

**THE INFLUENCE OF DIFFERENT LAND USE TYPES ON  
PLANT SPECIES DIVERSITY, COMPOSITION AND  
VEGETATION STRUCTURE IN THE KALAHARI  
WOODLANDS OF SALAMBALA CONSERVANCY, NORTH-  
EAST NAMIBIA**

A thesis submitted in partial fulfilment of the requirements for the degree of  
Master of Science in Biodiversity Management and Research at  
University of Namibia and Humboldt-Universität zu Berlin

By

Ivonne Hitjevi Mujoro

Supervisor: Dr. Isaac Mapaire (University of Namibia)

APRIL 2007

## ABSTRACT

Human societies have, for centuries, impacted and altered the natural environments through different land use practises. Unsustainable land use practices are seen as one of the major threats to biodiversity around the globe. Therefore, the main objective of this study was to assess the impacts of different land use types, mainly grazing and browsing by wildlife and livestock; land clearance for cultivation and wood harvesting on plant species diversity, composition and vegetation structure in the Kalahari woodlands of the Salambala conservancy in northeast Namibia. Three areas representing the different land use types were compared. These were the core, transitional and outside areas, which represented low, medium and high land use intensities, respectively. The nested plots design method was used to determine the minimal plot area. Trees (stem diameter >15cm) were assessed in 20m\*20m plots, shrubs (stem diameter <15cm) were assessed in 5m\*5m subplots and grasses and forbs were assessed in 1m\*1m subplots. The structural attributes measured were tree basal circumference (cm), tree and shrub height, woody cover (line-intercept method) and visual estimation of grass cover. The range condition was assessed based on decreaser-increaser method. Plant species diversity and richness were significantly higher in the core and transitional areas. The hierarchical cluster analysis (HCA) recognised three main floristic associations. These are, *Combretum collinum* mixed tall-sparse woodland, *Combretum collinum-Terminalia sericea* tall-dense woodland and *Combretum collinum* woodland thicket corresponding to the land use types in the core, transitional and outside areas respectively. The Detrended Correspondence Analysis (DCA) showed that 44.3% of the total variation in species composition was accounted for along the first axis, which was mainly associated with land use intensity. Tree density and total basal area were significantly higher in the transitional area; and higher in the core than the outside area, although not statistically supported. Stem density and woody cover were higher in the outside area. Grass cover was higher in the core area, but did not differ between the transitional and outside areas. Basal area and height class distribution differed significantly among the three sites. Shrub and forb densities did not differ significantly among the sites. The range condition in the core area was classified as selectively grazed (50%); 40% selectively and 40% overgrazed in the transitional area and 86% overgrazed in the outside area. Plant species diversity, richness and composition are clearly being negatively impacted by the different land use types, evident from significantly low diversity and richness in the highly utilised outside area. The effect of land use on species composition is more pronounced in the herbaceous layers, contributing more to the separation of the vegetation by the classification and ordination methods. There is clear evidence that the different land use types are gradually transforming Kalahari woodlands in the Salambala conservancy from woodlands to woodland thickets. The effects of past land use in the conservancy could also be linked to the current structure and composition of the vegetation. Future studies and research programmes especially in communal area conservancies, should take into consideration the assessment of the status of vegetation and other components of biodiversity, as well as carrying capacity and stocking rates of the range.

## DEDICATION

This thesis is a dedication to my parents Wily and Othilie Uanivi for the love, discipline, respect, patience and perseverance they nurtured in me and which always result in success in whatever I do, including the writing of this dissertation.

## ACKNOWLEDGEMENTS

I would like to first and foremost thank God the Almighty for giving me strength and ability to persevere until the completion of this thesis.

I am highly indebted to Dr. Isaac Mapaure for his tireless and critical academic guidance which made this thesis a success. The support of my fellow students during the duration of the entire course, especially Irene Nunes is highly valued and appreciated.

My utmost gratitude and appreciation go to the Government of the Republic of Namibia for granting me study leave, provision of transport for data collection through the Forestry headquarters in Windhoek, logistical and technical support from the Katima Mulilo Forestry regional office and the Bukalo district forestry office; and granting me a permit to conduct the study in the Salambala conservancy through the Directorate of Wildlife Management. Special and humble thanks go to the members of the Salambala conservancy management committee, especially Ms. Florence Siyambango, Fabian Libanda and Albius Nsundano for their assistance during data collection, thanks for magically keeping the elephants away.

To my three beautiful children Jeomba, Javee and Mwariovandu thank you for understanding. Last but most definitely not least to my soul mate, Nanguai Kasuto your moral support and unconditional love made everything look so easy.

## DECLARATIONS

This is a thesis prepared in partial fulfilment of the requirements for the degree of Master of Science in Biodiversity Management and Research, a joint programme of the University of Namibia (UNAM) in Windhoek, Namibia and Humbolt-Universität zu Berlin. This thesis is the original work of the author and it has not been submitted for a degree elsewhere. The views and opinions stated therein are those of the author and not necessarily those of the institution.

Enquiries:

Signature.....

Date.....

University of Namibia

Private Bag 13301

Mandume Ndemufayo Avenue

Pioneerspark

Windhoek

Namibia

## ACRONYMS AND ABBREVIATIONS

BC:	Basal Circumference
BIOTA:	Biodiversity Monitoring Transect Analysis in Africa
BTA:	Basubia Traditional Authority
CBNRM:	Community- Based Natural Resource Management
CBOs:	Community-Based Organisations
CGG:	Community Game Guard
CWA:	Core Wildlife Management Area
DCA:	Detrended Correspondence Analysis
DVS:	Department of Veterinary Services
GPS:	Global Positioning System
HCA:	Hierarchical Cluster Analysis
MAWF:	Ministry of Agriculture, Water and Forestry
MET:	Ministry of Environment and Tourism
NACSO:	Namibia Association for CBNRM Support Organisations
NBRI:	National Botanic Research institute
NGOs:	Non-Governmental Organisations
NRSC:	National Remote Sensing Centre
OU:	Outside Area
TA:	Transitional Area
WILD:	Wildlife Livelihood Diversification

## LIST OF TABLES AND FIGURES

		Page
TABLE 1	Floral and faunal diversity of the Caprivi region	22
FIGURE 1	Map of Namibia showing the location of the study area and sample plots	18
FIGURE 2	Zonation map of Salambala conservancy, showing the location of the core area.	19
FIGURE 3	The nested plot design used for the recording of grasses and forbs; shrubs and trees for 1m <sup>2</sup> , 25m <sup>2</sup> and 400m <sup>2</sup> respectively, showing the reference corner (north-west direction) where coordinates of each plot were recorded	27
FIGURE 4	Comparisons of species diversity (H') among three sites in the Kalahari woodlands of the Salambala conservancy, north-east Namibia.	36
FIGURE 5	Comparisons of species richness among three sites in the Kalahari woodlands of the Salambala Conservancy, northeast Namibia	37
FIGURE 6	Comparisons of mean tree and stem density among the three sites in the Salambala conservancy, northeast Namibia.	38
FIGURE 7	Comparison of individual shrub and stem densities, with standard error bars, among the three sites in the Salambala Conservancy, northeast Namibia	39
FIGURE 8	Differences in forbs densities, with standard error bars, in Kalahari woodlands at three sites in the Salambala conservancy, northeast Namibia.	40
FIGURE 9	Differences in total basal area (m <sup>2</sup> / ha), with standard error bars, among three sites in the Kalahari woodlands of the Salambala conservancy, northeast Namibia.	41
FIGURE 10	Comparisons of basal area frequency distribution patterns of trees in the Kalahari woodlands of the Salambala conservancy, northeast Namibia.	42
FIGURE 11	Comparisons of individual tree height frequency distribution patterns in the Kalahari woodlands of the Salambala conservancy, northeast Namibia.	44

FIGURE 12	Comparisons of shrubs height frequency distribution patterns in the Kalahari woodlands of the Salambala conservancy, northeast Namibia.	45
FIGURE 13	Variations in percentage woody and grass cover at three sites in the Kalahari woodlands of the Salambala conservancy, northeast Namibia. The bars represent standard error.	46
FIGURE 14a-c	Illustration of the range condition based on decreaser-increaser method, in the Kalahari woodlands of the Salambala conservancy, northeast Namibia across the three sites.	48
FIGURE 15	Hierarchical Cluster Analysis (HCA) dendrogram showing a classification of vegetation plots into 5 clusters based on species presence/absence data from the Kalahari woodlands of Salambala conservancy, northeast Namibia.	52
FIGURE 16	DCA ordination diagram showing the separation of vegetation plots into three main floristic groups relating to land use gradient in the Kalahari woodlands of the Salambala conservancy, north-east Namibia	54
FIGURE 17	Illustration of the appearance of vegetation in the core area (a); transitional area (b) and outside area (c) of the Kalahari woodland of Salambala Conservancy, northeast Namibia.	64

## LIST OF APPENDICES

Appendix 1	The grass species and herbaceous plant identified as key species for assessing range condition in the Kalahari woodlands, Mopane woodlands and Floodplains in the East Caprivi region of Namibia and used for the assessment of the range condition in the Kalahari woodlands of the Salambala conservancy, northeast Namibia.	96
Appendix 2a-d	Chi-square distribution tables (basal area and height frequency distribution classes) at three sites in the Kalahari woodlands of the Salambala conservancy, northeast Namibia	97
Appendix 3	The geographical location of plots in the Kalahari woodlands of the Salambala conservancy, northeast Namibia.	98
Appendix 4	List of recorded species at three sites in the Kalahari woodlands of the Salambala conservancy, northeast Namibia	99
Appendix 5	Species diversity matrix based on presence/absence of species at three sites in the Kalahari woodlands of the Salambala conservancy, northeast Namibia	101

## TABLE OF CONTENTS

Title.....	i
Abstract.....	ii
Dedication.....	iii
Acknowledgements.....	iv
Declarations.....	v
Acronyms and abbreviations.....	vi
List of tables and figures .....	vii
List of appendices.....	ix
<b>CHAPTER 1: INTRODUCTION.....</b>	<b>1</b>
1.1 General introduction.....	1
1.2 Statement of the problem.....	4
1.3 Objectives, questions and hypotheses.....	5
1.3.1 Overall objective.....	5
1.3.2 Specific objectives.....	6
1.3.3 Key questions.....	6
1.3.4 Research Hypotheses.....	6
<b>CHAPTER 2: LITERATURE REVIEW.....</b>	<b>9</b>
2.1 Land use practices: an overview.....	9
2.2 Land use practices: Namibian perspective.....	10
2.3 Land use types in the Caprivi Region.....	12

2.4 Impact of wildlife and livestock on vegetation.....	13
2.5 Impact of other land uses on vegetation.....	16
<b>CHAPTER 3: MATERIALS AND METHODS.....</b>	<b>17</b>
3.1 Description of study area.....	17
3.1.1 Location and extent.....	17
3.1.2 Climate.....	20
3.1.3 Geology and Soils.....	20
3.1.4 Physical features.....	21
3.1.5 Flora and Fauna.....	21
3.1.6 Historical background of the conservancy.....	22
3.2 Selection of study sites.....	24
3.2.1 Core Wildlife Area (CWA).....	25
3.2.2 Transitional Area (TA).....	25
3.2.3 Outside Area (OA).....	26
3.3 Demarcation of plots.....	26
3.4 Measurement of plant attributes.....	27
3.5 Measurement and estimation of woody and grass cover.....	29
3.6 Assessment of range condition.....	29
3.7 Data manipulation and analysis.....	31
3.7.1 Species diversity .....	21
3.7.2 Species richness.....	31
3.7.3 Vegetation structure.....	31

3.7.3.1 Density.....	31
3.7.3.2 Basal area.....	32
3.7.3.3 Height.....	33
3.7.3.4 Cover.....	33
3.7.3.5 Range condition.....	33
3.7.4 Determinants of vegetation structure and species composition.....	34
<b>CHAPTER 4: RESULTS.....</b>	<b>35</b>
4.1 Sample sizes .....	35
4.2 Species diversity and richness.....	35
4.3 Plant densities.....	37
4.3.1 Trees.....	37
4.3.2 Shrubs .....	39
4.3.3 Forbs.....	40
4.4 Basal areas .....	40
4.5 Height.....	43
4.5.1 Trees.....	43
4.5.2 Shrubs.....	44
4.6 Cover.....	45
4.6.1 Woody cover.....	45
4.6.2 Grass cover.....	46
4.7 Range condition .....	47
4.7 Determinants of vegetation structure and species composition .....	49

4.7.1	Vegetation classification.....	49
4.7.2	Ordination.....	53
<b>CHAPTER 5: DISCUSSION.....</b>		<b>55</b>
5.1	Differences in species diversity, richness and composition.....	55
5.2	Differences in vegetation structure .....	60
5.3	Range Condition.....	71
5.4	Determinants of vegetation structure and species composition.....	74
<b>CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS.....</b>		<b>78</b>
6.1	Conclusions.....	78
6.2	Recommendations.....	81
<b>REFERENCES.....</b>		<b>84</b>
<b>APPENDICES.....</b>		<b>96</b>





## **CHAPTER 1: INTRODUCTION**

### ***1.1 General Introduction***

Human societies have, for centuries, impacted and altered the natural environments through different land use practices. The rapid increase in human populations has been one of the most powerful agents of environmental change (Barnard 1998, Scoones 1995). Historically, the single most important factor generating reduction in biodiversity is human land use and the changes in land use practices (Huntely 1994, Barnard 1998, Leggett *et al.* 2002, Zhang 1998). In Namibia, humans and their lifestyles have influenced the natural environment for many centuries (Barnard 1998, Kreike 1995). The Namibian agricultural system, which in many ways is typical of dry land farming (Barnard 1998), has gone through various stages, ranging from the early hunter-gathers to semi-nomadic and eventually to sedentary lifestyles (Barnard 1998, Kreike 1995). These changes in land use practices, although not well documented in the Namibian context (Barnard 1998, Burke 2006) have undoubtedly affected habitats in many ways.

Land degradation in the form of overgrazing, deforestation and desertification are some of the major environmental problems associated with changes in land use practices in arid to semi-arid regions of the world, especially in African countries south of the Sahara (Scoones 1995, Kreike 1995, Beaumont 1993). The most dramatic changes in species composition and productivity and hence structure have been reported to occur near water points and human habitation, where trampling and intensive grazing form distinct zones or piospheres (Leggett *et al.* 2003, Sekhwela 2003, Zhang 1998).

Agricultural practices, especially crop production and animal husbandry, are the most dominant land use systems in the world's developing nations (Beaumont 1993, Huntely 1994). In Namibia, where about 70% of the population resides in communal or rural areas, subsistence livestock farming is a major land use practice (Kreike 1995). In the north-eastern regions of Namibia, agrosilvopasture is the main land use type, and agriculture is thus the main source of income and livelihood for the people of the Caprivi (Ashley 1997, Mendelsohn and Roberts, 1997). The woody vegetation therefore not only constitutes an important resource in its own right but also provides critical linkages between the various resources and components (Kreike 1995). Severe problems of land degradation and consequently loss of biodiversity have been reported as being a direct result of the pressure exerted on rangelands (Barnard 1998, Krieke 1995). Loss of diversity of plants and animals can lead to decreased productivity and income generation from rangelands or can exacerbate the effects of climatic variability and concomitant increased risks for subsistence and even commercial land users (Huntely 1994, Dalhbergh 1994).

Overgrazing especially by domestic animals, can result in the reduction of the production and competitiveness of those plants that are mostly desired by grazing and browsing animals. This shift in the competitive balance between plants may result in a near permanent change in plant species composition and vegetation structure. Cases where livestock are confined to fenced areas are even more severe, because the livestock tend to use available grazing or browse in a selective manner, leading to short-term and possibly long-term habitat changes (Barnard 1998).

Recent legislation in Namibia (1996) has encouraged communities to diversify land use and livelihoods through the management and utilization of wildlife, which was accomplished through developing communal area conservancies (NACSO 2002). This change in land use practice means that the vegetation, including rangelands in communal areas have to accommodate both domestic livestock and wildlife. In this study wildlife refers to game animals only, unless otherwise stated. Since the establishment of communal conservancies, marked increases in wildlife populations have been reported (NACSO 2002), with the re-introduction of wildlife in areas where they disappeared previously. According to Owen-Smith (2002), as livestock and game numbers increase competition for grazing and water resources will inevitably occur, particularly in drought years.

The manner in which wildlife is being managed in different conservancies in Namibia varies, but the most dominant one is having wildlife and domestic animals utilizing common rangelands. However, a number of conservancies are now moving towards zoning their areas for different land use practices, such as having certain areas put aside primarily for wildlife management and tourism. Despite the different zoning systems, there are at least no intentions of fencing off certain areas for specific land use, except in the case of crop fields and homesteads. There are, however some conservancies that have gone a step further by fencing off areas exclusively for wildlife management, a classical example of such conservancies is the Salambala conservancy in eastern Caprivi, which is the focus of this research project.

## ***1.2 Statement of the problem***

Most land use practices around the globe are seen as the major threats to biodiversity. The situation is even worse in the arid and semi-arid countries such as Namibia, where environments are fragile, coupled with variable and unpredictable weather patterns (Scoones 1994). Where aridity is coupled with poverty as in the case of many developing countries, dry land agriculture and increased pressure on the resource base have resulted on severe land degradation, such desertification, deforestation, overgrazing and bush encroachment (Beaumont 1993, Scoones 1994). The concentration of grazing in preferred areas or around focal points (e.g. water points) eventually results in adverse impacts on soil nutrients, vegetation structure, diversity and composition. In Namibia's communal grazing systems, however, the severity or magnitude of this foregoing problem is little understood (Kreike, 1995) especially in the wake of power devolution to local communities to also add wildlife management to their already dwindling rangeland resources.

