	.	.	.	.	.	.	9	.
Becium filamentosum	*Bec*	.	.	.	2	.	.	.	.	.	.
Berchemia discolor	*Ber*	.	.	7	2	.	.	.	3	.	4
Bidens biternata	*Bid*	.	.	.	.	.	9	.	3	.	15
Blepharis diversispina	*Ble*	.	.	.	.	.	.	.	.	3	.
Blepharis fleckii	*Ble*	.	11	.	.	.	.	.	.	.	.
Blepharis integrifolia		.	.	14	8	3	.	.	8	.	.
Blepharis leendertziae	*Ble*	.	.	.	5	.	.	.	.	.	.
Blepharis obmitrata	*Ble*	.	16	.	.	.	1	.	.	.	.
Boophane disticha	*Boo*	.	.	.	6	.	.	.	.	.	.
Boscia albitrunca	*Bos*	.	.	.	.	.	.	.	.	.	9
Brachiaria deflexa	*Bra*	.	.	.	5	.	5	.	3	.	6
Brachiaria dura	*Bra*	.	11	.	.	.	.	.	.	.	.
Brachiaria nigropedata	*Bra*	.	.	.	3	.	.	.	.	.	.
Brachiaria xantholeuca	*Bra*	.	47	71	55	27	64	.	28	.	13
Buchnera hispida	*Buc*	.	.	.	8	.	.	.	3	.	.
Bulbostylis hispidula	*Bul*	.	68	71	64	63	68	67	28	3	70
Burkea africana	*Bur*	.	.	.	.	.	.	.	.	.	4
Burnatia enneandra	*Bur*	.	11	.	.	.	3	.	.	.	.
Calostephane marlothiana	*Cal*	.	.	.	.	.	.	.	10	57	.
Camptorrhiza strumosa	*Cam*	.	.	.	.	.	3	.	.	.	.
Caralluma peschii	*Car*	.	.	.	.	1	1	.	.	.	.
Catophractes alexandri	*Cat*	.	.	.	.	.	.	.	8	40	.
Celosia species	*Cel*	.	.	.	2	.	.	.	.	.	.
Cenchrus ciliaris	*Cen*	.	5	.	.	.	1	.	.	3	.
Ceropegia lugardae	*Cer*	.	.	.	.	.	.	.	.	.	2
Ceropegia nilotica	*Cer*	.	.	.	2	.	1	.	.	.	.
Ceropegia species	*Cer*	.	.	.	.	2	.	.	.	.	.
Chamaecrista absus	*Cha*	.	.	.	3	1	1	.	10	.	19
Chamaecrista biensis	*Cha*	.	.	.	2	.	.	.	.	.	2
Chamaesyce inaequilatera	*Cha*	.	.	50	23	30	45	.	41	6	21
Chenopodium olukondae	*Che*	.	.	4	.	.	1	.	.	.	.
Chloris virgata	*Chl*	.	37	32	12	19	73	67	23	6	15
Chlorophytum calyptrocarpum	*Chl*	.	.	7	.	.	.	.	.	.	.
Citrullus lanatus	*Cit*	.	.	7	3	.	5	33	21	11	2
Cleome gynandra	*Cle*	.	.	7	6	.	4	67	.	.	2
Cleome hirta	*Cle*	.	.	.	.	.	3	.	3	.	9
Cleome macrophylla	*Cle*	.	.	.	.	.	1	.	.	.	.
Cleome monophylla	*Cle*	.	.	.	.	.	8	.	3	.	.
Cleome rubella	*Cle*	.	.	.	33	1	8	.	10	6	19
Clerodendrum species	*Cle*	.	.	.	2	.	1	.	.	.	.
Clerodendrum ternatum	*Cle*	.	.	.	2	.	.	.	8	23	.
Colophospermum mopane	*Col*	.	63	18	8	98	100	33	64	66	21
Combretum apiculatum	*Com*	.	.	.	2	3	.	.	.	.	.
Combretum collinum	*Com*	.	.	.	.	.	1	.	.	.	83
Combretum imberbe	*Com*	.	11	4	5	.	4	.	3	.	6
Combretum tenuipetiolatum	*Com*	.	.	.	.	.	.	.	.	.	2
Commelina africana	*Com*	.	.	.	2	.	3	.	5	.	.
Commelina benghalensis	*Com*	.	5	.	11	6	49	.	28	6	11
Commelina forskaolii	*Com*	.	.	11	.	1	6	.	.	.	.
Commelina livingstonii	*Com*	.	.	.	.	.	1	.	.	.	.
Commelina species	*Com*	.	.	.	.	.	4	.	.	.	2
Commelina subulata	*Com*	.	37	25	8	3	39	33	10	.	.
Commicarpus fallacissimus	*Com*	.	.	4	.	.	.	.	.	.	2
Commiphora africana	*Com*	.	.	.	.	.	.	.	5	17	4
Commiphora angolensis	*Com*	.	.	.	.	.	.	.	3	40	30

