A PHYTOSOCIOLOGICAL CLASSIFICATION OF THE VEGETATION OF ETOSHA HEIGHTS PRIVATE GAME RESERVE, NAMIBIA

Vimbai J. Marufu

Thesis submitted in partial fulfillment of the requirements for the degree of Master of Natural Resources Management at the Namibia University of Science and Technology

NAMIBIA UNIVERSITY OF SCIENCE AND TECHNOLOGY

Supervisor: Prof Ben Strohbach

(Namibia University of Science and Technology)

April 2023

Declaration

I, *Vimbai Marufu*, hereby declare that the work contained in the thesis entitled: *A phytosociological classification of the vegetation of Etosha Heights Private Game Reserve, Namibia* is my own original work and that I have not previously in its entirety or in part submitted it at any university or higher education institution for the award of a degree.

Signature:…………………………………………………… Date: …13 February 2023……

Retention and Use of Thesis

I, *Vimbai Marufu*, being a candidate for the degree of *Master of Natural Resources Management* accept the requirements of the Namibia University of Science and Technology relating to the retention and use of theses deposited in the Library and Information Services.

In terms of these conditions, I agree that the original of my thesis deposited in the Library and Information Services will be accessible for purposes of study and research, in accordance with the normal conditions established by the Librarian for the care, loan or reproduction of theses.

Signature:... Date: 13 February 2023

Table of Contents

Table of Contents iv
List of Figures vi
List of Tables viii
List of Acronyms ix
Acknowledgements x
Thesis outline xii
Abstract xiii
Chapter 1: General Introduction 1
1.1 Thematic background 1
1.2 Phytosociological classification of plants 2
1.3 Vegetation studies in Namibia 5
1.4 Landscape conservation 6
1.5 Administrative and economic history 7
1.6 Research Objectives 10
1.6.1 Statement of the Problem 10
1.6.2 Objectives 10
Chapter 2: The manuscript 11
A phytosociological description of the vegetation of Etosha Heights Private Reserve, Namibia 12
Abstract 12
Introduction 13
Methods 14
Study area 14
Field surveys 16
Soil sampling and analysis 16
Data analysis 17
Environmental gradients 18
Mapping 18
Results 19
A. *Combretum apiculatum–Terminalia prunioides* mountain veld 24

1. *Commiphora glaucescens–Combretum apiculatum* association ... 24
2. *Vachellia reficiens–Terminalia prunioides* association ... 25
3. *Commiphora glandulosa–Bothriochloa radicans* association ... 27
4. *Schmidtia kalahariensis–Combretum apiculatum* association ... 28
B. *Eragrostis trichophora–Setaria verticillata* wetlands and ecotones ... 28
5. *Eragrostis trichophora–Tragus racemosus* ... 29
6. *Aristida hordeacea–Panicum coloratum* ... 29
7. *Eragrostis porosa–Dichrostachys cinerea* ... 29
C. *Monechma genistifolium–Stipagrostis hirtugluma* savanna shrublands ... 31
8. *Petalidium englerianum–Eragrostis porosa* association ... 32
9. *Monechma genistifolium–Enneapogon desvauxi* grasslands and pans ... 33
9.1 *Gossypium triphyllum–Boscia albitrunca* ... 33
9.2 *Leucosphaera bainesii–Cenchrus ciliaris* ... 34
10.1 *Catophractes alexandrii–Leucosphaera bainesii* association ... 34
10.2 *Monechma genistifolium–Eragrostis echinochloidea association* ... 34
11. *Leucosphaera bainesii–Eragrostis porosa association* ... 35
Species Richness and diversity ... 38
Environmental gradients ... 39
Mapping ... 41
Discussion and conclusion ... 44
Comparisons to other vegetation surveys ... 45
Threatened habitats ... 46
Veld condition ... 47
Author contributions ... 48
References ... 49
Appendix 1 A phytosociological table of the vegetation of Etosha Heights Private Game reserve 57

List of Figures

Figure 1 Flowchart of stages in the subjective classification of relevés using the Braun-Blanquet method (adapted from Kent 2012) 4

Figure 2 Schematic workflow for a vegetation survey, as proposed by Strohbach (2001) 6

Figure 3 Map showing protected areas in Namibia adopted from (NACSO 2022)........ 9

Figure 4 Map showing location of study area, mountainous terrain and location of sampled points. Data source: Satelite image: Bing images; Etosha Heights boundaries: Namibia geo portal 14

Figure 5 Map showing (a) rainfall isohytes and tributaries and (b) climate diagram Data sources: Rainfall isohytes and tributaries: NARIS 2001; Climate diagram: (Walter et al. 1975); Climate data: NASA Ceres data. Geology: Geological Survey (1980) 15

Figure 6 Dendrogram of the modified TWINSPAN classification of the mountain relevés division into 4 associations. 20

Figure 7 Dendrogram of the modified TWINSPAN classification of the plains relevés showing how 9 clusters were condensed into 7 associations (Association 5 – 11) and 4 sub-associations (Association 9.1, 9.2, 10.1 and 10.2). 20

Figure 8 An illustration of the 4 mountain associations. (a)showing the steep slopes of association 1 (b) showing the stoniness of association 2; (c) illustrating the tall mopane clusters as an indication of deeper sands in association 3; and (d) Open shrubland dominated by Schmidtia kalahariensis on fairly red sand of association 4. 26

Figure 9 Box and whisker plots showing the various structure components of (a) Association 1, (b) Association 2 and (c) Association 3 and (d) Association 4 27

Figure 10: An illustration of the three wetlands associations a. showing a sparsely wooded grassland of Association 5, b. showing sloping land that occasionally floods typical of Association 6, and c. riparian woodlands of Association 7 30

Figure 11 Box and whisker plots showing the various structure components of wetlands associations (a) Association 5, (b) Association 6 and (c) Association 7 31

Figure 12: An illustration of the structural components of association 8. Note the stone cover and abundance of dwarf shrubs. 32

Figure 13 Box and whisker plots showing average structure of the various grassland associations. 36

Figure 14 Images summarizing the physical appearance of the various grassland associations. 37

Figure 15 Box and whisker plots illustrating the vegetation structure of Association 11 (a) and the photograph illustrating the diversity of the herb layer and the somewhat loose soil and distribution of dwarf shrubs Monechma genistifolium and Leucosphaera bainesii (b). 37

Figure 16 The Shannon and Simpson diversity indices of the vegetation of Etosha Heights. 38

Figure 17 Ordination diagram of the complete data set showing the clear separation of grassy pans (associations 9 and 10) and the mountains (associations1 – 4) indicated as convex hulls 40

Figure 18 Ordination of the mountain habitats indicated as convex hulls with environmental factors as bi-plots 40

Figure 19 Ordination diagram of the plains habitats 41

Figure 20 The vegetation map of Etosha Heights Private Game Reserve showing the summary of vegetation associations of the study area. 44

List of Tables

Table 1. Synoptic table for the vegetation of Etosha Heights Private Game Reserve illustrating the 11 vegetation associations.. 20

Table 2 Table of mapping units of the vegetation map of Etosha Heights Private Game Reserve. 42

List of Acronyms

asl – above sea level

EHPR – Etosha Heights Private Reserve

ENP – Etosha National Park

NJE – Namibia Journal of Environment

NMS – Non-metric multidimensional scaling

NOLIDEP – Northern Regions Livestock Development Projects

NUST – Namibia University of Science and Technology

QGIS – Qantum Geographic Information Systems

SAGA – System for Automated Geoscientific Analysis

SARDEP – Sustainable Animal and Range Development Program

SDGs – Sustainable Development Goals

SOTER – Global and National Soils and Terrain Digital Database (FAO 1993)

TWINSPAN – Two Way Indicator Species Analysis (Roleček et al 2009)

WIND – National Herbarium of Namibia

Acknowledgements

I wish to acknowledge the patience, guidance and endless support of my supervisor Prof. B. J. Strohbach. He has been more than just a supervisor. This is sincerely appreciated.

I would also like to thank my field partner A. Kanduvarisa for insightful discussions we had during fieldwork and to the entire team at Etosha Heights for a convenient accommodation. A special thank you to Mr John and Mr Natangwe, the mechanic Mr Mr Robert for always being ready to help when we were stuck with the car. The farmers that were interviewed Mr Berger, Mr Kippi and Mr H. Kreiner

Another big thank you to my husband Mr A. Makosa for taking up my family duties the entire time of my study.

The help and advise from my peers, Miss L. Naftal for insightful discussions during data analysis, Mr R. Hering, Nust internship students Mr Joseph and Mr Ezikiel are also acknowledged and appreciated.

My sincere gratitude to the Ministry of Agriculture Water and Forestry and the entire staff including the interns for assisting me with soil analysis, and the staff at NBRI for their assistance with plant identification.

This work was part of the ORYCS-project within the SPACES II program, supported by the German Federal Ministry of Education and Research (Grant Number FKZ 01LL1804A). Permission for this research was granted by the Ministry of Environment, Tourism and Forestry, Namibia and the Namibian National Commission on Research Science & Technology (certificate number RCIV00032018 with authorization numbers: 20190602, 20190808).

Dedication

I dedicate this thesis to my brave daughter Jade Makosa who had to endure lonely days when I was busy working on this thesis. She has been my inspiration, and to the rest of my family and friends for being supportive throughout the journey of this thesis.

Thesis outline

This thesis is a phytosociological description of the vegetation of Etosha Heights Private Game Reserve. It is against the claim that wildlife has less negative impacts on veld condition than livestock, therefore the need to have an account of the available resources as a baseline to validating the claim. This thesis is in the form of a manuscript for the Namibia Journal of Environment. Chapter 1 follows the requirements of NUST. Chapter 2 follows the requirements of the NJE.

Abstract

The description of vegetation becomes more and more important for land management in the face of global climate change. In this thesis a description of the vegetation of Etosha Heights Private Game Reserve (EHGR) and its condition thereof is given. The study was conducted at Etosha Heights Private Game Reserve in the Kunene region. The reserve is a collection of ten previously cattle farms adjacent to the southern border of the Etosha National Park in Namibia. It forms part of the Angolan Mopane Woodlands, with extensive Karst elements in the form of Dolomite ridges. The study area receives on average 300 – 350 mm MAP. The reserve was stratified according to terrain features identified on aerial images, aided by an SRTM digital terrain model. 192 plots were sampled across all initial stratification units using the Braun-Blanquet method. These relevés were classified with modified TWINSPAN using a synusial approach. In addition, samples of top soil were collected and analysed for chemical and physical properties. Environmental characteristics of each relevé were subjected to a Non-metric multidimensional scaling (NMS) ordination to understand correlations between species composition and environmental characteristics. From the initial vegetation classification, two major vegetation units of higher syntaxonomic ranking were identified, split and further analysed separately which then subdivided into 11 associations. Altitude, slope, sand, silt and clay are the major descriptors of these vegetation units. A comparison of these associations with existing vegetation descriptions for the Etosha National Park and other studies done of the Mopane veld is done. With this descriptive work, knowledge about natural vegetation in the under-sampled arid Mopane savanna in the Kunene Region of Namibia is expanding.

Chapter 1: General Introduction

1.1 Thematic background

Vegetation is defined as a basic unit of an ecosystem, a habitat within which an organism lives, grow, reproduce and die (Kent 2012). It is solely responsible for primary production and a medium of water and carbon cycles (Lieth 1975, Kent 2012, Leuschner 2013). The importance of vegetation cannot be over emphasized in the prevention of land degradation and desertification (Rohde and Hoffman 2012, Coetzee *et al.* 2014, Menestrey Schwieger and Mbidzo 2020). Vegetation can be used as indicators of available minerals and underground processes (Kruckeberg 2002). In addition, It is a source of raw materials and provides numerous other ecosystem services (Cole *et al.* 2014).

Despite the significance of plants for all their ecosystem services, scientific knowledge of the dynamics of vegetation composition is low in Africa (Lillesø *et al.* 2011). Vegetation is studied at different scales depending on the objectives of the study (Kent 2012). The description of spatial distribution is often summarized on maps. On a global scale, vegetation is classified by biogeographical descriptions e.g. classification into Biomes or mapping of Potential Natural Vegetation (Phytochorology) (Lillesø *et al.* 2011, Dengler 2017). Biome descriptions then becomes the basis of comparisons between finer detailed vegetation studies – Phytosociology (Werger 1978). Again, on a global scale, some studies seeks to explain vegetation assemblages and distribution based on its origins and dispersal mechanisms (Phytogeography). None-the-less, these studies are not detailed enough hence not relevant for local level planning and monitoring of natural resources. They do not quantify the available resources and their health state.

Other means of collecting information on vegetation include citizen science platforms (Bonney *et al.* 2016, Environmental Information Service Namibia | EIS). Occasionally, general field trips results in annotated species lists, while vegetation-environment interactions are often ignored. Phytosociology explains the small-scale patterns of an ecosystem (Mueller-Dombois and Ellenberg 1974, Kent 2012) and therefore applicable for local level management of natural resources. Available vegetation maps describes the dominant species and are not so effective for management planning (Moorsom *et al.* 1995, Ward *et al.* 2000). There was therefore a need to describe vegetation at habitat level.

There once was limited knowledge of the detailed vegetation composition of non-protected areas in Namibia (Burke and Strohbach 2000, Strohbach and Jürgens 2010). At present, a lot has been done since the organized approach of collecting this information through the Vegetation Survey of Namibia Project (Strohbach 2014). However, there is still a knowledge gap in the description of vegetation communities in the Kunene Region and North-Central Mopani savanna *sensu* (Giess 1971).

The Vegetation Survey of Namibia project established a set of guidelines for conducting phytosociological surveys in Namibia (Strohbach 2001, Hüttich *et al.* 2009, Strohbach and Kangombe 2012). The aim is to document vegetation assemblages as they occur in a given area as a baseline to vegetation inputs of development and management plans. These baseline studies can then be used to produce more accurate and reliable predictor models of the effects of climate change on vegetation and the mitigation measures thereof. They also become the basis of policy making of realistic sustainable development goals. The surveys of this thesis follow guidelines of this national project.

1.2 Phytosociological classification of plants

Mueller-Dombois and Ellenberg (1974), Kent (2012), Leuschner (2013), Dengler (2017) define phytosociology as the delimitation of vegetation types into plant assemblages using floristic characteristics of plants. Assemblages are plant species repeating themselves over space such that with spatial change, a different plant community is easily recognized. A number of factors influences these assemblages, including local topography, climate and soil properties. As such, understanding vegetation community compositions becomes the basis of understanding an ecosystem.

Vegetation can be studied for its own sake or in order to solve an ecological problem (Strohbach and Jürgens 2010, Strohbach *et al.* 2014, Strohbach 2018). The baseline of whichever study of vegetation is with classification. The ultimate goal of classification is to reduce data, be able to look for patterns and come up with communities. However, the classification of vegetation does not always result in clear distinct assemblages as was suggested by Clements, because in some cases plants occur on a continuum as was observed by Gleason and yet both theories complement each other (White 1983, Kent 2012).

There are several schools of phytosociology with subjective methods to vegetation classification. These schools of thought are mainly relevant and widely used in places where they originate. The Zürich-Montpellier School, the Uppsala School based in Scandinavia, the Raunkaier (Danish) School, 'Hybrid Schools' like the 'British' School of Poore and Ratcliffe , and Rieley and Page. The most common is the Zürich-Montpellier School also known as Braun-Blanquet approach (Kent 2012, Peet and Roberts 2014).

Professor Braun-Blanquet established the Zürich-Montpellier School in 1928. It is a comprehensive method with a set of standards and guidelines for data collection, analysis-classification, interpretation and naming of the resulting communities (Braun-Blanquet 1932). This school of thought also has a unique system of relevés wherein a quadrat is set to demarcate a plot and all the species present in the plot are recorded, their abundance and other environmental components observed at that time. For field surveys, the Braun-Blanquet method requires that the plot should be on a homogenous patch of vegetation which requirement is more attainable with field experience. For the classification process, relevés data is sorted by similarities in species composition to assemble a hierarchy of plant communities as columns in a phytosociological table. A plant community is the basic and most fundamental unit of vegetation (Kent 2012). An association is thus a plant community type obtained by grouping similar relevés together using species composition as the main criteria (Theurillat *et al.* 2021). The species composition is sorted using the fidelity concept (degree of occurrence of a species in a group relative to its occurrence in the rest of the data)(Bruelheide 2000, Chytrý *et al.* 2002). Furthermore, in the Zürich-Montpellier method, there is a system of nomenclature using the names of the characterising species and suffixes to denote the association (Kent 2012, Theurillat *et al.* 2021). Figure 1. shows a flow chart of this classification method. However, it should be noted that the method is not well described in literature. Therefore, there are many variations to achieving the final level of classification.

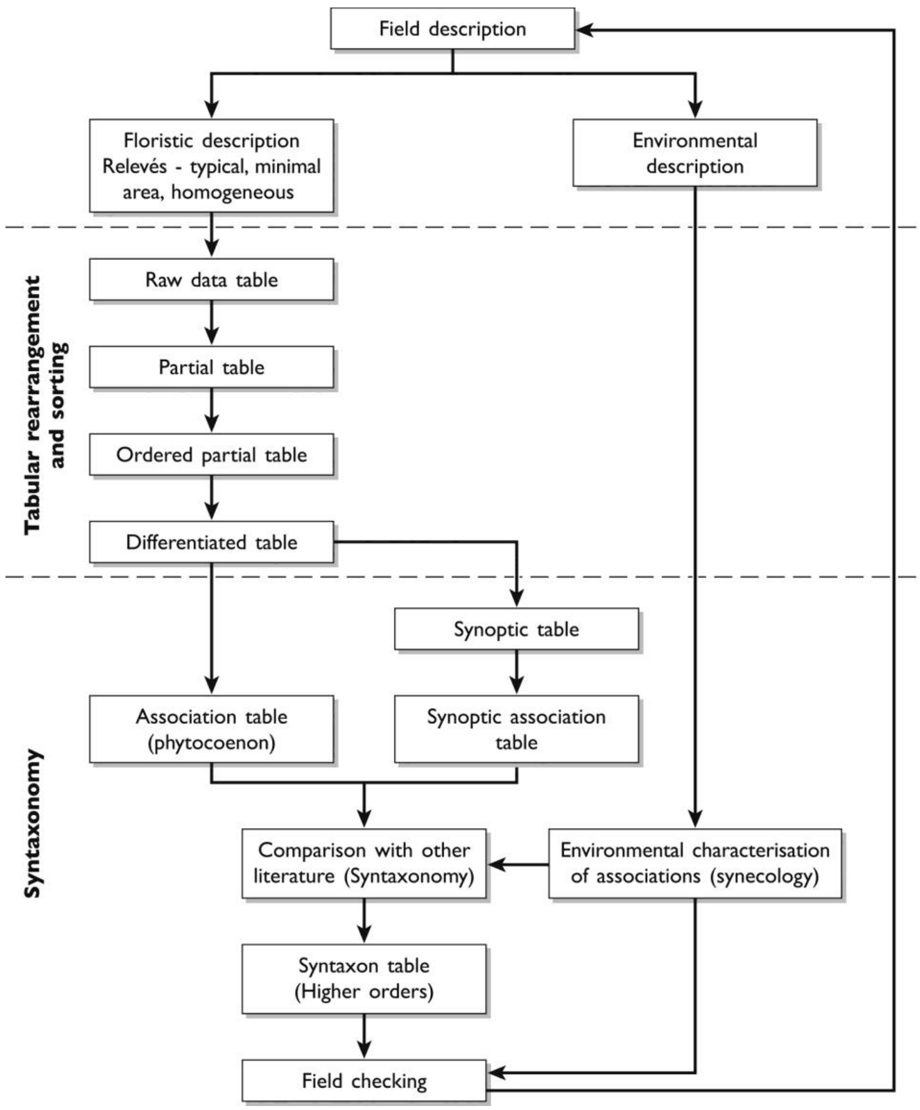


Figure 1 Flowchart of stages in the subjective classification of relevés using the Braun-Blanquet method (adapted from Kent 2012)

This school of Phytosociology is broadly criticized for being subjective in selecting homogenous vegetation for to place a plot in which to collect relevés data. However attempts have been made to counter this by introducing the stratification method prior to field surveys (Zingel *et al.* 2015). Another issue is the subjectivity of the fidelity concept during data analysis (Kent 2012). Modern fidelity measures and cocktail methods together with other objective numerical methods and ordination techniques counters the subjective effect of the fidelity concept. Therefore, the Braun-Blanquet method remains the widely used and most preferred in phytosociology for its comprehensiveness and adaptability to various vegetation types.

1.3 Vegetation studies in Namibia

The first complete vegetation classification records in Namibia was by (Giess 1971) wherein he classified by structure into grasslands, shrublands and woodlands subdivided into 14 vegetation types. Irish (1994) biogeographically classified Namibia into five Biomes namely Namib Desert; Succulent and Nama Karoo; Lakes and saltpans; and the Tree and shrub savanna. Outside this kind of classification, there are other groupings of vegetation done for development planning and management purposes like studies for the purpose of EIAs, harvesting for commercial use etc. Such studies were and are difficult to compile into a complete countrywide map because of the different approaches applied in their compilation. There was therefore a need for a standard procedure and guidelines to vegetation surveys. That need prompted the operations of the Vegetation Survey of Namibia project (Strohbach and Jürgens 2010). This project outlined and recommend procedures for desirable comprehensive vegetation assessment that if followed, a complete description of the vegetation in Namibia at habitat level. Figure 2 shows a schematic workflow of the classification and mapping that can be followed.

In a review of the vegetation studies in Namibia, Burke and Strohbach (2000) gives a comprehensive summary of the progress achieved over 35 years since 1966 and (Strohbach and Jürgens 2010) updates it to the year 2010. The results of the phytosociological classes has enabled compilation of EIAs, management plans, AEZs, livestock suitability index, (Strohbach 2012, 2014, 2018) that are relevant, site specific and practical. In the Kunene Region, a distribution map of endemic woody species was done in the Skeleton Coast- Iona Trans-frontier Conservation Area (Fillipus 2021). In the North-central Mopane Savanna, Le Roux *et al.* (1988) gives a comprehensive description of the vegetation of Etosha National Park. Siebert (2012) then attempted do describe the Mopane of the Angolan-Namibian patch while Kangombe (2010) looked at the wetter regions. This study therefore contributes to narrowing the knowledge gap of the hilly plains of the Namibian Mopane veld.