Although the variability and the unpredictability of climatic conditions have recently been reported by most ecological studies as the main drivers of vegetation changes in arid and semi-arid ecosystems (Archibald 1995, Scoones 1994, Leggett *et al.* 2003, Zeidler *et al.* 2002), overgrazing mainly by livestock in communal areas, land clearing for cultivation and wood harvesting, of which communal areas conservancies are not an exception, remain a land degradation issue (Zhang 1998, Svenning 1998, Sekhwela 2003, Kraaij and Milton, 2006). The re-introduction of wildlife in communal areas through conservancies will exert more pressure on the already overgrazed communal rangelands. Moreover, assessment and monitoring of

climatic conditions are long term, and often are carried out as part of big monitoring programmes. A number of studies and reports in Namibia on communal conservancies have been mainly on socio-economic issues, such as the increased number of wildlife in communal areas and the consequent benefits communities are deriving from such increases (Ashley 1997). However, the effect of the increase as well as the re-introduction of wildlife in communal areas on vegetation is yet to be studied and documented. This study therefore seeks to provide a stepping stone towards the assessment and monitoring of vegetation in mainly communal areas in the wake of community based natural resource management; by assessing the influence of different land use types, specifically livestock and game ranching in communal conservancies on plant species diversity, composition and structure. The information generated by this study will assist conservancy members in particular and other land users to take informed decisions regarding different management practices (eg. zoning). The study will also enable inferences to be made regarding the ecological sustainability of the reintroduction of wildlife in communal areas, through conservancy.

### ***1.3 Objective, questions and hypothesis***

#### **1.3.1 Overall objective**

The overall objective of this study is to compare plant species diversity, composition and vegetation structure between three areas under different land use management systems in the Kalahari Woodlands of the Salambala conservancy in the northeast of the Caprivi.

### 1.3.2 Specific objectives

- a. To compare plant species richness and diversity between the core wildlife area, transitional area and outside area.
- b. To compare plant species composition between the core wildlife management area, transitional area and outside area
- c. To determine whether vegetation structure differs between the core wildlife management area, transitional area and outside area.
- d. To compare the range condition between the core wildlife management area, transitional area and outside area.

### 1.3.3 Key questions

- a. How do species richness and diversity differ between the core wildlife management area, transitional area and outside area?
- b. How does species composition differ between the core wildlife management area, transitional area and outside area?
- c. How does the structure of the vegetation differ between the core wildlife management area, transitional area and outside area?
- d. How does the range condition differ between the core wildlife management area, transitional area and outside area?

### 1.3.4 Research hypotheses

- a. Plant species richness and diversity are expected to vary among the three sites, with the highest species richness and diversity expected in the core area which enjoys more protection status. Species richness and diversity are then

expected to decrease with increasing land use intensity, with the outside area expected to show the lowest species richness and diversity, due to the land use types mainly grazing and browsing by livestock, clearing land for cultivation and wood harvesting.

- b. Plant species composition is expected to differ among the three sites. The species composition in the core area is expected to be the least altered, because of low levels of disturbances. Due to its proximity to the highly utilized outside area, the species composition in the transitional area is expected to show some degree of changes. The species composition in the highly utilized outside area is expected have been altered completely as a result of human activities such as wood harvesting, livestock grazing and browsing and land clearing for cultivation.
- c. The structural attributes (plant density, basal area, height and cover) are expected to vary between the core wildlife management area, transitional area and outside area.
  - There will be high plant density in the core area mainly due to the absence of wood harvesting as well as relatively low levels of grazing and browsing. The plants in the core area are hypothesized to be bigger (i.e. basal circumference) and taller compared to those in the transitional and outside areas, because they are not subjected to cutting therefore they can be expected to grow bigger and taller. The woody vegetation cover (trees and shrubs) is expected to be high in the core area mainly because there is no harvesting of wood taking place under the current land use. The overall grass cover is equally expected to be relatively high, because the

area is not grazed and trampled heavily as compared to the other two areas.

- The plant density in the transitional area is envisaged to be higher than the outside area, but lower than the core area. Furthermore, this area is expected to have trees of mixed sizes, both the basal circumference and height, due to moderate levels of disturbances taking place in this area. The overall woody vegetation cover and grass cover will be expected to show similar trends as the core area.
  - The outside area on the other hand, is hypothesized to have much lower plant density, trees and shrubs will be smaller and shorter plants and overall woody and grass cover will also be low, due mainly to uncontrolled activities in this zone, as a result of the high level of activities such as grazing, land clearing and wood harvesting.
- d. The range condition is hypothesized to vary among the three sites, with the condition of the range expected to deteriorate with increasing land use intensities from the core area through to the outside area. This is mainly due to different grazing and browsing pressures exerted by livestock in the outside area compared to the core and transitional areas and also due to the different feeding habits of wildlife and livestock. The former seem to utilize different parts of the vegetation, while the latter are predominantly grazers and selective feeders (Leggett *et al.*, 2002).

## **CHAPTER 2: LITERATURE REVIEW**

### **2.1 Land use practices: an overview**

Land use activities, whether converting natural landscape for human use or changing management practices on human-dominated landscapes, have transformed a large proportion of the planet's land surface (Huntely 1994, Scoones 1995, Barnard 1998, Metzger *et al.*, 2004). Although land use practices vary greatly across the globe (Scoones 1995), their ultimate outcome is generally the same; the acquisition of natural resources for immediate human needs, more often at the expense of environmental degradation (Barnard 1998, Van den Berg and Kellner 2005). Most land use practices have been blamed for the loss of biodiversity, especially through the modification and fragmentation of natural habitats (Dalhberg 1994, Van den Berg and Kellner 2005).

Ironically, just as human's collective land use practices have degraded ecological conditions across the globe, humanity has become dependent on an ever-increasing share of the biosphere (Huntely 1994). Human activities are now said to appropriate one third to about half of the global ecosystem production (Loucougarg *et al.*, 2004) and as development and population pressure continue to mount, so is the pressure on the natural environment. Population growth and concomitant demand for land use products are seen as the major forces driving land use changes around the world.

Land use thus presents us with a dilemma; on the one hand land use practices are absolutely essential for humanity, as they provide critical and basic goods and services without which humans cannot survive. The bulk of the world's

carbohydrates is said to remain land-based despite new innovations such as hydroponics (Hunter, 1996, Barnard, 1998). Moreover, more than half of the world population which reside in developing countries depend on natural resources for their daily needs and survival. On the other hand, some forms of land use are degrading the ecosystems and their services upon which humanity depends. Crop land and pasture together were estimated to account for 40% of the global area, a close rivalry with forest lands (Van den Bergh and Kellner 2005). Therefore confronting the global environmental challenge of different land use types requires the assessment and monitoring of inherent trade-offs between meeting immediate human needs and maintaining the capacity of ecosystems to provide these services.

## **2.2 Land use practices: Namibian perspective**

The combination of low precipitation coupled with high evaporation make Namibia the driest country in Sub-Saharan Africa, with mean annual precipitation as low as 20mm in the west coast and more than 600mm in the north-east (Mendelsohn *et al.*, 2002). Land use practices in Namibia, like in many African countries, went through several transformations (Barnard 1998, Kreike 1995, Scoones 1995). The mostly nomadic pastoralist lifestyle has been replaced by sedentary lifestyles mainly as a result of colonial legislation of tribal segregations in rural areas (Barnard 1998). The confinement of people and animals to relatively small areas had and still has serious environmental implications, evident in the form of, for example deforestation in the north-central Namibia, where more than half of Namibia's population resides (Kreike 1995). Agricultural farming, mostly with livestock and crops as its major activity and

wildlife tourism as the next major activity makes up 80% of the total land use in Namibia (Mendelssohn *et al.* 2002).

The dominant land use practice in the north-east is agrosilvopastoral system, which combines crops, trees and livestock (Kreike 1995, Mendelssohn and Roberts 1997). Although these indigenous and traditional land use systems received criticisms in the past in terms of their negative impacts on the environment (Sullivan 1999, Verlinden and Dayot 2004), they were however, able to sustain the people even during droughts and wars (Kreike 1995, Sullivan 1999). This implies some degree of resistance and resilience of these traditional land use systems. However, with the new paradigm shift in conservation, from strictly state control of natural resources to community based natural resource management, traditional land use systems are once again undergoing some transformation. After independence, the Namibian Government adopted a policy of power devolution to local communities to manage their natural resources (mainly wildlife) in a sustainable manner (Barnard 1998, NACSO 2002). Since 1998 a total of 50 communal conservancies have been registered, making up 10% of the total land area (MET, 2006).

This legislation has seen a huge increase in wildlife numbers in communal areas, which previously were reduced to even regional extinction (Mendelssohn *et al.* 2002). The Sorris-Sorris conservancy for example is said to be one of the areas in the world where the population of Black Rhinos has recovered dramatically (NACSO 2002). A number of studies have already been conducted and some are still underway to evaluate mainly the economic viability of communal area

conservancies, measured mainly against the number of wildlife increments (Long 2004). However, the ecological implications of the reintroduction or increase in wildlife populations in communal areas are yet to be evaluated. Recently, communities in conservancies have embarked on zoning exercises, mainly directed towards minimizing human-wildlife conflicts (NACSO 2002), but also to enable the sustainable management of the natural resources. The challenge facing both the communities as well as the organizations involved in conservancies (Government and Non-Governmental Organizations) is to ensure the resource base on which the people, wildlife and domestic livestock depend is managed in a sustainable manner (Margules 2000).

### **2.3 Land use types in the Caprivi region**

The land making up Caprivi, 20 009km<sup>2</sup> (Ashley 1997, Mendelsohn and Roberts 1997) is either under state or communal management. The land generally regarded as communal in the Caprivi region covers an area of about 11 239 km<sup>2</sup> (Mendelsohn and Roberts 1997). The dominant form of land use in most parts of areas under communal management is subsistence farming, although several other commercial types of land uses are made in the communal areas including tourist lodges and hunting concessions. Subsistence farming in Caprivi comprises mainly stock and crop farming. Stock farming is dominated by cattle.

The number of cattle in the whole region of the Caprivi was said to have increased over the past 26 years and to have more than doubled over the past 11 years (Mendelsohn and Roberts 1997). According to recent counts by the Directorate of

Veterinary Services (DVS) in the Ministry of Agriculture, Water and Forestry (MAWF), the number of cattle in the eastern Caprivi district is 155 647 cattle. Other stock includes goats, chickens, sheep and pigs. Three main crops dominate subsistence crop farming in the Caprivi; these are Mahangu (Pearl millet) which make up 47% of cultivated land, Sorghum (27%) and Maize (26%) (Mendelssohn *et al.* 2002).

Another land use type that has gained momentum in Namibia and especially in the Caprivi is community based natural resources management (CBNRM), which includes communal area conservancies, community forests and community based tourism. There are five registered conservancies in Caprivi, making up a total land area of 1586 km<sup>2</sup>. These are Salambala, total area = 930 km<sup>2</sup>; Mashi, total area = 297 km<sup>2</sup>; Kwandu, total area = 190 km<sup>2</sup>; Mayuni, total area = 151 km<sup>2</sup> and Wapuro, total area = 148 km<sup>2</sup> (MET, 2006).

#### **2.4 Impact of wildlife and livestock on vegetation**

Before the advent of permanent human settlement, savanna vegetation in southern Africa was utilized by numerous species of wild herbivores and nomadic pastoralists (Dalhberg 1994, Scoones 1995) whose combined effects influenced and shaped savanna structure and helped maintain the balance between herbaceous and woody components of the savanna. However, with the reduction in mobility of pastoralists in arid and semi-arid pastoral systems (Vetter 2005) and the consequent concentration of grazing pressure on the resources and reduction in the opportunities

for resting parts of the vegetation, increased risks of degradation become eminent (Zhang 1998).

The relationship between vegetation and herbivores has been well studied and documented. It has been widely reported that grazers alter landscape heterogeneity, rates of nutrient cycling and vegetation composition and productivity (Dalhberg 1994, Van den Berg and Kellner 2005, Sisay and Baars 2002). According to Relva *et al.* (1998) livestock, through their consumption of fruits, seeds and plants, play determining roles in the regeneration success of plants, hence reducing the forest biomass levels well below the potential of the site. A study carried out by Metzger *et al.* (2004) in the Serengeti ecosystem concluded that grazing has an important evolutionary force of shaping the biodiversity of vegetation including their structure. According to Kaufmann and Krueger (1984), cattle trampling leads to soil compaction, herbage removal, which in turn can result in increased temperature and evaporation to the soil surface.

Wild grazers are separated in their foraging habits ecologically, with different species utilizing different parts of the vegetation (Leggett *et al.* 2002, Metzger *et al.* 2004). Although wildlife, in particular elephants, have been regarded as significant agents in changing vegetation in arid and semi arid-arid systems (Ben-Shahar 1996;1998), their larger migratory ranges have been considered less damaging on vegetation than domestic stock that are generally kept at higher stocking densities (Leggett *et al.* 2002), thus subjecting the vegetation to continuous grazing pressures. This implies that wild herbivores utilize the rangeland in an ecologically sound

manner, compared to domestic livestock, especially cattle and sheep that only turn to browsing during the dry season and drought. According to Kreike (1995) however, most indigenous cattle breeds like the Sanga have in a way adapted to long dry seasons of Namibia and are said to be equally browsers. Therefore, land use practices of having cattle and wildlife combined, especially in the north-central Namibia, where the traditional Sanga breed still dominate, could have implications on the rangeland resources, as the Sanga breed could be in direct competition with game for forage resources.

Continuous intensive grazing leads to vegetation changes such as the replacement of palatable grasses by less palatable plant species, replacement of perennial grasses by annuals, bush encroachment, lower standing biomass and reduced basal cover (Vetter 2005, Leggett *et al.* 2002, Metzger *et al.* 2005, Zeidler *et al.* 2002). Another study by Evans *et al.* (1997) revealed that grazing pressure in communal area resulted in changes in spatial and temporal heterogeneity of water, nitrogen and other soil resources. The reduction in ground cover associated with overgrazed rangelands and degraded woodlands (Archibald 1995, Evans *et al.* 1997) leads to increase in effective energy of raindrops and consequently less rain filters into the soil (Evans *et al.* 1997). Heavy grazing pressure, especially near water points and human habitation (Leggett *et al.* 2002) can result in dramatic changes in species composition and productivity.

## 2.6 Impact of other land uses on vegetation

The impact of different land uses on the structure of vegetation and composition under different or similar climatic conditions has been widely studied (Vaughan *et al.* 2002, Svenning 1998, Walter *et al.* 1990, Zapfack *et al.* 2002). In arid and semi-arid savanna ecosystems where woody species are in great demand for fuel and shelter (Archibald 1995) especially in communal areas, continual removal of the protective plant cover leads to soil erosion and irreversible destruction of the land. This process has been reported to be severe in the Sahelian region of Africa, where heavy demands on the land combined with dry conditions have resulted in severe desertification (Archibald 1995). Intense exploitation for firewood and timber in the Tansa Valley of India has dramatically reduced the biomass and plant diversity, with the only large trees close to the villages being those with a particular value for the villagers (Veitch 2003).

In Namibia similar trends have been observed, especially in the extreme northern regions (former Owamboland) where severe deforestation has resulted in the reduction of plant diversity and density (Kriek 1995, Mapaura 2006) and large fruit trees such as *Sclerocarya birrea* and *Berchemia discolor* are scattered around homesteads and crop fields. Wood harvesting in some villages in Botswana has been linked to reduction in tree density mainly around the villages (Sekhwela 2003). In their study on the effect of land use intensity on range condition, Zeidler *et al.* (2002) reported that land use intensity can have adverse effects on soil biota, which are main contributors to nutrient cycling and hence rangeland productivity.

## **CHAPTER 3: MATERIALS AND METHODS**

### ***3.1 Description of study area***

#### ***3.1.1 Location and extent***

The study was carried out in the Salambala Conservancy which is located between 17°39'24"S & 17°25'15"S and 24°32'45"E & 24°48'19"E in the eastern Caprivi region (Figure 1), immediately north across the Chobe River from the Chobe National Park in northern Botswana. The conservancy, which covers a total land area of 92 000ha, was initiated in 1995 and was registered on the 19 June 1998. It is divided into a core wildlife management area (14 000ha, which represent 6.6% of conservancy area), which is set aside for wildlife reintroduction and tourism activities and a multiple use area where hunting, grazing and settlement take place. This multiple-use area makes up the rest of the conservancy area and is referred to as the buffer zone (Figure 2).