Commiphora glandulosa	*Com*	.	.	.	3	5	13	.	28	51	19
Commiphora mollis	*Com*	.	.	.	.	1	1	.	.	.	.
Commiphora tenuipetiolata	*Com*	.	.	.	.	.	.	.	.	.	6
Corallocarpus welwitschii	*Cor*	.	.	.	2	.	.	.	.	.	.
Corchorus tridens	*Cor*	.	5	11	5	3	28	.	5	.	11
Courtoisina cyperoides	*Cou*	.	.	7	.	.	1	.	.	.	.
Crinum macowanii	*Cri*	.	.	4	2	.	.	.	.	.	.
Crinum rautanenianum	*Cri*	.	32	.	.	.	1	.	.	.	.
Crotalaria barkae	*Cro*	.	.	.	.	.	1	.	.	.	.
Crotalaria barnabassii	*Cro*	.	.	.	.	.	1	.	.	.	.
Crotalaria flavicarinata	*Cro*	.	.	.	.	.	.	33	.	.	.
Crotalaria pisicarpa	*Cro*	.	.	.	18	1	15	.	33	26	26
Crotalaria platysepala	*Cro*	.	.	.	.	.	.	.	.	.	9
Crotalaria podocarpa	*Cro*	.	.	11	2	.	10	.	5	.	17
Crotalaria species	*Cro*	.	.	.	.	.	.	.	.	3	.
Crotalaria sphaerocarpa	*Cro*	.	.	7	.	3	.	.	3	.	11
Croton gratissimus	*Cro*	.	.	.	.	.	.	.	.	11	6
Cyathula lanceolata	*Cya*	.	.	.	2	.	.	.	3	.	.
Cycnium tubulosum	*Cyc*	.	.	4	.	.	.	.	.	.	.
Cynodon dactylon	*Cyn*	.	11	61	30	2	3	.	3	.	.
Cyperus amabilis	*Cyp*	.	.	21	.	.	10	.	8	.	.
Cyperus compressus	*Cyp*	.	21	32	2	4	11	100	.	.	.
Cyperus cuspidatus	*Cyp*	.	.	.	.	2	1	.	3	.	.
Cyperus difformis	*Cyp*	.	.	18	.	3	.	.	.	.	.
Cyperus digitatus	*Cyp*	.	5	.	.	.	.	.	.	.	.
Cyperus esculentus	*Cyp*	.	5	.	2	.	3	.	.	.	.
Cyperus fulgens	*Cyp*	.	11	14	2	5	34	33	15	.	2
Cyperus margaritaceus	*Cyp*	.	.	.	2	.	.	.	.	.	4
Cyperus procerus	*Cyp*	.	16	.	.	.	3	.	.	.	.
Cyperus schinzii	*Cyp*	.	16	46	35	25	38	.	26	.	2
Cyphostemma congestum	*Cyp*	.	.	4	2	3	5	.	.	.	21
Cyphostemma sandersonii	*Cyp*	.	.	.	.	.	.	.	.	.	2
Dactyliandra welwitschii	*Dac*	.	.	.	.	.	1	.	.	.	.
Dactyloctenium aegyptium		.	37	54	39	10	38	100	13	.	9
Datura ferox	*Dat*	.	.	.	.	.	1	.	.	.	.
Datura inoxia	*Dat*	.	.	.	.	.	1	.	.	.	.
Dicerocaryum eriocarpum	*Dic*	.	.	.	8	.	.	.	.	.	34
Dichapetalum tomentosum	*Dic*	.	.	.	.	1	1	.	.	.	.
Dichrostachys cinerea	*Dic*	.	.	7	9	.	5	33	23	57	15
Dicoma schinzii	*Dic*	.	.	32	11	16	4	.	8	11	47
Dicoma tomentosa	*Dic*	.	.	4	14	5	49	33	64	74	15
Digitaria gayana	*Dig*	.	.	.	.	.	.	.	.	.	6
Digitaria milanjiana	*Dig*	.	.	4	9	1	1	.	.	.	.
Digitaria seriata	*Dig*	.	.	4	2	.	1	.	.	.	.
Digitaria species	*Dig*	.	.	.	2	.	.	.	.	.	.
Diospyros lycioides	*Dio*	.	.	.	.	.	.	.	3	.	.
Diospyros mespiliformis	*Dio*	.	5	4	2	.	4	.	.	.	.
Dipcadi glaucum	*Dip*	.	.	.	2	.	1	.	.	.	.
Dipcadi marlothii	*Dip*	.	.	.	2	.	.	.	3	.	.
Diplachne fusca	*Dip*	100	53	36	.	.	13	.	.	.	.
Dovyalis caffra	*Dov*	.	.	.	.	.	1	.	.	.	2
Drimia species	*Dri*	.	.	4	.	.	.	.	.	.	.
Echinochloa colona	*Ech*	.	.	36	.	1	3	.	.	.	.
Echinochloa crus-galli	*Ech*	.	26	.	.	.	1	.	.	.	.
Echinochloa stagnina	*Ech*	100	5	.	.	.	.	.	.	.	.
Ehretia rigida	*Ehr*	.	.	.	.	.	.	.	.	.	2
Eleocharis acutangula	*Ele*	.	5	.	.	.	.	.	.	.	.
Eleocharis species	*Ele*	.	.	.	2	.	.	.	.	.	.
Elephantorrhiza elephantina	*Ele*	.	.	.	.	.	.	.	3	.	.
Elephantorrhiza schinziana	*Ele*	.	.	.	.	.	.	.	3	34	.
Elephantorrhiza suffruticosa	*Ele*	.	.	.	.	.	.	.	3	6	.
Elytrophorus globularis	*Ely*	.	21	.	.	.	.	.	.	.	.
Emilia ambifaria	*Emi*	.	21	.	44	.	5	.	21	.	.
Endostemon tenuiflorus	*End*	.	.	.	.	.	5	.	.	.	2
Enneapogon cenchroides	*Enn*	.	.	.	2	.	25	.	28	77	13
Enneapogon desvauxii	*Enn*	.	.	.	.	.	.	.	5	.	.
Eragrostis annulata	*Era*	.	.	.	2	.	.	.	.	.	.
Eragrostis cilianensis	*Era*	.	63	32	6	.	19	.	5	11	2