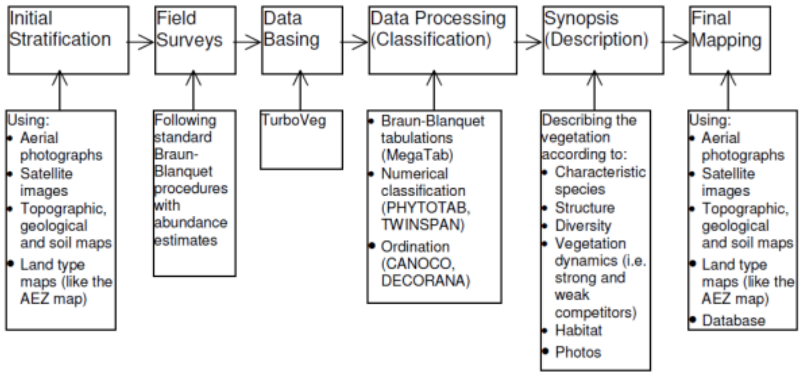


Figure 2 Schematic workflow for a vegetation survey, as proposed by Strohbach (2001)

1.4 Landscape conservation

The effects of global climate change have resulted in the shift of vegetation communities (Thuiller *et al.* 2006, Munyayi 2015, Mupambwa *et al.* 2021). It is predicted and experienced that seasons are becoming dryer and hotter while rainfall periods get shorter and erratic (Jarvis *et al.* 2022). This shift of vegetation communities together with other anthropogenic factors have made most places unsuitable for livestock farming. Therefore, SDGs and national policies are advocating for game farming as a means of sustainably utilizing our rangelands. Over the years, there has been an expansion of protected areas worldwide. In southern Africa, in addition to National Parks there has been the establishment of conservancies (NACSO 2022). Successful conservation required an integrated approach to the management of natural resources. There are more benefits socially and economically with conservation at landscape level (Scarlett and McKinney 2016, Baldwin *et al.* 2018). This would mean expanding protected areas or creating corridors that connect protected areas. Although there are contradicting views to this initiative, it is evident that the idea is beneficial for wildlife (especially migratory species and the big five) and biodiversity. This approach has resulted in an increase in wildlife population in Africa. Unfortunately, with global treaties it may be complicated to regulate wildlife populations as there are mixed feelings on the best humane way of doing so (Taylor *et al.* 2010, CITIES 2016, Di Minin *et al.* 2016, Brown 2017).

In Namibia about 40% of total land cover is under protection (Turpie *et al.* 2010, NACSO 2022). Seventeen percent of the land is within state owned protected areas (national parks). Another 17% of Namibia's terrestrial land is communal conservancies. Figure 3 illustrates distribution of protected areas in Namibia. With communal conservancies, the communal people living on communal land establish an agreement to pool their natural resources and utilize them as a community thereby allowing for zonation of the area for various land uses like cultivation, grazing, core-wildlife areas and tourism.

In addition, there are also privately owned conservation areas sometimes referred to as freehold conservancies that accounts for 6% of the total land cover. Freehold conservancies are private game farm owners who pool their resources and share the benefits thereof. Some freehold conservancies can also opt to not engage in trophy hunting and therefore sorely benefit from tourism (G Herger 2020, January, personal communication)[1].

In addition to the conservancy and national parks concept, there is an initiative to build wildlife corridors by removing fences or partially opening up migratory corridors. Though it comes with its complications of who then becomes the owner of the wildlife in the event of trophy hunting, this initiative may be good for fauna and flora species richness and diversity (Newmark 2008, Hoole and Berkes 2010, Mannetti *et al.* 2017, 2019). Various livelihoods and livestock projects in Namibia like the NOLIDEP (1998) and SARDEP (1996) seemed to commend and duplicate commercial farmers approach to profitable productivity, it is not always true that this was done sustainably (Duvel and Stephanus 2000, Rothauge 2001).

It is within this cause that a German funded ORYCS project took the initiative to investigate the benefits of landscape conservation in Kunene region by evaluating biodiversity on farmlands and protected areas. Therefore, this study is a baseline description of the vegetation composition and structure of a freehold conservancy (previously farmlands but now game reserve).

1.5 Administrative and economic history

The study site is adjacent to the southern border of Etosha National Park (ENP). Etosha National Park was declared a protected area in 1907 at an extent of 100 000 km^2 stretching all the way to the Skeleton Coast

[1] Gudrun Heger, CANAM Treasurer & Secretary, 062-503778/081-2805901

(far west) (Hoole and Berkes 2010, Dieckmann 2021). After the boundary was contested, the reserve was reduced to its current size of about 20 000 km^2. Between the Skeleton Coast National Park and western border of Etosha National Park are communal areas and a resettlement farm largely inhabited by the Ovahimba tribe. The Ovahimba are nomadic cattle farmers (Menestrey Schwieger and Mbidzo 2020). The communities formed into conservancies therefore economically benefits from both livestock farming and wildlife conservation. South of ENP were commercial cattle farms. These farms are south of the Red Cordon Fence thus has a commercial advantage to export their cattle products (Mannetti *et al.* 2019).

However, comparing with the 1950s, the suitability of the area for livestock farming has decreased significantly mainly due to the loss of perennial grasses (Nott *et al.* 2019). Moreover, overgrazing, bush encroachment and climate change also contribute to this degradation. With bush encroachment, efforts are being made to harvest the bush sustainably and generate income from charcoal with the hope that grasses will regenerate (Ward *et al.* 2000, Rohde and Hoffman 2012). However, it will take a long period to get to recovery of perennial grasses, as rainfall is erratic and lesser with climate change (Jarvis *et al.* 2022). In the past 18 years there is a moderate to strong increase in bare ground, an indicator of ecosystem health (Jarvis *et al.* 2022). This further supports the predictions that the current rainfall patterns that allow for cattle farming will shift further north-west, thereby forcing the farmers to shift to small stock farming.

As livestock farming became unsustainable due to droughts and predation, some of the farmers resorted to mixed farming with livestock and game. (Berger 2020[2], personal communication, June; and H Kreiner[3] 2021, May). Others have invested into game farming and therefore acquired neighboring farms to enlarge the landscape (Ms Johana[4] 2021, personal communication, May). The study site is a collection of 8 previously cattle farms. On the southern and eastern periphery of the EHPR are cattle farms. It was highlighted that the reserve was established in 1999 and game was gradually re-introduced. Until 2002 the livelihoods of the inhabitants of these the then farms were mainly sustained by livestock farming. In

[2] Mr Berger, Farm owner of Hulugia Farm

[3] Mr H Kreiner, Farm owner of Ekongo Farm

[4] Ms Johana, Farm manager at ERMO farm

the same year, all internal boundary fences were removed and ever-since, the reserve is strictly into game conservation (Kippi 2021, personal communication, October). However, there are more than 40 active boreholes to supply game with water throughout the year. An on-site butchery supplying game meat to restaurants and nearby towns sustained the operations and transition of the reserve until recently. It is therefore a research and tourism centre. Hunting is for own use to sustain the rations of the employees and game guards of the reserve.

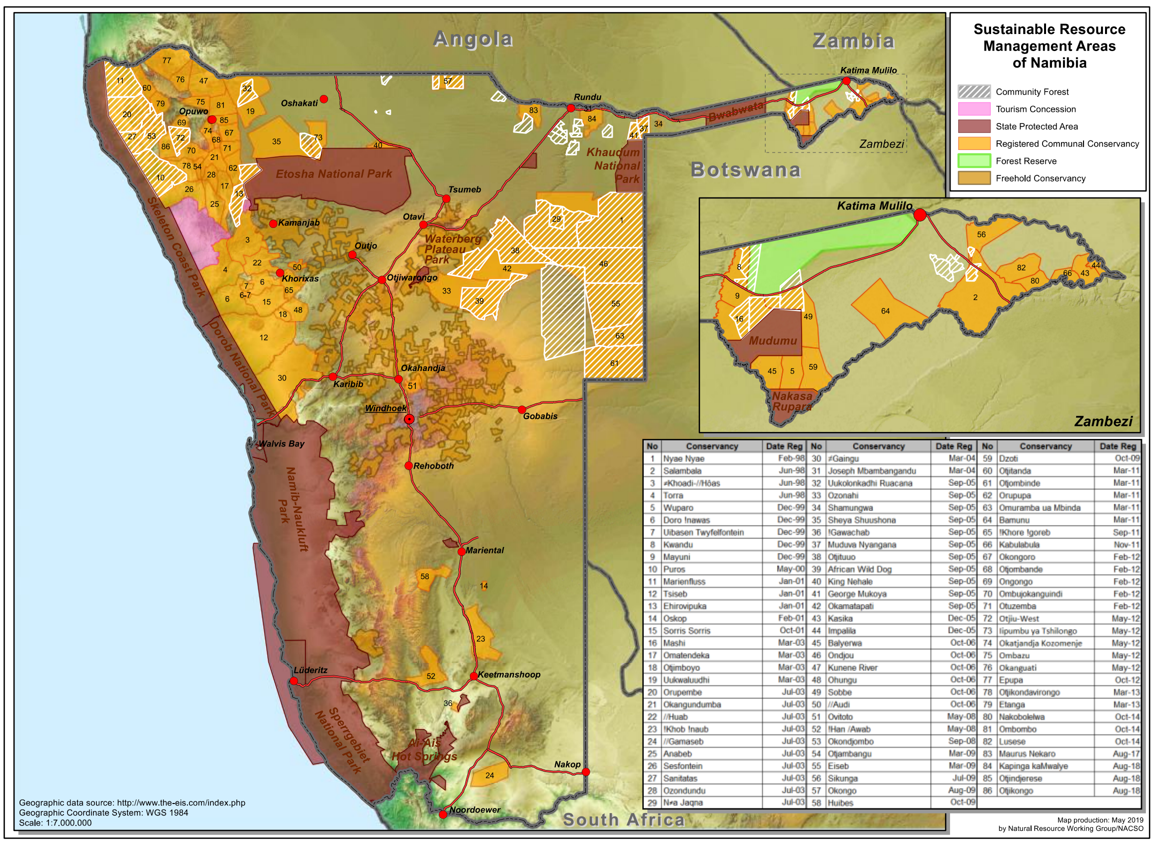


Figure 3 Map showing protected areas in Namibia adopted from (NACSO 2022)

1.6 Research Objectives

1.6.1 Statement of the Problem

Many of the protected areas in Namibia have undergone intensive vegetation studies in the past (Burke and Strohbach 2000). However, for most privately owned game farms, freehold conservancies and even farmland such baseline information is limited (Burke and Strohbach 2000) especially in the Mopane Savanna of north-western Namibia limited data is available (du Plessis 2001).

1.6.2 Objectives

This study aims to provide a baseline assessment of the floral biodiversity of the Etosha Heights Private Reserve. The following objectives are formulated for this study:

The objective of this study is to describe the vegetation of EHPR and its relationship to the abiotic habitat and to provide information on specific threatened habitats requiring special conservation measures and general recommendations towards sustainable land use.

Chapter 2: The manuscript

A phytosociological description of the vegetation of Etosha Heights Private Reserve, Namibia

V. Marufu[1], B. Strohbach[2]

[1]Biodiversity Research Center, Namibia University of Science and Technology, Private Bag 13388, Windhoek, Namibia.

[2] Department of Agricultural and Natural Resources Science, Namibia University of Science and Technology, Private Bag 13388, Windhoek, Namibia.

Vimbai Marufu (corresponding author, e-mail: marufu.v@gmail.com

Ben Strohbach (bstrohbach@nust.na)

Abstract

The description of soils and vegetation becomes more and more important for land management in the face of global climate change. In this manuscript, we describe the vegetation of Etosha Heights Private Game Reserve in the Kunene region. The Etosha Heights Private Game Reserve is a collection of ten previously cattle farms adjacent to the southern border of the Etosha National Park in Namibia. It forms part of the Angolan Mopane Woodlands, with extensive Karst elements in the form of Dolomite ridges. The study area receives on average 300 – 350 mm MAP. The reserve was stratified according to terrain features identified on aerial images, aided by an SRTM digital terrain model. 192 relevé were sampled across all initial stratification units using the Braun-Blanquet method. These were classified with modified TWINSPAN using a synusial approach. In addition, 167 top soil samples were collected to describe the typical soil units. The soil samples were analysed for soil chemical and physical properties. Environmental characteristics of each relevés were subjected to a Non-metric multidimensional scaling ordination to determine the environmental drivers responsible for these associations. From the initial vegetation classification, two major vegetation units of higher syntaxonomic ranking were identified, which are subdivided into 11 associations. Altitude and slope, sand silt and clay are the major descriptors of these vegetation units. A comparison of these associations with existing vegetation descriptions for the Etosha National Park and other studies done in the Mopaneveld. With this descriptive work, we will expand the knowledge about vegetation in the hitherto under-sampled arid Mopane savanna in the Kunene Region of Namibia.

Key words: modified TWINSPAN, Mopane savanna, Phytosociology, slope, soil depth, Syntaxonomy

Introduction

Baseline description of vegetation is increasingly becoming more important. With the effects of global climate change, more questions arise about the dynamics of natural resources. The reliability and accuracy of predictor models is depended on the accuracy of the input thereof. Baseline descriptions becomes the invaluable foundation sought after.

The mapping of Namibian vegetation back dates to the colonial era with Giess (1971) producing the very first. The boundaries were recently modified based on water availability and soil type (Jarvis *et al.* 2022). The previously Mopane savanna was shifted further north and replaced by the Karstveld. Therefore, for this study the both the former and latter maps are adopted and the study area is in the Mopane savanna on Karstveld.

In the vegetation mapping history of Namibia, the need to shift from livestock to wildlife to sustain livelihoods has brought another need to understand the dynamics of natural ecosystems. The impacts of wildlife on vegetation can only be quantified with knowledge of the available resources.

In vegetation studies, phytosociological classification has given a basis to more perspectives and explanations of vegetation dynamics. (Lillesø *et al.* 2011, Dengler 2017). Several studies have been done in the Mopane savanna.

In Namibia, the first phytosociological description was by Le Roux *et al.* (1988) for Etosha National Park. Strohbach (2000a, 2000b) and Kangombe (2010) have described the wetter parts of the South-western Mopane Bioregion (Siebert 2012). There is no description of the dryer parts thus far. Therefore, this study aims to contribute to the description of the dryer area of Mopane savanna.

Methods

Study area

The study site is situated in the Kunene Region in north-western Namibia (14° 48' – 15° 22' E; 19° 11' – 19° 21' S) with the northern border adjacent to Etosha National Park. The reserve is about 480 km^2 (or 48,000 ha) in extent, stretching up to 57.34 km in an east-west direction. See Figure 4. The climate is hot Arid desert following the definition of (Köppen 1936). Rain occurs during summer months between October and March (Jarvis *et al.* 2022) ranging between 300 - 350 mm MAP. Maximum temperatures exceeds 36 °C and monthly mean values are summarized in Figure 5 (Walter *et al.* 1975). Etosha Heights is situated in the eastern peripheries of the Kunene mountain range. The reserve lies on the surface of the Damara sequence with the ridges forming from the limestone and dolomite deposits in the shallow seas of the pre-Gondwana era (Otavi group) (Goudie and Viles 2015). The interspersing plains and pans are underlain by the Mulden group and calcareous outcrops which developed following carbonate precipitation of the limestone and dolomite (Schneider 2004, Goudie and Viles 2015). The soils are generally shallow Petric Calcisols around the plains, Solonetz in the grassy pans and Leptosols on the mountains (Nortjé 2019).

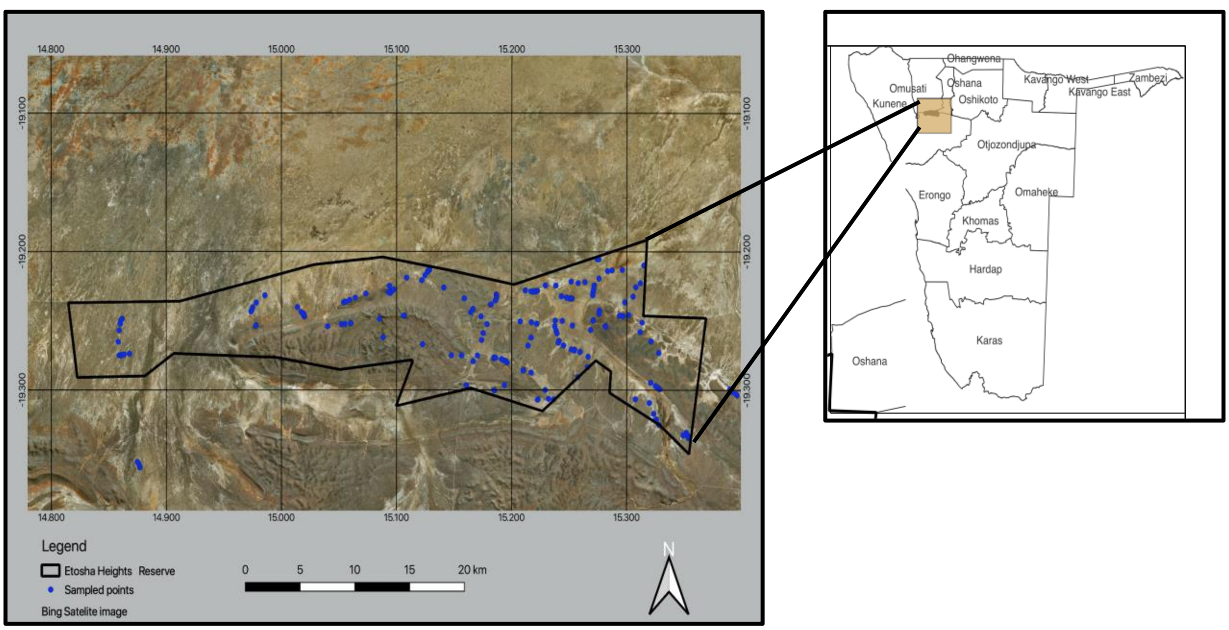


Figure 4 Map showing location of study area, mountainous terrain and location of sampled points. Data source: Satelite image: Bing images; Etosha Heights boundaries: Namibia geo portal

The mountains are characterized by *Commiphora species, Combretum apiculatum, Terminalia prunioides* and *Vachelia reficience,* which then transitions into the Mopani shrublands. The grasses *Anthephora schinzii, Enneapogon desvauxi, Schmidtia kalahariensis, Chloris virgata* and *Aristida adscensionis* forms part of the understory flora of the landscape (Le Roux *et al.* 1988).

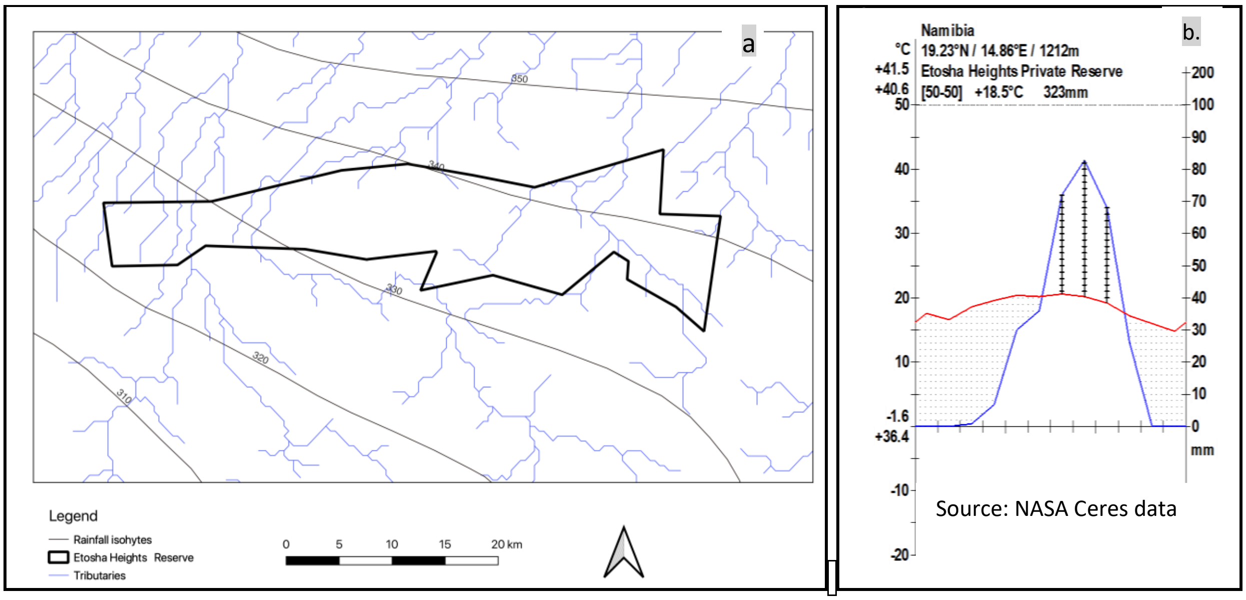


Figure 5 Map showing (a) rainfall isohytes and tributaries and (b) climate diagram Data sources: Rainfall isohytes and tributaries: NARIS 2001; Climate diagram: (Walter *et al.* 1975)*; Climate data: NASA Ceres data. Geology: Geological Survey (1980) .*

Giess (1971) described the vegetation type of the area as Mopane Savanna (Olson *et al.* 2001). The rich variety of fauna inhabiting the marginal grasslands and pan includes a large number of springboks *(Antidorcas marsupialis*), plains Zebras (*Equus burchellii)*, Wildebeest (*Connochaetes taurinus*), the selective waterbuck (*Kobus ellipsiprymnus*) and oryx (*Oryx gazella*), mixed feeders Eland *(Taurotragus oryx)*, Impala (*Aepyceros melampus*) and browsers like Kudu (*Tragelaphus strepsiceros*) and some mega herbivores.

Field surveys

Vegetation sampling was between May 2020 and May 2021. A baseline map stratified the reserve according to terrain features identified on aerial images aided by a SRTM digital terrain model (Jarvis *et al.* 2008). 192 relevés were sampled using the Braun-Blanquet method (Mueller-Dombois and Ellenberg 1974, Kent 2012) and from these 172 species were recorded. Each relevé was 20 m x 50 m, the standard size used in the Vegetation Mapping project of Namibia (Strohbach 2001, 2012, Brown and Bredenkamp 2018). This was placed inside a homogenous vegetation patch. In narrower topographical units like the riverbeds, dimensions were adjusted to 10 m x 100 m so to still fit in a homogenous unit. The data collected was of all species present within the plot, and their estimated percentage cover. Unknown species and reference specimens were collected, identified, and deposited at the National Herbarium of Namibia (WIND). Environmental features such as lithology, slope, stone cover, terrain type erosion and disturbances were recorded in accordance with the SOTER methodology (FAO 1993) standards (Engelen and Dijkshoorn 2013). The vegetation data was then captured in the TurboVeg database to form part of the GVID AF-NA-001 (Dengler *et al.* 2011, Strohbach and Kangombe 2012).