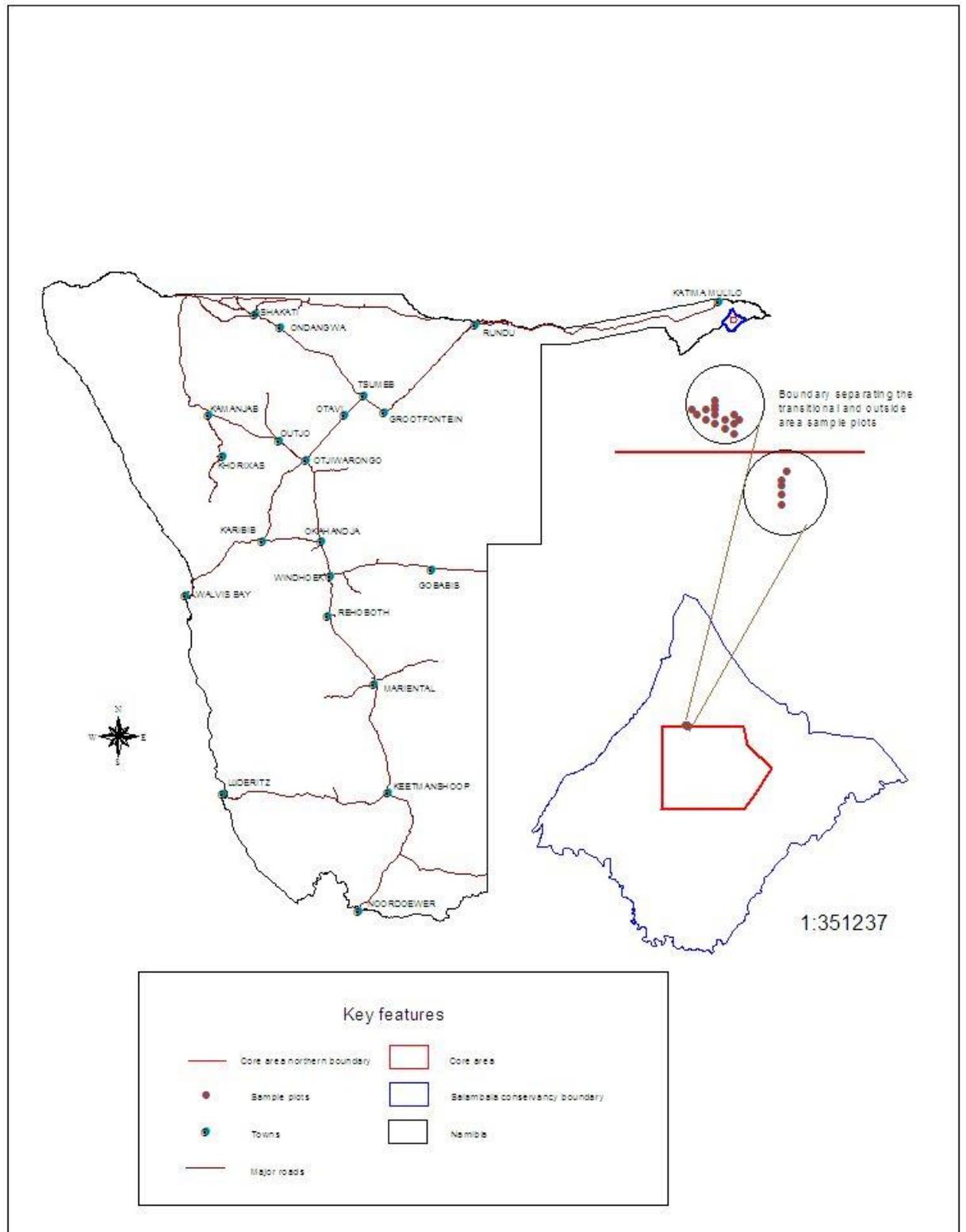
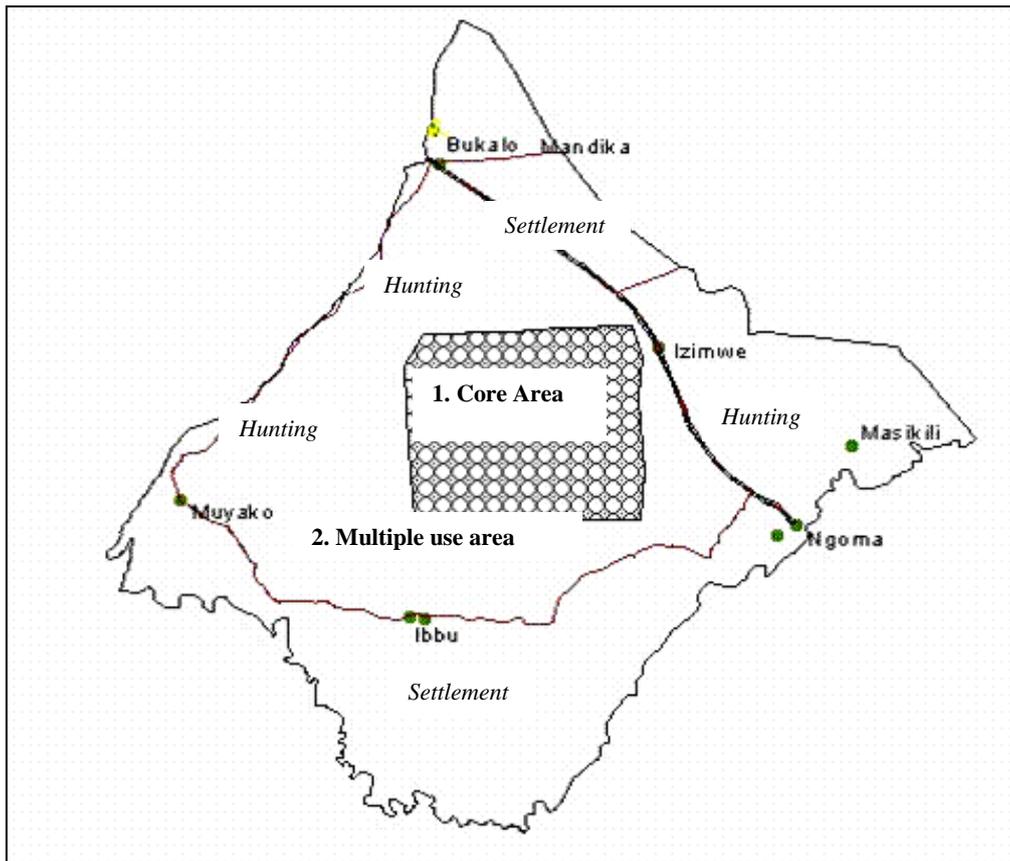


Figure 1: Map of Namibia showing the location of the study area and sample plots.



<p>1. Core Area for tourism and wildlife introduction          No grazing          No hunting          No settlement</p>	<p>2. Multiple use area          Grazing          Wood harvesting          Cultivation          Settlements</p>
--	---

Figure 2: Zonation Map of Salambala Conservancy, showing the core wildlife management area. Adapted and modified from NACSO, 2002.

### **3.1.2 Climate**

The rainfall patterns in the Caprivi Region, in which the study area is located, are distinctively more tropical than any other regions in the country. However as in the case of the rest of Namibia, the rainfall in this region varies from year to year and from place to place. Rainfall is more variable in the southern-most part of the region and most predictable in the eastern areas. The rainfall in the Salambala area averages approximately 620 mm per annum (19 year mean between 1972/2000, with 95% of the rain falling between October and April (Mendelssohn *et al.* 2002).

The area is hot during the dry and wet seasons (summer) but cold in winter (June-August). Incidence of frost is insignificant in the Salambala area. Mean maximum temperatures vary from 29 °C in July to 36°C in January while temperatures in October may be as high as 38°C (Namibia Bureau of Meteorology 2006). Average daily temperatures vary between 15°C and 20°C in summer and 5°C and 10°C in winter (Mendelssohn *et al.* 2002). The highest temperatures are experienced in September, October and November, when average daily maximum temperatures exceed 40°C. The coldest days are experienced in July and the average daily minimum temperatures range between 20°C in summer and 5°C in winter.

### **3.1.3 Geology and soils**

The Caprivi Region is covered in deep Kalahari sands with little underlying bedrock, except along certain sections of river courses. The soils in this region are part of the Kalahari Basin, a vast inland deposit that formed some 130-180 million years ago (Mendelssohn *et al.* 2002). Much of the Kalahari consists of sand shaped by wind

into dunes. The dominant soil types in the Salambala area are ferrallic arenosols and eutric fluvisols. The former is associated with the Kalahari woodlands while the latter is more common in the Mopane woodlands.

#### **3.1.4 Physical features**

The dominant landscape of the Caprivi is the Kalahari sandveld, which is particularly flat with undulations in some areas as a result of sands that have been moulded into dunes. The extensive Kalahari sands and the rivers with their associated floodplains, channels and deposits are the major features which shape the landscape of the Caprivi Region. The region is associated with three out of the five perennial rivers found in the country, the Okavango, Zambezi and Kwando Rivers. The Salambala area is mainly associated with the Chobe and Linyati rivers which are tributaries of the Zambezi and Kwando rivers, respectively. Most parts of the Salambala area are not flooded and the only standing water in Salambala area associated with the floodplains.

#### **3.1.5 Flora and Fauna**

The Salambala conservancy comprises three major vegetation types. There are Mopane woodlands, which make up approximately 60% of the area, Kalahari woodlands, about 26% and finally dense grassland, which includes the important floodplain ecosystems of the conservancy. The Kalahari woodlands are further divided into 11 sub-vegetation units, including the *Burkea-Combretum* woodland, *Burkea-Pterocarpus angolensis* woodland, *Burkea-Terminalia* woodland and *Burkea-Baikiaea plurijuga* woodland. The common sub-vegetation unit in the

Salambala area is the *Burkea-Terminalia* woodland, which occurs on a large ridge which has been extensively revoked by the flow of water. *Terminalia sericea* occurs commonly in the low tree layer. Most grasses associated with this sub-unit are annuals and of poor quality and the perennials are generally woody and unpalatable.

The Caprivi is generally high in terrestrial biodiversity. Table 1 below summarises floral and faunal diversity in the Caprivi.

Table 1: Floral and faunal diversity of the Caprivi region (adopted from Mendelssohn and Roberts, 1997)

<b>Type</b>	<b>Estimated number of species</b>
Higher plants	300-400
Mammals	106-120
Reptiles	17-80
Birds	>230
Frogs	28-35
Termites	13-20
Scorpions	6-10

### ***3.1.6 Historical background of the conservancy***

The Salambala forest area was once the traditional hunting sites for the Basubia Royalty (the main tribal group in eastern Caprivi) and was home to a vast abundance of game species including Elephants, Buffalos, Sable and Roan Antelopes and Rhinos. However, a prolonged war (1968-1989) in and adjacent to the Caprivi Strip and uncontrolled poaching during and after the war led to the decimation of nearly all of Salambala's wildlife. The Basubia Traditional Authority (BTA) and the people therefore initiated the formation of the Salambala conservancy, with the main interest

of the re-establishment of their dwindling wildlife populations in order to enhance the social, cultural and economic welfare of the community.

The formation of the conservancy was commenced in 1995 and with the assistance of the Ministry of Environment and Tourism (MET) and Non-Governmental Organisations (NGOs) and Community Based Organisations (CBOs) the Salambala conservancy was finally registered in 1998. The conservancy consists of 2100 members representing approximately 7135 individuals and there are 19 villages distributed widely within the conservancy (NACSO 2002). The core wildlife management area (CWA) was established in 1995 and as a result 16 Basubia families voluntarily moved from the core area. The core area was fenced off soon after its establishment on three sides with cattle-proof fence and is equipped with two artificial wildlife water points. The establishment of the CWA has provided a peaceful haven for the re-introduced impala to breed and fragmented populations of other game species to return to and settle. The Salambala Conservancy members' new and welcoming attitude toward wildlife has induced wildlife from Botswana's neighbouring Chobe National Park to move freely into Salambala's complementary floodplain and forest habitats. Evidence of growing wildlife populations include:

- Increase of the impala population from 7 in 1995 to more than 250 in 2002;
- Establishment of a resident conservancy elephant population of more than 600 as contrasted with only seasonal movements of elephants into the area prior to 1995;

- In 1998, plains zebra began migrating from Botswana to the Salambala Conservancy for the first time since the early 1970s. By 2002, more than 1,500 plains zebra were residing in the Conservancy for at least six months of the year; and
- The recovering wildlife populations have been followed by the permanent presence of lion populations in the conservancy. In 2001, three prides of lions (19 individuals in total) had established residence in the Conservancy, making it the first time since the 1970s that lions had permanently settled in the area.

### **3.2 Selection of study sites**

The study area was stratified into 4 strata of Kalahari woodlands. Stratification was done with the aid of a satellite image and by driving around the area physically identifying Kalahari woodlands inside and outside the core area. The Kalahari woodlands in the broader conservancy which are located far from the core area, such as those south-west of the Bukalo-Ngoma road, were deliberately excluded from the study, as they could hinder direct comparisons between the different land-use types. Therefore the study mainly covered the Salambala area Kalahari woodlands, that is those associated with the Salambala area forest. The study sites were selected within three broader zones representing the land use types. These were the core wildlife management area, a transitional area and the outside area.

### **3.2.1 Core Area (CWA)**

The core area is earmarked exclusively for wildlife re-introduction and management, as well as tourism activities. Therefore there are no other activities such as hunting, cutting, “intentional” grazing and browsing by livestock and cultivation. The core area (as will be referred to in the rest of the document) covers an area of 14 000ha and has two artificial wildlife water points and several natural ponds, swamps and pans including the famous Salambala pan. The core area is thus accorded high conservation status and is fenced off on three sides with a cattle proof fence. The unfenced side is to allow free movement of wildlife, between the conservancy and other conservation areas, most especially the Chobe National Park in Botswana (NACSO, 2002).

### **3.2.2 Transitional Area (TA)**

The transitional area is situated at the northern border of the core area and the outside area. The only activity that is allowed in this zone is wildlife grazing and browsing. Other activities such as grazing and browsing by livestock, cultivation and human settlements are not allowed in the transitional area. However due to its proximity to the settled areas, wood harvesting, collection of thatching grass and livestock grazing and browsing are common. The transitional area thus represents an area of intermediate utilization.

### **3.2.3 Outside Area (OA)**

The outside area is situated in the broader conservancy area, but adjacent to the transitional area. This area consists of settlements, cultivated areas, grazing and browsing by wildlife and domestic animals, firewood collection and other activities associated with human settlements. Therefore, the outside area is highly utilized and to some extent there is no control of activities in this zone.

### **3.3 Demarcation of plots**

After stratification of the study area, line transects were selected at random in each stratum in the different land use zones. The nested plot design (Figure 3) was used to determine the minimal plot area, which is the smallest area within which the species of the community are adequately sampled (Barbour *et al.*, 1999, Kent and Coker 1994, Werger, 1972). Square plots of the following sizes 1m\*1m, 5m\*5m and 20m\*20m were placed along the transects. The 1m\*1m plots were nested within the 5m\*5m plots and the latter nested in the 20m\*20m. The 20m\*20m plots were spaced at 20 meters from each other and their location was recorded on a Geographical Positioning System (GPS). (Appendix 3).

The number of samples to be taken during a given study depends heavily on the objectives of the study, the characteristics of community being sampled (e.g. sessile vs. mobile organisms) (Gauch 1982). One of the recommendations for selecting a number of samples in a sample set given by Whittaker is that along a well-defined gradient of vegetation and environment, relatively few samples in the order of 5-20 taken at fixed intervals may suffice (Abd-El-Ghani, 1998). In this study, the sample

size was mainly determined and limited by the size of Kalahari woodlands in a Mopane dominated landscape. The sample sizes per stratum were therefore 7, 10 and 15 in the core area, transitional area and outside area, respectively.

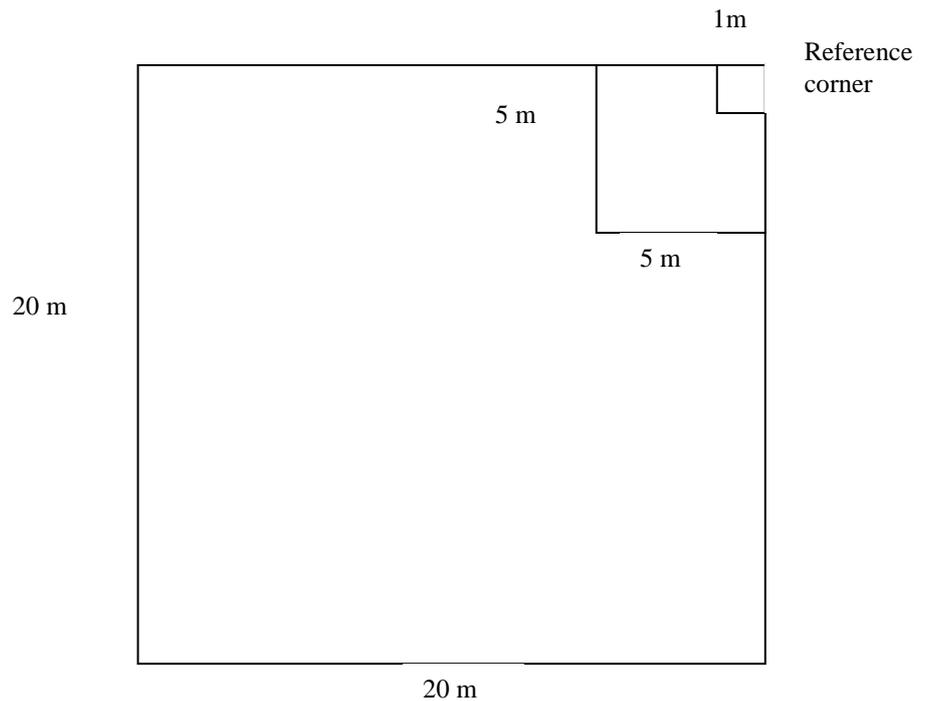


Figure 3: The nested plot design used for the recording of grasses and forbs; shrubs and trees for  $1\text{m}^2$ ,  $25\text{m}^2$  and  $400\text{m}^2$  respectively, showing the reference corner (north-west direction) where coordinates of each plot were recorded (not drawn to scale).

### 3.4 Measurement of plant attributes

Most vegetation studies involve the grouping of plants into broad categories based on their growth forms (Bonham 1989). The major life forms commonly used in

vegetation studies are tree, shrub, grass and forb (Kent and Coker 1994) and these life forms often provide basis for the description of terrestrial plant communities (Bonham 1989).

In this study trees were regarded as all woody plants with one or several stems basal circumference >15cm, branching well above the ground; shrubs were considered as perennial woody plants that have many stems (basal circumference <15cm) arising from and branching from the ground, and forbs as herbaceous plants other than a grass (Curtis and Mannheimer 2005, Hickey and King 2000, Werger *et al.*, 1988).

In each of the 20m\*20m plots, all individual trees were identified and recorded to species level where possible. Height and basal circumference were measured for all trees. Height was measured with the aid of a 7.5m measuring rod. For trees higher than 7.5 meters, height was estimated to the nearest half meter. Basal circumference (BC) was measured with a measuring tape, just at the base of the tree. For multi-stemmed trees, basal circumference for each stem was measured separately.

In each of the 5m\*5m subplots, all individual shrubs of basal circumference < 15cm (Anderson and Walker 1974) were identified to species level. Height for all shrubs was measured in the same way as that of trees and stems were counted and recorded.

In each of the 1m\*1m subplots, all grass species and all forbs were identified to species level and recorded.

All plant species that could not be identified in the field were pressed in a plant press and later identified at the National Botanical Research Institute (NBRI). Some plants were allocated local vernacular names with the aid of community game guards (CGG) and these were also later verified at the NBRI.

### **3.5 Measurement and estimation of woody and grass cover**

The woody cover for each location was determined using the line intercept method. A 30m measuring tape was stretched for 30m from the reference corner of each plot. The beginning and end of each plant foliage intercepting the tape was measured and recorded. For taller plants which intercepted the tape, the intercepting part was projected onto the tape and the distance recorded. The overall grass cover for each plot was visually estimated (Barbour *et al.* 1999).

### **3.6 Assessment of range condition**

In order to determine the range condition each plot was assessed for grazing intensity using the methods developed by Trollope and others (2000) for range condition assessment in East Caprivi. The 20m\*20m were inspected for the presence of decreaser, increaser I and increaser II grass species; if found they were recorded. The list of key grass species used as a guide for the assessment of range condition is given in Appendix 1.