Eragrostis cylindriflora	*Era*	.	.	.	.	.	.	67	.	.	2
Eragrostis dinteri	*Era*	.	.	.	.	.	.	.	18	63	9
Eragrostis leersiiformis	*Era*	.	.	.	2	.	.	.	8	6	.
Eragrostis lehmanniana	*Era*	.	.	.	.	7	3	.	10	.	49
Eragrostis pallens	*Era*	.	.	.	.	.	.	.	.	.	2
Eragrostis pilgeriana	*Era*	.	.	32	.	.	4	.	3	.	.
Eragrostis porosa	*Era*	.	5	.	14	1	24	.	.	.	.
Eragrostis rotifer	*Era*	.	68	32	.	11	34	67	5	.	.
Eragrostis superba	*Era*	.	.	14	.	8	10	.	3	.	2
Eragrostis trichophora	*Era*	.	74	93	98	93	93	67	79	6	60
Eragrostis viscosa	*Era*	.	11	57	15	92	14	67	38	.	11
Eriospermum abyssinicum	*Eri*	.	.	.	.	.	.	.	3	.	.
Eriospermum bakerianum	*Eri*	.	.	.	18	1	.	.	8	.	.
Eriospermum rautanenii	*Eri*	.	.	.	15	.	.	.	3	.	.
Eriospermum species	*Eri*	.	.	.	2	.	.	.	.	.	.
Erythrococca menyharthii	*Ery*	.	.	.	.	.	.	.	3	11	.
Euclea divinorum	*Euc*	.	.	.	.	.	1	.	.	.	4
Euphorbia crotonoides	*Eup*	.	.	.	.	.	.	.	.	.	2
Euphorbia forskalii	*Eup*	.	.	.	.	.	.	.	.	.	6
Euphorbia monteiroi	*Eup*	.	.	.	.	.	.	.	5	.	.
Evolvulus alsinoides	*Evo*	.	.	25	.	6	5	.	13	14	4
Felicia alba	*Fel*	.	.	4	3	8	10	.	8	.	.
Ferraria glutinosa	*Fer*	.	.	.	2	.	.	.	3	.	.
Ficus capreifolia	*Fic*	.	.	.	.	.	3	.	.	.	.
Ficus sycomorus	*Fic*	.	.	4	3	.	.	.	.	.	.
Fimbristylis microcarya	*Fim*	.	.	36	.	.	1	.	.	.	.
Fockea multiflora	*Foc*	.	.	.	.	.	8	.	.	3	.
Gardenia volkensii	*Gar*	.	.	4	.	.	3	.	.	.	.
Geigeria acaulis	*Gei*	.	.	18	.	32	18	.	21	9	.
Geigeria alata	*Gei*	.	.	.	2	.	.	.	.	.	.
Geigeria ornativa	*Gei*	.	26	54	27	30	23	.	31	26	.
Geigeria pectidea	*Gei*	.	.	.	3	.	.	.	8	.	.
Gisekia africana	*Gis*	.	21	54	56	56	85	33	38	14	79
Gloriosa superba	*Glo*	.	.	4	.	1	3	.	5	.	4
Gomphocarpus tomentosus	*Gom*	.	.	.	.	.	.	.	.	.	15
Gomphrena celosioides	*Gom*	.	21	96	3	19	15	.	3	.	4
Gossypium herbaceum s. africanu	*Gos*	.	.	.	.	.	.	.	3	.	.
Grewia avellana	*Gre*	.	.	.	.	.	.	.	3	.	.
Grewia falcistipula	*Gre*	.	.	.	.	.	.	.	3	3	.
Grewia flava	*Gre*	.	.	.	.	.	3	.	.	46	6
Grewia flavescens	*Gre*	.	.	.	.	6	4	.	10	26	34
Grewia species	*Gre*	.	.	.	.	.	1	.	.	.	.
Grewia tenax	*Gre*	.	.	.	.	.	1	.	.	.	.
Harpagophytum procumbens	*Har*	.	.	.	.	.	.	.	.	17	.
Harpagophytum zeyheri	*Har*	.	.	.	8	.	.	.	3	9	2
Helichrysum candolleanum	*Hel*	.	.	18	5	31	6	.	46	11	19
Helinus spartioides	*Hel*	.	.	.	.	.	.	.	3	11	.
Heliotropium ciliatum	*Hel*	.	.	.	2	.	.	.	3	.	.
Heliotropium marifolium	*Hel*	.	.	.	5	.	.	.	.	.	2
Heliotropium ovalifolium	*Hel*	.	.	14	.	.	.	.	.	.	.
Heliotropium species	*Hel*	.	.	.	3	.	1	.	3	.	17
Heliotropium strigosum	*Hel*	.	.	.	.	.	.	.	.	.	9
Heliotropium zeylanicum	*Hel*	.	.	.	.	.	.	.	8	54	11
Hemizygia bracteosa	*Hem*	.	.	.	.	.	.	.	.	14	6
Hermannia guerkeana	*Her*	.	.	.	.	.	.	.	.	.	6
Hermannia modesta	*Her*	.	.	14	32	2	13	.	31	26	30
Hermannia species	*Her*	.	.	4	.	.	3	.	.	.	11
Hermannia tomentosa	*Her*	.	.	.	5	.	1	.	3	29	2
Hermbstaedtia argenteiformis	*Her*	.	.	.	.	.	.	67	5	.	4
Hermbstaedtia odorata	*Her*	.	.	.	.	.	.	.	5	11	2
Hermbstaedtia scabra	*Her*	.	.	.	.	.	.	.	.	.	4
Hermbstaedtia species	*Her*	.	.	4	.	.	.	.	.	.	.
Heteropogon contortus	*Het*	.	.	.	.	.	1	.	.	.	.
Hibiscus caesius	*Hib*	.	.	.	.	.	.	.	3	3	.
Hibiscus calyphyllus	*Hib*	.	.	.	.	.	3	.	.	.	13
Hibiscus castroi	*Hib*	.	.	.	2	.	.	.	.	.	.
Hibiscus elliottiae	*Hib*	.	.	.	3	.	.	.	.	.	.
Hibiscus mastersianus	*Hib*	.	.	.	6	1	.	.	.	3	9