Soil sampling and analysis

Top soils were collected from 167 of the 192 relevés at a depth of not more than 3cm and were stored in zip lock bags for analysis in the lab. Soil pH and electrical conductivity were measured with a 1:2.5 soil KCl ratio on a mass basis and structure particle size was determined using the titration method following standard procedures (Pansu and Gautheyrou 2006).

Data analysis

Data analysis followed methods commonly applied for the Vegetation Survey of Namibia project (Strohbach and Jürgens 2010, Strohbach 2012). To reduce the effect of seasonal bias of forbs, it was decided to reduce the matrix for classification to phanerophytes, chamaeophytes and graminoids. This follows the integrated synusial approach to vegetation classification developed by Gillet and Julve (2018). The floristic data of 192 relevés and 110 species was subjected to a numerical classification using modified TWINSPAN (Roleček *et al.* 2009) with average Sørensen dissimilarity distance measure and 1 pseudospecies cut level of 0% cover. Furthermore, minimum group size was set at 2 clusters and a maximum division to 20 clusters. The size of all groups was standardized to equal size. The initial classification of 192 relevés resulted in two main groups (mountains - 70 relevés and plains – 122 relevés) according to which the data was split and further classified, also using synusial data and average Sørensen dissimilarity distance measure. The number of clusters at which to interpret the data was determined by the peak of the crispness of classification values (Botta Dukat *et al.* 2005). Once a stable, ecologically interpretable result was achieved, herbs (62 species) were added to the classification results for better interpretation.

From the final classification, a synoptic table (See Table 1) and a phytosociological table See Appendix 2 were created. Diagnostic species were determined using the phi-coefficient of association (Tichý *et al.* 2020). Species with phi-coefficient >30 were considered as diagnostic and with phi-coeffient >60 as highly diagnostic while species with at least 30% frequency were regarded as constant. However, species with a non-significant fidelity α=0.05 at Fishers exact test were omitted. Though this study covers only a very small part of the Mopane savanna, *sensu* (Giess 1971) there was an attempt to describe the higher syntaxonomic groupings. Box and whisker plots were constructed to illustrate the structure for each height class, using the floristic data. Description of the vegetation structure follows Edwards (1983). The description of geomorphology and landscape elements follows Strohbach (2012) and Jasiewicz and Stepinski (2013).

Environmental gradients

A Nonmetric Multidimensional Scaling ordination (NMS) (Kruskal 1964) was calculated with PC-ORD version 7.02 MjM software (McCune and Mefford 2016), using the Sørensen distance measure. The ordination was calculated in three dimensions based on an initial scree plot of stress versus dimensions (McCune *et al.* 2002, Peck 2016). The solutions were calculated with 200 iterations using real data and 249 runs using randomized data for Monte Carlo test. For species data, the reduced matrix of phanerophytes, chamaephytes and grasses was used in the NMS as was used in the initial classification. The categorical variables used as secondary matrix parameters were; the association, type of landscape and lithology while numerical variables were stoniness, altitude, aspect, slope, soil depth and soil pH, electric conductivity, and texture. Altitude was determined using Garmin Geographical Position System. The exhaustive list is on the headers of the phytosociological table in Appendix 2. To aid the interpretation of the resulting scatter plots, the environmental variables were overlain as a joint plot onto a scatter diagram of the plots, with an r cutoff level of 0.150.

Mapping

An attempt to map the vegetation of Etosha Heights was once done by a bachelors exchange student (personal communication with Prof B. Strohbach, 2020). Therefore, that preliminary map was re-digitised and used for stratified sampling. The re-digitised map was then used as the base map for the final vegetation map of EHPR. The vegetation map presented in this thesis is as a ground truthing of the re-digitised stratification map. Aerial images, obtained from an SRTM digital terrain model were subjected to Terrain analyses were used to delineate boundaries of the mountainous habitats. The Digital Elevation Model images were adjusted for no sinks and analysed in SAGA GIS version 8.4.1 (Conrad *et al.* 2015). A geomorphon classification was set at a threshold angle of 1^0 and radial limit of 2 500 (Jasiewicz and Stepinski 2013). Data points were overlaid on the geomorphon output file and Association 1, 2 and 3 were on the ridges, slopes and footslopes respectively.

Plains habitats were visualized using a Landsat 8 satellite image from the scenes of path 180 row 073 dated June-August 2020. False-colored image with bands 6.5.4 in RGB combination were used. However, due to the mosaic nature of the plains classes the map was digitized mainly using field notes against the Google Bing Satellite image. The plain habitats occurred as a continuum and was therefore complicated to map at a scale of 1:10 000 for mapping purposes, data points of the plains habitats were overlain on the previously re-digitised shapefile. Vegetation units were identified on a Bing Satellite image. Photographs taken during data collection and field notes were consulted for more information. The units were combined to form “major mapping units” (Le Roux *et al.* 1988).

Results

The classification results are summarized in the dendrograms in Figures 6 and 7 below. The first division of the data set resulted in two main groups of distinct habitats– mountains and plains. Re-analysis of the separated groups resulted in, four clusters of mountain associations (70 relevés) and: thirteen clusters of the plains (122 relevés) which were condensed into nine associations and four sub-associations. The mountainous habitats classified along an altitude/slope gradient. The four associations range from high gradient hills, medium gradient inselbergs, calcareous outcrops, and foot-slopes. The plains seven associations classified along a soil depth gradient and are easily identified by their differences in physical structural growth. These plains associations vary from woodlands in deeper sand to shrublands on talus, to grassy plains and pans.

In Figure 7, clusters 7 and 8 could not be differentiated through diagnostic species but only through subtle differences in the dominant and constant species. Therefore, these clusters were combined to form Association 7. Subsequently, clusters 10 and 11 were combined to form an association with two sub-associations (9.1 and 9.2) for the same reasons as in the previous combination. On the contrary, cluster 12 was split into two sub-associations (10.1 and 10.2) using the split from the 20th division of modified TWINSPAN though the rest of the plains were interpreted at the 9th division. Splitting this association made the most ecological sense as it resulted in diagnostic species. The split improved the classification in that the sub-associations obtained diagnostic species and the values of the positive fidelity and sharpness improved by at most 3.86 units.

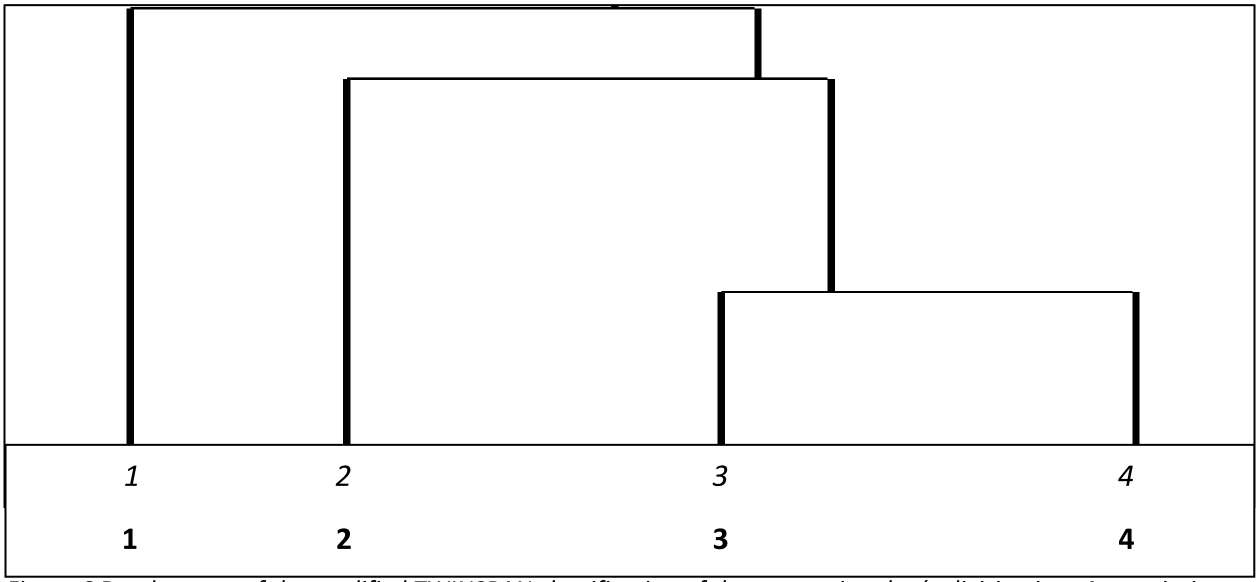


Figure 6 Dendrogram of the modified TWINSPAN classification of the mountain relevés division into 4 associations.

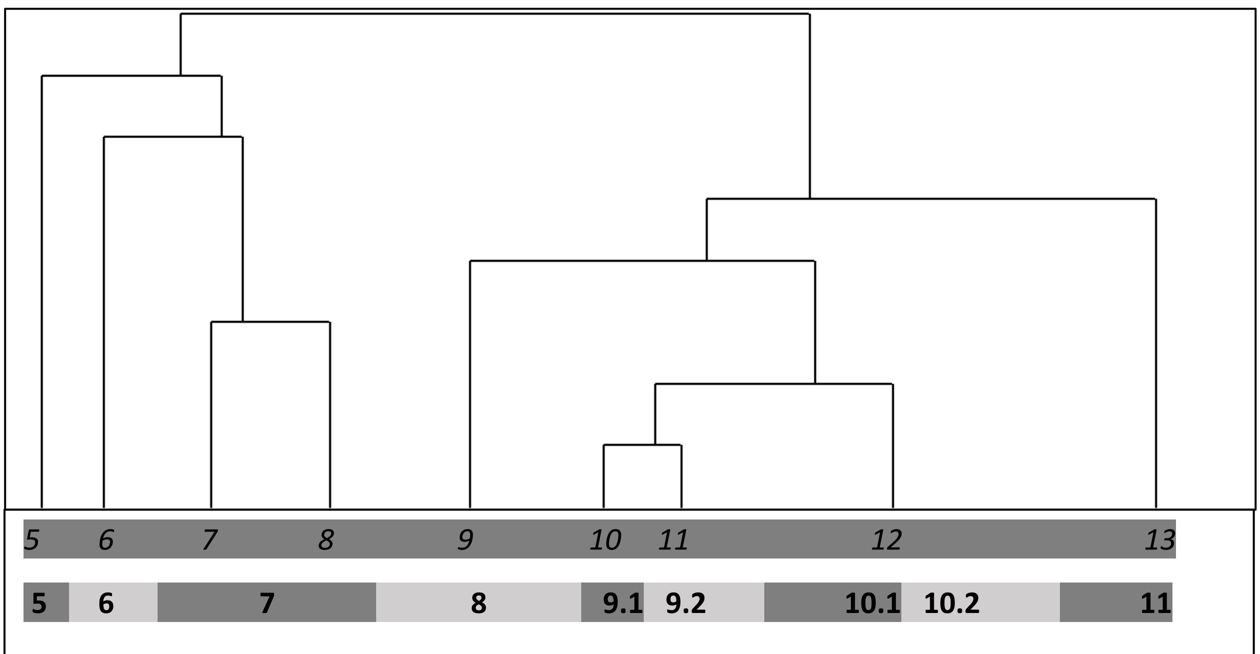


Figure 7 Dendrogram of the modified TWINSPAN classification of the plains relevés showing how 9 clusters were condensed into 7 associations (Association 5 – 11) and 4 sub-associations (Association 9.1, 9.2, 10.1 and 10.2).

Table 1. Synoptic table for the vegetation of Etosha Heights Private Game Reserve illustrating the 11 vegetation associations.

Synoptic Table for the vegetation of Etosha Heights Private Game Reserve, Namibia

phi: fidelity (phi coeff. of µ)

%: frequency (% of relevés in which species occurs)

Cluster			1		2		3		4		5		6		7		8		9		10		11		12		13	
Association			1		2		3		4		5		6		7		8		9.1		9.2		10.1		10.2		11	
Number of relevés			15		19		3		33		8		4		23		21		5		10		8		23		20	
Mean number of species per relevé			21.4		21.11		24.33		24.03		22.25		20.25		23.52		20.19		23.6		21.6		16.13		18.04		24.35	
Number of species observed in association			77		87		50		99		62		41		94		80		49		65		44		74		80	
Number of diagnostic species			11		3		4		4		6		7		1		1		6		3		1		2		3	
	Growth Form	Species Group	Phi	%	Phi	%	Phi	%	Phi	%	Phi	%	Phi	%	Phi	%	Phi	%	Phi	%	Phi	%	Phi	%	Phi	%	Phi	%
Commiphora glaucescens	ts		91	100	---	0	---	0	---	18	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Danthoniopsis dinteri	a		72	60	---	0	---	0	---	6	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Combretum mossambicense	ts		39	20	---	0	---	0	---	0	---	0	---	0	---	4	---	0	---	0	---	0	---	0	---	0	---	0
Pupalia lappacea	h		38	33	---	5	---	0	---	3	---	13	---	0	---	0	---	10	---	0	---	0	---	0	---	0	---	0
Sterculia africana	ts	A	35	13	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Pachypodium lealii	ts		35	13	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Kirkia acuminata	ts		35	13	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Eragrostis lehmanniana	a		31	13	---	0	---	0	---	3	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Senegalia senegal	ts		---	0	48	32	---	0	---	3	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	5
Grewia flavescens	ts	B	---	40	35	63	---	33	19	42	---	0	---	0	---	26	---	5	---	0	---	0	---	0	---	0	---	15
Commelina benghalensis	h		---	0	32	16	---	0	---	6	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Bothriochloa radicans	p	C	---	0	---	5	53	67	---	0	---	25	---	0	15	26	---	0	---	0	---	0	---	0	---	0	---	15
Grewia retinervis	ts		---	7	---	0	51	33	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Schmidtia kalahariensis	a		---	0	---	26	---	0	52	64	---	0	---	25	---	4	---	0	---	0	---	0	---	0	---	4	---	5
Pogonarthria fleckii	p	D	---	0	---	0	---	0	46	42	---	0	---	0	---	13	---	0	---	0	---	0	---	13	---	4	---	0
Euphorbia austro-occidentalis	ts		---	0	---	0	---	0	38	15	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Ipomoea species	d		---	0	---	0	---	0	---	0	67	63	---	0	---	9	---	0	---	0	---	10	---	0	---	0	---	0
Eragrostis subglandulosa	a		---	0	---	0	---	0	---	0	49	25	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Eragrostis trichophora	a	E	---	0	---	16	---	33	---	18	45	100	---	25	23	65	---	29	---	0	---	20	---	13	---	30	---	25
Lantana angolensis	ts		---	0	---	0	---	0	---	0	44	25	---	0	---	4	---	0	---	0	---	0	---	0	---	0	---	0
Indigofera adenocarpa	h		---	0	---	16	---	0	---	9	36	38	---	0	---	4	---	0	---	0	---	10	---	0	---	9	---	0
Panicum coloratum	p		---	0	---	0	---	0	---	0	---	0	69	50	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Aristida hordeacea	a		---	7	---	11	---	0	15	30	---	0	53	75	---	4	---	0	---	20	---	0	---	0	---	4	---	20
Cucumis anguria	h	F	---	0	---	0	---	0	---	0	---	0	49	25	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Vachellia nilotica	ts		---	0	---	0	---	0	---	0	---	0	44	25	---	4	---	0	---	0	---	0	---	0	---	0	---	0
Monelytrum luederitzianum	p		---	0	---	0	---	0	---	0	---	0	44	25	---	4	---	0	---	0	---	0	---	0	---	0	---	0
Amaranthus thunbergii	h	G	---	0	---	0	---	0	---	12	---	0	---	25	34	39	---	10	---	0	---	0	---	0	---	4	---	10
Petalidium englerianum	d	H	---	0	---	0	---	33	---	0	---	0	---	0	---	9	37	48	---	0	---	10	---	0	---	13	---	15
Indigofera adenoides	h		---	0	---	5	---	0	---	0	---	0	---	25	---	4	---	14	51	60	---	10	---	0	---	0	---	0
Leucas pechuelii	h		---	0	---	5	---	0	---	0	---	0	---	0	---	4	---	10	49	40	---	0	---	0	---	0	---	0
Gossypium triphyllum	ts	I	---	0	---	0	---	33	---	3	---	13	---	0	---	4	---	5	49	60	---	10	---	0	---	0	---	0
Nidorella species	h		---	0	---	5	---	0	---	0	---	0	---	0	---	0	12	14	45	40	---	10	---	0	---	0	---	0
Hermbstaedtia species	h		---	27	---	32	---	0	28	70	---	38	---	25	---	17	---	10	34	80	---	30	---	13	---	9	---	5
Heliotropium steudneri	h		---	0	---	0	---	0	---	3	---	13	---	0	---	4	---	0	---	0	39	30	---	0	---	0	---	0
Cenchrus ciliaris	p	J	---	0	---	5	---	67	---	3	---	38	---	0	12	39	---	5	---	0	33	70	---	0	8.9	35	---	25
Aristida stipitata	a		---	0	---	0	---	0	---	12	28	38	---	25	---	0	---	5	---	0	31	40	---	0	---	0	---	0
Euphorbia inaequilatera	h	K	---	0	8.6	16	---	33	---	0	---	0	---	0	---	0	---	5	---	0	---	10	32	38	---	0	---	0
Eragrostis echinochloidea	p	L	---	0	---	11	---	0	---	21	---	38	---	25	---	48	17	52	---	0	---	50	---	0	37	83	---	15
Eragrostis porosa	p		---	0	---	0	---	33	---	33	---	13	---	0	27	70	---	43	---	20	---	10	---	0	32	78	24	65
Panicum novemnerve	a		---	0	---	5	---	0	---	0	---	0	---	0	24	26	---	5	---	0	---	0	---	0	---	4	41	40
Eragrostis nindensis	p	M	---	7	---	0	---	0	---	6	---	0	---	0	---	13	---	0	---	20	---	20	---	13	---	17	36	50
Geigeria ornativa	d		---	0	---	0	---	33	---	21	---	13	---	0	---	0	---	5	---	0	---	0	---	0	---	13	34	45
Commiphora glandulosa	ts		48	100	---	16	48	100	24	64	---	0	---	0	---	4	---	5	---	20	---	20	---	0	---	4	---	15
Combretum apiculatum	ts		40	73	25	53	---	33	35	67	---	0	---	0	---	0	---	0	---	0	---	0	---	13	---	4	---	5
Brachiaria marlothii	p		40	60	---	0	74	100	---	0	---	0	---	0	---	9	---	0	---	0	---	0	---	0	---	0	---	5
Tragus racemosus	a		---	0	---	32	---	0	---	21	39	100	39	100	---	9	---	5	27	80	21	70	---	38	---	4	---	0
Eragrostis biflora	a		---	0	---	0	---	0	---	0	---	0	53	75	---	4	---	0	40	60	---	0	---	25	---	0	---	5