This method by Trollope and others (2000) involved the identification of key grass species based on the potential of the grass sward to produce forage for grazing domestic livestock and wild ungulates in each of the main vegetation units of East

Caprivi, i.e. Kalahari Woodlands, Mopane Woodlands and the Floodplains. The identification of these key grass species (appendix 1) was based on forage production because the major portion of the rangeland in East Caprivi is used as grazing, mainly for cattle. The key grass species were then classified into Decreaser and Increaser species according to their reaction to a grazing gradient i.e. from high to low grazing intensities as follows:

- Decreaser Species: Grass and other herbaceous species that decrease when rangeland is under-grazed or over-grazed
- Increaser I Species: Grass and other herbaceous species that increase when rangeland is under- or selectively grazed.
- Increaser II Species: Grass and other herbaceous species that increase when rangeland is over-grazed.

Using the above classification, the range can then be described whether it is being moderately, under, selectively or over-grazed. The criteria used for deciding the intensity of grazing is that if the rangeland is dominated by decreaser grass and other herbaceous species then it is being moderately grazed. If it is dominated by Increaser I grass and other herbaceous species then it is being under-grazed. If it is dominated by Increaser II grass and other herbaceous species then it is being over-grazed. Finally, if it is dominated by both Increaser I & II grass and other herbaceous species, it is being selectively grazed. Herbaceous species other than grasses were not included as determinants of range condition in this study, as the range condition method employed does not list them separately. Only two grazing categories were considered in the study, i.e under-grazing and overgrazing.

### **3.7 Data manipulation and analysis**

#### **3.7.1 Species Diversity**

The Shannon-Weiner diversity index was used to calculate the plant species diversity (excluding grasses) for each plot in the Core Area, Transitional Area and the Outside Area:  $H' = -\sum (p_i * \ln p_i)$ , where  $p_i$  proportion of individuals found in the  $i$ th species and  $\ln$  is the natural logarithm (Hunter 1996). The data were tested for normality using the Kolmogorov-Smirnov normality test in SPSS 14.0 (Norusis 2004). A one-way analysis of variance (ANOVA) was then used to test for significant differences in species diversity between the three sites. The Tukey HSD *post hoc* test was used to detect significant differences.

#### **3.7.2 Species Richness**

The number of all plant species in each plot was obtained; the Kolmogorov-Smirnov test was run to test for normality and a Kruskal-Wallis test was used to test for significant differences in plant species richness among the three sites. The Mann-Whitney U test, a non-parametric equivalent of the independent samples t-test (Dythan 2003) was used to detect significant differences.

#### **3.7.3 Vegetation Structure**

##### **3.7.3.1 Density**

The densities of individual trees and shrubs per plot were calculated and expressed per hectare. Forb density was calculated and expressed per square meter. Stem density was obtained in the same manner as for trees and shrubs. The mean density, standard deviation and standard error for individuals and stems in each plot were calculated using the formulae in Microsoft Excel. The data were tested for normality using the Kolmogorov-Smirnov normality test in SPSS 14.0 (Norusis 2004). A Kruskal-Wallis test was then run to test for differences in mean individual and stem densities. The Mann-Whitney multiple comparison test was used to detect significance differences.

### **3.7.3.2 Basal Area**

Basal area was calculated using the following formula:  $BA = c^2 / (4 * \pi)$ , assuming that all stems were circular: Basal area distribution was obtained by arranging the basal area values of individual trees in the following basal area classes in  $\text{cm}^2$  ( $\leq 100.99$ ; 101-200.99; 201-300.99; 401-500.99; 501-600.99; 601-700.99 and  $\geq 701$ ). A chi-square test was used to test for the differences in basal area classes among the core area, transitional area and outside area. In the case of significant differences, the chi-square tables were inspected for notable differences between observed and expected values.

The basal areas for all trees in a plot were added together to give total basal area in square meters per hectare ( $\text{m}^2/\text{ha}$ ). The Kolmogorov-Smirnov test was run to test for normality. A Kruskal-Wallis test was run to test for the differences in mean basal area

among the three sites. A Mann-Whitney U test was used in case of significant differences.

### **3.7.3.3 Height**

The height values were arranged in following height classes. Trees: ( $\leq 2.5$ ; 2.51-3.5; 3.51-4.5; 4.51-5.5; 5.51-6.5; 6.51-7.5 and  $\geq 7.5$ m). Shrubs and Saplings:  $\leq 1$ ; 1.1-1.5; 1.6-2.0; 2.1-2.5; 2.6-3.0; 3.1-3.5; and  $\geq 3.5$ m). A Chi-square test was used to test for the differences in height among the core area, transitional area and outside area. In the case of significant differences, the Chi-square tables were inspected to identify notable differences between observed and expected values.

### **3.7.3.4 Cover**

The mean woody cover, standard deviation and standard error were calculated using Microsoft Excel for Windows formulae. Percentage woody cover per plot =  $\sum ((intercepted\ distances)/30m)*100$ . A Kruskal-Wallis test was then used to test for differences in percentage woody and grass cover between the three sites. A Mann-Whitney U test was used in order to elucidate where the significant differences were in the data.

### **3.7.3.5 Range condition**

The range condition at each site was described whether it is under-grazed, selectively- grazed or over-grazed base on the frequency of occurrence of increaser I

species and increaser II grass species. A Chi-square test was used to test for the differences in the condition of the range among the core area, transitional area and outside area, using actual observed counts. In the case of significant differences, the Chi-square tables were inspected to identify notable differences between observed and expected values.

#### **3.7.4 Determinants of vegetation structure and species composition**

A hierarchical cluster analysis, which involves the grouping of similar entities together into classes (Gauch 1982) using average linkage method was performed on a matrix of 32 plots and 39 species, using presence and absence data. This was done in SPSS 14.0 for Windows (Norusis 2004).

Detrended Correspondence Analysis (DCA) is one of the popular ordination methods especially since late seventies and early eighties. According to Gauch (1982), DCA does not only ordinate sample plots and species, but also provides a non-linear rescaling of the ordination axes in units of mean standard deviation of species turnover. DCA was performed on the species-plots matrix to reveal relations among the various plant associations and underlying environmental gradients (Kent and Coker 1994). DCA was run using default settings, non-linear rescaling of axes and detrending by segments (ter Braak and Prentice 1988). The intention of detrending is to ensure that, at any point along the first axis of the ordination diagram, the mean value of the sample scores on the subsequent axes is approximately zero (Gauch 1982, Longman *et al.* 1995). Therefore detrending enables the removal of the “arch-effect” or “horseshoe effect” common in most ecological data (Kent and Coker 1994,

Gauch 1982). Ordination was done with CANOCO for Windows version 4.5 (ter Braak and Smilauer, 2002).

## **CHAPTER 4: RESULTS**

### **4.1 Sample sizes**

A total of 563 trees, 178 shrubs, 78 forbs, were assessed in all the three sites combined. This breaks down into 92 trees, 71 shrubs and 24 forbs in the core area; 256 trees, 74 shrubs and 29 forbs in the transitional area and 209 trees, 82 shrubs and 25 forbs in the outside area.

### **4.2 Species diversity and richness**

Plant species diversity ( $H'$ ) ranged from 1.52 to 2.33 per plot in the core area, from 1.31 to 2.30 per plot in the transitional area and from 1.21 to 2.01 per plot in the outside area. Statistical comparisons indicated significant differences in mean plant species diversity ( $F = 6.620$ ,  $df = 2$ ,  $p < 0.01$ ), among the three sites. A *post hoc* analysis further revealed significantly higher plant species diversity in the core area and the transitional area than the outside area ( $p < 0.01$  in both cases). There was, however, no significant difference in mean plant species diversity between the core area and the transitional area (Figure 4).

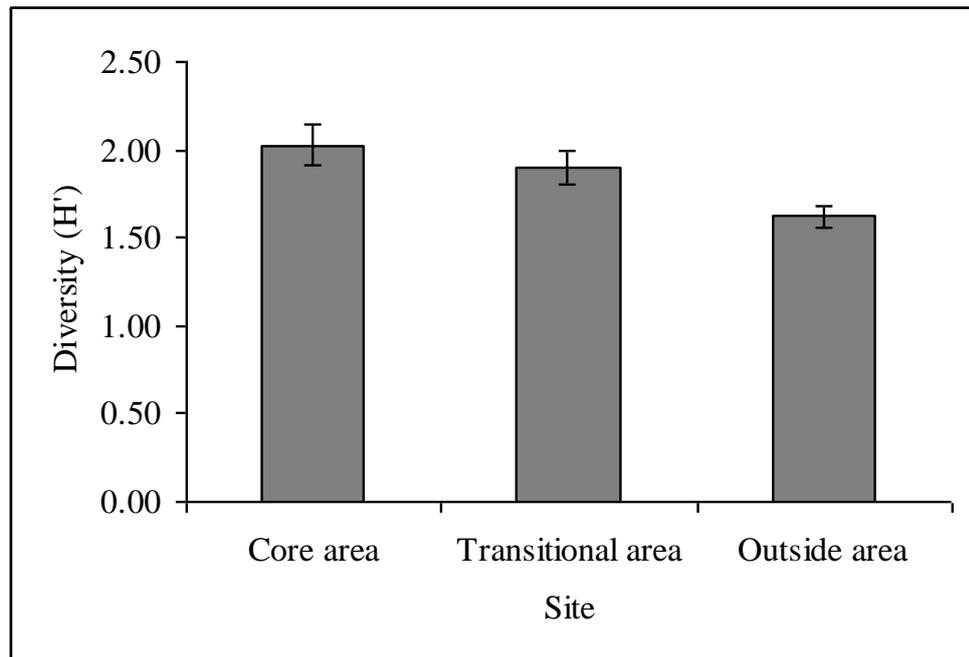


Figure 4: Comparisons of species diversity ( $H'$ ) among three sites in the Kalahari woodlands of the Salambala conservancy, north-east Namibia. The bars indicate standard errors.

Plant species richness ranged from 7 to 12 plant species/plot in the core area, 6 to 12 plant species/plot in the transitional area and from 5 to 10 plant species/plot in the outside area. Mean plant species richness was not normally distributed.

Statistical comparisons revealed significant differences in mean plant species richness among the three sites ( $H = 12.857$ ,  $p < 0.05$ ). Multiple comparisons using the Mann-Whitney test indicated significantly higher species richness in the core area and the transitional area than the outside area ( $p < 0.01$ ) in both cases (Figure 5). However, there were no significant differences in mean species richness between the core and the transitional area.

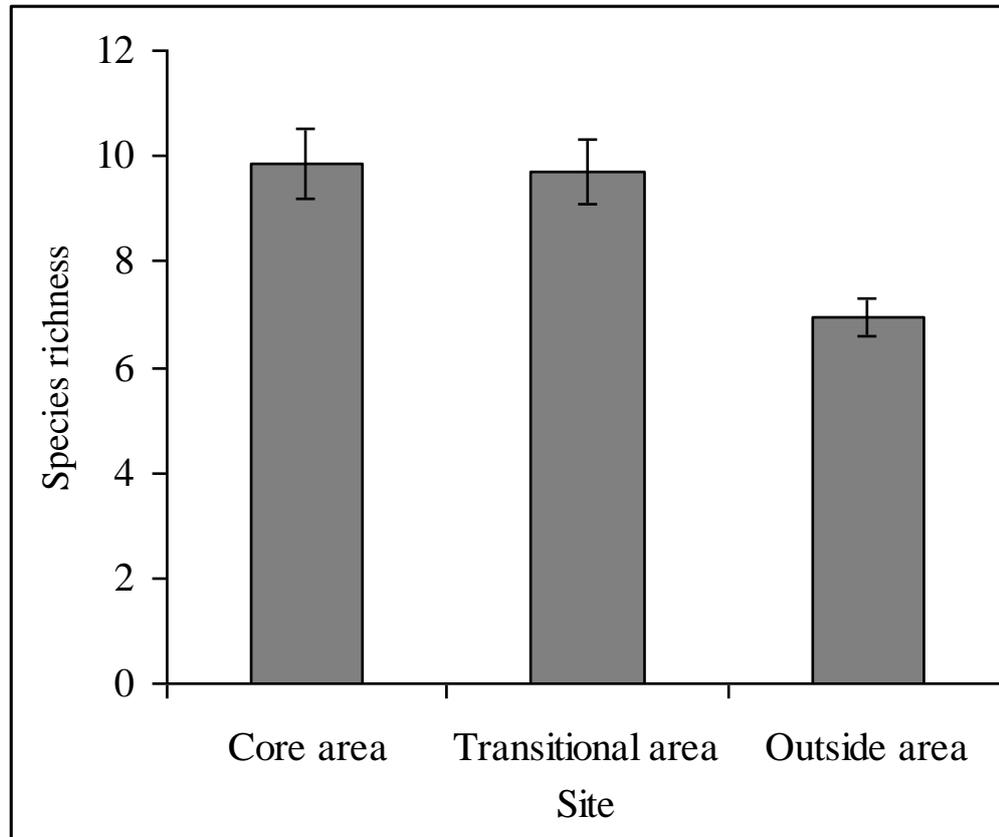


Figure 5: Comparisons of species richness among three sites in the Kalahari woodlands of the Salambala Conservancy, northeast Namibia. The bars indicate standard errors.

### 4.3 Plant densities

#### 4.3.1 Trees

The densities of individual trees ranged from 150 to 450/ha in the core area, 425 to 975/ha in the transitional area and from 200 to 475 for the outside area. The densities of stems ranged from 175 to 650/ha in the core area, 450 to 1075/ha in the transitional area and in the outside area stem densities ranged from 1000 to 1975/ha. Mean individual tree densities were not normally distributed, while stem densities were normally distributed.

The statistical comparisons between the density of individual trees and stems at each site showed significant differences at all three sites. Stem densities were significantly higher than tree densities in the core area ( $t = 2.98$ ,  $df = 6$ ,  $p < 0.05$ ), transitional area ( $t = 4.05$ ,  $df = 9$ ,  $p < 0.05$ ) and outside area ( $t = 15.25$ ,  $df = 14$ ,  $p < 0.001$ ).

There were significant differences in individual tree densities among the three sites ( $H = 17.422$ ,  $p < 0.001$ ) (Figure 6). The transitional area had significantly higher individual tree densities than both the core and outside area ( $p < 0.001$  in both cases), but there was no significant difference in tree density between the core and the outside area. There were also significant differences in stem densities among the three sites ( $H = 17.33$ ,  $p < 0.001$ ) (Figure 6). The outside area had significantly higher stem densities than both the transitional and the core area ( $p < 0.001$  in both cases). The transitional area had also significantly higher stem densities than the core area ( $p < 0.05$ ).

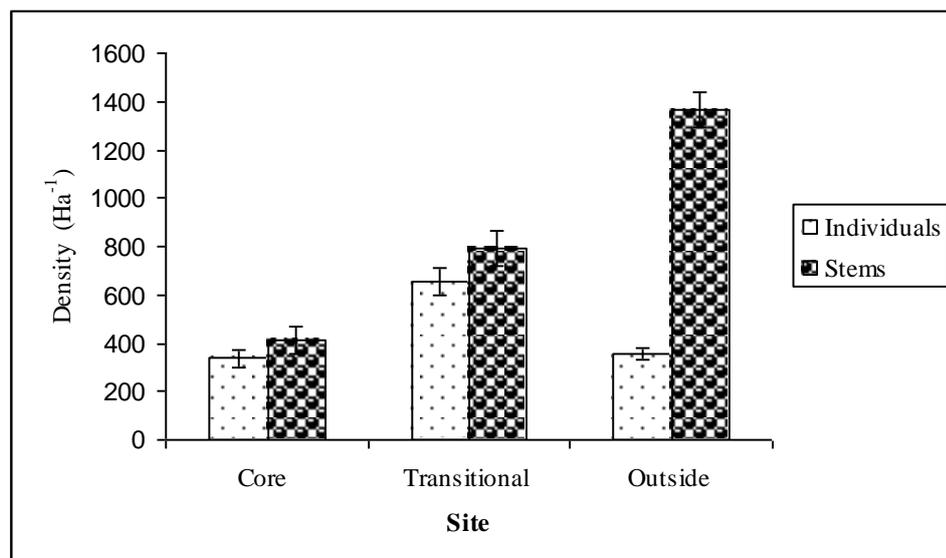


Figure 6: Comparisons of mean tree and stem density, with standard error bars, among the three sites in the Salambala conservancy, northeast Namibia

### 4.3.2 Shrubs

The densities of individual shrubs ranged from 1 to 45/ha in the core area, 11 to 123/ha in the transitional area and from 0 to 77/ha in the outside area. The stem densities ranged from 400 to 18 000/ha in the core area, 4400 to 49 200/ha in the transitional area and from 0 to 30 800/ha in the outside area. Both individual shrub densities and stem densities were not normally distributed. The statistical comparisons between individual shrub densities and stem densities indicated significant differences at all three sites (Figure 7). The stem densities were significantly higher than the individual shrub densities in the core area ( $t = 4.81$ ,  $df = 6$ ,  $p < 0.05$ ), transitional area ( $t = -4.35$ ,  $df = 9$ ,  $p < 0.05$ ) and in the outside area ( $t = -7.11$ ,  $df = 14$ ,  $p < 0.001$ ). There were, however, no significant differences between individual shrub densities among three sites and between stem densities among the three sites.