Hibiscus meeusei	*Hib*	.	.	.	.	.	1	.	3	.	9
Hibiscus micranthus	*Hib*	.	.	4	.	1	5	.	.	.	.
Hibiscus rhabdotospermus	*Hib*	.	.	.	.	.	1	.	.	.	21
Hibiscus sidiformis	*Hib*	.	.	.	5	18	34	.	5	.	11
Hibiscus species	*Hib*	.	.	.	.	.	1	.	.	.	4
Hirpicium echinus	*Hir*	.	11	.	.	10	.	.	.	.	.
Hirpicium gazanioides	*Hir*	.	.	.	3	.	.	.	.	.	.
Hirpicium gorterioides	*Hir*	.	32	4	76	8	21	.	41	6	17
Hirpicium species	*Hir*	.	.	39	.	.	4	.	.	.	.
Hoodia parviflora	*Hoo*	.	.	.	.	3	.	.	.	.	.
Hybanthus densifolius	*Hyb*	.	.	.	.	.	.	.	3	.	.
Hypericum lalandii	*Hyp*	.	.	4	.	1	3	.	.	.	.
Hyphaene petersiana	*Hyp*	.	5	82	44	.	3	.	3	.	13
Indigastrum costatum	*Ind*	.	.	.	.	.	4	.	3	.	4
Indigastrum parviflorm	*Ind*	.	.	.	.	.	4	.	3	.	4
Indigofera annua	*Ind*	.	.	.	.	.	1	.	3	.	.
Indigofera astragalina	*Ind*	.	.	.	.	.	.	.	.	.	9
Indigofera charlieriana	*Ind*	.	16	14	36	4	54	.	33	49	51
Indigofera cryptantha	*Ind*	.	5	.	.	.	1	.	.	.	9
Indigofera daleoides	*Ind*	.	.	.	2	.	.	.	5	23	26
Indigofera flabellata	*Ind*	.	.	4	.	.	.	.	.	.	2
Indigofera flavicans	*Ind*	.	.	21	20	.	.	.	8	11	72
Indigofera hololeuca	*Ind*	.	.	.	.	.	1	.	.	.	.
Indigofera holubii	*Ind*	.	.	4	.	.	.	.	3	.	2
Indigofera schinzii	*Ind*	.	.	.	2	.	.	.	.	.	.
Indigofera species	*Ind*	.	.	.	.	.	1	.	.	.	28
Indigofera torulosa	*Ind*	.	.	61	.	2	6	.	5	.	2
Ipomoea adenioides	*Ipo*	.	.	.	.	.	1	.	.	.	.
Ipomoea bolusiana	*Ipo*	.	.	.	6	.	5	.	3	9	2
Ipomoea coptica	*Ipo*	.	16	7	24	9	53	33	38	.	4
Ipomoea hackeliana	*Ipo*	.	.	.	5	.	.	.	.	.	34
Ipomoea hochstetteri	*Ipo*	.	.	.	.	.	5	.	.	.	13
Ipomoea magnusiana	*Ipo*	.	.	.	.	.	.	.	.	6	17
Ipomoea sinensis	*Ipo*	.	.	.	.	.	1	.	13	9	4
Jacquemontia tamnifolia	*Jac*	.	.	.	.	.	.	.	.	.	9
Justicia exigua	*Jus*	.	37	14	.	2	16	.	.	.	4
Justicia heterocarpa	*Jus*	.	.	.	.	.	.	.	.	.	2
Kleinia longiflora	*Kle*	.	.	.	2	10	8	.	13	.	11
Kohautia aspera	*Koh*	.	.	25	8	32	40	67	54	23	32
Kohautia azurea	*Koh*	.	47	39	39	62	63	100	26	.	17
Kohautia caespitosa	*Koh*	.	.	.	5	1	.	.	15	.	.
Kyllinga alata	*Kyl*	.	.	11	30	43	9	.	.	.	2
Kyllinga alba	*Kyl*	.	.	.	24	2	6	.	8	.	.
Kyllinga albiceps	*Kyl*	.	.	4	.	2	3	.	.	.	.
Kyllinga intricata	*Kyl*	.	26	.	.	.	5	.	3	.	.
Kyphocarpa angustifolia	*Kyp*	.	.	11	.	.	1	.	13	23	.
Lantana angolensis	*Lan*	.	.	.	2	2	3	.	3	3	.
Lapeirousia littoralis s. cauda	*Lap*	.	.	.	2	.	.	.	5	.	.
Lapeirousia rivularis	*Lap*	.	.	7	.	.	.	.	.	.	.
Lapeirousia species	*Lap*	.	.	4	.	.	.	.	.	.	4
Larryleachia dinteri	*Lar*	.	.	.	.	.	1	.	.	.	.
Ledebouria cooperi	*Led*	.	11	.	.	.	1	.	.	.	.
Leucosphaera bainesii	*Leu*	.	.	.	.	.	.	.	5	11	.
Limeum fenestratum	*Lim*	.	.	.	.	.	.	.	.	17	15
Limeum myosotis	*Lim*	.	32	29	36	22	75	.	28	.	43
Limeum sulcatum	*Lim*	.	.	.	26	.	5	.	5	.	.
Lindneria clavata	*Lin*	.	.	.	.	.	.	.	.	.	4
Litogyne gariepina	*Lit*	.	.	.	6	.	.	.	.	.	.
Lonchocarpus nelsii	*Lon*	.	.	.	.	.	.	.	.	6	9
Lophiocarpus tenuissimus	*Lop*	.	.	.	2	.	.	.	.	6	19
Lotononis brachyantha	*Lot*	.	.	4	.	4	5	.	13	.	2
Lycium eenii	*Lyc*	.	.	.	.	.	.	.	.	.	9
Lycopersicon esculentum	*Lyc*	.	.	.	.	.	1	.	.	.	.
Maerua schinzii	*Mae*	.	.	.	.	2	.	.	.	.	.
Mariscus albomarginatus	*Mar*	.	11	7	.	47	.	.	.	.	.
Mariscus confusus	*Mar*	.	.	.	.	.	.	.	3	.	.
Mariscus hamulosus	*Mar*	.	.	.	.	.	1	.	3	.	.
Marsdenia sylvestris	*Mar*	.	.	.	.	.	3	.	3	.	2