Geigeria acaulis	d		---	0	---	0	---	0	24	30	---	13	---	0	---	13	---	0	---	0	---	10	---	0	---	4	29	35
Leucosphaera bainesii	d		---	0	---	21	---	0	---	0	---	63	---	75	---	57	10	67	---	40	18	80	22.3	88	---	52	27	95
Tragus berteronianus	a		---	20	---	21	---	67	---	24	---	25	---	50	9	61	---	33	---	80	---	30	---	50	---	43	23	85
Megalochlamys marlothii	d		---	0	---	5	---	0	---	3	---	0	---	0	---	4	---	5	---	0	---	20	---	0	---	0	22	20
Grewia villosa	ts		---	7	---	16	---	33	---	9	---	0	---	0	---	13	---	0	---	0	---	10	---	0	---	4	16	25
Stipagrostis hirtigluma subsp. *hirtigluma*	a		---	7	---	74	---	0	---	61	---	75	---	25	---	0	22	95	---	100	19	90	---	75	---	70	16	85
Catophractes alexandri	ts		---	20	---	53	---	67	9.7	70	---	38	---	0	---	17	---	52	---	80	---	60	27.2	100	---	52	16	80
Eragrostis annulata	h		---	13	---	37	---	33	---	42	---	88	---	25	---	74	19	90	---	40	---	60	---	88	14	83	16	85
Sericorema sericea	h		---	13	---	47	---	0	---	27	---	13	---	0	---	17	14	48	---	60	---	40	---	13	---	13	16	50
Enneapogon desvauxii	a		---	47	---	74	---	33	---	36	---	38	---	50	---	57	15	90	---	100	---	70	---	75	13	87	15	90
Aristida adscensionis	a		---	80	---	58	---	67	---	88	---	75	---	100	---	83	---	62	---	100	---	60	---	88	11	96	14	100
Chloris virgata	a		---	7	---	5	---	67	---	30	---	63	---	100	25	96	---	48	---	80	---	40	---	13	---	65	13	75
Crotalaria kurtii	h		---	13	---	0	---	0	---	24	---	13	---	50	---	35	---	19	---	60	23	60	---	0	---	17	13	45
Stapelia species	succ		---	0	---	0	---	0	---	0	---	0	---	0	---	4	---	0	---	0	---	0	---	0	---	0	---	0
Aptosimum species	h		---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	4	---	0
Dichrostachys cinerea	ts		---	7	---	42	---	67	25	64	---	50	---	0	20	57	---	5	---	0	---	10	---	13	---	4	---	20
Tribulus zeyheri	h		---	13	---	11	---	67	---	27	---	25	---	25	12	43	---	33	---	0	---	10	---	38	---	22	---	20
Tribulus terrestris	h		---	0	---	0	---	0	---	0	---	0	---	0	28	9	---	0	---	0	---	0	---	0	---	0	---	0
Dactyliandra welwitschii	cr		---	7	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Prenia tetragona	h		---	7	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Blepharis leendertziae	h		---	0	---	0	---	0	---	0	---	0	---	0	22	9	---	5	---	0	---	0	---	0	---	0	---	0
Euphorbia virosa	h		---	7	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Ptycholobium biflorum	h		---	0	---	11	---	33	---	0	---	13	---	0	---	0	---	5	---	0	---	0	---	0	---	9	---	0
Grewia bicolor	cr		---	13	---	11	---	0	---	6	---	13	---	0	---	0	---	5	---	0	---	10	---	0	---	0	---	0
Searsia marlothii	ts		---	0	---	5	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Sesamothamnus guerichii	ts		---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	5
Aristida effusa	a		---	20	---	5	---	0	---	12	---	0	---	0	---	0	---	19	---	0	---	0	---	0	---	4	---	5
Mollugo walteri	h		---	0	---	0	---	0	---	3	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Eragrostis rotifer	a		---	0	---	5	---	0	---	0	---	0	---	0	21	9	---	0	---	0	---	0	---	0	---	0	---	0
Setaria verticillata	a		---	40	---	5	---	67	---	15	---	63	---	75	30	91	---	38	---	60	---	20	---	0	---	35	---	20
Geigeria africana	d		---	0	---	0	---	0	---	0	---	0	---	0	28	9	---	0	---	0	---	0	---	0	---	0	---	0
Solanum lichtensteinii	h		---	0	---	0	---	0	---	0	---	13	---	0	21	13	---	0	---	0	---	0	---	0	---	4	---	0
Maerua juncea	ts		---	0	---	5	---	0	---	3	---	0	---	0	26	17	---	10	---	0	---	0	---	0	---	0	---	0
Hermannia modesta	h		---	20	---	11	---	0	---	24	24	63	---	50	---	26	---	24	---	20	---	40	---	38	---	4	---	25
Euphorbia guerichiana	h		---	0	---	0	---	0	---	3	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Asparagus nelsii	ts		---	7	---	16	---	33	---	6	---	0	---	0	---	0	---	5	---	0	---	10	---	25	---	0	---	20
Seddera suffruticosa	h		---	0	---	0	---	0	---	3	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Moringa ovalifolia	ts		---	7	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Senegalia erubescens	ts		---	7	---	5	---	0	---	9	---	0	---	0	---	0	---	5	---	0	---	0	---	0	---	0	---	0
Cephalocroton mollis	ts		---	0	---	0	---	0	---	0	---	0	---	0	---	4	---	0	---	0	---	0	---	0	---	0	---	0
Kyphocarpa angustifolia	h		19	60	---	32	---	67	---	45	---	0	---	0	---	52	---	43	---	0	---	0	---	13	---	22	---	50
Eragrostis superba	p		---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	4	---	0
Sesamum species	h		---	0	---	0	---	0	---	9	---	0	---	0	---	4	---	10	---	0	---	0	---	13	---	4	---	5
Fingerhuthia africana	p		---	0	---	5	---	33	---	0	---	0	---	0	---	4	---	0	---	0	---	0	---	0	---	0	---	5
Flaveria bidentis	h		---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	5	---	0	---	0	---	0	---	0	---	0
Searsia species	ts		---	0	---	5	---	0	---	6	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Combretum albopunctatum	ts		---	0	---	0	---	0	---	3	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Hibiscus species	h		---	0	---	0	---	0	---	0	---	0	---	0	---	4	---	0	---	0	---	0	---	0	---	0	---	0
Achyranthes aspera var. *sicula*	h		---	20	---	47	---	33	---	48	---	50	---	50	---	52	---	19	---	60	---	30	---	13	---	13	---	30
Opilia campestris	ts		---	0	---	5	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Datura inoxia	h		---	0	---	0	---	0	---	0	---	0	---	0	---	4	---	5	---	0	---	0	---	0	---	0	---	0
Cleome suffruticosa	h		---	0	---	0	---	0	---	0	---	0	---	0	---	4	---	0	---	0	---	0	---	0	---	0	---	0
Helinus integrifolius	cr		---	0	---	0	---	0	---	0	---	0	---	0	---	4	---	10	---	0	---	10	---	0	---	4	---	0
Portulaca kermesina	h		---	0	---	11	---	0	---	6	---	0	---	0	---	4	---	0	---	0	---	10	---	0	---	0	---	0
Athanasia species	h		---	0	---	5	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Aristida meridionalis	p		---	0	---	5	---	0	---	3	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Rhynchosia species	h		---	0	---	0	---	0	---	3	---	13	---	0	---	0	---	5	---	0	---	0	---	0	---	4	---	5
Bidens biternata	h		---	47	---	26	---	100	---	42	---	38	---	75	11	61	---	19	---	20	---	20	---	25	---	26	---	40
Monsonia senegalensis	h		---	0	---	5	---	0	---	3	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Seddera schizantha	h		---	0	---	0	---	0	---	3	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Datura ferox	h		---	0	---	0	---	0	---	0	---	0	---	0	---	4	---	0	---	0	---	0	---	0	---	0	---	5
Rogeria adenophylla	h		---	7	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Enneapogon scoparius	p		---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	13	---	4	---	0
Rhigozum brevispinosum	ts		---	7	---	0	---	0	21	9	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Aristida congesta	a		---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	20	---	0	---	13	---	0	---	0
Heteropogon contortus	h		---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	5
Indigofera daleoides	h		20	27	---	5	---	33	11	18	---	0	---	0	---	0	---	5	---	0	---	10	---	0	---	0	---	5

Triraphis ramosissima	h		22	13	---	0	---	0	---	6	---	0	---	0	---	0	---	0	---	0	---	10	---	0	---	0	---	0
Kirkia dewinteri	ts		---	7	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Croton menyharthii	ts		24	27	23	26	---	0	---	3	---	0	---	0	---	4	---	5	---	0	---	0	---	0	---	0	---	20
Cleome rubella	h		---	40	---	16	---	33	23	52	---	25	---	25	---	22	---	10	---	20	---	10	---	0	---	0	---	5
Aristida rhiniochloa	a		17	60	29	79	---	33	---	30	---	13	---	0	---	17	---	24	---	60	---	0	---	50	---	22	---	35
Montinia caryophyllacea	ts		---	7	---	0	---	0	18	9	---	0	---	0	---	4	---	0	---	0	---	0	---	0	---	0	---	0
Stipagrostis uniplumis	p		---	7	---	5	---	0	17	9	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Acrotome inflata	h		---	27	---	26	---	33	---	39	---	13	---	0	---	35	---	33	---	20	---	20	---	25	---	39	---	35
Abutilon fruticosum	h		---	33	19	47	---	0	---	27	---	38	---	0	---	30	---	29	---	0	---	40	---	0	---	9	---	20
Limeum argute-carinatum	h		---	0	23	16	---	0	---	0	---	0	---	0	---	0	---	0	---	20	---	0	---	0	---	0	---	0
Monechma spartoides	d		---	0	21	11	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	10	---	0	---	0	---	0
Vachellia reficiens	ts		---	20	28	84	---	33	---	27	---	25	---	50	---	26	21	71	---	40	---	50	---	0	---	9	---	45
Senegalia mellifera subsp. *detinens*	ts		---	27	18	32	---	0	---	3	---	13	---	0	---	22	---	0	---	0	---	30	---	0	---	13	---	10
Dicoma tomentosa	h		---	40	---	16	---	33	8	42	---	25	---	75	---	35	---	0	---	40	---	20	---	13	---	9	---	40
Vachellia nebrownii	ts		---	0	---	5	---	0	---	0	---	25	---	0	---	0	22	29	---	0	24	30	---	0	---	9	---	5
Monechma divaricatum	d		---	7	---	11	---	33	---	0	---	0	---	0	---	0	20	24	---	0	---	0	---	13	---	0	---	0
Euphorbia glanduligera	ts		---	0	---	5	---	33	---	0	---	0	---	0	---	0	13	19	---	20	---	0	---	13	---	4	---	0
Emilia ambifaria	h		---	13	---	0	---	67	---	6	---	50	---	25	11	52	11	52	---	40	---	40	---	25	11	52	---	30
Hirpicium gazanioides	h		---	0	---	5	---	33	---	21	---	63	---	50	---	48	---	62	---	40	---	70	---	63	28	96	---	55
Monechma genistifolium	d		---	0	---	11	---	33	---	3	---	13	---	25	---	0	---	38	---	60	18	60	---	50	24	70	---	40
Urochloa brachyura	a		---	33	---	11	---	0	---	64	---	88	---	100	---	65	---	24	---	80	18	90	---	88	14	83	---	40
Terminalia prunioides	ts		27	93	21	84	---	67	18	79	---	13	---	75	---	48	---	19	---	20	---	20	---	13	---	22	---	65
Mundulea sericea	ts		---	0	---	11	---	0	---	0	---	0	---	0	---	0	23	14	---	0	---	0	---	0	---	0	---	5
Gisekia africana	h		---	33	---	37	---	33	16	36	---	0	---	0	---	22	---	5	---	0	---	0	---	13	---	9	---	20
Helinus species	ts		---	0	---	5	---	0	---	6	---	13	---	0	---	0	---	0	---	0	27	20	---	0	---	0	---	0
Eragrostis cylindriflora	p		---	0	---	0	---	0	---	6	---	0	---	0	---	0	30	14	---	0	---	0	---	0	---	0	---	0
Heliotropium nelsonii	h		---	0	---	0	---	0	---	6	---	0	---	0	---	4	24	14	---	0	---	0	---	0	---	4	---	0
Tephrosia burchellii	h		---	7	---	47	---	33	---	42	18	75	---	50	---	39	---	38	---	40	21	80	---	63	---	30	---	25
Melinis repens subsp. *grandiflora*	a		27	87	---	47	---	100	13	64	---	38	---	25	---	48	---	19	---	20	---	20	---	13	---	17	---	35
Evolvulus alsinoides	h		---	7	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Steganotaenia araliacea var. *araliacea*	ts		---	7	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Zehneria marlothii	h		---	0	---	0	---	33	8.5	9	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	4	---	0
Cissus nymphaeifolia	ts		---	7	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Acalypha indica	h		---	27	14	32	---	0	---	15	---	0	---	0	---	9	---	10	---	40	---	30	---	25	---	0	---	0
Peristrophe paniculata	h		---	0	21	11	---	0	---	0	---	0	---	0	---	0	---	5	---	0	---	0	---	0	---	0	---	5
Helichrysum tomentosulum	h		---	0	---	0	---	0	---	0	---	0	---	0	---	4	---	0	---	0	---	0	---	0	---	0	---	5
Colophospermum mopane	ts		---	93	---	89	---	100	---	109	---	63	---	75	---	100	---	105	---	80	---	70	---	63	---	52	---	100
Phyllanthus pentandrus	h		---	0	---	0	---	0	---	6	---	13	---	0	---	9	---	0	---	0	---	0	---	0	---	0	---	10
Launaea intybacea	h		---	0	---	0	---	0	---	0	---	0	---	0	---	4	---	0	---	0	---	0	---	0	---	0	---	0
Solanum rigescentoides	h		---	0	---	0	---	0	---	0	---	0	---	0	---	4	---	0	---	0	---	0	---	0	---	4	---	5
Triraphis purpurea	p		---	13	---	0	---	0	---	3	---	0	---	0	---	13	---	5	---	0	---	0	---	0	---	9	---	15
Mollugo cerviana	h		---	0	---	0	---	0	---	3	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Ziziphus mucronata	ts		---	0	---	0	---	0	---	0	---	13	---	0	---	4	---	0	---	0	---	0	---	0	---	0	---	0
Boscia albitrunca	ts		20	47	---	21	---	0	---	27	---	0	---	0	---	22	17	43	---	60	---	0	---	0	---	9	---	20
Monsonia species	h		---	0	---	0	---	0	---	3	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Vachellia hebeclada	ts		---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	20	---	0	---	0	---	4	---	0
Galenia papulosa	h		---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	5
Oropetium capense	p		---	13	26	37	---	0	14	24	---	13	---	0	---	0	---	5	---	20	---	0	---	0	---	0	---	20
Momordica humilis	h		---	0	---	0	---	0	---	0	---	0	---	25	---	9	---	5	---	20	---	0	---	0	---	0	---	0
Enneapogon cenchroides	p		---	87	---	84	---	67	---	76	---	63	---	50	---	78	---	76	---	80	---	90	---	88	---	83	---	95
Vachellia kirkii	ts		---	7	---	11	---	0	15	18	---	13	---	0	---	4	---	0	---	0	---	20	---	0	---	4	---	0
Kohautia caespitosa subsp. *brachyloba*	h		---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	5
Cucumis africanus	cr		---	13	---	21	---	33	---	15	---	25	---	0	---	13	---	14	---	20	---	20	---	0	---	4	---	10
Grewia olukondae	ts		---	7	---	0	---	33	---	6	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	4	---	5
Anthephora schinzii	a		16	93	17	95	---	33	12	88	---	63	---	75	---	65	---	48	---	80	---	60	---	50	---	48	---	85
Striga gesnerioides	h		---	0	---	5	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Croton gratissimus	ts		---	7	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0	---	0
Tephrosia dregeana var. dregeana	h		---	0	---	0	---	0	---	0	---	13	---	0	---	0	---	0	---	0	---	10	---	0	---	4	---	0

Above is a synoptic table presented as Table 1 that summarise the species distribution into various associations. Plant communities were named according to diagnostic species and simplified structural classes pending the syntaxonomic descriptions of the Namibian-Angolan Mopane Savanna. The vegetation units of Etosha heights can be summarised into 4 major vegetation units A: Mountain veld, B: Wetlands and Ecotones and C: Savanna shrublands, D. pans and grasslands which are subdivided into 11 associations. The associations are numbered corresponding to the numbering on the dendrogram.

A. *Combretum apiculatum–Terminalia prunioides* mountain veld

This community occurs on mountains, slopes and rocky habitats of the study area. They are characterized by an occurrence of *Commiphora glaucescens, Commiphora glandulosa*, *Terminalia prunioides*, *Combretum apiculatum*, *Schmidtia kalahariensis* and various *Aristida* species.   This species matrix is common within all dolomite, limestone and quartzite substrates in the reserve but different species combinations are dominant in different localized habitats thereof. Figure 8 illustrates the structural difference of these associations in the form of box and whisker plots. Though the *Combretum apiculatum-Terminalia prunioides* community has been classified as four associations, there is some variation within the associations and therefore potential of further division or higher syntaxonomy. However, for this baseline study the following four associations were identified; *Commiphora glaucescens–Danthoniopsis dinteri* high gradient hills, *Senegalia senegal-Grewia flavescens* medium gradient slopes and calcareous outcrops, *Brachiaria marlothii – Commiphora glandulosa* ecotones, and, *Schmidtia kalahariensis – Hermbstaedtia argenteiformis* footslopes.

1. *Commiphora glaucescens–Combretum apiculatum* association

This vegetation association occurs on high gradient and steep slope ridges ranging between 7.0447 ° - 17.6837 °. These ridges are of the Otavi group. It is defined by moderately closed short woodland See Figure 8. The vegetation of this association is dominated by *Commiphora glaucescens* and *Commiphora glandulosa*, *Combretum apiculatum* subsp *apiculutum*, *Kirkia acuminata, Moringa ovalifolia, Sterculia africana* and *Pachypodium lealii*. The grasses *Danthoniopsis dinteri* and *Brachiaria marlothii*, *Chloris virgata* frequently accompany them. The

Commiphora glaucescens–Combretum apiculatum hills occur at altitudes of between 1184 and 1332 m asl. This association has the narrowest pH range of 7.53-8.25 and the soils are sandy-loam leptisols which supports the trees at a height rarely more than 5 m. A similar association was described by Le Roux *et al.* (1988) as dolomite inselbergs of Etosha National Park. However, the Etosha National Park is on the Nosib sub-group of the Otavi Group.

2. *Vachellia reficiens–Terminalia prunioides* association

This association is most prominent on elevated landscapes where surface soil is almost completely covered in calcrete rubble. It also occurs on limestone and dolomite talus slopes and on quartzite ridges and pedeplains. Slope ranges between 0 ° - 4.619 ° with the exception of 2 relevés on hilly plots whose slope were above 10 °. The woody vegetation cover in this association is more dense than on steeper gradients and the grass layer is relatively tall. *Terminalia prunioides*, *Combretum apiculatum* and *Vachellia reficiens* always occur together accompanied by *Anthephora schinzii, Enneapogon cenchroides* and numerous preferential grass species listed in the Species Group B of the synoptic table (Table 1) below. The abundance of *Commiphora glandulosa* and *Commiphora glaucescens* is very limited in this association to the extent of one Commiphora species per 1 000 m^2. The soils are generally sandy-loam with pedeplains more loamy than sandy. This association forms part of the Mopane tree veld described by (Le Roux *et al.* 1988).

Figure 8 An illustration of the 4 mountain associations. (a)showing the steep slopes of association 1 (b) showing the stoniness of association 2; (c) illustrating the tall mopane clusters as an indication of deeper sands in association 3; and (d) Open shrubland dominated by Schmidtia kalahariensis on fairly red sand of association 4.

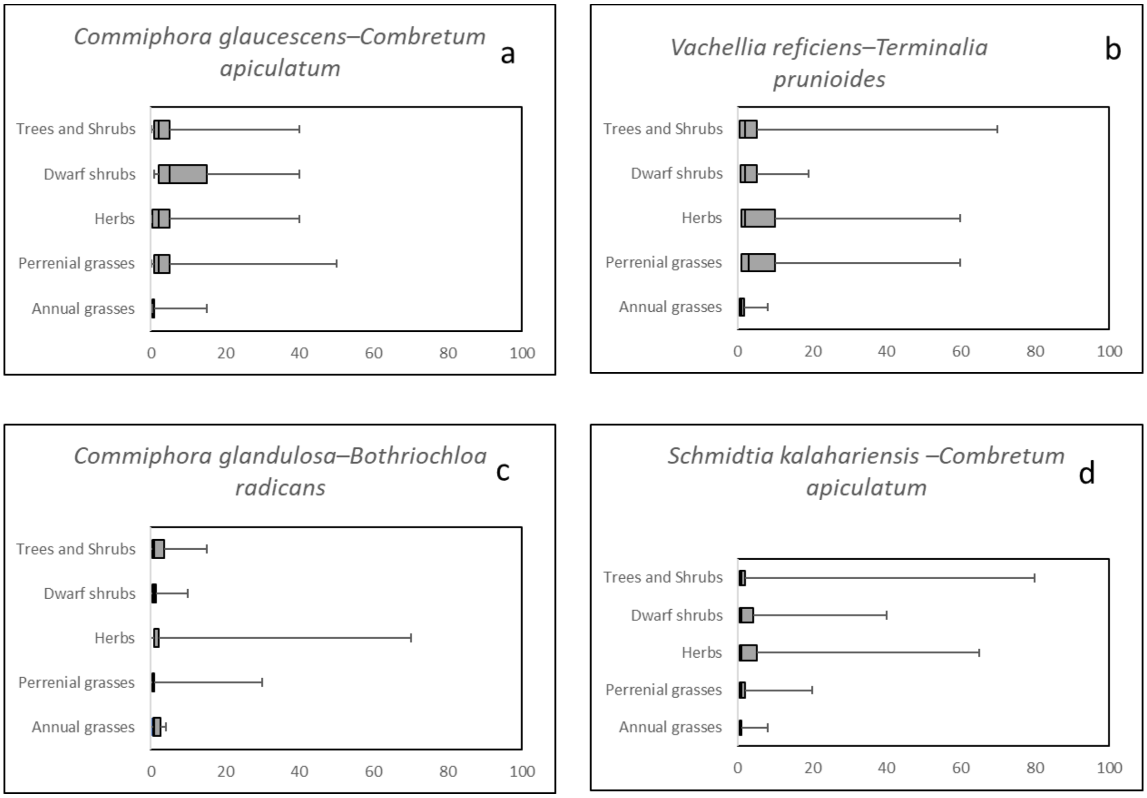


Figure 9 Box and whisker plots showing the various structure components of (a) Association 1, (b) Association 2 and (c) Association 3 and (d) Association 4

3. *Commiphora glandulosa–Bothriochloa radicans* association

This association is the most diverse of the mountainous communities. It occurs in areas transitioning from calcareous outcrops into Mopane shrub-veld. In this association are mountain species and dwarf shrubs that are common in the plains. *Monechma genistifolium* and *Brachiaria marlothii* are also common in this association. The occurrence of wetland species like the latter and name giver could be an indication that these areas accumulate higher moisture and have deeper soils than adjacent vegetation units. An account of the diagnostic species of this association is listed in the Species Group C of Table 1.

4. *Schmidtia kalahariensis–Combretum apiculatum* association

This vegetation association covers lower gradient hills, adjacent slopes and pedeplains. Woody species richness decrease with distance from rocky outcrops. In this association, *Commiphora gladulosa* occurs in very low abundance on quartzite hills rather than on limestone and dolomite ridges. *Schmidtia kalahariensis* defines this association occurring in a minimum cover of 30% per 1 000 m^2, always occurring with *Terminalia prunioides.* Other species that frequently accompany them include *Aristida adscensionis, Combretum apiculatum* subsp *apiculatum, Combretum mossambicense, Catophractes alexandri, Stipagrostis hirtigluma, Chloris virgata and Eragrostis porosa*. Occurance of *Vachellia reficiens* becomes rare with distance from the mountain top. This association is an open shrubland *sensu* Edwards (1983) with phanerophytes not exceeding a height of 2 m. There is very little herb cover as illustrated in Figure 9c with the exception of the abundance of *Schmidtia kalahariensis* which covers up to 70% of a relevé. The soils are of a coarse sandy-loam to loamy-sand structure and are slightly more acidic than all other associations, ranging between pH 6.7-8.5. Hilly areas have a slope range of 7 ° – 14 ° while the plains range from 0.09 ° and 6.80 °.

B. *Eragrostis trichophora–Setaria verticillata* wetlands and ecotones

The *Eragrostis trichophora-Setaria verticillata* community is the wetlands sections of the reserve that are in the watercourses, adjacent to head waters, and in vleis. The vegetation composition in this community is also common around trampling zones. Woody species that are usually found in these areas include *Colophospermum mopane, Terminalia prunioides* and the herbaceous layer is dominated by *Aristida adscensionis, Urochloa brachyura, Chloris virgata, Tragus racemosus*, *Leucosphaera bainesii,* and *Setaria verticillata.* The habitats were classified into three associations: *Eragrostis trichophora–Tragus racemosus, Aristida hordeacea–Eragrostis biflora,* and*, Amaranthus thunbergii–Setaria verticillata***.**

5. *Eragrostis trichophora–Tragus racemosus*

This association occurs as herby-shrublands with a minimum grass cover of 62% per 1000 m^2 and forbs covering more than 2/3 of a plot in some instances. These herby shrublands occur in vleis and depressions where water collects during the rainy season. Species that differentiates this association from other wetlands are *Aristida stipitata Eragrostis trichophora*, and *Lantana angolensis* and occasionally *Eragrostis annulata, Tephrosia burchelli* and *Stipagrostis hirtigluma*. Soil capping is common in these areas. Generally, this association can be termed wooded grasslands (Edwards 1983). *Colophosperma mopane, Dichrostachys cinerea* and *Catophractes alexandrii* dominates the woody layer. A summary of this structure is illustrated in Figure 10 and 11.