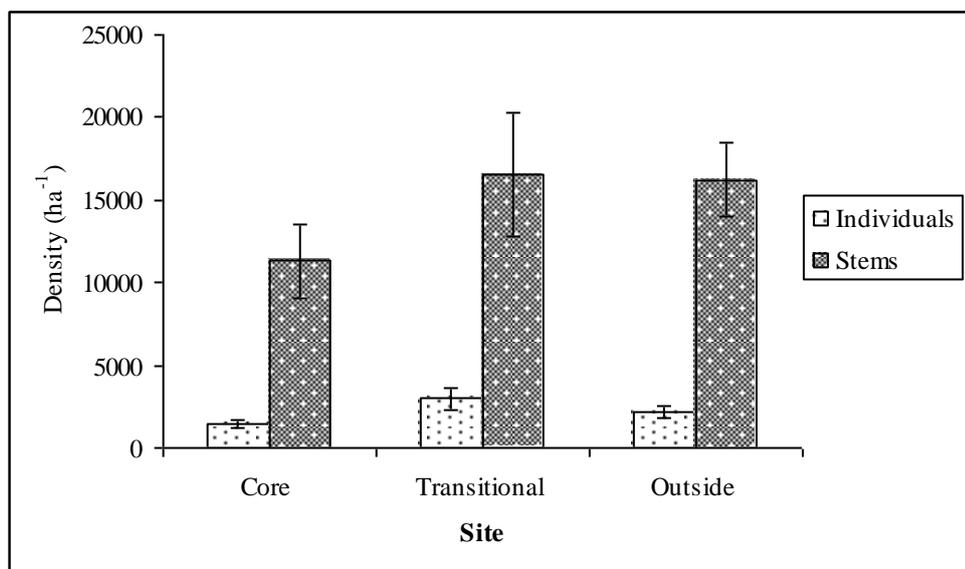


Figure 7: Comparison of individual shrub and stem densities, with standard error bars, among the three sites in the Salambala Conservancy, northeast Namibia

### 4.3.3 Forbs

The densities of forbs ranged from 1 to 6/m<sup>2</sup> in the core area, 0 to 9/ m<sup>2</sup> in the transitional area and from 0 to 7/ m<sup>2</sup> in the outside area. Mean forbs densities were not normally distributed. There were no significant differences in mean forbs density among the three sites (Figure 8).

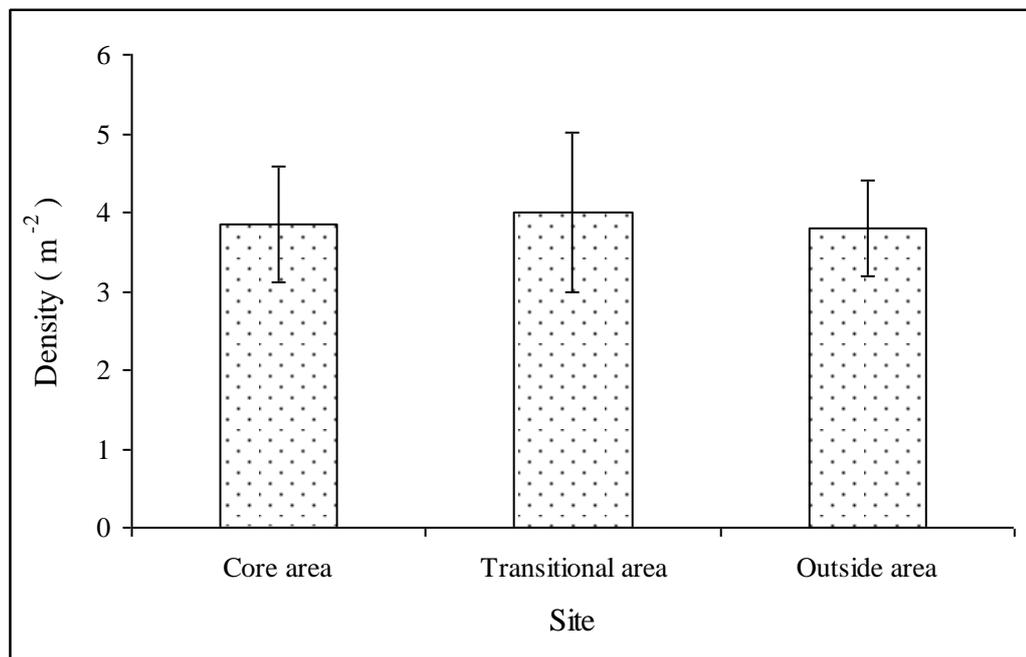


Figure 8: Differences in forb densities, with standard error bars, in Kalahari woodlands at three sites in the Salambala conservancy, northeast Namibia

### 4.4 Basal areas

The tree basal area ranged from 1.28 to 20.37m<sup>2</sup>/ha in the core area; from 2.41 to 32.24m<sup>2</sup>/ha in the transitional area and from 3.92 to 14.47m<sup>2</sup>/ha in the outside area. The mean basal areas were not normally distributed. The statistical test indicated that there were significant differences in tree basal areas among the three sites ( $H= 7.156$ ,  $p<0.05$ ) (Figure 9). The basal area was significantly higher in the transitional area than in the core area ( $p<0.05$ ) and than in the outside area ( $p<0.001$ ). There were,

however, no significant differences in the basal area between the core area and the outside area.

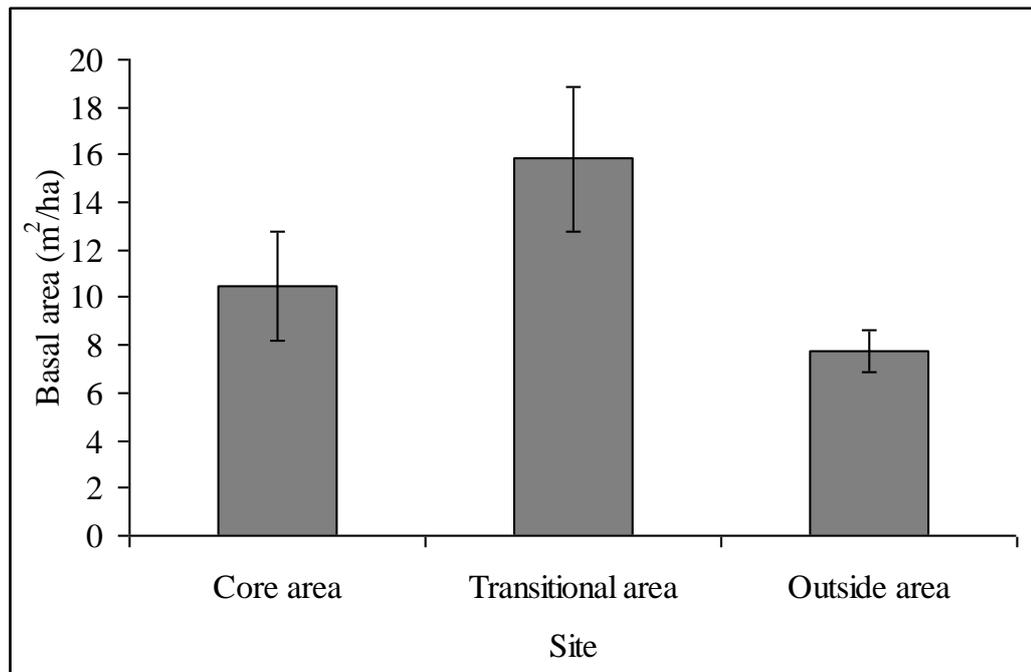


Figure 9: Differences in basal areas of trees, with standard error bars, in the Kalahari woodlands of the Salambala conservancy, northeast Namibia

Basal area frequency distribution patterns revealed higher proportions of trees in the middle-sized trees range (71 to 490.99 cm<sup>2</sup>) than the smaller- sized trees range ( $\leq 70.99$  cm<sup>2</sup>) and the bigger sized trees range ( $\geq 491$ cm<sup>2</sup>) in the core area and outside area. In the transitional area the distribution patterns showed higher proportions of trees in the smaller-sized trees range ( $\leq 70.99$  cm<sup>2</sup>) than the middle sized trees ranges (71 to 490.99 cm<sup>2</sup>) and bigger sized trees range ( $\geq 491$ cm<sup>2</sup>), a typical inversed-J shape (Figure 10).

Statistical comparisons revealed significant differences in basal area distribution patterns among the three sites ( $\chi^2= 117.140$ ,  $df = 14$ ,  $p<0.001$ ). These differences can mainly be attributed to much higher than expected numbers of trees recorded in the core area for class range  $\geq 491\text{cm}^2$ , in the transitional area for class range  $\leq 70.99\text{cm}^2$  and for classes ranges  $141 - 210.99\text{cm}^2$  and  $211-280.99\text{cm}^2$  in the outside area; and much lower than expected numbers of trees in the core area for class range  $\leq 70.99\text{cm}^2$ , in the transitional area for class ranges  $141 - 210.99\text{cm}^2$  and  $211-280.99\text{cm}^2$  and in the outside area for class ranges  $\leq 70.99\text{cm}^2$  (Appendix 2a).

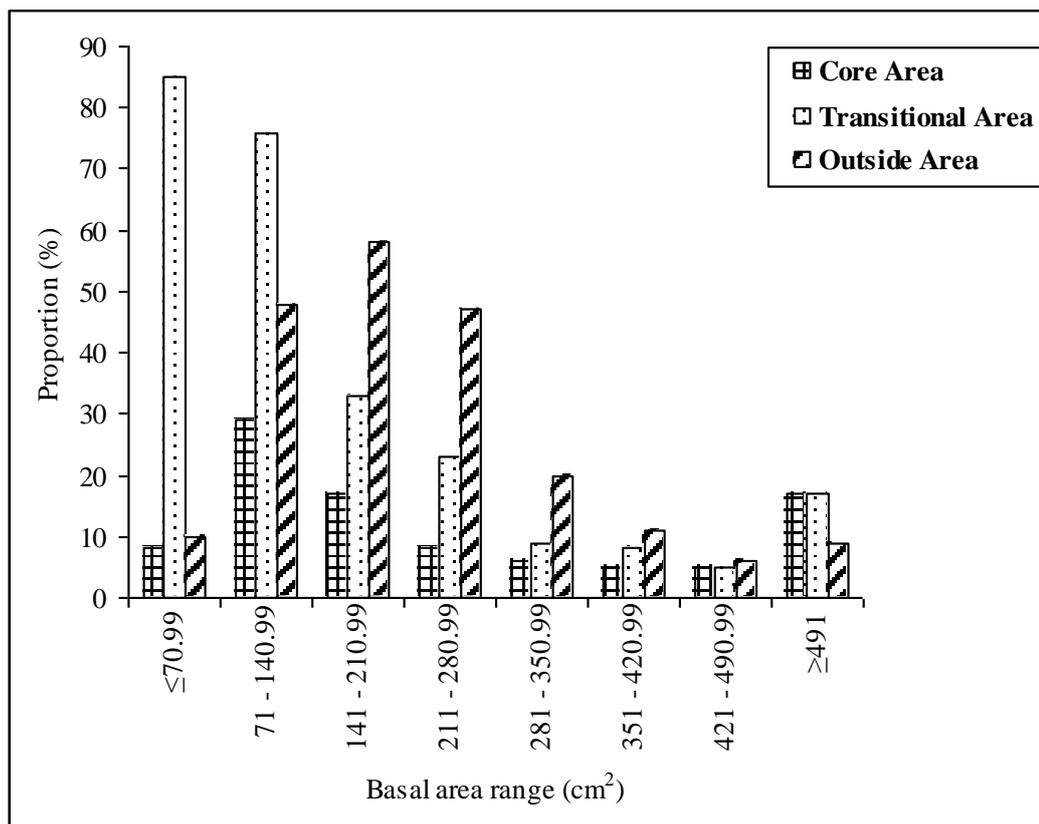


Figure 10: Comparisons of the basal area frequency distribution patterns of trees in the Kalahari woodlands of the Salambala conservancy, northeast Namibia

## **4.5 Height**

### **4.5.1 Trees**

The height of trees ranged from 2 to more than 7.5m in the core area, from 1.2 to more than 7.5m in the transitional area and from 1.6 to more than 7.5m in the outside area. The height frequency distribution patterns indicated higher proportions of tall trees ( $\geq 7.5\text{m}$ ) in the core area, high proportion of trees in the middle height class ranges (2.51-3.5m) and (3.51m-4.5m) in the transitional and outside areas (Figure 11). Statistical comparisons indicated significant differences in height distribution among the three sites ( $\chi^2 = 122.94$ ,  $df = 12$ ,  $p < 0.001$ ). These differences were mainly due to higher than expected individual trees in the core area for height class  $>7.5\text{m}$ , in the transitional area for classes  $< 2.5\text{m}-3.5$ ;  $5.51-6.5\text{m}$  and  $6.51-7.5\text{m}$  and for classes  $2.51-3.5$  and  $3.51-4.5\text{m}$  in the outside area. The differences were also due to much less than expected individual trees in the core area and transitional area for classes  $2.51-3.5$  and  $3.51-4.5\text{m}$  and in the outside area for classes  $4.51-5.5$ ;  $5.51-6.5$ ;  $6.51-7.5$  and  $>7.5\text{m}$  (Appendix 2b)

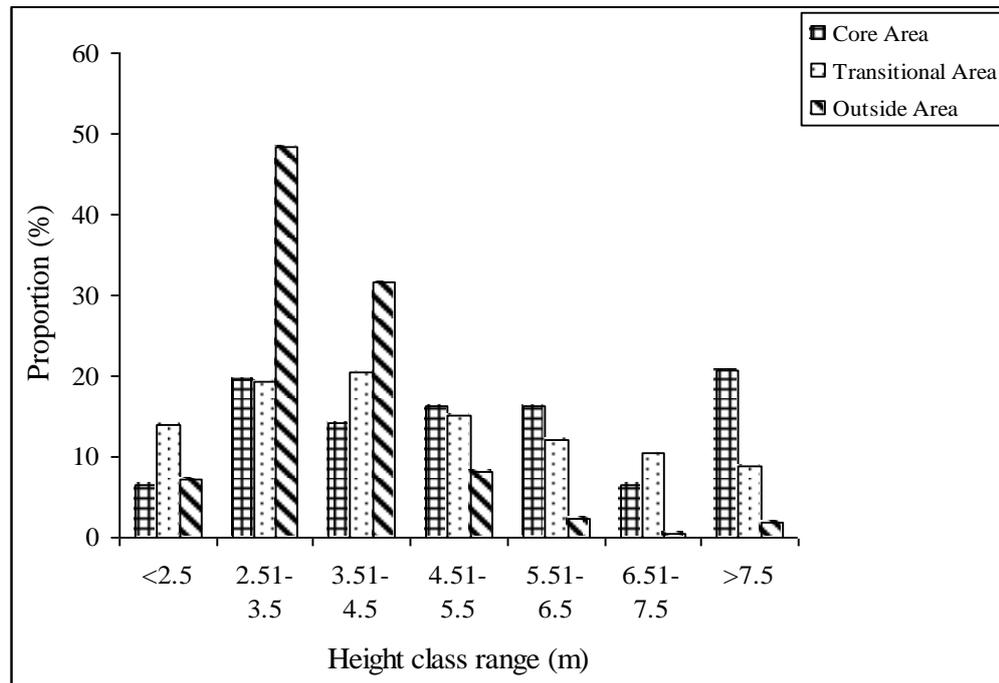


Figure 11: Comparisons of individual tree height frequency distribution patterns in the Kalahari woodlands of Salambala conservancy, northeast Namibia.

#### 4.5.2 Shrubs

The height of shrubs ranged from 0.9- 3.7m in the core area and from 0.3 – 2.8m in both the transitional area and the outside area. Height frequency distribution patterns indicated higher proportions of shrubs in the short to middle-height (<1-3.5m) shrubs than the taller (>3.5m) shrubs. There were no shrubs recorded for height classes 3.1-3.5m and >3.5m in the transitional and outside area and for class 2.6-3.0m in the core area. There were significant differences in height frequency distribution among the three sites ( $\chi^2 = 56.22$ ,  $df = 12$ ,  $p < 0.001$ ) (Figure 12). The core area showed much higher than expected shrubs in class 1.6-2.0m, the transitional area in class 1.1-1.5m. There were also much less than expected shrubs in the core area for classes <1 and 1.1-1.5m) and much less than expected shrubs in the transitional area for height class 2.1-2.5m (Appendix 2c).

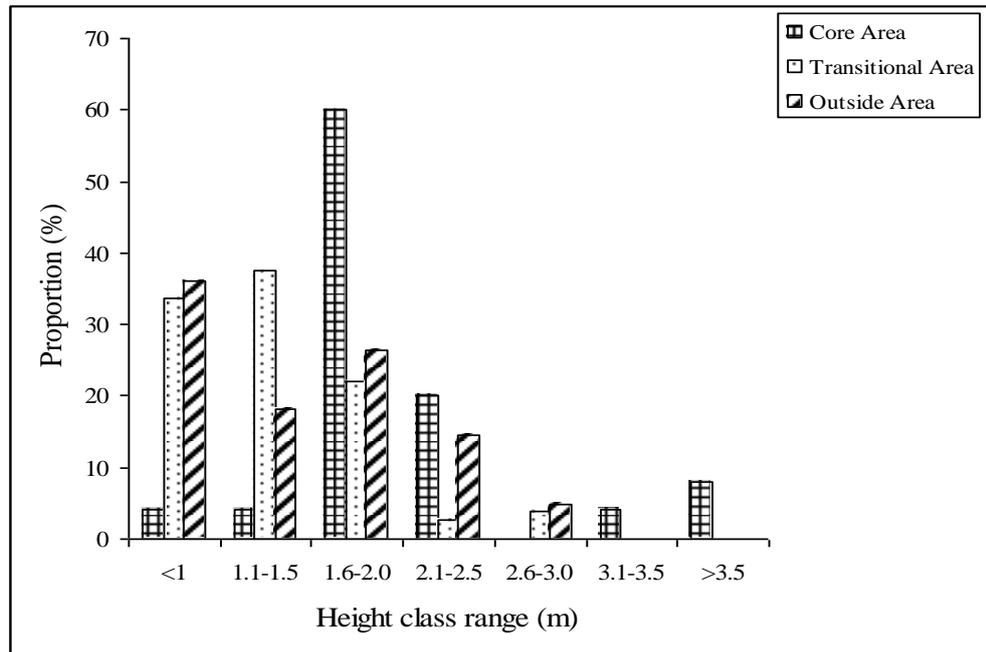


Figure 12: Comparisons of height frequency distribution patterns of shrubs at three sites in the Kalahari woodlands of the Salambala conservancy, northeast Namibia.

## 4.6 Cover

### 4.6.1 Woody cover

The woody cover ranged from 10.3% to 19.3% per plot in the core area; from 25.2% to 50.5% per plot in the transitional area and from 42.7% to 91.3% per plot in the outside area. Statistical comparisons revealed significant differences in mean woody cover among the three sites ( $H = 9.76$ ,  $p < 0.01$ ) (Figure 13). Mean woody cover was higher in the outside area than the core area and transitional area ( $p < 0.001$  in both cases) and higher in the transitional area than the core area ( $p < 0.001$ ).