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Marsilea species		.	53	7	.	1	6	.	.	.	.
Marsilea vera	*Mar*	.	.	29	.	1	1	.	.	.	.
Maytenus senegalensis	*May*	.	.	.	.	.	.	.	3	11	2
Megaloprotachne albescens	*Meg*	.	.	.	3	.	.	.	.	.	19
Melhania acuminata	*Mel*	.	.	.	.	.	.	.	3	9	2
Melinis nerviglumis	*Mel*	.	.	.	.	.	.	.	.	9	.
Melinis repens s. grandiflora		.	.	.	.	.	5	.	15	43	13
Melinis repens s. repens	*Mel*	.	.	.	2	.	.	.	.	3	.
Merremia palmata	*Mer*	.	.	.	.	.	.	.	.	3	.
Microcharis disjuncta v. disjun	*Mic*	.	.	.	.	2	.	.	.	.	.
Microchloa caffra	*Mic*	.	.	4	24	12	5	.	15	.	.
Microloma species	*Mic*	.	.	.	.	2	.	.	.	.	.
Mollugo cerviana	*Mol*	.	.	32	27	64	55	100	15	.	2
Mollugo nudicaulis	*Mol*	.	.	.	.	2	5	.	.	.	.
Momordica balsamina	*Mom*	.	.	.	.	.	1	.	.	3	4
Momordica species	*Mom*	.	.	.	.	.	.	.	.	.	2
Monandrus squarrosus	*Mon*	.	26	54	45	19	64	67	23	.	.
Monechma genistifolium	*Mon*	.	.	.	.	.	.	.	8	6	.
Monechma spartioides	*Mon*	.	.	.	2	.	.	.	.	.	.
Monelytrum luederitzianum	*Mon*	.	.	.	3	.	.	.	10	9	.
Monsonia angustifolia	*Mon*	.	.	.	2	.	3	.	3	3	.
Monsonia senegalensis	*Mon*	.	.	.	.	.	.	.	.	3	2
Mundulea sericea	*Mun*	.	.	.	.	.	.	.	8	6	28
Neorautanenia amboensis	*Neo*	.	.	.	.	.	.	.	3	3	.
Neptunia oleracea	*Nep*	100	.	.	.	.	.	.	.	.	.
Nerine laticoma	*Ner*	.	.	.	.	.	6	.	.	.	.
Nerine species	*Ner*	.	.	.	5	.	.	.	.	.	.
Nesaea species	*Nes*	.	.	29	.	1	5	.	.	.	.
Nymphaea nouchali	*Nym*	100	21	21	.	.	4	.	.	.	.
Nymphoides rautanenii	*Nym*	.	11	.	.	.	.	.	.	.	.
Nymphoides species	*Nym*	.	.	.	.	.	3	.	.	.	.
Ochna pulchra	*Och*	.	.	.	.	.	.	.	.	.	4
Ocimum americanum	*Oci*	.	.	21	3	3	5	.	10	3	.
Odyssea paucinervis	*Ody*	.	.	14	52	7	4	.	21	6	.
Ophioglossum polyphyllum	*Oph*	.	.	.	15	.	.	.	3	.	.
Orbeopsis lutea	*Orb*	.	.	.	3	2	3	.	3	.	.
Ornithogalum species	*Orn*	.	.	.	.	2	.	.	.	.	.
Orthanthera jasminiflora	*Ort*	.	.	11	12	.	.	.	.	6	51
Oryzidium barnardii	*Ory*	100	.	.	.	.	.	.	.	.	.
Otoptera burchellii	*Oto*	.	.	.	.	.	.	.	3	34	.
Ottelia exserta	*Ott*	.	.	4	.	.	.	.	.	.	.
Oxygonum alatum	*Oxy*	.	.	.	38	.	9	.	18	66	17
Ozoroa schinzii	*Ozo*	.	.	.	.	.	.	.	.	29	.
Panicum gilvum	*Pan*	.	26	.	.	.	3	33	.	.	.
Panicum maximum	*Pan*	.	.	.	.	.	.	.	.	.	2
Panicum species	*Pan*	.	.	.	2	.	.	.	3	.	.
Panicum trichonode		.	37	14	12	.	1	.	3	.	.
Pavetta zeyheri	*Pav*	.	.	.	.	.	.	.	3	6	.
Pavonia burchellii	*Pav*	.	.	7	3	.	.	.	.	.	.
Pavonia clathrata	*Pav*	.	.	.	.	.	.	.	.	.	4
Pechuel-Loeschea leubnitziae	*Pec*	.	.	50	74	20	10	.	51	26	57
Peltophorum africanum	*Pel*	.	.	.	.	.	1	.	3	.	.
Pennisetum glaucum	*Pen*	.	.	.	.	.	.	100	.	.	.
Pergularia daemia	*Per*	.	.	.	2	.	.	.	.	6	17
Perotis patens	*Per*	.	.	.	.	.	.	.	.	.	6
Petalidium engleranum	*Pet*	.	.	.	.	.	.	.	.	6	.
Phyllanthus maderaspatensis	*Phy*	.	.	.	.	.	.	.	.	.	2
Phyllanthus mendesii	*Phy*	.	.	.	.	.	.	.	.	.	2
Phyllanthus niruri	*Phy*	.	5	.	.	1	20	33	3	.	13
Phyllanthus omahekensis	*Phy*	.	.	.	6	1	.	.	.	23	28
Phyllanthus pentandrus	*Phy*	.	.	7	.	11	1	.	3	.	21
Phyllobolus congestus	*Phy*	.	.	.	.	.	.	.	.	.	2
Pogonarthria fleckii	*Pog*	.	.	39	42	81	69	67	72	94	38
Pogonarthria squarrosa	*Pog*	.	.	.	.	.	.	.	.	.	2
Pollichia campestris	*Pol*	.	.	.	.	.	.	.	.	3	2
Polycarpaea corymbosa	*Pol*	.	.	.	2	.	.	.	10	9	.
Polygala albida	*Pol*	.	.	.	.	.	.	.	3	.	.
Polygala erioptera	*Pol*	.	.	.	.	.	1	.	3	6	.