6. *Aristida hordeacea–Panicum coloratum*

This association is along foot-slopes of relatively low gradient hills. It is also visible in the fringes of sodic soils in the northwestern area of the study site. The soils are deeper in these areas as they are at the headwaters and adjacent to me hills. The soils are loam to sandy-loam with pH ranging in between 7.73 – 8.15. In the southern parts, it shows as a grass fringe with woody species not more than 1 m in height. Species that characterize these wetlands and occurs in high abundance are *Monelytrum luederitzianum* in the south; *Hermania modesta* in the north; and in the east, *Chloris virgata*. Other iconic species are *Aristida hordeacea, Tragus racemosus, Vachellia nilotica, Eragrostis biflora* and *Panicum coloratum*.

7. *Eragrostis porosa–Dichrostachys cinerea*

This association occurs in riverbeds and their flooding peripheries. It is also prominent in calcarious piospheres of the study area. In the far west it occurs on vleis with shallow soils therefore the woody layer is short, not exceeding 1.5 m in height.

The habitat is recovering from overgrazing and carries stands of climax grass species like *Cenchrus ciliaris* and *Bothriochloa radicans.* Standing water then promotes growth of herbs such as *Setaria verticillata, Amaranthus thunbergii* and *Eragrostis porosa*. In the East, this occurs in riverbeds and on foot slopes that are in water courses. Important species in these areas are *Terminalia prunioides, Vachellia nilotica, Achyranthes aspera* var. *sicula* and *Enneapogon cenchroides*.

The occasionally flooding areas have rich loam, sandy-loam calcrete soils with dense grass cover in sparse woody vegetation. The soils have a high conductivity ranging between 300 to 700 µS/cm thereby promoting the growth of the herb layer under the woody species. Nutrients from animal excretion as they rest under the shade of these trees could contribute to the high conductivity. Definite distinction between this and other plain associations is the absence of *Monechma genistifolium* and *Stipagrostis hirtigluma.*

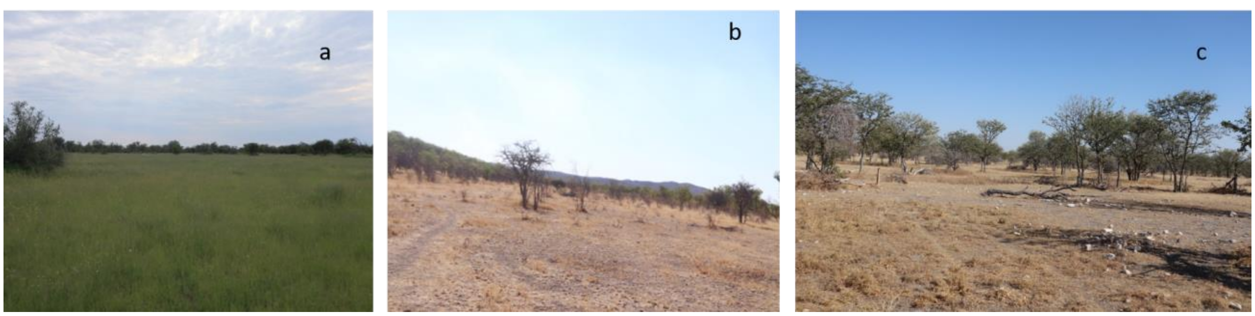


Figure 10: An illustration of the three wetlands associations a. showing a sparsely wooded grassland of Association 5, b. showing sloping land that occasionally floods typical of Association 6, and c. riparian woodlands of Association 7

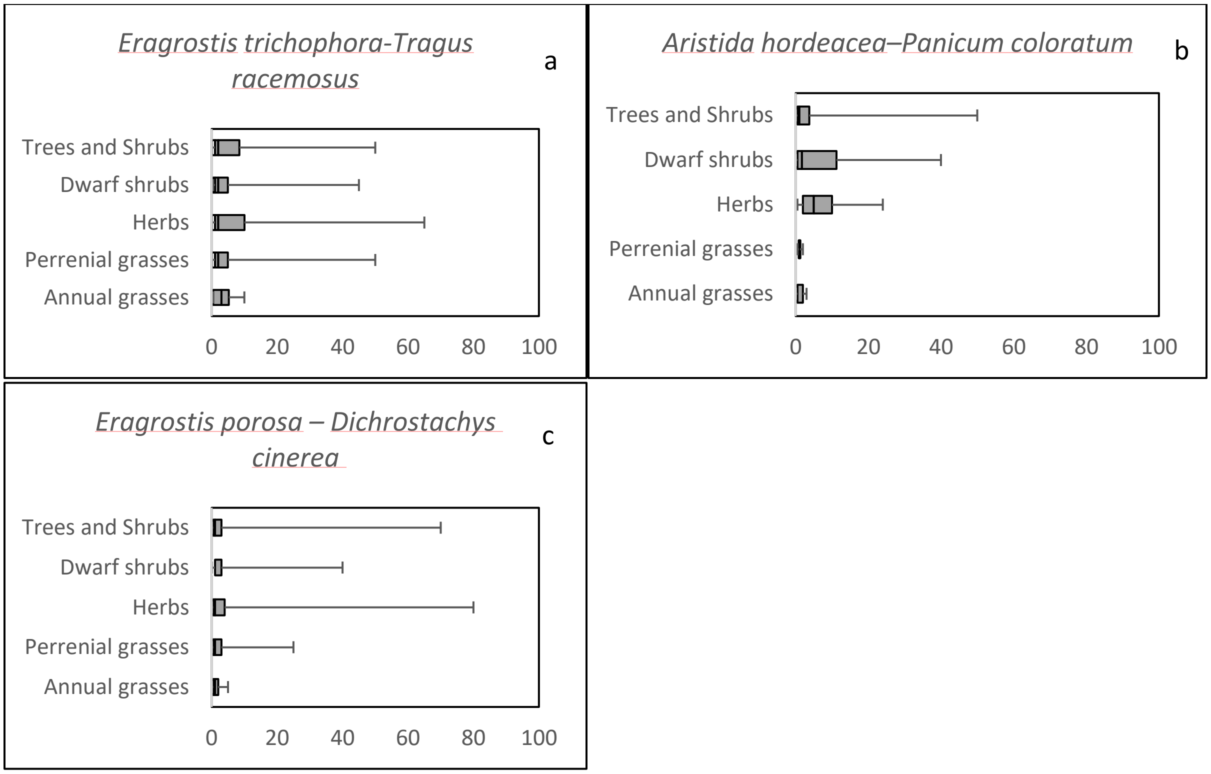


Figure 11 Box and whisker plots showing the various structure components of wetlands associations (a) Association 5, (b) Association 6 and (c) Association 7

C. *Monechma genistifolium–Stipagrostis hirtugluma* savanna shrublands

This community represents the plains of the study area. Slopes range between 0.2 ° - 3 °. Vegetation transitions from the wetland ecotones (*Eragrostis trichophora-Setaria verticillata* community) into these plains, grasslands and pans. Therefore, this community is divided into those three associations with the grasslands association further divided into 4 sub-associations. *Colophospermum mopane*, *Vachellia* and *Senegalia* species, *Catophractes alexandri* are constantly present in this community and the dwarf shrubs *Petalidium englerianum, Monechma genistifolium*, and *Leucosphaera bainesii* always accompany them. Each of these three dwarf shrub species is a diagnostic species of the three associations of this community. Common herbs are *Hirpicium gazanioides, Eragrostis annulata, Stipagrostis hirtigluma, Enneapogon cenchroides* and *Enneapogon desvauxii.* However, treeless grasslands are also classified within this community. The terrain transitions from rocky and stoney to pebbles.

The soils are generally shallow with relatively deeper soils flowing in from the Kalahari debris from ENP in the north while calcrete precipitating from the hills underlay the pans (Hipondoka 2005).

8. *Petalidium englerianum–Eragrostis porosa* association

This association is a shrubland community prominent on the eastern parts of the study area. It occurs as a combination of *Colophospermum mopane* with *Vachellia reficiens*, *Vachellia nebrownii, Catophractes alexandri* and occasionally as pure stands of the same species. These are usually on calcrete deposits. The stones cover at least 30% of the land surface. The soils are sandy-loam. pH range between 7.49 - 8.32. Plains in the East are at a lower altitude than plains in the West. Moreso, the east receive about 20 mm more rain than the west as depicted in figure 4. Therefore, it is highly likely that these plains receive more runoff than those in the west. Coupled with the stone cover, it would also be expected that evaporation is lesser in the eastern areas, and hence wetland species are also present in this association. This vegetation unit occurs in close proximity to the *Eragrostis porosa–Dichrostachys cinerea* association, occurring as flooding areas of that association.

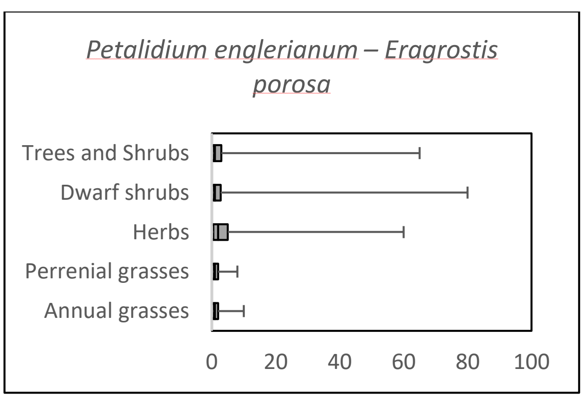


Figure 12: An illustration of the structural components of association 8. Note the stone cover and abundance of dwarf shrubs.

9. Monechma genistifolium–Enneapogon desvauxi grasslands and pans

This association is the most important community of Etosha Heights. This association is a grassland unit though structurally diverse. Where there is more moisture, the woody vegetation generates. The woody vegetation seems to follow a soil depth and moisture gradient. Figure 14 illustrates the structural difference following this gradient. Common species are *Aristida adscensionis, Urochloa brachyura, Enneapogon cenchroides, Enneapogon desvauxi, Stipagrostis hirtigluma, Hirpicium gazanoides and Eragrostis annulata*. Floristically, a combination of *Colophosperma mopane* and *Catophractes alexandrii*, *Vachellia reficiens* and/or *Vachellia nebrownii* makes this association easy to identify. A few relevés (association 6.1) of this association occur also on loamy floodplains in a mosaic. The actual diagnostic feature of this association is the dwarf shrub understory dominated by *Monechma genistifolium* and the grass *Enneapogon desvauxi*. What then differentiates one sub-association from the other is the absence of key species in the sub-associations of the same community.

9.1 ***Gossypium triphyllum–Boscia albitrunca***

This sub-association occurs on transition zones between wetlands and mopane shrublands. It occurs as shrublands of *Colophosperma mopane* and *Catophractes alexandrii.* The local topography is gently undulating and stoney. In addition to the common species of this association mentioned above, *Aristida hordacea* and A. *rhiniochloa* are also frequently present. The soils are loamy-sand. Differential species are *Gossypium triphylum*, *Eragrostis biflora, Indigofera adenoides*, *Leucas pechuelii, Hermbstaedtia argenteiformis* and *Nidorella resedifolia*. The absence of *Cenchrus ciliaris* differentiates this association from the other wetlands associations. In Figure13 is a summary of the structural composition of this sub-association.

9.2 *Leucosphaera bainesii–Cenchrus ciliaris*

This association occurs as an ecotone transitioning into association 8 (*Petalidium englerianum–Eragrostis porosa)*. It occurs as grasslands with woody species (wooded grasslands). The diagnostic species of this association are *Heliotropium steudneri and Cenchrus ciliaris*. Woody species occurring less than 4% per 1 000 m^2 are *Vachellia mellifera, Colophosperma mopane* and *Vachellia reficiens* though *Catophractes alexandrii* tends to occur in higher abundance. Le Roux *et al.* (1988) described a similar habitat in ENP as the sweetveld on lime. It is in its sub climax transitioning stage and has a higher abundance of climax perennial *Cenchrus ciliaris* compared to the rest of the reserve. Except for the sparsely woody vegetated grasslands, the woody vegetation in this unit does not exceed 1.5 m in height. See Figure 13 for a summary of this unit's structure.

10.1 *Catophractes alexandrii–Leucosphaera bainesii* association

This association might have been previously grasslands. It occurs in the grassland fringes as wooded grasslands and occasionally as pure stands of *Colophosperma mopane* shrubs. Important species are *Colophosperma mopane, Catophractes alexandrii Stipagrostis hirtigluma, Aristida adscencionis and Enneapogon desvauxi. The absence of Vachellia reficiens, Setaria verticillata, Eragrostis porosa, Chloris virgata,* and *Dicoma tomentosa* differentiates this association from *Eragrostis stipitata – Cenchrus ciliaris* ecotone. The presence of *Tragus berteronianus* and *Acalypha indica* which are absent in association *Leucosphaera bainesii – Panicum novemnerve* differentiates it from the rest of the grasslands sub-associations.

10.2 *Monechma genistifolium–Eragrostis echinochloidea association*

In this sub-association, the structural composition depends on where the grassland is situated relative to other associations. In addition, the species composition is dependent on the substrate of that grassland.

Around ridges and calcareous outcrops, the grasslands are treeless and dominated by *Aristida adscencionis*. Where soils are deeper, *Catophractes alexandrii* occasionally encroaches into the grasslands.

Grasslands adjacent to riparian woodlands are dominated by *Chloris virgata* and *Aristida adscencionis* and these are usually treeless and over-utilised. In the north-eastern pan area of the reserve, the grasslands are dominated by *Enneapogon desvauxi, Monechma genistifolium* and *Leucosphaera bainesii.* These are often encroached by thickets of *Vachellia nebrownii* and in less abundance *Catophractus alexandrii*. Other important species in this vegetation association are *Enneapogon desvauxi, Hirpicium gazanioides, Eragrostis porosa, Petalidium englerianum, Kyphocarpa angustifolia* and *Eragrostis echinocloidea.*

11. Leucosphaera bainesii–Eragrostis porosa association

This association occurs as a combination of *Colophospermum mopane, Terminalia prunioides Catophractes alexandri* and *Enneapogon desvauxii* and regularly as pure stands of *Catophractes alexandri* or *Enneapogon desvauxii* grasslands. It occurs in close proximity to the *Amaranthus thunbergii* – *Colophospermum mopane* riparian woodlands community. Though half of the relevé in this association occur in vleis, the species composition is typical of savanna shrublands possibly making it a transition zone. Other common species include *Anthephora schinzii* and *Tragus berteronianus*. The diagnostic species of this association are listed in Table 1. In the east, the association occurs in the adjacent sandy patches of *Petalidium englerianum* – *Eragrostis porosa* association. In the West it occurs in the watercourses adjacent to the shallower flooding areas of association *Amaranthus thunbergii* – *Setaria verticillata*. However, in the far west *Leucosphaera bainesii* is replaced by *Petalidium englerianum*.

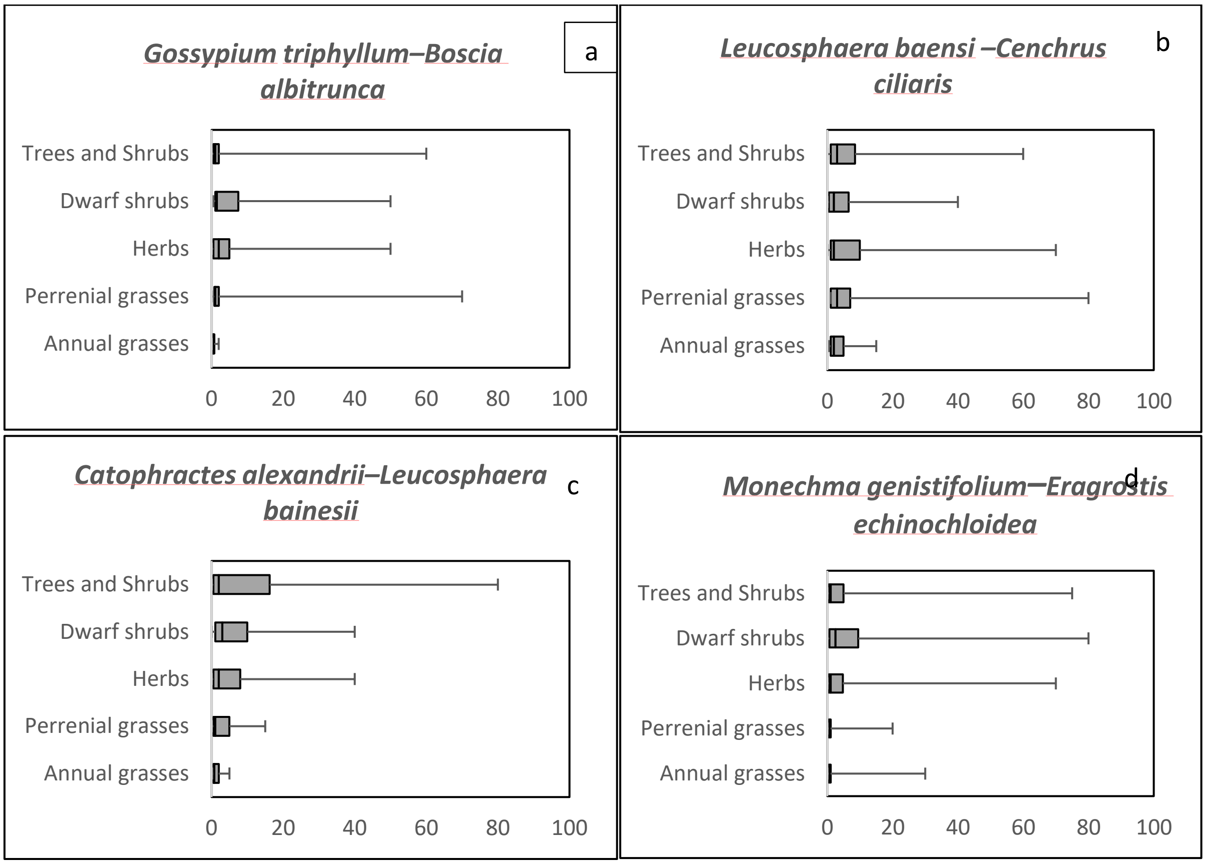


Figure 13 Box and whisker plots showing average structure of the various grassland associations.

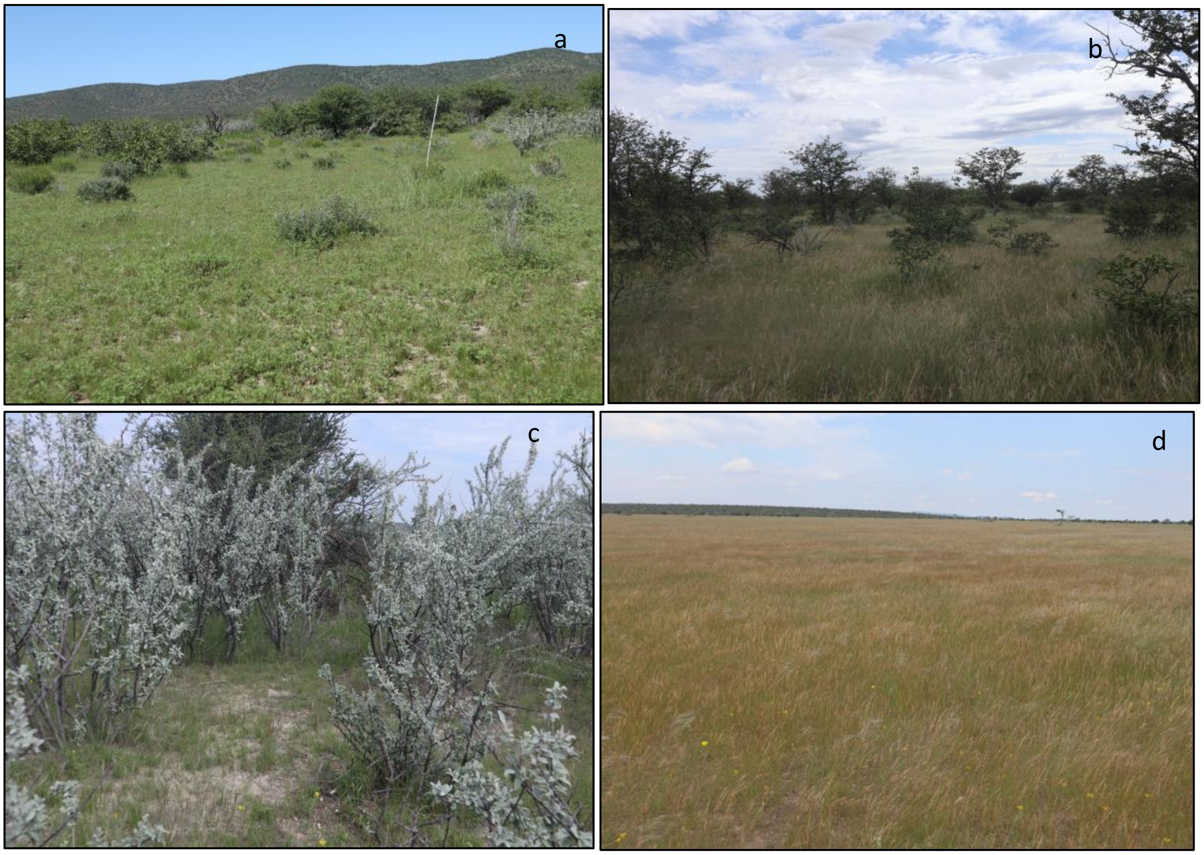


Figure 14 Images summarizing the physical appearance of the various grassland associations.