#### 4.6.2 Grass Cover

The grass cover ranged from 45% to 60% per plot in the core area; from 0% to 20% per plot in the transitional area and from 0% to 35% in the outside area. There were significant differences in mean grass cover between the three sites ( $H = 16.4$ ,  $p < 0.001$  (Figure 13). The mean grass cover was higher in the core area than the transitional and outside areas ( $p < 0.001$  in both cases). There were, however, no significant differences in mean grass cover between the transitional and outside areas.

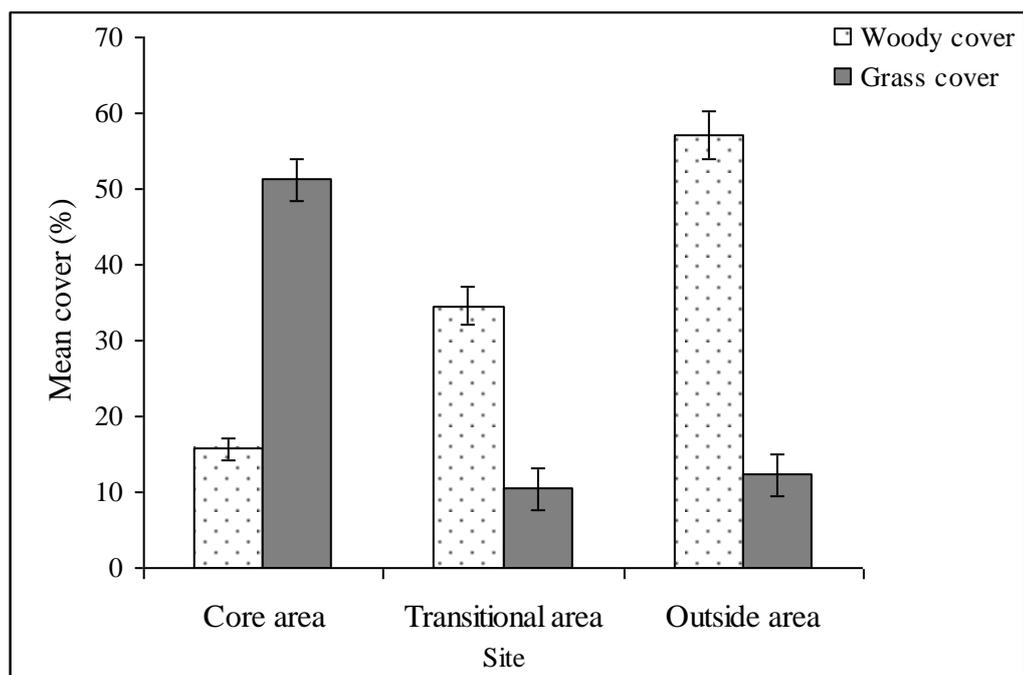
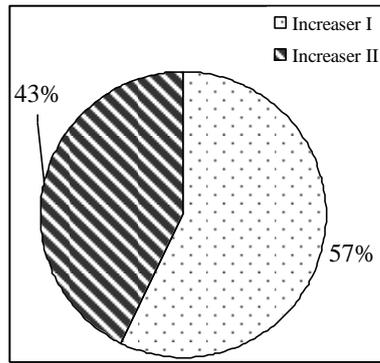


Figure 13: Variations in percentage woody and grass cover at three sites in the Kalahari woodlands of the Salambala conservancy, northeast Namibia. The bars represent standard error.

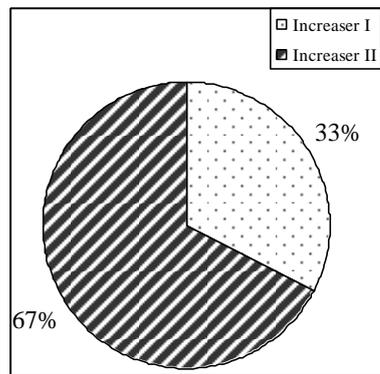
#### 4.7 Range condition

There were no decreaser grass species encountered through out the study area. The increaser I grass species encountered were *Aristida stipitata* and *Erogrostis pallens*, increaser II species found were *Pogonarthria fleckii*, *Dactyloctenium giganteum*, and *Perotis patens*. Statistical comparisons revealed significant differences in the frequencies of occurrence of increaser I and increaser II grass species among the three sites ( $\chi^2 = 6.956$ ,  $df = 2$ ,  $p < 0.05$ ) (Figures 14a-c). These differences are a result of less than expected increaser I species in the core area and the outside area and more than expected increaser II species in the outside area (Appendix 2d).

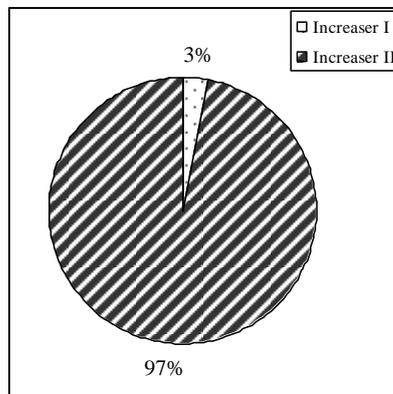
The rangeland in the core area was predominantly under-grazed (57%) given the high number of increaser I grass species, and 43% over-grazed (Figure 14a). The rangelands in the transitional and outside areas were clearly overgrazed, given the high occurrence of increaser II grass species in the two areas (Figure 14 b and c). Overgrazing thus accounted for 67% and 97% in the transitional area and outside areas respectively. The occurrence of increaser I grass species that represent under grazing accounted for 33% in the transitional area and only 3% in the outside area.



a) Core area



b) Transitional area



c) Outside area

Figure 14 a-c: Illustration of the range condition based on frequency of occurrence of increaser I and II grass species, in the Kalahari woodlands of the Salambala conservancy, northeast Namibia across the three sites.

## 4.8 Determinants of vegetation structure and species composition

### 4.7.1 Vegetation classification

The Hierarchical cluster analysis (HCA) separated the vegetation into three main floristic associations, with two sub-clusters under cluster 1 (Figure 15). Physiognomic classes follow Edwards (1983) and Mendelssohn and Roberts (1997). The three floristic associations are described below:

(a) *Combretum collinum* short dense woodland-thicket (Cluster I): The short *Combretum collinum* dominated woodland-thicket occurs mostly in the outside area plots. This woodland consists mainly of even-aged stands of *C. collinum* trees of up to 3.7m in height. Other common trees include *Combretum mossambicense*, *Combretum zeyheri*, *Terminalia sericea*, *Dichrostachys cinerea* and *Acacia erioloba*. The shrub layer is dominated by a thicket of *Markhamia obtusifolia*. Other common shrubs include *Ochna pulchra* and *Grewia retinervis*. The herbaceous layer is invariably poor and sparse both in structure and composition; mainly dominated by the weed *Bidens biternata* and the unpalatable perennial grass species *Dactyloctenium giganteum* and annuals grass species such as *Pogonarthria fleckii*. Other commonly occurring forbs include *Citrulus lanatus*, *Tephrosia lupinifolia* and *Vernonia poskeana*.

Cluster I was further sub-divided into two sub-clusters (1a and 1b) representing two sub-vegetation types. The tree layer in cluster 1a was mainly dominated by *C. collinum*, often with a co-dominance of other Combreteceae., such as *Combretum mossambicense*, *Combretum zeyheri* and *Terminalia sericea*. Most tree layer species

were also present in the shrub layer of this sub-cluster, with the addition of only *M. obtusifolia*. The herbaceous layer is mainly dominated by increaser II grass species *P. fleckii* and *D. giganteum* as well as the weed *B. biternata*.

Cluster 1b was also dominated by *C. collinum* in the tree layer, however with occasional occurrence of emergents such as *Erythrophleum africanum*, *Burkea africana* and *Guibortia coleosperma* associated mainly with the two transitional area plots (14 and 15). The shrub layer was co-dominated by *O. pulchra* and *M. obtusifolia*. The herbaceous layer in this sub-cluster although dominated by increaser II grass species *P. fleckii* and *D. giganteum* as well as the weed *B. biternata*, was also characterized by grass species such as *Tricholaena monachne* and *E. pallens* as well as forbs such as *Tephrosia lupinifolia* and *Vernonia poskeana*. Most plots associated with this sub-cluster were situated far from the settlements.

(b) *Combretum collinum-Terminalia sericea* tall-close woodland (Cluster II): This woodland occurs mainly in the transitional area, with two plots (plots 27 and 32) from the outside area. It is dominated by relatively tall, 5m and more *Combretum collinum* and *Terminalia sericea* trees. Other notable tree species in this cluster include *Erythrophleum africanum*, *Burkea africana*, *Guibortia coleosperma*, *Acacia erioloba*, *Commiphora angolensis*, *Philoneptera nelsii*, *Dichrostachys cinerea* and *Combretum zeyheri*. The shrub layer of this woodland is dominated by *M. obtusifolia* and *O. pulchra*, which are however sparsely distributed as compared to the thickets associated with the shrub layer in cluster 1. The height structure of the shrub *M. obtusifolia* differs from those associated with cluster 1, as the ones in this cluster are

much taller often reaching 2.5 meters compared to the mostly less than 1m *M. obtusifolia* shrubs found in cluster 1. Another notable difference in the shrub layer of this cluster compare to cluster 1 is the absence of the shrub *Grewia retinervis* from this cluster. The herbaceous layer is mainly dominated by annual grass species such as *Tricholaena monachne*, *Aristida stipitata*, *Perotis patens* and *Eragrostis pallens*. The most common forbs are *Hemizygia bracteosa*, *Vernonia poskeana* and *Citrulus lanatus*. Another notable feature of the herbaceous layer is the reduced occurrence of the weed *B. biternata* and the unpalatable perennial grass *D. giganteum*. Whereas in cluster 1, these two species occurred in all the plots constituting this cluster, in this cluster they only occurred in three plots (plots 12, 15 and 27).

(c) *Combretum collinum* mixed, tall, sparse woodland (Cluster III): This woodland is confined to plots from the core area and only one plot from the transitional area. The main distinguishable feature of this woodland is the sparse distribution of the trees across the landscape and the moderately developed herbaceous layer. The tree layer is dominated by *C. collinum* and a mixture of *T. sericea* and *Burkea africana*. Other notable trees include *Erythrophleum africanum*, *Amblygonocarpus andongensis*, *Commiphora angolensis*, *Acacia erioloba*, *Terminalia brachystemma* and *Albizia harveyi*. The shrub layer of this woodland is dominated by *Ochna pulchra* and *Grewia flavescens*. Other commonly occurring shrubs include *Markhamia obtusifolia*, *Ximenia caffra* and *Terminalia sericea*. The most dominant grass species was the woody perennial *Tricholaena monachne* and the annuals *Pogonarthria fleckii* and *Aristida stipitata*. Common herbs in this cluster include *Tephrosia lupinifolia*, *Euphorbia crotonoides*, *Vernonia poskeana* and *Citrulus lanatus*.

Rescaled distance cluster combine

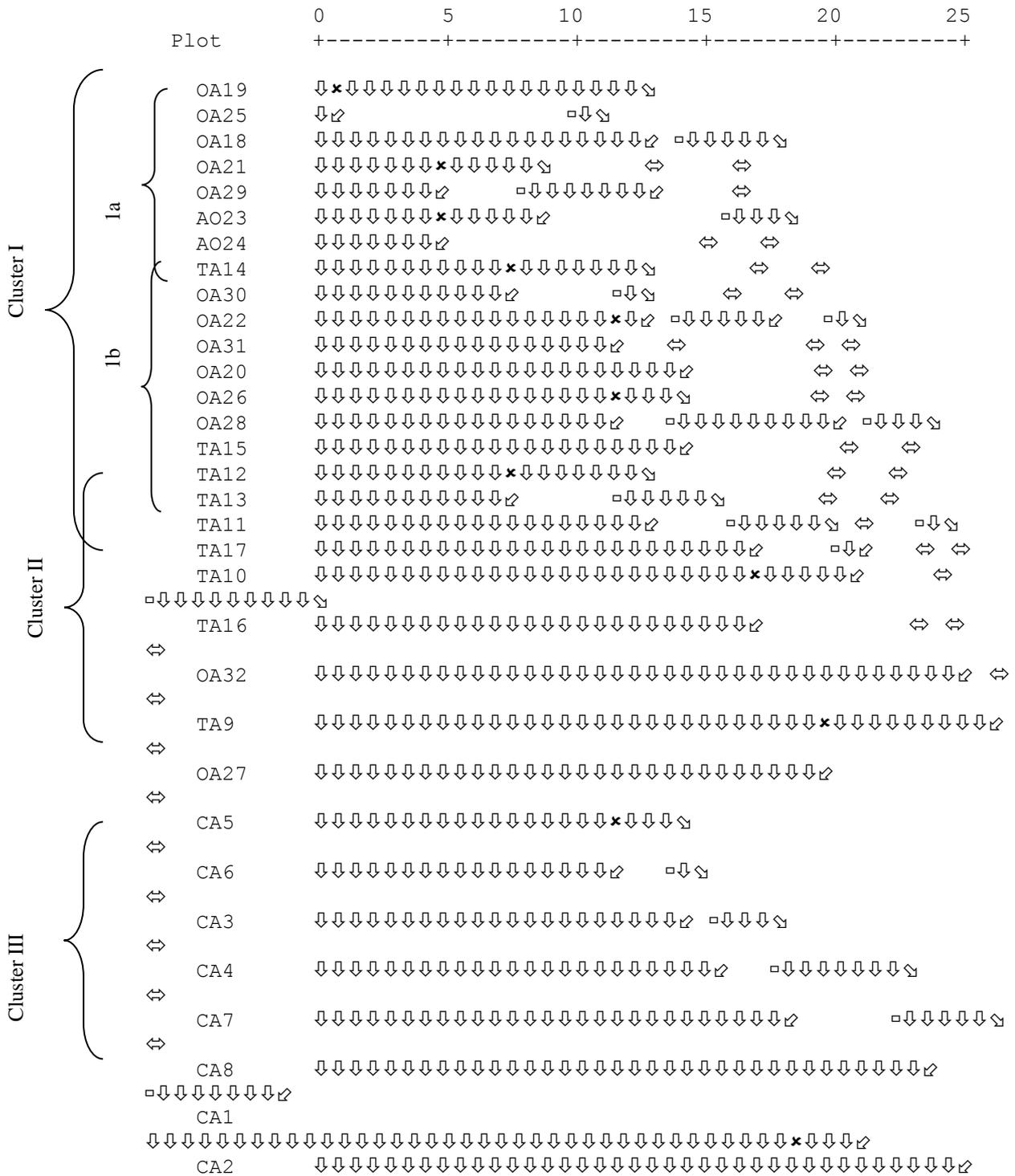


Figure 15: Hierarchical Cluster Analysis (HCA) dendrogram showing a classification of vegetation plots into 5 clusters based on species presence/absence data from the Kalahari woodlands of Salambala conservancy, northeast Namibia. (CA = core area plots); (TA = transitional area plots) and (OA = outside area plots)

#### 4.7.2 Ordination

The results of the DCA applied to the 32 plots and 39 species (Appendix 5), indicates that Axis 1 accounts for 44.3% of the variation in the vegetation, whereas Axes 2, 3, and 4 account for 19.2%, 13.9% and 7.6%, respectively. Groupings of plots using Axes 1 and 2 are shown in Figure 16. The DCA clearly separated the sparse woodland associated with the core area (group III) which represents a tall, sparse *Combretum collinum* mixed woodland, from I & II which represent two main Kalahari woodland sub-types dominated by *Combretum collinum* and *Terminalia sericea* species. There is a clear overlap between Groups I and II. There is a greater separation of the groups along Axis 1 than along Axis 2, with Axis 1 having a longer gradient (3.5 SD) compared to Axis 2 (2.5 SD). The gradient along Axis 1 is mainly associated with differences in land use intensity.

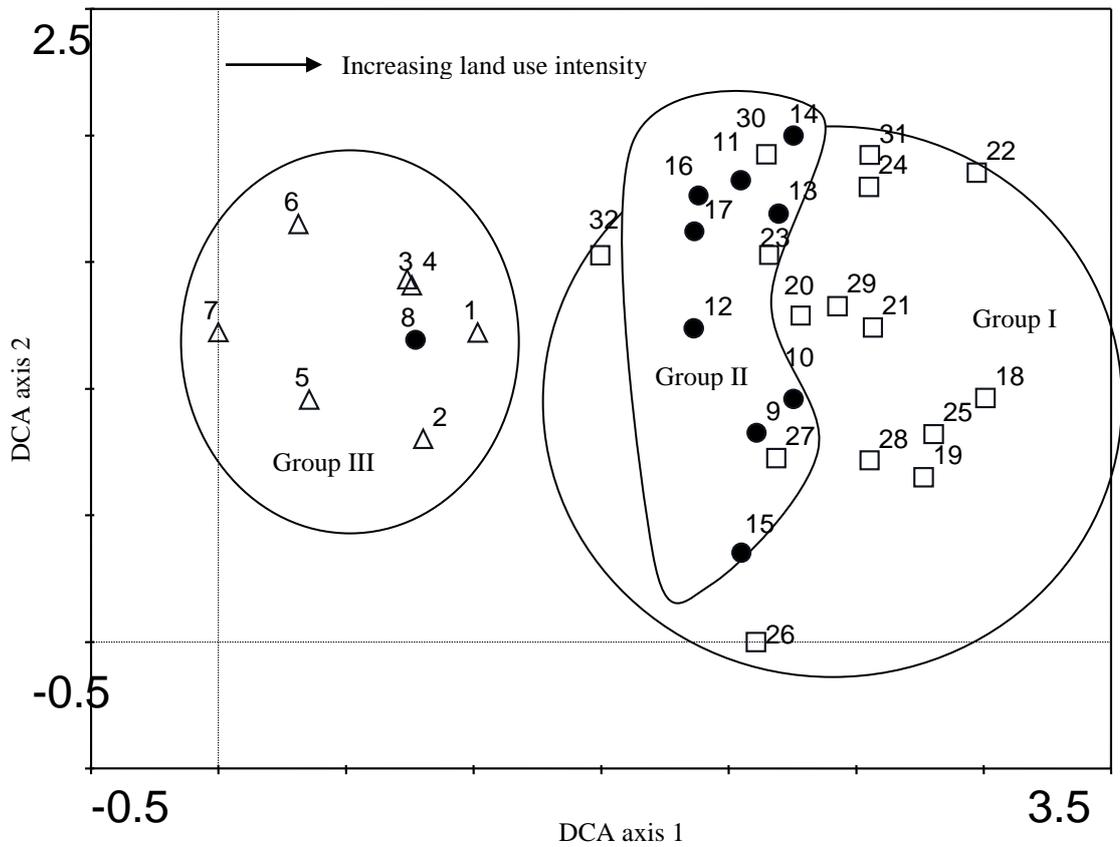


Figure 16: DCA ordination diagram showing the separation of vegetation plots into three main floristic groups relating to land use gradient in the Kalahari woodlands of the Salambala conservancy, northeast Namibia.  $\Delta$  = core area;  $\bullet$  = transitional area;  $\square$  = outside area.