Portulaca hereroensis	*Por*	.	11	4	3	62	39	.	15	.	2
Portulaca kermesina	*Por*	.	.	11	.	6	.	.	.	3	.
Portulaca oleracea	*Por*	.	.	.	.	.	1	33	.	.	.
Portulaca species	*Por*	.	.	14	.	2	8	.	.	.	.
Psydrax livida	*Psy*	.	.	.	2	.	.	.	.	.	.
Pterodiscus aurantiacus	*Pte*	.	.	11	5	19	19	.	.	.	9
Pterygota augouardii	*Pte*	.	.	.	.	.	.	.	.	.	2
Pulicaria scabra	*Pul*	.	.	.	.	.	.	.	.	.	2
Pupalia lappacea	*Pup*	.	.	.	3	.	.	.	3	.	.
Pycnanthus marchalianus	*Pyc*	.	.	.	.	.	1	.	.	.	2
Pycreus chrysanthus	*Pyc*	100	21	.	.	.	1	.	.	.	2
Raphionacme lanceolata	*Rap*	.	.	.	.	.	1	.	3	.	.
Raphionacme species	*Rap*	.	.	.	3	.	1	.	5	.	.
Raphionacme velutina	*Rap*	.	.	.	2	6	3	.	3	3	.
Requienia sphaerosperma	*Req*	.	.	.	.	.	.	.	.	.	2
Rhigozum brevispinosum	*Rhi*	.	.	.	2	1	1	.	8	60	9
Rhus tenuinervis	*Rhu*	.	.	.	.	.	1	.	3	6	2
Rhynchosia minima v. minima	*Rhy*	.	.	.	.	.	.	.	3	.	.
Rhynchosia sublobata	*Rhy*	.	.	.	.	.	.	.	.	3	.
Rhynchosia totta	*Rhy*	.	.	.	2	.	.	.	.	.	.
Rhynchosia venulosa	*Rhy*	.	.	.	.	.	.	.	3	20	6
Ruellia species	*Rue*	.	.	.	2	.	.	.	.	.	.
Salvadora persica	*Sal*	.	.	.	.	.	3	.	.	.	.
Sansevieria pearsonii	*San*	.	.	.	2	1	.	.	.	.	.
Sarcostemma viminale	*Sar*	.	.	.	.	.	.	.	.	.	4
Schinziophyton rautanenii	*Sch*	.	.	.	.	.	.	.	.	.	2
Schizachyrium exile	*Sch*	.	.	.	.	.	.	.	.	3	.
Schmidtia kalihariensis	*Sch*	.	.	18	26	11	1	.	51	91	68
Schmidtia pappophoroides	*Sch*	.	.	14	.	4	6	.	10	26	11
Schoenoplectus corymbosus	*Sch*	100	.	.	.	.	.	.	.	.	.
Schoenoplectus muricinux	*Sch*	.	.	4	.	.	.	.	.	.	.
Schoenoplectus roylei	*Sch*	.	21	11	.	4	1	.	.	.	.
Scilla nervosa	*Sci*	.	.	.	2	.	.	.	3	.	.
Sclerocarya birrea	*Scl*	.	.	7	8	.	.	.	3	.	9
Sebaea exigua	*Seb*	.	.	4	.	1	3	.	.	.	.
Seddera suffruticosa	*Sed*	.	.	.	.	1	.	.	3	17	.
Senna italica	*Sen*	.	.	29	.	1	3	.	5	.	2
Sericorema sericea	*Ser*	.	.	.	2	.	.	.	3	.	.
Sesamothamnus guerichii	*Ses*	.	.	.	.	.	.	.	5	.	.
Sesamum alatum	*Ses*	.	.	.	.	.	.	.	.	.	11
Sesamum pedalioides	*Ses*	.	.	.	.	.	3	.	.	.	17
Sesamum species	*Ses*	.	.	.	.	.	.	33	8	.	.
Sesamum triphyllum	*Ses*	.	.	.	11	1	1	33	13	66	9
Sesbania sesban	*Ses*	.	.	4	2	.	3	33	.	.	.
Sesuvium sesuvioides	*Ses*	.	21	39	35	8	60	67	26	.	2
Setaria sagittifolia	*Set*	.	.	.	.	.	3	.	.	.	.
Setaria verticillata	*Set*	.	.	7	.	.	6	.	3	.	2
Sida cordifolia	*Sid*	.	.	7	26	4	1	.	3	.	47
Sida ovata	*Sid*	.	11	21	.	.	4	.	3	.	2
Solanum catombelense	*Sol*	.	.	.	.	2	.	.	.	11	.
Solanum delagoense	*Sol*	.	.	14	3	4	4	.	8	9	4
Solanum incanum	*Sol*	.	.	.	.	.	1	.	.	.	.
Solanum multiglandulosum	*Sol*	.	11	4	9	1	1	.	.	.	.
Solanum rigescens	*Sol*	.	11	18	.	4	4	.	5	3	9
Solanum species	*Sol*	.	.	4	.	.	.	.	.	.	4
Spermacoce senensis	*Spe*	.	.	4	2	.	1	.	3	.	32
Sphaeranthus peduncularis	*Sph*	.	.	.	.	8	.	.	3	.	.
Sporobolus conrathii	*Spo*	.	.	.	.	.	.	.	5	.	.
Sporobolus coromandelianus	*Spo*	.	.	61	3	5	15	.	5	.	4
Sporobolus ioclados	*Spo*	.	37	43	44	2	36	.	3	.	.
Sporobolus nebulosus	*Spo*	.	.	.	.	.	.	.	8	.	.
Sporobolus rangei	*Spo*	.	.	.	2	.	.	.	3	.	.
Sporobolus species	*Spo*	.	.	.	12	.	.	.	3	.	.
Sporobolus spicatus	*Spo*	.	.	.	3	.	.	.	.	3	.
Stapelia species	*Sta*	.	.	.	.	11	.	.	3	.	4
Stipagrostis uniplumis	*Sti*	.	.	.	2	.	21	.	41	83	15
Striga bilabiata	*Str*	.	.	.	.	1	.	.	3	.	.
Strophanthus amboensis	*Str*	.	.	.	2	.	4	.	.	.	.