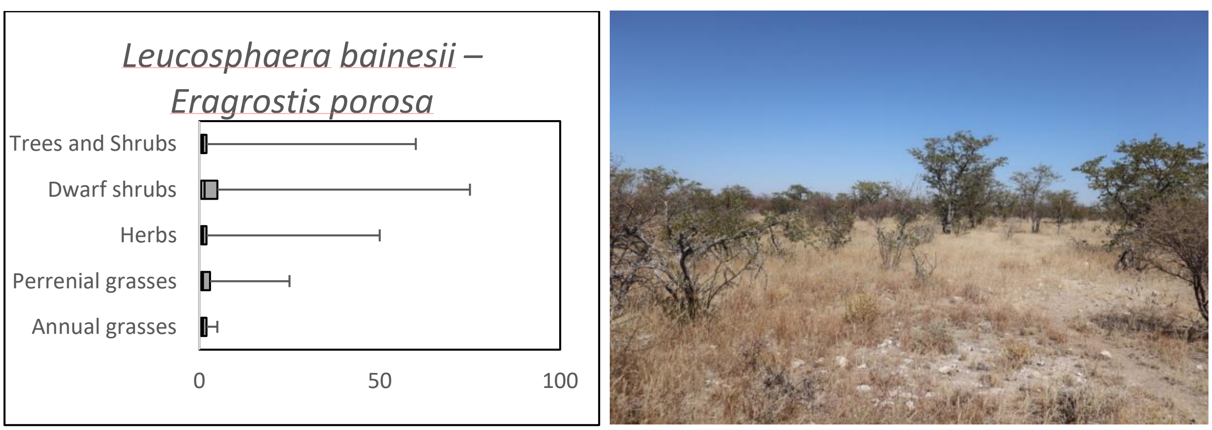
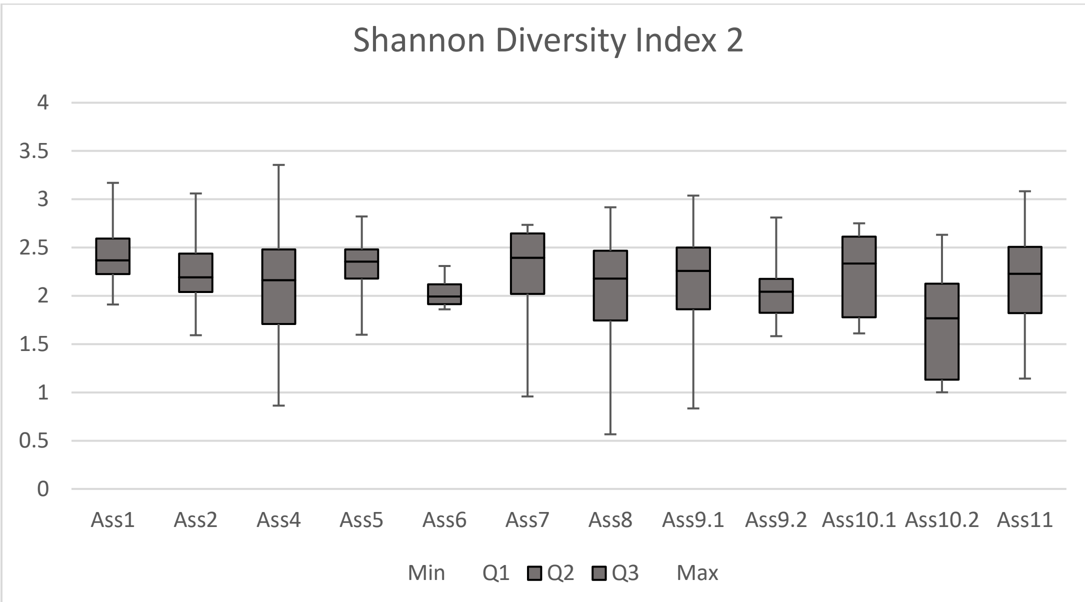


Figure 15 Box and whisker plots illustrating the vegetation structure of Association 11 (a) and the photograph illustrating the diversity of the herb layer and the somewhat loose soil and distribution of dwarf shrubs Monechma genistifolium and Leucosphaera bainesii (b).

Species Richness and diversity

Species richness across the landscape shows that there are more annual grasses than perennials and a rich forb diversity. The highest tree diversity is in the mountainous habitat (Associations 1-4) with a richness of 32 species in the high gradient association. Riverbeds have the highest forb species richness (Association 7).



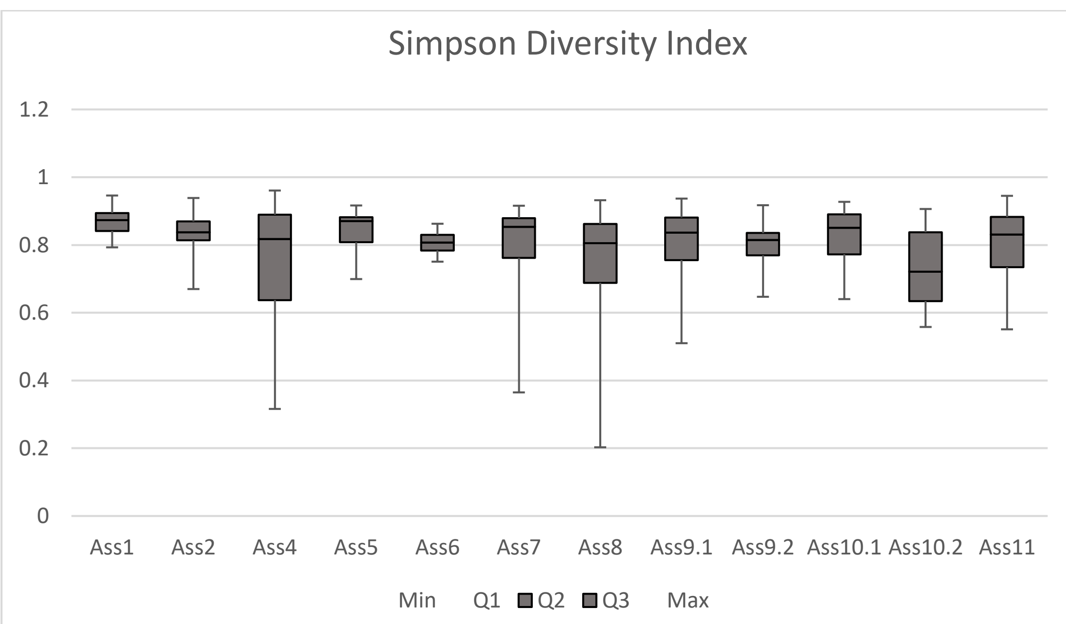


Figure 16 The Shannon and Simpson diversity indices of the vegetation of Etosha Heights.

Environmental gradients

The NMS of the whole data set produced an ordination in three dimensions, with the final stress for the best solution being 16.933, and an instability of 0.0000 after 84 iterations. The mountain veld (Associations 1 – 4) is distinctly separate from the plains along Axis 3, whilst the *Monechma genistifolium–Enneapogon desvauxi* grasslands (Associations 9.1 – 10.2) are clearly separated from the rest of the plains habitats in Axis 1 (Figure 17). The overlap between association 2 (*Vachellia reficiens–Terminalia prunioides* hills and outcrops) and association 3 (*Commiphora glandulosa–Bothriochloa radicans*) with the rest of the plains indicates the close relationship between these groupings.

The NMS on the mountains associations only (Associations 1-4), produced an ordination in three dimensions with final stress levels being 14.554, and an instability of 0.000, after 99 iterations. Axis 1 presents a soil structure and altitude gradient. Altitude is correlated to Axis 1 with $r = 0.355$, whilst soil structure in the form of silt and clay correlates to this axis with $r = 0.431$ and 0.344 respectively (Figure 18).

The NMS on the plains habitat (Figure 19) produced an ordination in two dimensions with final stress levels being 20.292, and an instability of 0.0001, after 131 iterations. Association 9.1, 9.2, 10.1 and 10.2 stand out from the rest of the plains data. These are diverse grasslands with *Monechma genistifolium* occurring in most plots. Some of the plots are in a sub-climax transitioning state. These are important grazing areas during wet season as they provide some highly nutritious graze for game. There are possibilities that these grasslands were previously over-utilised during the livestock farming era and the woody vegetation encroached. However, the plains habitats did not correlate with any of the given environmental variables, therefore will not be discussed in this section.

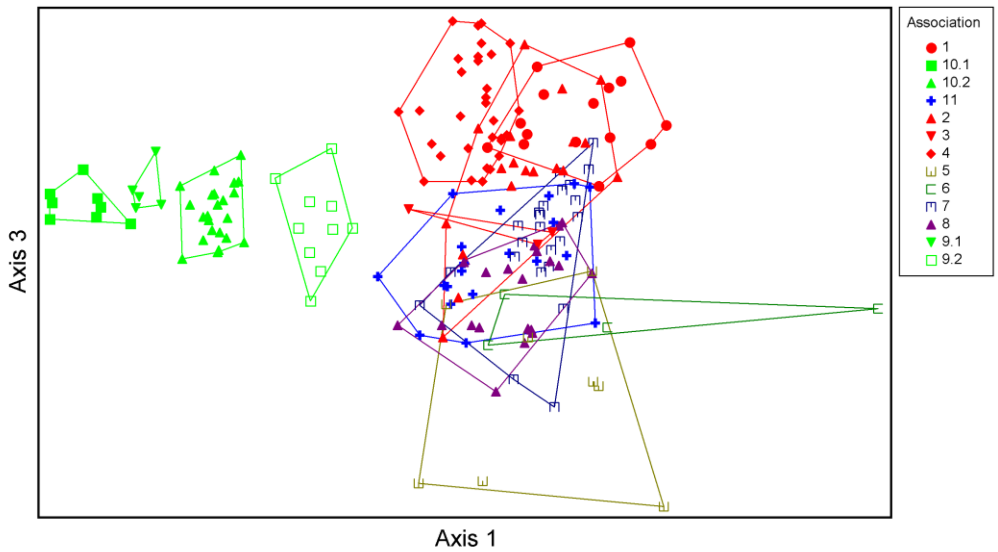


Figure 17 Ordination diagram of the complete data set showing the clear separation of grassy pans (associations 9 and 10) and the mountains (associations1 – 4) indicated as convex hulls

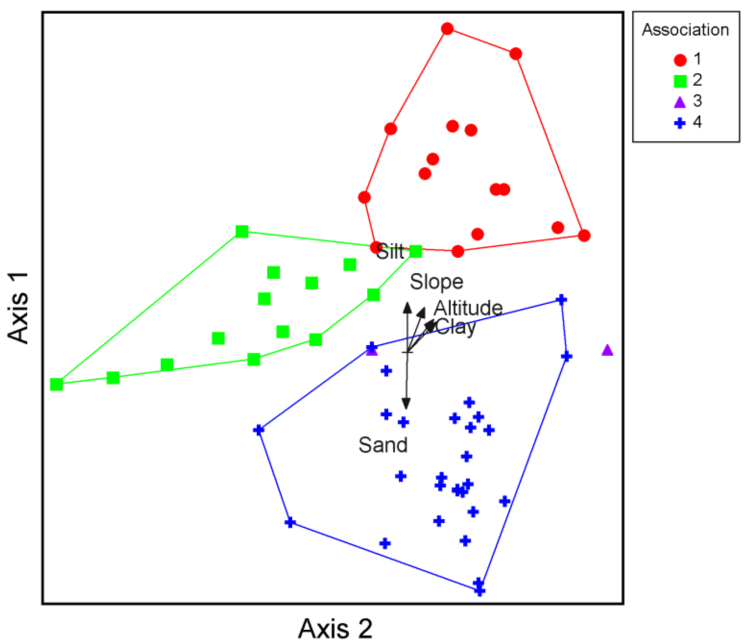


Figure 18 Ordination of the mountain habitats indicated as convex hulls with environmental factors as bi-plots

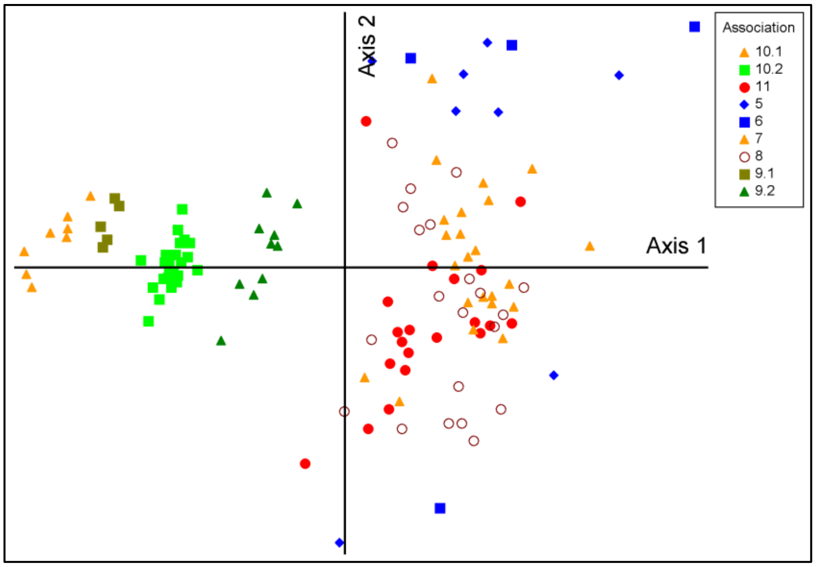


Figure 19 Ordination diagram of the plains habitats

Mapping

It was not possible to map all vegetation types as many units are spatially small to map with the 30 m ground resolution of Landsat 8 images. This holds true for the plains associations 7 and 11 which occurs in ridges with very limited spatial extent. For this reason, the landscape map was produced (Figure 19) to differentiate between plains and wet areas, grasslands, the Mopane shrubveld and mountainous areas. Ideally, a detailed vegetation sampling at farm level like this study site is “seeding” data for larger regional studies (Strohbach 2014). Pans and riverine vegetation are difficult to map at any scale smaller than 1:10 000. Table 1 illustrates the groupings into major mapping units. Therefore, the map illustrates the continuum pattern of the plains.

Table 2 Table of mapping units of the vegetation map of Etosha Heights Private Game Reserve.

Association	Mapping unit	Components
1	*Commiphora graucenscens-Combretum apiculutum*	89% *Commiphora graucenscens-Combretum apiculutum* 10% *Vachellia reficiens-Terminalia prunioides* 1% *Schmidtia kalahariensis-Combretum apiculatum*
2 and 3	*Vachellia reficiens-Terminalia prunioides*	99% *Vachellia reficiens-Terminalia prunioides*
		1% *Commiphora glandulosa-Bothriocloa radicans*
4	*Schmidtia kalahariensis-Combretum apiculatum*	100% *Schmidtia kalahariensis-Combretum apiculatum*
5	*Eragrostis trichophora-Tragus racemosus*	100% *Eragrostis trichophora-Tragus racemosus*
7	*Eragrostis porosa-Dichrostachys cinerea*	100% *Eragrostis porosa-Dichrostachys cinerea*
8	*Petalidium englerianum-Eragrostis porosa*	99% *Petalidium englerianum-Eragrostis porosa*
		1% *Vachellia reficiens-Terminalia prunioides*
9.1	*Gossypium triphyllum-Boscia albitrunca*	10% *Gossypium triphyllum-Boscia albitrunca*
		57% *Petalidium englerianum-Eragrostis porosa*
		20% *Leucosphaera bainesii-Cenchrus ciliaris*
		7% *Aristida hordecea-Panicum coloratum*
		6% *Leucosphaera bainesii-Eragrostis porosa*
9.2	*Leucosphaera bainesii-Cenchrus ciliaris*	25% *Leucosphaera bainesii-Cenchrus ciliaris*
		1% *Catophractes alexandrii-Leucosphaera bainesii*
		1% *Eragrostis porosa-Dichrostachys cinerea*

		1% *Eragrostis trichophora-Tragus racemosus*
		10% *Gossypium triphyllum-Boscia albitrunca*
		25% *Monechma genistifolium-Eragrostis echinochloidea*
		25% *Petalidium englerianum-Eragrostis porosa*
		10% *Schmidtia kalahariensis-Combretum apiculatum*
10.1	*Catophractes alexandrii-Leucosphaera bainesii*	99% *Catophractes alexandrii-Leucosphaera bainesii*
		1% *Leucosphaera bainesii-Eragrostis porosa*
10.2	*Monechma genistifolium-Eragrostis echinochloidea*	89% *Monechma genistifolium-Eragrostis echinochloidea*
		10% *Vachellia reficiens-Terminalia prunioides*
		1% *Schmidtia kalahariensis-Combretum apiculatum*
11	*Leucosphaera bainesii-Eragrostis porosa*	63% *Leucosphaera bainesii-Eragrostis porosa*
		37% *Eragrostis porosa-Dichrostachys cinerea*

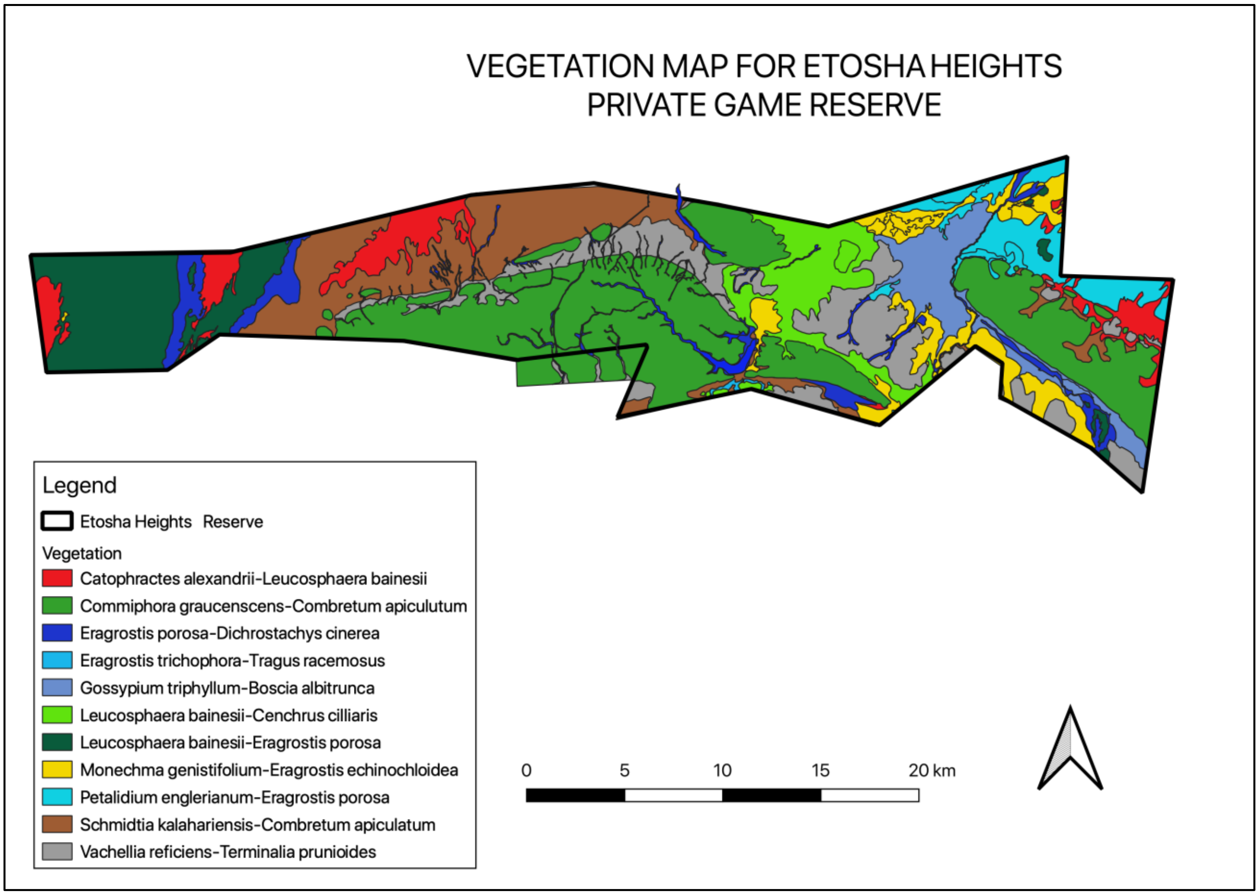


Figure 20 The vegetation map of Etosha Heights Private Game Reserve showing the summary of vegetation associations of the study area.

Discussion and conclusion

Ordination of the two major habitats (mountains and plains) separated show the same results as of the habitats combined. Obtaining the same ordination results on all three data sets used, reflects the qualitative consistency among the NMS ordinations (Peck 2016). These results validates the classification of the vegetation of EHGR into three major groupings; A. mountain veld; B. wetlands ecotones; and C, grasslands and savanna shrublands. The ordinations further illustrate the similarities of communities B and C and how unique the grassy pans are from the rest of this shrubland savanna. This study therefore has contributed a valid and valuable baseline to the understanding of vegetation interactions in this part of the Mopane savanna.

Comparisons to other vegetation surveys

Four distinct higher syntaxonomic groupings can be recognized in this study being the mountains veld, wetland areas, grasslands and Mopane shrublands. These could however not be assigned to a specific syntaxonomic rank due to limited data within the bigger Angolan Mopane savanna in north-western Namibia.

The *Commiphora glaucescens–Combretum apiculatum* association corresponds with the dolomite inselbergs described by Le Roux *et al.* (1988). However, *Sclerocarya caffra* seems to be absent in the Etosha Heights' ridges. Though not recorded in any of the sampled relevés, *Euphorbia guerichiana* and *Moringa ovalifolia* are occasionally present as was noted by Joubert (1971) in the "*Commiphora–Sterculia* association on rocky outcrops".

Vachellia reficiens–Terminalia prunioides(Association 2) is similar to Le Roux *et al.* (1988) mapping units (8) and "dry western sand veld". The slight difference in the species composition from Le Roux *et al.* (1988) units is that in Etosha Heights this association occur on the footslopes of adjacent hills.

Petalidium englerianum–Eragrostis porosa (Association 8) corresponds to Le Roux *et al.* (1988) mapping unit (9) while (association 11) *Leucosphaera bainesii–Eragrostis porosa* corresponds to Le Roux *et al.* (1988) mapping unit (25) *Acacia reficience/Colophosperma mopane/Terminalia prunioides* thorn scrub. This further conforms with the abrupt gradient between plains on shallow soils and vegetation on foot slopes within the limestone dolomite – calcrete landscapes shown in this study area. The same gradient was also observed by Cole and Brown (1976) in their classification of vegetation in Ghanzi District, Botswana.