## **CHAPTER 5: DISCUSSION**

### **5.1 Differences in species diversity, richness and composition**

The results reveal significantly high plant species diversity and richness in the core area than the outside area. The differences in plant species diversity and richness between the core area and the transitional area were, however, not supported statistically. The core wildlife management area, which is earmarked for tourism and wildlife re-introduction showed the highest species diversity and richness as evident from the relatively high Shannon Weiner diversity index and the number of species per plot. This concurs with the research hypothesis, which predicted high plant species diversity and richness in the less disturbed area, especially the core area as compared to the outside area.

The relatively high plant species diversity and richness in the core area and the transitional area can be explained by the types and intensities of land use. The land use in both these zones is limited to wildlife grazing and browsing. The land use types in the core area and the transitional area can therefore be equated to moderate levels of disturbances, because human-related activities such as livestock grazing, wood harvesting and cultivation which had been often linked to high levels of disturbance and hence high land use intensities (Leggett *et al.* 2002, Zeidler *et al.*

2005, Veach *et al.* 2003) are not practiced in these two zones. Many studies and literature have linked species diversity and richness to the general concept of disturbance (Beeby 1993, Fox 1985, Van Wyk and Midgley 1993, Mackey and Currie 2001, Walpole *et al.* 2004). It has been widely stated that species diversity and its measures such as richness and evenness should rise and then fall as disturbances rate increases, with maximum diversity occurring at intermediate levels of disturbances, a concept often referred to as the “intermediate-disturbance” hypothesis (Fox 1985, Mackey and Currie 2001). This hypothesis proposes that physical disturbances prevent competitively dominant species from excluding others from the community. Therefore at low levels of disturbance, diversity should be expected to be low because only the best competitors persist. Similarly, intense or frequent disturbances result in the persistence or repeated colonization of few species after every disturbance, resulting in low species diversity. Zeidler *et al.* (2002) associated higher plant species numbers to sites under low land-use intensity in western Namibia.

Therefore high plant species diversity and richness in these two areas can be explained by the “intermediate-disturbance” hypothesis. Furthermore, the proximity of the transitional area to the highly utilized outside area seemed to not have negatively affected the plant diversity and richness, hence the lack of statistical support in the differences in species diversity and richness between the two areas. However, the effects of the proximity of the transitional area to settlements and highly utilized areas appear to be manifested in species composition.

The commonly occurring species such as *C. collinum* and *T. sericea* were mixed with *E. africanum*, *G. coleosperma*, *A. erioloba*, *C. angolensis*, *B. africana*, and *D. cinerea* in the transitional area and with *B. africana*, *E. africanum*, *A. andongensis*, *A. erioloba*, *C. angolensis*, *T. brachystemma* and *A. harveyi* in the core area. The generally common occurring shrubs in the study area *M. obtusifolia* and *O. pulchra*, were mixed with *G. retinervis* in the transitional area and with *G. flavescens*, *X. caffra* and *T. sericea* in the core area. The differences in species composition between the core area and the transitional area appear to be more pronounced in the herbaceous layer. The herbaceous layer in the woodland associated with the transitional area is dominated by *D. giganteum*, *T. monachne*, *A. stipitata*, *P. patens*, *E. pallens*, *H. bracteosa*, *V. poskeana*, *C. lanatus* and the weed *B. biternata* (Holm 1977, Bromilow 2001), whereas the herbaceous layer in the woodland associated with the core area is dominated by *T. monachne*, *P. fleckii*, *A. stipitata*, *T. lupinifolia*, *E. crotonoides*, *V. poskeana* and *C. lanatus*.

It can therefore be argued that the activities in the outside area are having spill-over effects on species composition of the transitional area, especially on the ground layer vegetation. Since the differences in species composition is mainly pronounced in the herbaceous layer, this can be linked directly to grazing and browsing by livestock from the surrounding villages. This is consistent with several other studies that have found the effect of grazing and browsing by livestock to be more pronounced in species composition of especially the herbaceous layer (BIOTA 2003, Veach and other 2003, Cadotte *et al.* 2002). Mapaure (2001) stated that herbaceous and shrub layers are relatively unstable and more sensitive to disturbance events compared to

tree layers. Furthermore in their study on plant species diversity changes in an abandoned Chestnut (*Castanea sativa*) grove, Gondard *et al.* (2000) reported the highest rates of changes in the ground layer vegetation.

The relatively low plant species diversity and richness in the outside area is typical of highly disturbed areas. Removal of plants, through wood harvesting for construction and other household needs and land clearing for settlements and crop cultivation in the outside area can explain the low plant species diversity and richness. This finding is supported by Veach *et al.* (2003) who found that intense exploitation for firewood and timber severely reduced plant species diversity and richness. Over-grazing in the outside area, as evident from the high occurrence of increaser II grass species (Section 4.7) can also be linked to the low plant species diversity and richness. The removal of the herbaceous layer through overgrazing can result in the proliferation of certain plants, especially those that inhabit disturbed areas, thus reducing plant species diversity and richness. Overgrazing can also result in the reduction of the production and competitiveness of those plants that area mostly desired by grazing and browsing animals, thus negatively affecting the plant diversity and richness of an area.

This study also revealed that the woodland associated with the overgrazed outside area is mainly dominated by *C. collinum* (Section 4.7.1), further explaining the low species diversity and richness in the area. This is consistent with a number of other studies that have associated low species diversity and richness to intensive grazing. A study by Leggett *et al.* (2003) in the Hoanib River catchment in Namibia found low

vegetation abundance and diversity in Palmfontein, an area subjected to intensive grazing. Evans *et al.* (1997) reported that as grazing pressure increases, plant species diversity decreases and the areas became dominated by few karroid species resulting in the overall low species diversity.

Species composition in the outside area differed from that of the other two areas, especially the tree layer which was mainly dominated by Combretaceae species such as *C. collinum*, *T. sericea*, *C. zeyheri* and *C. englerii*. This outcome is quite the opposite of what was described above in terms of the ability of trees to tolerate disturbances. The species composition in the outside area appears to have been altered by some cutting activities, as most trees were of the same height and size, giving the woodland in this area an even-aged structural appearance. The species composition of the shrub layer was similar to that of the transitional area, although a thicket of *M. obtusifolia* dominated this layer, with *O. pulchra* and *G. retinervis* occurring in low abundance. Herbaceous species dominating in the outside area included the unpalatable woody perennial *D. giganteum* and the weed *B. biternata*. Other species include *C. lanatus* and *P.fleckii*.

The differences in species composition especially in the herbaceous layer among the three sites can chiefly be linked to overgrazing, which results in the proliferation of unpalatable grass species (Vetter 2005, Legget *et al.* 2003, Burke, 2006). Furthermore, the high occurrence of the weed *Bidens biternata* in the outside area and to some extent in the transitional area is indicative of disturbance and over exploitation of the vegetation. According to Walter *et al.* (1990) weeds can occupy niches created by reduced plant cover and perhaps reduced root mass of perennial

species. Furthermore, the increasing dominance of *M. obtusifolia* in the transitional area and the outside area, a shrub that is known to easily colonise disturbed areas (Curtis and Mannheimer, 2005) can be attributed to increasing land use intensities from the core area through to the transitional area and the outside area.

A common trend that emerged in terms of species composition is the decreasing frequency of occurrence of important Kalahari woodland trees such as *E. africanum* and *B. africana* with increasing land use intensity. This indicates over harvesting of these species, as their timber makes good, straight and strong poles and will thus be preferred for construction material by the community. There is therefore indication of the effect of land use on species composition, as some land use types such as wood harvesting and land clearing for settlements and cultivation can alter species composition. These types of changes in species composition especially the reduced dominance of common species not only negatively affects biodiversity, but could also have serious implications on current localized vegetation classifications, which might need to be determined to accommodate the changes in species composition brought along by different land use types.

## **5.2 Differences in vegetation structure**

There were significant differences in individual tree and stem densities among the three sites, with the transitional area showing the highest individual tree density and the outside area the highest stem density. There were significant differences between individual shrub and stem densities among the sites. The shrubs in the core area had significantly more stems than the transitional and outside areas. The differences in individual shrubs and stem densities as well as forb density among the three sites

were however not supported statistically. The results further revealed significant differences in total basal area among the sites, with the transitional area having the highest total basal area than the core and outside areas. This is refuting the research hypothesis that envisaged tree density (individuals and stems) and tree size (basal area) to be higher in the core area than both the outside and transitional area.

The low tree density in the core area, an area which is protected from wood harvesting, is not supported by most studies done on vegetation structure and disturbance in Africa and elsewhere. For example, Sekhwela (2003) linked increasing tree density to increasing distance away from settlements in Botswana. Another study by Ramirez-Marcial *et al.* (2000) in Chiapas, Mexico, reported an increase in absolute tree density with decreasing disturbance intensities. Although land use alone could not explain the differences in population densities and structure in a study carried out by Neke (2002) in South African savanna, there were however clearly lower tree and stem densities in the communal area compared to the protected area.

The relatively small sample size in the core area due to the size of Kalahari woodlands in this particular area and which was alluded to earlier in the methods, could be one possible explanation of the low tree density. Nevertheless, most trees in this area were big and mostly single-stemmed, which can also be linked to low tree density. The structure of the woodland associated with the core area seems to be typical of savanna woodlands where big trees are found scattered across a landscape allowing a healthy herbaceous cover (Figure 18a). Furthermore, the Kalahari

woodlands fall under the broad-leaved woodland savanna, which are characterized by moderately tall trees (Mendelssohn *et al.* 2002) with spacing of the trees equal to more than the diameter of the canopy (Archibald 1995).

Another possible explanation of the low tree density in the core area is poor regeneration and recruitment mainly as a result of the dense ground layer (Section 4.6.2). According to Scholes and Archer (1997), an increase in grasses may regulate woody plant recruitment mainly through competition for light, water and nutrients. Davis *et al.* (1999) also reported poor establishment of woody seedlings to be limited or entirely prevented as a result of competition with herbaceous vegetation for soil water, especially at the young seedling stage. Water might not be necessarily a limiting factor in Caprivi given its relatively tropical climate; but the poor water holding capacity of Kalahari sands (Scholes and Archer 1997; Mendelssohn *et al.* 2002) could limit the availability of water in the topsoil, thus increase competition for surface soil moisture between tree seedlings and ground layer vegetation. It should however be born in mind that the conservancy is relatively young (10 years since its establishment in 1995), therefore effects of past land use such as wood harvesting can also explain the low tree density in the now well protected core area.

The significantly high tree density in the transitional area is indicative of high regeneration and recruitment, which can be linked to the moderate levels of disturbances. This is further evident from the significantly high proportion of small trees in the transitional area compared to the other two areas. The relatively high stem density indicates some previous and/ or present cutting activities (Dembélé *et al.* 2006, Sekhwela 2003). The multi-stemmed nature of most trees in the transitional

thus points out two major issues. Firstly, the trees are showing signs of over harvesting from the nearby villages, during current land use practice. Secondly, the trees seem to have not recovered properly from these past over cutting effects associated with the previous land use practice.

The high stem density (1975 stems/ha) in relation to individual tree density ( 475 trees/ha) in the outside area is a direct indication of the effect of land use types such as wood cutting, land clearance for cultivation and grazing and browsing pressures. Tree cutting can reduce the number of trees, thus explaining the low tree density. The high stem density relative to individual tree densities is an indication of coppicing. That is after being cut, the trees are re-growing either from stumps or adopt a multi-stemmed strategy, to compensate for repeated cuttings (Chamberlin and Aarssen, 1996). According to Zolho (2005) vegetative reproduction through sprouting and coppicing are common, probably as adaptations to frequent fires, cutting, drought and herbivory by elephants. Despite the high occurrence of fires in the Caprivi region (NRSC, 2003/2004), fires have been reduced dramatically in the Salambala conservancy since its establishment (Siyambango<sup>1</sup>, *pers. comm.*). Therefore, it can be argued that the vegetation in the area is reacting to repeated cutting and herbivory.

Although high tree density has been extensively associated with decreasing land use intensity as alluded to earlier, according to Sekhwela (2003) bush density was high near human settlements. Furthermore, in their study on the patterns of vegetation along human disturbance gradient in the Sahelian area of Mali, Dembélé *et al.* (2006)

associated high numbers of sprouts or stem per stump to over-cutting of trees and shrubs. According to Sheuyange (2002) areas around settlements in northern Namibia had on average 62% bush density compared to areas situated far from villages. Another study by Banda *et al.* (2006) that compared woody vegetation structure and composition along a protection gradient in Zimbabwe, found mean tree stems density to increase with decreasing protection. Therefore, the consequent effect of land use practices such as wood harvesting is not only a reduction in individual tree density, but repeated cutting can lead to increased stem densities. High stem densities often results into the thickening of vegetation, which in turn can negatively affect stand productivity and hence threaten biodiversity and human well-being.

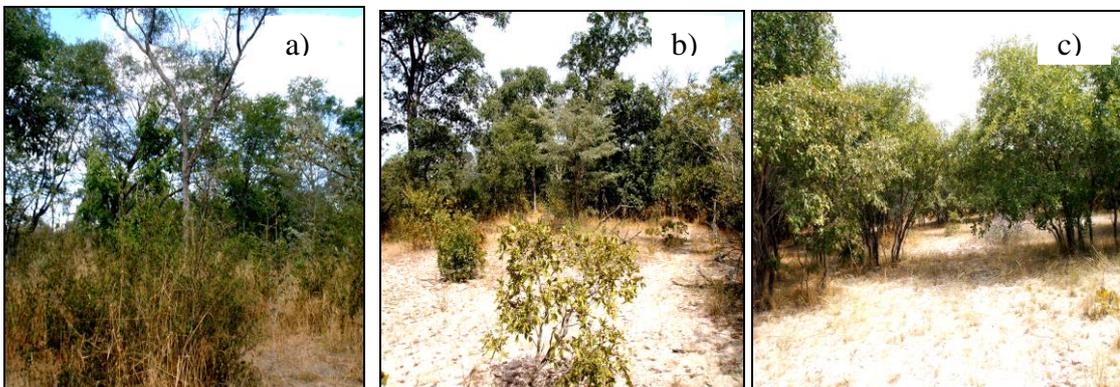


Figure 18a-c: Illustration of the appearance of vegetation in the core area (a); transitional area (b) and outside area (c) of the Kalahari woodland of Salambala Conservancy, northeast Namibia.

The significantly higher total basal area in the transitional area can be expected because of high tree density. Since basal area is seen as a good estimate of the growing stock (Geldenhuys and Venter 2002), the high basal area in this zone

---

<sup>1</sup> Florence Siyambango, Salambala Conservancy Resource Monitor, interviewed on 18<sup>th</sup> April 2006

coupled with the high proportion of small trees is therefore indicative of a healthy growing population. Ramirez-Marcial *et al.* (2003) found that mean total basal area of *Pinus* spp. was highest at intermediate disturbed sites and low in well preserved old-growth stands. Furthermore, although most trees in the transitional area were small (85% in the  $\leq 70.99 \text{ cm}^2$ ), the proportion of big trees ( $\geq 491 \text{ cm}^2$ ) was equal to that of the core area (Figure 10). Therefore the relatively high proportion of big trees coupled with the high tree density in this area could explain the high total basal area. According to Kadaval and Parthasarathy (1999) denser and voluminous stands are linked to minimal to moderate resource extraction, which is a characteristic of the land use type in the transitional area.

Although the outside area has a high stem density, most trees were small and multi-stemmed hence the low total basal area. Since most trees in the outside area are re-sprouting and coppicing, due to the high levels of disturbances such as cutting and land clearing, the stems are small, which can also explain the low basal area. Low basal area in the outside area can also be attributed to low biomass production due firstly to physical damage to the vegetation (e.g. trampling and rubbing) (Kaufmann and Krueger 1984, Legget *et al.* 2002, 2003); and reduction in the ground layer cover, which can be detrimental to regeneration and recruitment.

The low total basal area in the relatively undisturbed (core area) is however in contrast with findings of a number of studies, which have linked low total basal area to increasing disturbance intensities (Ramirez-Marcial *et al.* 2003, Banda *et al.* 2006, Neke 2000). Kadaval and Parthasarathy (1999) found forest stands that area situated

away from human habitation to be denser and voluminous. One plausible explanation of the low basal area in the core area could be a relatively low sampling size (92 trees compare to 256 and 209 trees in transitional area and outside area respectively), as the trees in this area are sparsely distributed (low tree density) and hence fewer trees could be enumerated per hectare compared to the other two areas. Past land use types such as wood harvesting can also explain the significantly low total basal area in the core area, as it appears that the forest stand has not really recovered, judging from the lack of a well established middle layer.

There were significant differences in basal areas and height frequency distribution patterns among the three sites. There were few small-sized trees ( $\leq 70.99 \text{ cm}^2$ ) and more middle-sized trees in the core area. However, the proportion of big trees ( $\geq 491 \text{ cm}^2$ ) was relatively high (18%) compared to 30% proportion of small trees. The transitional area is characterized by a high proportion of smaller trees as evident from the 'inverse J'-shaped basal area distribution pattern (Figure 10), which characterizes stands with abundant and constant rejuvenation (Brown and Bredenkamp, Lykke 1998). Most of the trees in the outside area (>50%) were in the middle-size class ranges (71-140  $\text{cm}^2$ ; 141-210.99  $\text{cm}^2$  and 211-280.99  $\text{cm}^2$ ). These findings do not strictly concur with the research hypothesis as tree size was envisaged to increase with low disturbances such as those associated with the core area.