Stylosanthes fruticosa	*Sty*	.	.	.	.	.	.	.	3	3	.
Talinum caffrum	*Tal*	.	.	.	.	.	1	.	.	.	.
Talinum species	*Tal*	.	.	.	.	.	4	.	.	.	.
Tapinanthus guerichii	*Tap*	.	.	.	.	.	.	.	.	.	4
Tapinanthus oleifolius	*Tap*	.	.	.	3	.	8	.	5	.	9
Tavaresia barklyi	*Tav*	.	.	7	.	8	5	.	3	.	4
Tephrosia burchellii	*Tep*	.	.	.	.	.	1	.	.	.	15
Tephrosia dregeana	*Tep*	.	.	.	26	.	3	.	8	.	4
Tephrosia lupinifolia	*Tep*	.	.	.	5	.	.	.	.	11	51
Tephrosia purpurea	*Tep*	.	.	.	.	1	.	.	3	40	17
Terminalia prunioides	*Ter*	.	.	7	2	3	6	.	21	37	.
Terminalia sericea	*Ter*	.	.	.	.	.	.	.	3	37	28
Trachyandra arvensis	*Tra*	.	.	4	23	1	.	.	3	.	11
Trachyandra laxa	*Tra*	.	5	.	12	.	.	.	3	.	.
Tragia okanyua	*Tra*	.	.	.	.	.	.	.	.	9	.
Tragia pogostemonoides	*Tra*	.	.	.	2	.	.	.	.	.	.
Tragus berteronianus	*Tra*	.	.	7	8	4	5	.	3	.	13
Tragus racemosus	*Tra*	.	.	46	12	24	39	.	21	3	19
Tragus species	*Tra*	.	.	.	.	.	1	.	.	.	.
Tribulus terrestris	*Tri*	.	.	11	11	2	13	33	8	.	9
Tribulus zeyheri	*Tri*	.	.	.	3	.	4	.	5	.	30
Tricholaena monachne	*Tri*	.	.	.	.	.	.	.	.	.	6
Trichoneura grandiglumis	*Tri*	.	.	.	.	.	.	.	3	17	.
Trifolium tembense	*Tri*	.	.	4	.	.	.	.	.	.	.
Triraphis schinzii	*Tri*	.	.	.	.	.	.	.	3	.	.
Triraphis species	*Tri*	.	.	.	.	.	1	.	.	.	.
Urginea altissima	*Urg*	.	.	.	.	.	.	.	.	.	2
Urochloa brachyura	*Uro*	.	11	57	39	.	51	.	23	.	13
Vahlia capensis	*Vah*	.	21	.	3	14	1	.	5	.	.
Vangueria infausta	*Van*	.	5	.	2	.	1	.	.	.	30
Vernonia poskeana	*Ver*	.	.	4	9	27	.	.	28	60	4
Vigna oblongifolia	*Vig*	.	.	.	.	.	8	.	.	.	.
Vigna species	*Vig*	.	5	.	.	.	1	.	.	.	.
Walleria nutans	*Wal*	.	.	.	2	.	.	.	3	.	4
Waltheria indica	*Wal*	.	.	.	3	.	.	.	.	.	.
Willkommia newtonii	*Wil*	.	.	.	.	.	1	.	.	.	.
Willkommia sarmentosa	*Wil*	.	58	82	77	63	66	33	8	.	.
Xenostegia tridentata	*Xen*	.	.	.	.	2	1	.	3	31	21
Xerophyta humilis	*Xer*	.	.	4	.	1	3	.	.	.	.
Ximenia americana	*Xim*	.	.	.	.	.	5	.	.	3	9
Ximenia caffra	*Xim*	.	.	.	.	.	.	.	.	.	6
Zehneria marlothii	*Zeh*	.	.	.	.	.	1	.	.	.	4
Ziziphus mucronata	*Ziz*	.	11	4	.	.	5	.	5	9	2
Zornia glochidiata	*Zor*	.	.	18	5	5	3	.	5	.	13
Zornia milneana	*Zor*	.	.	.	.	1	1	.	31	9	6