Le Roux *et al.* (1988) also describes the sweet veld on lime as comprising of grasslands in shallow soils that are underlain by a calcrete pan. Though treeless, in some patches occur thickets of *Vachellia reficiens, V. nebrowni*. However, in this study this *sensu* Le Roux *et al.* (1988) "sweet veld on lime" was further divided into 2 Associations with 2 sub-associations. The ordination (Figure 14c) validates the uniqueness of each sub - association. Nonetheless, the drivers of this uniqueness could not be established from the available environmental variables. It is anticipated that Axis 1 could be a soil depth gradient or a rooting depth gradient. Axis 2 could be a soil structure gradient where sub–associations 9 and 10 have a narrow range and the rest of the plains have a wider range. This calls for further study.

The description of *Eragrostis trichophora–Tragus racemosus* (Association 5) grasslands association corresponds to *Eragrostis trichophora–Colophosperma mopane "Acacia nilotica* dry shrublands sub association. described by Kangombe (2010). *Colophosperma mopane-Terminalia prunioides* association sub-association *Aristida adscencionis-Colophosperma mopane* by the same author corresponds to the *Eragrostis trichophora–Setaria verticillata wetlands* (associations 5, 6 and 7) identified in this study. Both authors concur to the ecotone nature of the association. However, in the case of EHGR, these ecotones were divided into various association as an adaptation to the absence of a clear cut between the plains associations.

Threatened habitats

The reserve's piospheres are expanded by bush clearing caused by elephants. It is common knowledge that elephants are attracted to places where they can find water just like most of the species in the animal kingdom (De Beer *et al.* 2006). In EHGR, there are about 40 active waterholes placed within 480 km^2 (each waterhole servicing an area 12 km^2 in extent). Auer (1997) proposed a distance of at least 15 km^2 between water points or three times the daily travel distance of the elephants. Considering the previous land use (commercial livestock farming), this was a necessity. Conventional rangeland management systems attempts to reduce the intrinsic differences among pasture areas so that all areas produce as uniformly as possible. Ideally, during livestock farming, water points were increased to subject all sections of the property to similar levels of grazing pressure. Now that the focus is on game, which are more resilient than livestock, it may not be necessary to have many artificial water sources. Since there are no more fences to demarcate paddocks for rotational grazing, constant availability of water will only lead to overutilization of the forage. In the Kruger National Park, it was noticed that the longer the distance to the waterhole, the lesser the chances of calf survival and therefore populations were regulated. Depending on the goals of the reserve, this can be considered as a way of regulating elephant populations. However, Owen-Smith *et al.* (2006) puts in perspective other means of controlling elephant populations. Waterholes in ENP are in the central parts of the park (Personal communication with Mr Daniel Shagama[5], August 2022). The management plan for ENP states that waterholes of neighboring farms should be placed at least 2km away from the fence as a way of discouraging animals in ENP from crossing over to drink in neighboring farms.

The area around Gruisgat waterhole is threatened by the undesirable smelly bush *Pechuel-Loeschia leubnitziae* which is invading the cleared trampled area, taking over all the bare spaces. This species is known to be unpalatable and invasive. *Datura* species also occasionally occur around piospheres. Timeous clearing of these invasive species may reduce their spread thereof. Considerations to remove these unpalatable invasive species would only be worthwhile if they are being replaced with other plants to avoid soil erosion. Re-seeding with palatable grasses or other pioneer plants is also recommended. Such sites can be used for research purposes to test the potential of re-seeding.

Veld condition

The dominance of annual graminoids and forbs in a “dryland” is an indication of poor veld condition. In years of good rains, the biomass from the veld will be high despite the abundance of annual grasses than perennials. In years of drought when rainfall is below the expected average the veld will give a poor yield (Espach *et al.* 2006). Like any other rangeland, EHGR does not have a uniform landscape. There are areas with higher abundance of perennial grasses than others or more bushes than others. In Namibia, the common practice of commercial livestock farming is partitioning a range into wet season grazing area, early dry season area, dry season area and drought reserve (Behnke 1998). Usually by the time livestock is moved to the next grazing area, there would be very little grazing left sometimes not even for regeneration. That is how most of the palatable climax perennial grasses are lost (Owen-Smith 2000). This is probably

[5] Mr Daniel Shagama, Warden in Etosha National Park

what might have happened in the study area. In events of prolonged drought periods like is common in Namibia, the veld is left with less utilizable biomass thereby requiring three times as much land to support the same number of animals (Nott *et al.* 2019). The grassland fringes are invaded by thickets of *Vachellia nebrowni, Vachellia reficiens* and *Catophractes alexandrii* bush and encroachment is another indicator of degradation. However, there is potential for veld recovery as within the inaccessible thickets of *Catophractes alexandrii*, there are preserved strands of *Cenchrus ciliaris* a highly palatable perennial grass species. Therefore, the bush clearing method to be applied should conserve this grass species.

However, waterholes close to the northern fence of EH are hotspots for grazers. Since some authorities, notably Le Roux *et al.* (1988) regard presence of *Monechma genistifolium* as indicative of former cover grasslands, which were disturbed by progressive overgrazing and maybe fire, studies could be done to investigate the effects of under-utilization of *Monechma genistifolium* before considering closing the eastern waterholes.

Author contributions

VM collected and classified vegetation data. BS coordinated and supervised the collection, analysis and writing up of this manuscript.

This work was part of the ORYCS-project within the SPACES II program, supported by the German Federal Ministry of Education and Research (Grant Number FKZ 01LL1804A). Permission for this research was granted by the Ministry of Environment, Tourism and Forestry, Namibia and the Namibian National Commission on Research Science & Technology (certificate number RCIV00032018 with authorization numbers: 20190602, 20190808).

References

Auer, C., 1997. Water availability and chemical water quality as important factors for sustainable wildlife management in the Etosha National Park and for domestic stock in farming areas of Namibia. *In*: *Directorate of Environmental Affairs, Ministry of Environment and Tourism*. 1–33.

Baldwin, R.F., Trombulak, S.C., Leonard, P.B., Noss, R.F., Hilty, J.A., Possingham, H.P., Scarlett, L., and Anderson, M.G., 2018. The Future of Landscape Conservation. *BioScience*, 68 (2), 60–63.

De Beer, Y., Kilian, W., Versfeld, W., and Van Aarde, R.J., 2006. Elephants and low rainfall alter woody vegetation in Etosha National Park, Namibia. *Journal of Arid Environments*, 64 (3), 412–421.

Behnke, R.H., 1998. *Grazing Systems in the Northern Communal Areas of Namibia: A Ssummary of NOLIDEP Socio-economic Research on Range Management*.

Bonney, R., Phillips, T.B., Ballard, H.L., and Enck, J.W., 2016. Can citizen science enhance public understanding of science? *Public Understanding of Science*, 25 (1), 2–16.

Botta Dukat, Z., Chytrý, M., Hájková, P., and Havlová, M., 2005. Vegetation of lowland wet meadows along a climatic continentality. *Preslia*, 89–111.

Braun-Blanquet, J., 1932. *Plant sociology : the study of plant communities*. 1st ed. New York London: McGraw-Hill Book Co.

Brown, C., 2017. *The important link between hunting & tourism in Namibia both working for conservation*.

Brown, L.R. and Bredenkamp, G.J., 2018. An overview of the vegetation classification approach in South Africa. *Phytocoenologia*, 48 (2), 163–170.

Bruelheide, H., 2000. A new measure of fidelity and its application to defining species groups. *Journal of Vegetation Science*, 11 (2), 167–178.

Burke, A. and Strohbach, B.J., 2000. Review : Vegetation Studies in Namibia. *Dinteria*, 26 (26), 1–24.

Chytrý, M., Tichý, L., Holt, J., and Botta-Dukát, Z., 2002. Determination of diagnostic species with statistical fidelity measures. *Journal of Vegetation Science*, 13 (1), 79–90.

CITIES, 2016. Informing decisions on trophy hunting. *IUCN Briefing paper*.

Coetzee, M., Kinyaga, V., Kruger, B., Seely, M., and Werner, W., 2014. Combating land degradation in Namibia over 23 years: learning what matters in DLDD. *Transactions of the Royal Society of South Africa*, 69 (3), 171–174.

Cole, D., van Schalkwyk, R., and Lorck, H., 2014. *Indigenous Plant Products in Namibia: The Commercialisation of Indigenous Natural Plant Products in Namibia*.

Cole, M.M. and Brown, R.C., 1976. The Vegetation of the Ghanzi Area of Western Botswana. *Journal of Biogeography*, 3 (3), 169–196.

Conrad, O., Bechtel, B., Bock, M., Dietrich, H., Fischer, E., Gerlitz, L., Wehberg, J., Wichmann, V., and Böhner, J., 2015. System for Automated Geoscientific Analyses (SAGA) v. 2.1.4. *Geoscientific Model Development*, 8 (7), 1991–2007.

Dengler, J., 2017. Phytosociology. *International Encyclopedia of Geography: People, the Earth, Environment and Technology*, (iDiv), 1–6.

Dengler, J., Jansen, F., Glöckler, F., Peet, R.K., de Cáceres, M., Chytrý, M., Ewald, J., Oldeland, J., Lopez-Gonzalez, G., Finckh, M., Mucina, L., Rodwell, J.S., Schaminée, J.H.J., and Spencer, N., 2011. The global index of vegetation-plot databases (GIVD): A new resource for vegetation science. *Journal of Vegetation Science*, 22 (4), 582–597.

Dieckmann, U., 2021. ' The vast white place ': a history of the Etosha National Park in Namibia and the Hai //om. *Nomadic Peoples , New Series*, 5 (2), 125–153.

Duvel, G.H. and Stephanus, A.L., 2000. Production Constraints and Perceived Marketing Problems of Stock Farmers in Some Districts of the Northern Communal Areas of. *South African Journal of Agricultural Extension*, 29, 89–104.

Edwards, E., 1983. A broad-scale structural classification of vegetation for practical purposes. *Bothalia*, 14 (3/4), 705–712.

Engelen, V.W.P. van and Dijkshoorn, J.A., 2013. *Global and National Soils and Terrain Digital Databases (SOTER), Procedures Manual Version 2.0*. ISRIC-World Soil Information. Wageningen.

Environmental Information Service Namibia | EIS: Choose option [online], 2022. Available from: http://www.the-eis.com/ [Accessed 1 Aug 2022].

Espach, C., Lubbe, L.G., and Ganzin, N., 2006. Determining grazing capacity in Namibia: Approaches and methodologies. *Agricola*, 16, 28–39.

FAO, 1993. FAO, 1993. Global and national soils and terrain digital databases (SOTER). Procedures manual.

Fillipus, A.V., 2021. Mapping and predicting the distribution of socio-economic important and endemic woody species of the Namibian-Angolan Kaokoveld. Namibia University of Science and Technology.

Geological Survey, 1980. *South West Africa/Namibia: Geological Map 1:1 000 000. Geological Survey of the Republic of South Africa and South West Africa/Namibia, Windhoek, Namibia.*

Giess, W., 1971. A Preliminary Vegetation Map of South West Africa. *Dinteria*, 4, 1-114.

Gillet, F. and Julve, P., 2018. The integrated synusial approach to vegetation classification and analysis Algengesellschaften und Nutzung zur Bioindikation-algal communities and the use for bioindication View project CATMINAT : Tree part View project.

Goudie, A. and Viles, H., 2015. *Landscapes and landforms of Namibia*. Etosha pan and Karstveld. New York: Springer.

Hipondoka, M., 2005. The development and evolution of Etosha Pan, Namibia. der Universität Wuerzburg.

Hoole, A. and Berkes, F., 2010. Breaking down fences: Recoupling social-ecological systems for biodiversity conservation in Namibia. *Geoforum*, 41 (2), 304–317.

Hüttich, C., Gessner, U., Herold, M., Strohbach, B.J., Schmidt, M., Keil, M., and Dech, S., 2009. On the Suitability of MODIS Time Series Metrics to Map Vegetation Types in Dry Savanna Ecosystems : A Case Study in the Kalahari of NE Namibia. *Remote Sensing*, 1, 620–643.

Jarvis, A., Mendelsohn, J., Mendelsohn, M., and Robertson, T., 2022. *Atlas of Namibia*. Namibia Nature Foundation.

Jarvis, A., Reuter, H.I., Nelson, A., and Guevara, E., 2008. SRTM 90m Digital Elevation Database v4.1.

Jasiewicz, J. and Stepinski, T.F., 2013. Geomorphons-a pattern recognition approach to classification and mapping of landforms. *Geomorphology*, 182, 147–156.

Joubert, E., 1971. Vegetative Characteristics found in the western Etosha National. *Madoqua*, 1 (4), 5–

31.

Kangombe, F.N., 2010. The vegetation of Omusati and Oshana Regions , central- northern Namibia.

Kent, M., 2012. *Vegetation Description and Data Analysis: A Practical Approach*. 2nd Editio. New Jersey: John Wiley and Sons.

Köppen, W., 1936. *Das Geographische System der Klimate.* Bornträger Verlag. Berlin, Germany.

Kruckeberg, A.R., 2002. *Geology and plant life : the effects of landforms and rock types on plants*. University of Washington Press.

Kruskal, J.B., 1964. Non-Metric Multidimensional Scaling: A numerical method. *Psychometrika*, 29 (2), 115–129.

Leuschner, C., 2013. Vegetation and Ecosystem. *In*: E. van der Maarel and J. Franklin, ed. *Vegetation Ecology.* Chichester, UK: John Wiley & Sons, Ltd, 285–307.

Lieth, H., 1975. *Primary Productivity of the Biosphere*. Berlin, Heidelberg: Springer Berlin Heidelberg.

Lillesø, J.B., Breugel, P. Van, Kindt, R., and Bingham, M., 2011. Potential Natural Vegetation of Eastern Africa Uganda and Zambia) Legend for the maps, 1 (2011).

Mannetti, L.M., Göttert, T., Zeller, U., and Esler, K.J., 2017. Expanding the protected area network in Namibia: An institutional analysis. *Ecosystem Services*, 28, 207–218.

Mannetti, L.M., Göttert, T., Zeller, U., and Esler, K.J., 2019. Identifying and categorizing stakeholders for protected area expansion around a national park in Namibia. *Ecology and Society*, 24 (2).

Map of Namibia biomes (Irish 1994), including the sampling sites. | Download Scientific Diagram [online], 2022. Available from: https://www.researchgate.net/figure/Map-of-Namibia-biomes-Irish-1994-including-the-sampling-sites_fig1_297750249 [Accessed 14 Jun 2022].

McCune, B., Grace, J.B., and Urban, D.L., 2002. Analysis of Ecological Communities.

McCune, B. and Mefford, M., 2016. PC ORD. Multivariate analysis of ecological data.

Menestrey Schwieger, D.A. and Mbidzo, M., 2020. Socio-historical and structural factors linked to land degradation and desertification in Namibia’s former Herero ‘homelands’. *Journal of Arid Environments*, 178 (August 2019), 104151.

Di Minin, E., Leader-Williams, N., and Bradshaw, C.J.A., 2016. Banning Trophy Hunting Will Exacerbate Biodiversity Loss. *Trends in Ecology and Evolution*, 31 (2), 99–102.

Moorsom, R., Franz, J., Mupotola, M., Namibian Economic Policy Research Unit., Namibia. Ministry of Agriculture, W., and United Nations Environment Programme., 1995. *Coping with aridity : drought impacts and preparedness in Namibia--experiences from 1992 93*. Frankfurt am Main ;Windhoek Namibia: Brandes & Apsel ;;NEPRU.

Mueller-Dombois, D. and Ellenberg, H., 1974. *Aims and Methods of Vegetation Ecology*. Aims and Methods of Vegetation Ecology. New York: John Wiley and Sons.

Munyayi, R., 2015. Forests, rangelands and climate change in Namibia. *Think Namibia Fact Sheet*, 8, 1–4.

Mupambwa, H.A., Hausiku, M.K., Namwoonde, A.S., Liswaniso, G.M., Haulofu, M., and Mafwila, S.K., 2021. Climate change implivations and mitigation in a hyperarid country: a case of Namibia. *African Handbook of Climate Change Adaptation*, 2247–2268.

NACSO, 2022. Namibian Association of Community Based Natural Resource Management (CBNRM) Support Organisations [online]. Available from: https://www.nacso.org.na/index.php [Accessed 29 Jul 2022].

Newmark, W.D., 2008. Isolation of African protected areas. *Frontiers in Ecology and the Environment*, 6 (6), 321–328.

Nortjé, G., 2019. *A game drive optimisation strategy for Etosha Heights Game Safaris - Etosha heights, Namibia*. Tshwane.

Nott, C., Boys, J., and Nzehengwa, J., 2019. Reviving Namibia’s Livestock Industry: Regenerative Livestock Production.

Olson, D.M., Dinerstein, E., Wikramanayake, E.D., Burgess, N.D., Powell, G.V.N., Underwood, E.C., D’Amico, J.A., Itoua, I., Strand, H.E., Morrison, J.C., Loucks, C.J., Allnutt, T.F., Ricketts, T.H., Kura, Y., Lamoreux, J.F., Wettengel, W.W., Hedao, P., and Kassem, K.R., 2001. Terrestrial ecoregions of the world: A new map of life on Earth. *BioScience*, 51 (11), 933–938.

Owen-Smith, N., 2000. The animal factor in pasture management. *In*: *Pasture Management in South Africa*. 53–65.

Owen-Smith, N., Kerley, G.I.H., Page, B., Slowtow, R., and van Aarde, R.J., 2006. Management of Elephants in the. *South African Journal Of Science*, 102 (October), 389–395.

Pansu, M. and Gautheyrou, J., 2006. Handbook of soil analysis: Mineralogical, organic and inorganic methods. *Handbook of Soil Analysis: Mineralogical, Organic and Inorganic Methods*, 1–993.

Peck, J.E., 2016. *Peck_Multivariate Analysis for Ecologists-Step by step_Ed2.pdf*.

Peet, R.K. and Roberts, D.W., 2014. Classification of Natural and Semi-Natural Vegetation. *In*: E. Van der Maarel and J. Franklin, eds. *Encyclopedia of Environmental Change*. John Wiley and Sons Ltd, 28–70.

du Plessis, F., 2001. A phytosociological synthesis of Mopaneveld. University of Pretoria.

Rohde, R.F. and Hoffman, M.T., 2012. The historical ecology of Namibian rangelands: Vegetation change since 1876 in response to local and global drivers. *Science of the Total Environment*, 416, 276–288.

Roleček, J., Tichý, L., Zelený, D., and Chytrý, M., 2009. Modified TWINSPAN classification in which the hierarchy respects cluster heterogeneity. *Journal of Vegetation Science*, 20 (4), 596–602.

Rothauge, A., 2001. for Namibian Ranchers Strategies Management Drought. *Agricola*.

Le Roux, C.J.G., Grunow, J.O., Bredenkamp, G.J., Morris, J.W., and Scheepers, J.C., 1988. A classification of the vegetation of the Etosha National Park. *South African Journal of Botany*, 54 (1), 1–10.

Scarlett, L. and McKinney, M., 2016. Connecting people and places: The emerging role of network governance in large landscape conservation. *Frontiers in Ecology and the Environment*, 14 (3), 116–125.

Schneider, G., 2004. *The roadside geology of Namibia*. Berlin ; Stuttgart: Gebrüder Borntraeger.

Siebert, F., 2012. A phytosociological synthesis of Mopaneveld vegetation at different spatial scales using various classification methods, (August), 244.

South African Committee for Stratigraphy. and Geological Survey (South Africa), 1980. Stratigraphy of South Africa.

Strohbach, B. and Kangombe, F., 2012. National Phytosociological Database of Namibia. *In*: J.H.J. Dengler, J., Oldenland, J., Jansen, F., Chytry, M., Ewald, J., Finckh, M., Glöckler, F., Lopez-Gonzalez, G., Peet, R.K., Schaminée, ed. *Vegetation databases for the 21st Century - Biodiversity and ecology*.

298–298.

Strohbach, B.J., 2000. Vegetation degradation trends in the northern Oshikoto Region : II . The Colophospermum mopane shrublands. *Dinteria*, (26), 63–75.

Strohbach, B.J., 2001. Vegetation Survey of Namibia. *Namibia Scientific Society*, 49, 93–124.

Strohbach, B.J., 2012. Providing relevant, useful information on Namibian Vegetation Types. *Agricola*, 22, 7–39.

Strohbach, B.J., 2014. Vegetation Survey of Namibia : Conceptualisation and implementation of a nation-wide vegetation survey serving practical land management needs. University of Hamburg.

Strohbach, B.J., 2018. Making more of vegetation classification results : A livestock farming suitability index as tool for land-use planning in Namibia. *Phytocoenologia*, 48 (1), 7–22.

Strohbach, B.J. and BJ, S., 2000. Vegetation degradation trends in the northern Oshikoto Region III. The Terminalia prunioides woodlands and Andoni grasslands. *Dinteria*, 26 (26), 77.

Strohbach, B.J. and Jürgens, N., 2010. Towards a user-friendly vegetation map of Namibia: ground truthing approach to vegetation mapping. *In*: *Biodiversity in southern Africa.* 45–56.

Strohbach, B.J., Kutuahuripa, J.T., Sciences, S., and Strohbach, B.J., 2014. Vegetation of the eastern communal conservancies in Namibia: II. environmental drivers. *Koedoe*, 56 (1), 1–12.

Taylor, P.D., Fahrig, L., and With, K.A., 2010. Landscape connectivity: a return to the basics. *In*: *Connectivity Conservation*. 29–43.

Theurillat, J.P., Willner, W., Fernández-González, F., Bültmann, H., Čarni, A., Gigante, D., Mucina, L., and Weber, H., 2021. International Code of Phytosociological Nomenclature. 4th edition. *Applied Vegetation Science*, 24 (1).

Thuiller, W., Midgley, G.F., Hughes, G.O., Bomhard, B., Drew, G., Rutherford, M.C., and Woodward, F.I., 2006. Endemic species and ecosystem sensitivity to climate change in Namibia. *Global Change Biology*, 12 (5), 759–776.

Tichý, L., Hennekens, S.M., Novák, P., Rodwell, J.S., Schaminée, J.H.J., and Chytrý, M., 2020. Optimal transformation of species cover for vegetation classification. *Applied Vegetation Science*, 23 (4), 710–717.

Turpie, J., Barnes, J., de Longcamp, M., and Paxton, M., 2010. Sustainable Financing Plan for Namibia's Protected Area System: *Ministry of Environment and Tourism*.

Walter, H., Harnickell, E., Mueller-Dombois, D., and Springer-Verlag., 1975. Climate-diagram maps of the individual continents and the ecological climatic regions of the earth, 36.

Ward, D., Ngairorue, B.T., Ward, D., and Ngairorue, B.E.N.T., 2000. Are Namibia ' s grasslands desertifying ? *Journal of Range Management*, 53 (2), 138–144.

Werger, M.J.A., 1978. Biogeographical division of southern Africa. *In*: *Biogeography and Ecology of Southern Africa*. The Hague: Dr W. Junk bv Publishers, 145–170.

White, F., 1983. The vegetation of Africa: A descriptive memior to accompany the UNESCO/AETFAT/UNESO, 356.

Zingel, M.W., Supervisor, P., Prof, :, and Somers, M.J., 2015. Optimising vegetation assessments to facilitate wildlife management. University of Pretoria.

Appendix 1: Phytosociological Table for the vegetation of Etosha Heights Private Game Reserve, Namibia

Association	
Releve number	
Date (yyyymmdd)	
Altitude (m)	
Aspect (degrees)	
Latitude (digital degrees)	
Longitude (digital degrees)	
Gravel cover	
Pebble (small stone) cover	
Medium stone cover	
Large stone cover	
Rock cover	
Landscape	
Local topography	
Slope (degrees)	
Slope class	
Lithology	
Texture	
Sand-%	
Silt-%	
Clay-%	
pH	
Electric conductivity (µS/m)	

No.	Species	Growth form
1	*Commiphora glaucescens*	ts
2	*Danthoniopsis dinteri*	a
3	*Combretum mossambicense*	ts
4	*Pupalia lappacea*	h
5	*Sterculia africana*	ts
6	*Pachypodium lealii*	ts
7	*Kirkia acuminata*	ts
8	*Eragrostis lehmanniana*	a
9	*Senegalia senegal*	ts
10	*Grewia flavescens*	ts
11	*Commelina benghalensis*	h
12	*Bothriochloa radicans*	p
13	*Grewia retinervis*	ts
14	*Schmidtia kalahariensis*	a
15	*Pogonarthria fleckii*	p
16	*Euphorbia austro-occidentalis*	ts
17	*Ipomoea* species	d
18	*Eragrostis subglandulosa*	a
19	*Eragrostis trichophora*	a
20	*Lantana angolensis*	ts
21	*Indigofera adenocarpa*	h
22	*Panicum coloratum*	p
23	*Aristida hordeacea*	a
24	*Cucumis anguria*	h
25	*Vachellia nilotica*	ts
26	*Monelytrum luederitzianum*	p
27	*Amaranthus thunbergii*	h
28	*Petalidium englerianum*	d
29	*Indigofera adenoides*	h
30	*Leucas pechuelii*	h
31	*Gossypium triphyllum*	ts
32	*Nidorella species*	h
33	*Hermbstaedtia species*	h
34	*Heliotropium steudneri*	h
35	*Cenchrus ciliaris*	p
36	*Aristida stipitata*	a
37	*Euphorbia inaequilatera*	h
38	*Eragrostis echinochloidea*	p
39	*Eragrostis porosa*	p
40	*Panicum novemnerve*	a
41	*Eragrostis nindensis*	p
42	*Geigeria ornativa*	d
43	*Commiphora glandulosa*	ts
44	*Combretum apiculatum*	ts
45	*Brachiaria marlothii*	p
46	*Tragus racemosus*	a
47	*Eragrostis biflora*	a
48	*Geigeria acaulis*	d
49	*Leucosphaera bainesii*	d
50	*Tragus berteronianus*	a
51	*Megalochlamys marlothii*	d
52	*Grewia villosa*	ts
53	*Stipagrostis hirtigluma* subsp. *hirtigluma*	a
54	*Catophractes alexandri*	ts
55	*Eragrostis annulata*	h
56	*Sericorema sericea*	h
57	*Enneapogon desvauxii*	a
58	*Aristida adscensionis*	a
59	*Chloris virgata*	a
60	*Crotalaria kurtii*	h
61	*Stapelia species*	succ
62	*Aptosimum species*	h
63	*Dichrostachys cinerea*	ts
64	*Tribulus zeyheri*	h
65	*Tribulus terrestris*	h
66	*Dactyliandra welwitschii*	cr
67	*Prenia tetragona*	h
68	*Blepharis leendertziae*	h
69	*Euphorbia virosa*	h
70	*Ptycholobium biflorum*	h
71	*Grewia bicolor*	cr
72	*Searsia marlothii*	ts
73	*Sesamothamnus guerichii*	ts
74	*Aristida effusa*	a
75	*Mollugo walteri*	h
76	*Eragrostis rotifer*	a
77	*Setaria verticillata*	a
78	*Geigeria africana*	d
79	*Solanum lichtensteinii*	h
80	*Maerua juncea*	ts
81	*Hermannia modesta*	h
82	*Euphorbia guerichiana*	h
83	*Asparagus nelsii*	ts
84	*Seddera suffruticosa*	h
85	*Moringa ovalifolia*	ts
86	*Senegalia erubescens*	ts
87	*Cephalocroton mollis*	ts
88	*Kyphocarpa angustifolia*	h
89	*Eragrostis superba*	p
90	*Sesamum species*	h
91	*Fingerhuthia africana*	p
92	*Flaveria bidentis*	h
93	*Searsia species*	ts
94	*Combretum albopunctatum*	ts
95	*Hibiscus species*	h
96	*Achyranthes aspera* var. *sicula*	h
97	*Opilia campestris*	ts
98	*Datura inoxia*	h
99	*Cleome suffruticosa*	h
100	*Helinus integrifolius*	cr
101	*Portulaca kermesina*	h
102	*Athanasia species*	h
103	*Aristida meridionalis*	p
104	*Rhynchosia species*	h
105	*Bidens biternata*	h
106	*Monsonia senegalensis*	h
107	*Seddera schizantha*	h
108	*Datura ferox*	h
109	*Rogeria adenophylla*	h
110	*Enneapogon scoparius*	p
111	*Rhigozum brevispinosum*	ts
112	*Aristida congesta*	a
113	*Heteropogon contortus*	h
114	*Indigofera daleoides*	h
115	*Triraphis ramosissima*	h
116	*Kirkia dewinteri*	ts
117	*Croton menyharthii*	ts
118	*Cleome rubella*	h
119	*Aristida rhiniochloa*	a
120	*Montinia caryophyllacea*	ts
121	*Stipagrostis uniplumis*	p
122	*Acrotome inflata*	h
123	*Abutilon fruticosum*	h
124	*Limeum argute-carinatum*	h
125	*Monechma spartoides*	d
126	*Vachellia reficiens*	ts
127	*Senegalia mellifera* subsp. *detinens*	ts
128	*Dicoma tomentosa*	h
129	*Vachellia nebrownii*	ts
130	*Monechma divaricatum*	d
131	*Euphorbia glanduligera*	ts
132	*Emilia ambifaria*	h
133	*Hirpicium gazanioides*	h
134	*Monechma genistifolium*	d
135	*Urochloa brachyura*	a
136	*Terminalia prunioides*	ts
137	*Mundulea sericea*	ts
138	*Gisekia africana*	h
139	*Helinus species*	ts
140	*Eragrostis cylindriflora*	p
141	*Heliotropium nelsonii*	h
142	*Tephrosia burchellii*	h
143	*Melinis repens* subsp. *grandiflora*	a
144	*Evolvulus alsinoides*	h
145	*Steganotaenia araliacea* var. *araliacea*	ts

	Association		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3
	Releve number		13426	13427	13494	13495	13496	13497	13498	13499	13500	13501	13502	13503	13504	13505	13546	13469	13490	13506	13507	13508	13509	13519	13520	13522	13523	13528	13542	13543	13544	13562	13569	13578	13591	13597	13418	13444	13512
146	*Zehneria marlothii*	h																																					
147	*Cissus nymphaeifolia*	ts																																					
148	*Acalypha indica*	h		1												1																				1			
149	*Peristrophe paniculata*	h																			1																		
150	*Helichrysum tomentosulum*	h																																					
151	*Colophospermum mopane*	ts	5	15	6		5	3	10	5	15	7	8	1	2	5	4	3		4	8	3	10	20	12	15		70		30	10		10	3		12	2	1	
152	*Phyllanthus pentandrus*	h																																					
153	*Launaea intybacea*	h																																					
154	*Solanum rigescentoides*	h																																					
155	*Triraphis purpurea*	p																	1																				
156	*Mollugo cerviana*	h																																					
157	*Ziziphus mucronata*	ts																																					
158	*Boscia albitrunca*	ts				1			1	2					1								1			2						1							
159	*Monsonia species*	h																																					
160	*Vachellia hebeclada*	ts																																					
161	*Galenia papulosa*	h																																					
162	*Oropetium capense*	p		1																						3	40			20	5	1		25		4			
163	*Momordica humilis*	h																											1										
164	*Enneapogon cenchroides*	p		1	1	2	1	3	5			5	1	20	30		1	5		20	40		2		6	2		2		20	20	10		10	15	2	3		
165	*Vachellia kirkii*	ts	1	1																																			
166	*Kohautia caespitosa* subsp. *brachyloba*	h																																					
167	*Cucumis africanus*	cr																															2	5					
168	*Grewia olukondae*	ts									1																												
169	*Anthephora schinzii*	a		2	20	15	10	5	5	3	10	30	50	20	5	5	3	1		15	2	20	3		8		5		2	15	15		15	15		10			
170	*Striga gesnerioides*	h																																					
171	*Croton gratissimus*	ts																																					
172	*Tephrosia dregeana var. dregeana*	h																																10					

	Association		4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	Releve number		13407	13408	13409	13410	13421	13422	13423	13424	13440	13451	13453	13455	13456	13491	13530	13598	13406	13417	13435	13492	13493	13521	13529	13545	13547	13552	13567	13570	13571	13572	13576	13586	13599
146	*Zehneria marlothii*	h																																	2
147	*Cissus nymphaeifolia*	ts																																	
148	*Acalypha indica*	h															2	1							1		2								
149	*Peristrophe paniculata*	h																																	
150	*Helichrysum tomentosulum*	h																																	
151	*Colophospermum mopane*	ts	5	7	10	10		2	2	2		2		5	5	15	5	19	2	1	5	5	15	10	20		2			17	30	24	10	60	3
152	*Phyllanthus pentandrus*	h																																	
153	*Launaea intybacea*	h																																	
154	*Solanum rigescentoides*	h																																	
155	*Triraphis purpurea*	p																																	
156	*Mollugo cerviana*	h																																	
157	*Ziziphus mucronata*	ts																																	
158	*Boscia albitrunca*	ts					1										1	2																	
159	*Monsonia species*	h																																	4
160	*Vachellia hebeclada*	ts																																	
161	*Galenia papulosa*	h																																	
162	*Oropetium capense*	p																4																	5
163	*Momordica humilis*	h																																	
164	*Enneapogon cenchroides*	p		1	5	5	1	2	2	1		2	5	10	4	1	5	5	2	2	2		1		2		10	15	5				10	5	4
165	*Vachellia kirkii*	ts	1																											1	5			4	
166	*Kohautia caespitosa* subsp. *brachyloba*	h																																	
167	*Cucumis africanus*	cr															1				1				1						2	1	3	2	
168	*Grewia olukondae*	ts											1																						
169	*Anthephora schinzii*	a	2	1	2	2				1			3	1	10		15	25		10	2	2	2	10	60	10	15		5		5			25	8
170	*Striga gesnerioides*	h																																	
171	*Croton gratissimus*	ts																																	
172	*Tephrosia dregeana var. dregeana*	h																																	

	Association		5	5	5	5	5	5	5	5	6	6	6	6	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
	Releve number		13536	13555	13574	13580	13579	13581	13587	13589	13518	13553	13564	13565	13401	13411	13412	13415	13420	13432	13436	13439	13446	13457	13458	13459	13460	13467	13470	13487	13541	13554	13573	13588	13483	13585
146	*Zehneria marlothii*	h																																		
147	*Cissus nymphaeifolia*	ts																																		
148	*Acalypha indica*	h					1																													
149	*Peristrophe paniculata*	h																																		
150	*Helichrysum tomentosulum*	h																																		
151	*Colophospermum mopane*	ts		15	20	45	10	37	12		15	30	5	24	5	5	1	2	1	2	5		30	5	5	16		3	8	30	30		10			
152	*Phyllanthus pentandrus*	h																																		
153	*Launaea intybacea*	h																																		
154	*Solanum rigescentoides*	h																																		
155	*Triraphis purpurea*	p																																		
156	*Mollugo cerviana*	h																																		
157	*Ziziphus mucronata*	ts																																		
158	*Boscia albitrunca*	ts																										2								
159	*Monsonia species*	h																																		
160	*Vachellia hebeclada*	ts																																		
161	*Galenia papulosa*	h																																		
162	*Oropetium capense*	p					5																													
163	*Momordica humilis*	h		1																												2				
164	*Enneapogon cenchroides*	p			10		10	1			5	5	10	5		5	15		1	2			2	3	15			1	40	20				30		7
165	*Vachellia kirkii*	ts							2												1															
166	*Kohautia caespitosa* subsp. *brachyloba*	h																																		
167	*Cucumis africanus*	cr			2																												1	3		
168	*Grewia olukondae*	ts																																		
169	*Anthephora schinzii*	a		20	1		15	5	2	5		15				2	3	15		2	2			4	5	5	25	1	3		70	2	2			
170	*Striga gesnerioides*	h																																		
171	*Croton gratissimus*	ts																																		
172	*Tephrosia dregeana var. dregeana*	h																																4		8

	Association		8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	9.1	9.1	9.1	9.1	9.1
	Releve number		13402	13403	13405	13428	13438	13462	13464	13466	13471	13480	13482	13486	13488	13489	13513	13514	13526	13532	13539	13559	13560	13540	13557	13558	13561	13566
146	*Zehneria marlothii*	h															2											
147	*Cissus nymphaeifolia*	ts				1																						
148	*Acalypha indica*	h																										
149	*Peristrophe paniculata*	h							1																			
150	*Helichrysum tomentosulum*	h																										
151	*Colophospermum mopane*	ts		5	2	2		2			25		10			10	1	40	4		24	30	10	28	10	4	25	24
152	*Phyllanthus pentandrus*	h																										
153	*Launaea intybacea*	h																										
154	*Solanum rigescentoides*	h																										
155	*Triraphis purpurea*	p				1																						
156	*Mollugo cerviana*	h																										
157	*Ziziphus mucronata*	ts																										
158	*Boscia albitrunca*	ts				1										1								8			1	
159	*Monsonia species*	h																										
160	*Vachellia hebeclada*	ts																				2						
161	*Galenia papulosa*	h																										
162	*Oropetium capense*	p																									1	
163	*Momordica humilis*	h																										
164	*Enneapogon cenchroides*	p	2	2	2	2	1	10	10		5		1			2				80	1		20	2			15	10
165	*Vachellia kirkii*	ts																										
166	*Kohautia caespitosa* subsp. *brachyloba*	h																										
167	*Cucumis africanus*	cr																					2					
168	*Grewia olukondae*	ts																										
169	*Anthephora schinzii*	a		1	1			10	1		3	15						4	4		80	2	1	5	2	1		1
170	*Striga gesnerioides*	h																										
171	*Croton gratissimus*	ts				2																						
172	*Tephrosia dregeana var. dregeana*	h																										

	Association		9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1
	Releve number		13510	13515	13537	13538	13556	13575	13582	13583	13590	13600	13454	13516	13517	13531	13534	13535	13548	13550
146	*Zehneria marlothii*	h																		
147	*Cissus nymphaeifolia*	ts																		
148	*Acalypha indica*	h								2		2						1		
149	*Peristrophe paniculata*	h																		
150	*Helichrysum tomentosulum*	h																		
151	*Colophospermum mopane*	ts	2	2	30	30	5	20		12		15	5	5	8	15	1		37	
152	*Phyllanthus pentandrus*	h							15											
153	*Launaea intybacea*	h																		
154	*Solanum rigescentoides*	h																		
155	*Triraphis purpurea*	p																		
156	*Mollugo cerviana*	h																		
157	*Ziziphus mucronata*	ts							5											
158	*Boscia albitrunca*	ts										1								
159	*Monsonia species*	h																		
160	*Vachellia hebeclada*	ts																		
161	*Galenia papulosa*	h																		
162	*Oropetium capense*	p						2				2								
163	*Momordica humilis*	h																		
164	*Enneapogon cenchroides*	p	1	10		20	5	15		12	25	2	10		2			1		
165	*Vachellia kirkii*	ts							5										1	
166	*Kohautia caespitosa* subsp. *brachyloba*	h																		
167	*Cucumis africanus*	cr						1												
168	*Grewia olukondae*	ts																		
169	*Anthephora schinzii*	a	3			1	50	10		5	1		1			1			15	
170	*Striga gesnerioides*	h																		
171	*Croton gratissimus*	ts																		
172	*Tephrosia dregeana var. dregeana*	h																		

	Association		10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2
	Releve number		13419	13425	13437	13441	13442	13443	13447	13448	13449	13450	13452	13465	13474	13476	13477	13478	13479	13484	13525	13527	13549	13551	13584
146	*Zehneria marlothii*	h																							
147	*Cissus nymphaeifolia*	ts																							
148	*Acalypha indica*	h																							2
149	*Peristrophe paniculata*	h												1											
150	*Helichrysum tomentosulum*	h																							
151	*Colophospermum mopane*	ts	11	2	10	10			5	4	3	1	1	2	15		3			80		50	19	40	
152	*Phyllanthus pentandrus*	h																							
153	*Launaea intybacea*	h																							
154	*Solanum rigescentoides*	h																							
155	*Triraphis purpurea*	p																							
156	*Mollugo cerviana*	h																							
157	*Ziziphus mucronata*	ts																							
158	*Boscia albitrunca*	ts									1			2								1			
159	*Monsonia species*	h																							
160	*Vachellia hebeclada*	ts																							
161	*Galenia papulosa*	h																							
162	*Oropetium capense*	p																							
163	*Momordica humilis*	h																							
164	*Enneapogon cenchroides*	p	15		3	5	20	30		2	5	2	2	40	10	1	5			1			1	10	10
165	*Vachellia kirkii*	ts																			5				
166	*Kohautia caespitosa* subsp. *brachyloba*	h																							
167	*Cucumis africanus*	cr															1								
168	*Grewia olukondae*	ts	1																						
169	*Anthephora schinzii*	a		2		2				1				1	1		1	20			20		8	15	3
170	*Striga gesnerioides*	h																							
171	*Croton gratissimus*	ts																							
172	*Tephrosia dregeana var. dregeana*	h																							

	Association		11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
	Releve number		13404	13413	13414	13416	13429	13430	13431	13433	13434	13461	13463	13468	13472	13473	13475	13481	13485	13533	13563	13577	13601
146	*Zehneria marlothii*	h																					
147	*Cissus nymphaeifolia*	ts																					
148	*Acalypha indica*	h																					
149	*Peristrophe paniculata*	h																					
150	*Helichrysum tomentosulum*	h																					
151	*Colophospermum mopane*	ts	2	12	1	5		3	2	3	5	28	3	10	1	3	3	2		30	8	35	49
152	*Phyllanthus pentandrus*	h																					
153	*Launaea intybacea*	h																					
154	*Solanum rigescentoides*	h																					
155	*Triraphis purpurea*	p																					
156	*Mollugo cerviana*	h																					
157	*Ziziphus mucronata*	ts																					
158	*Boscia albitrunca*	ts														1							
159	*Monsonia species*	h																					
160	*Vachellia hebeclada*	ts																					
161	*Galenia papulosa*	h																					
162	*Oropetium capense*	p									2												
163	*Momordica humilis*	h																					
164	*Enneapogon cenchroides*	p	4				2	1	1		1		1	2	15	2	20	2			15		10
165	*Vachellia kirkii*	ts																					
166	*Kohautia caespitosa* subsp. *brachyloba*	h																					
167	*Cucumis africanus*	cr																		2	1		2
168	*Grewia olukondae*	ts																					
169	*Anthephora schinzii*	a		2	15	20	1	5	5	2	3	15			5	1							15
170	*Striga gesnerioides*	h																					
171	*Croton gratissimus*	ts																					
172	*Tephrosia dregeana var. dregeana*	h																					

Notes

Growth form

ts	tree/shrub
h	herb
a	annual grass
p	perennial grass
cr	creeper
d	dwarf shrub

Stone cover (gravel, pebbles, medium, large, rock):

0	None
1	0-2%
2	2-5%
3	5-15%
4	15-40%
5	40-80%
6	> 80%

Slope class:

0	Flat, 0-1° (0-2%)
1	Gently undulating, 1-3° (2-5%)
2	Undulating, 3-6° (5-10%)
3	Rolling, 6-9° (10-15%)
4	Moderately steep, 9-17° (15-30%)
5	Steep, 17-30° (30-60%)
6	Very steep, 30-50° (60-120%)
7	Extremely steep, >50° (>120%)

(Based on FAO, 1995, Global and national soils and terrain digital databases (SOTER), World Soil Resources Reports, No. 74 Rev. 1. Land and Water Development Division, Food and Agriculture Organisation of the United Nations, Rome.)

Landscape type and Local topography

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	Temporary 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 zor	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			

(Based on FAO, 1995, Global and national soils and terrain digital databases (SOTER), World Soil Resources Reports, No. 74 Rev. 1. Land and Water Development Division, Food and Agriculture Organisation of the United Nations, Rome.)

Lithology

Acidic igneous rock	IA1	Granite	Clastic sediments	SC1	Conglomerate, Breccia
	IA2	Grano-diorite		SC2	Sandstone, greywacke, arkose
	IA3	Quartz-doirite		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	Marine
Acidic metamorphic rock	MA1	Quartzite		UC	Colluvial
	MA2	Gneiss, magmatite		UE	Eolian
Basic metamorphic rock	MB1	Slate, phylite (peltic rocks)		UG	Glacial
	MB2	Schist		UP	Pyroclastic
	MB3	Gneiss rich in ferro-magnesian minerals		UO	Organic
	MB4	Metamorphic limestone (marble)		UCa	Calcrete

(Based on FAO, 1995, Global and national soils and terrain digital databases (SOTER), World Soil Resources Reports, No. 74 Rev. 1. Land and Water Development Division, Food and Agriculture Organisation of the United Nations, Rome.)

GPS setting

WGS84	World Geodetic System 1984
Accuracy	3 meters