Appendix IV (b)

The TWINSPAN/Phytosociological Table, outlining the plant communities of Omusati and Oshana Regions, central-northern Namibia is herewith attached.

For logical presentation of TWINSPAN results, the phytosociological table has been reduced to a maximum of 10 relevés per association. This was done using the "rand()" function in excel , where each relevé is randomly assigned a unique value. All relevés in a single community is then sorted from largest to smallest, followed by deletion of excess relevés. Rare species were also omitted from this summary table. A full inventory of all species encountered in the study is given in Appendix III. Diagnostic species groups for each association have been enclosed in the black-margin squares while some groups of species that distinctly over-lap between adjacent associations have been highlighted in blue-margin squares.

Appendix V: The Vegetation Map of Omusati and Oshana regions, showing the different vegetation units mapped in this study, upto sub-community level.

Appendix VI: A table indicating the monitoring plots of Ogongo and Omano observatories for which vegetation data were analysed in this study.

Relevé number in 2006	Observatory plot number	Observatory name
89001	Plot 00	Ogongo
89002	Plot 02	Ogongo
89003	Plot 03	Ogongo
89004	Plot 13	Ogongo
89005	Plot 31	Ogongo
89007	Plot 22	Ogongo
89008	Plot 25	Ogongo
89009	Plot 38	Ogongo
89010	Plot 29	Ogongo
89011	Plot 53	Ogongo
89012	Plot 64	Ogongo
89013	Plot 65	Ogongo
89017	Plot 85	Ogongo
89018	Plot 96	Ogongo
89026	Plot 85	Omano
89032	Plot 25	Omano
89034	Plot 21	Omano
89036	Plot 92	Omano
89037	Plot 71	Omano
89044	Plot 01	Omano

Appendix VII: A table indicating total monthly rainfall records for Ondangwa Meteorological Station, between 2006 and 2009.

	Year			
Month	2006	2007	2008	2009
Jan	240	100.2	195.5	213.2
Feb	132	48.7	177.5	378.4
Mar	***	78.6	164.2	94.4
Apr	53.9	24.3	2.6	7.6
May	0	6.3	1.5	0
Jun	0	0	0	0
Jul	***	0	0	0
Aug	0	0	0	0
Sep	***	0	0	0
Oct	80.1	11.8	0	21.3
Nov	23.3	24.7	73.4	58
Dec	10.9	5	77.5	***

*** = no data available

Acknowledgements

I wish to thank my academic supervisor Prof. G.J. Bredenkamp as well as the entire Department of Plant Sciences of the University of Pretoria for their guidance and endless support throughout the duration of the study. Many thanks to my mentor Mr. Ben Strohbach, Head of the National Botanical Research Institute for his continued guidance and valued input throughout the proceedings of this work.

I would also like to thank the management at Ogongo Agricultural College and the surrounding communities for the opportunity, facilities and co-operation, particularly during the data collection phase of the study. The staff of the National Botanical Research Institute are also acknowledged for their assistance during fieldwork as well as identification of specimens collected in the study. Remote sensing and GIS assistance received through the Department of Geography at the Julius-Maximillian University in Wüerzburg, Germany is also greatly appreciated.

My friends and family have been very supportive during the ongoing acitivities of this research and for that, I am grateful.

This work was funded by BIOTA southern Africa as part of the BIOLOG programme under the German Federal Ministry of Education and Research.