The lower frequency of individuals within the small basal area classes in the core area could be a possible indicative of low recruitment (Neke 2002, Brown and Bredenkamp, 2004). The possibility of low recruitment in the core area can not be

ruled out as the area is characterized by a dense herbaceous layer which in turn could hinder seedling development (Smit *et al.* 1996, Parsons *et al.* 1997, Davis *et al.* 1999, Scholes and Archer 1997). The size class distribution pattern in the transitional area is indicative of regular recruitment (Neke 2000, Beeby 1993, Condit *et al.* 1998, Lykke 1998). According to Kadaval and Parthasarathy (1999) a high number of trees in the lower girth size classes show that the stand harbours a growing and healthy population. The fact that the land use in the transitional area is of intermediate level (protection status accorded by management coupled with activities from the outside area) can explain the relatively healthy growing population associated with it. Moreover, a number of theories, including the “intermediate-disturbance” hypothesis and studies have concluded that moderate levels of disturbance regimes are favourable to vegetation structure, diversity and its measurements.

The vegetation in the outside area appears more like even-aged stands (> 50% of trees of middle size) with mostly multi-stemmed trees and poor vertical stratification, which can clearly be associated with over-exploitation. Most trees especially the dominant *C. collinum* were re-sprouting from stumps, clearly indicating previous cutting activities. Furthermore, excessive grazing pressure, such as that in the outside area can prevent the establishment of seedlings, thus producing an even-aged non-reproducing vegetative community, similar to the one associated with the outside area (Hiernaux 1998, Kaufmann and Krueger 1984).

The trees in the core area were significantly taller than those in the transitional and outside area, as evident from the high proportion (22%) of trees reaching a height of

more than 7.5 meters. The proportion of tall trees in the transitional area and outside area was 9.8% and 0.5% respectively. The shrubs in the core area were taller than the other two sites, evident from a high proportion of shrubs in the middle-height class. Furthermore, only the core area has shrubs in the 3.1-3.5m and > 3.5m classes (Figure 12). This is consistent with the hypothesis of the study, which predicted trees in the core area to be taller than those of the other two sites.

The height class distribution in the core area seemed to be almost similar to that of size class distribution, with few proportions of small trees corresponding to the low proportion of short trees. The high proportion of tall trees and shrubs in the core area clearly indicates the absence of cuttings and to reduced competition due to their low density (Beeby, 1993). The height class distribution patterns of trees in the transitional area is again a testimony of a healthy growing stock, evident from the reasonable representation of trees in all height classes (Curtis and Mannheimer, 2005). Human related activities, such as harvesting and browsing from the outside area seem to have contributed to the high proportion of short shrubs in the transitional area, as evident from nearly similar proportions of shrubs which are <1m in height. The height class distribution patterns of trees in the outside area clearly indicate that the trees are recovering from previous exploitation, especially when the area was still under communal management. It also appears that the vertical growth of trees has been stunted by repeated cuttings and browsing pressures (Smit *et al.* 1996, Omeja *et al.* 2004).

The total woody and grass cover differed significantly among the sites. In terms of woody cover, the outside area showed the highest woody cover, followed by the transitional area, whilst the core area rather unexpectedly has the lowest woody cover. The trend was however reversed in the case of grass cover, which was higher in the core area and did not differ statistically between the transitional area and the outside area. The research hypothesis in this case is rejected as quite the opposite was predicted, with the core area expected to show high woody and grass cover, the transitional area to show similar trends to the core area and finally the outside area to have both low woody and grass cover. The low grass cover in the outside area was however supported by the research findings.

The low woody cover and high grass cover in the core area and the reverse in the outside area appear to be linked to the number of stems per hectare, although no strong correlation could be found. The core area which was characterized by low tree density, supports significantly high grass cover (Figure 18 a) and the outside area on the other hand which showed significantly high stem density, is characterized by significantly low grass cover (Figure 18b). Another point to make is that the vegetation in the outside area was so dense that, in some cases the canopies formed a continuous overlap on the tape that was used to measure the woody cover.

The trends in woody and grass cover in the core area and outside area fit in well with Walter's two layer hypothesis, which states that grasses typically out compete trees in open savanna by growing fast and intercepting moisture from the upper soil layer thus preventing trees from gaining access to precipitation in the lower soil where

their roots area are mostly found (Walter 1971). Furthermore, Van Vegten (1983) identified overgrazing of grasses as the main cause of woody plant increase in the savanna areas of eastern Botswana. Increased woody plant cover was reported to decrease herbaceous cover and productivity in a semi-arid lowveld of South-Africa (Parsons *et al.* 1997). Although, bush encroachment is not yet a major problem in eastern Caprivi (De Klerk 2004) the high density of short multi-stemmed trees in the outside area, 1975 woody stems per hectare coupled with low grass cover could be a sign of bush encroachment. A number of encroaching tree species were encountered such as *T. sericea* and *D. cinerea*. The latter was more abundant in the outside area than the other two areas. The encroaching *D. cinerea* was mainly found along the road or at the edge of settlements, indicating its invading habits. Kadavul and Parthasarathy (1999) associated dense growth of *Lantana camara* in the forest interior and on the edge of forest stand to past disturbance events.

Despite the compliance of this study and other studies with the two-layer theory, several field data and theoretical models have produced conflicting evidence. Hipondoka *et al.* (2003) for example concluded that where water table is too low for tree root tapping, such as on Kalahari sands, (Archibold, 1995 Beeby 1993), both trees and grasses tend to invest the bulk of their roots in the surface horizons. This therefore implies that, where water table is too low, trees do not effectively utilize underground water as the bulk of their roots are near the surface. Moreover, in recent quests to find out about the causes of bush encroachment, several models and experiments have been deduced to try and move away from what Ward (2000) called the 'single-factor' explanation of the causes of bush density. However, given the

scope of this study it is only fair to relate low grass cover in the outside area to increase woody cover, which in turn can be linked to overgrazing. It should further be borne in mind that further investigations of the type of trees and shrubs contributing to the increased in woody cover are essential in order to relate increased woody cover to decreased grass cover. Parsons *et al.* (1997) for example identified the increase in shallow rooted *Acacia mellifera* and *Grewia flava* in the semi-arid lowveld of South Africa to have resulted from overgrazing of the grass layer.

The proximity of the transitional area to the outside area again appears to have affected the vegetation in this zone, evident from the relatively low grass cover. Increased pressure from grazing by livestock might have contributed to the low grass cover, as livestock could be seen grazing freely or herded in the transitional area during the duration of the study as some sections of the fence between the two zones were broken and lying on the ground (*pers. obs*). Figure 18(b) illustrates the appearance of vegetation in the transitional area. The canopies of tall and emergent trees were almost overlapping compared to those in the core area and the shrub layer was relatively dense. The bare ground patches due perhaps to some degree of overgrazing are clearly visible, hence the low grass cover in this area.

### **5.3 Range Condition**

The condition of the range differed significantly among the three sites representing the different land use types. The range condition appears to deteriorate with increasing land use intensity from the core area through to the outside area. The rangeland of core area is predominantly under-grazed, while the rangelands of the

transitional area and outside area are overgrazed, evident from the high occurrence of increaser II grass species. This is consistent with the research hypothesis, which predicated range condition to deteriorate with increasing land use intensities.

The condition of the range in the core area can be explained by two main factors. Firstly, the area harbours a dense herbaceous cover (measured by grass cover), which this study linked to the low tree density, explained by Walter's two-layer model. In itself high herbaceous cover, especially grass cover has been linked to under utilization of the range (Legget *et al.* 2002, Metzger *et al.* 2004, Burke, 2006). Therefore, the second factor which can be linked to the condition of the range in the core area is the fact that the range is utilized by a wide variety of wild herbivores. This multi-species utilization of the range thus enables grazing heterogeneity, compared to fewer species of livestock in the over-grazed outside area.

The range condition in the transitional area appears to show some degree of deterioration, as evident from the increasing occurrence of increaser II grass species such as *D. giganteum* in comparison to the core area. This can be explained by the proximity of the transitional area to the settlements, which means that although the core and transitional areas receive the same protection status, grazing pressure is higher in the latter. Furthermore, the difference in grass cover between the transitional area and the outside area was not supported statistically, therefore it can be argued that the range condition in the transitional area could approach that of the outside area, that is could suffer from overgrazing, in the absence of any management interventions.

The poor condition of the range in the outside area was expected also as evident from significantly low grass cover and can clearly be linked to grazing and browsing pressures, from livestock and also wildlife. The high occurrence of unpalatable grass species such as *D. giganteum* and *E. pallens* and the dominance of the herbaceous layer by the weed *B. biternata* are further indications of the state of the range in the outside area. The high occurrence of weeds is common in overgrazed rangelands, as a result of increased grazing and browsing pressure can open up the vegetation and create niches in which weeds can establish (Loucourgarg *et al.* 2004, Kaufmann and Krueger 1984, Hiernaux 1998). It has been extensively reported that overgrazing chiefly by livestock results in high dominance of the rangeland by unpalatable grasses and weeds (Vetter 2005, Zhang 1998, Legget *et al.* 2003, Ziedler *et al.* 2002, Mapaure 2001). Furthermore, the high densities of *C. collinum* and *M. obtusifolia* are likely to reduce the carrying capacity and prevent or inhibit the establishment of forage species. The fact that there were no decreaser species encountered in any of the three sites could mean that the range condition is generally being overgrazed. However, most grasses associated with the Kalahari woodlands are annuals and of poor quality and the perennials are generally woody and unpalatable (Mendelssohn and Roberts 1997).

The evolutionary relationship between grazing and semi-arid ecosystems has been demonstrated in several studies and conclusions have been drawn to suggest that semi arid ecosystems tend to show resilience to grazing pressures (Metzger 2005, Evans 1997, Sala 1988, Petit *et al.* 1995). However, heavy grazing has been linked to

the reduction of above ground biomass and to degraded rangelands (Sisay and Baars 2002, Metzger *et al.* 2005). Therefore there seems to be mixed opinions among scholars regarding the relationship between grazing and the condition of the range in general. However, one clear sentiment is that increasing grazing pressure is detrimental especially to semi-arid rangelands. This study demonstrated just that as the range in the outside area, which is under intensive grazing, is in a poor condition as judged from the high proportions of increaser II grass species. The increase in unpalatable grass species often referred to as invaders (Sisay and Baars 2002) can lead to the decrease in the condition of that specific range (Trollope *et al.* 2000, Walter *et al.* 1990).

#### **5.4 Determinants of vegetation structure and species composition**

The classification and ordination using the hierarchical cluster analysis and detrended correspondence analysis, respectively, differentiated between two major structural types, woodland-thicket and woodland. The woodlands were associated with the core and transitional areas, while the woodland thicket was associated with the outside area. The three floristic associations (*Combretum collinum* woodland thicket, *Combretum collinum- Terminalia sericea* dense woodland and the *Combretum collinum* mixed, tall, sparse woodland) appear to be derivatives of two main sub-vegetation units of the Kalahari woodlands, the *Burkea-Terminalia* and *Burkea- Combretum* woodland, despite the increased dominance of *C. collinum* and low numbers of *B. africana* recorded during this study. All three floristic associations

were clearly dominated by Combretaceae, with *Combretum collinum* and *T. sericea* being the most dominant species across all three sub-vegetation types.

There is clear evidence of the influence of the different land use types on vegetation structure and composition, as the vegetation appear to be changing from woodland to woodland thicket in the core area through to the transitional and outside areas. The woodland thicket (cluster D), which is associated with the highly utilized outside area, is mainly dominated by *C. collinum* with common Kalahari woodland species such as *E. africanum* and *B. africana* occurring only as emergents. The shrub layer of this woodland thicket was also quite homogeneous in terms of composition, with the dominance of the shrub *M. obtusifolia*. The dominance of the weed *B. biternata* and unpalatable grasses such *D. giganteum* in the herbaceous layer of the woodland thicket is indicative of the effect of the land use types (mainly livestock grazing, land clearance for crop cultivation and wood harvesting) in the outside area. According to Mapaire (2001) the prevalence of weeds including *B. biternata* indicated some degrees of localized degradations linked to management practices. The pressure on the vegetation in the outside area representing the broader conservancy could be exacerbated by the presence of wildlife such as elephants and buffaloes, which move freely around the conservancy despite the fence (Siyambango 2006). Furthermore, a tendency towards an increase in unpalatable grass species has been linked extensively to high land use intensities, particularly high grazing intensities and land clearance (Legget *et al.* 2003, Zapfack *et al.* 2002, Veach *et al.* 2003, Straede *et al.* 2002).

The *Combretum collinum-Terminalia sericea* woodland (Cluster II) and the *Combretum collinum* mixed woodland (Cluster III) associated mainly with the transitional area and the core area respectively were relatively similar in species composition especially the tree layer, which is different from the species composition in the outside area. Equally, species composition in the shrub layers of these two areas did not differ substantially, except the increasing dominance of *M. obtusifolia* in the transitional area, which was only represented by one plant in the core area. The herbaceous layers of the two areas however differed significantly, which could have resulted in the separation of the sites by the classification method. Furthermore, the grass species *D. giganteum* and the weed *B. biternata* mainly dominated the herbaceous layers in the transitional and outside areas, but were minimal in the core area. Therefore, the land use in the transitional area, mainly increasing grazing and browsing by livestock has impacted negatively on the vegetation as evident from changes in species composition of the herbaceous layers. This can on the one hand be attributed to the proximity of the transitional area to the highly utilized outside area and on the other hand to past grazing and browsing pressures. That is, when the conservancy was still under pure communal land management. The increasing dominance of *M. obtusifolia* in the transitional area could be indicative of changes in species composition of the shrub layer. As shrub and herbaceous layers have generally been reported to be more prone to disturbance events in comparison to trees (Gondard *et al.* 2000, Mapaure 2001), changes in their species composition and structure can serve as good indicators of some stress in the system.

Most of the variation in the vegetation is explained along the first DCA ordination axis (44.3%) which is largely associated with increasing land use intensity. Like with the classification method the woodland associated with the core area (group III) is clearly classified separately from the *Combretum collinum* woodland thicket (group I) and the *Combretum collinum-Terminalia sericea* woodland (group II), which are showing considerable overlaps. The separation between two extreme plots (plots 7 and 22) along the first axis is 3.5 SD units. Plot 7 was situated in the core area and plot 22 in the outside area, further indicating the association of the variation along the first axis with increasing land use intensity. The 3.5 SD units represent less than 50% species turnover. Although the results reveal some differences in species composition, the fact that there is a less than 50% species turn over means that the vegetation in the core area for example have not recovered from effects of the past land use.

It appears that the different land use types in the Salambala conservancy are having an influence on both species composition and vegetation structure, with a change from sparse tall woodlands to woodland thickets dominated by Combretaceae species. The rate of conversion is high in the outside area where big trees have disappeared especially around settlements and near previously cultivated areas and in turn have given way to dense or rather thickety woodlands. Furthermore, the different land use types appear to have altered the dominance of common Kalahari woodland species especially *B. africana*, whose frequency of occurrence decreased with increasing land use intensity, most especially in the outside area. The effects of the past land use in the area are still evident, most especially in the herbaceous layer vegetation of the

transitional area, which shows closer similarities in composition to those in the outside area.

## **CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS**

### **6.1 Conclusions**

The main objective of this study was to determine the influence of different land use types on plant species diversity, composition and vegetation structure in the Kalahari woodlands of the Salambala conservancy in eastern Caprivi Region. The study shows that the different land use types, represented by the core, transitional and outside areas do have an influence on the different parameters studied. The least disturbed areas (core and transitional) showed the highest species diversity compared to the highly impacted outside area, which has the lowest species diversity and richness. In terms of species composition, the influence of land use was much pronounced in the herbaceous layer. This was clearly evident from species composition of the herbaceous layer in the core area, which was different from that of the transitional area and outside areas. However, the herbaceous layers of the transitional area and outside area were mainly dominated by *D. giganteum* and *B. biternata*. The former has been used extensively as an indicator of poor range condition and has been classified as increaser II grass species; whilst the latter has been extensively linked to degraded landscapes.

It can therefore be concluded, in this regard, that the types of land use in the outside area, chiefly grazing and browsing by livestock, wood harvesting and land clearance for cultivation, are negatively affecting the vegetation and these effects are spilling over to the edges of the protected core area (represented by the transitional area in this study).

Most structural attributes used to elucidate the effect of land use on vegetation differed significantly among the three sites. These include tree density (individuals and stems), woody and grass cover, total basal area, basal area and height class distribution patterns. The only structural attributes that were not significantly different among the three sites were shrub (individuals and stems) and forb densities.

The trees in the core area are significantly tall, big, predominantly single-stemmed and sparsely distributed across the landscape, which contributed to low tree density (individuals and stems) and woody cover. The herbaceous layer is thick, as evident from significantly high grass cover. The low tree density and woody cover in the core area which was rather not expected and also not supported by most studies can be attributed to poor germination and consequently poor recruitment as well as to observed elephant damage to the vegetation. Furthermore, the low woody cover and high grass cover in this area fits well with Walter's two-layer model, which has been and is still used extensively to explain the woody to herbaceous layer ratio in most savanna ecosystems, despite its recent criticisms, by Hipondoka *et al.* 2003 and Ward (2000).

The transitional area was characterized by relatively high numbers of trees per hectare, multi-stemmed trees, intermediate woody cover, significantly low grass cover and a high proportion of small trees (inverse J-shaped size class distribution pattern). In terms of height, the trees were represented well in all height classes, although not evenly, while a high proportion of shrubs were of middle height. The low grass cover and increasing multi-stemmed nature of the trees in the transitional area can be seen as one of the major indications of the effect of its proximity to the outside area and the consequent effects of increase land use intensities. The low grass cover is an indication of increased grazing and browsing pressure from livestock and relatively high numbers of multi-stemmed trees compared to the core area are linked to human activities mainly illegal wood harvesting, as no wood harvesting is allowed in this area. Moreover, the range condition of the transitional area is showing some degrees of deterioration, evident from increasing occurrence of increaser II grass species. The trees in the outside area on the other hand were significantly shorter, multi-stemmed, predominantly of middle size and occurred in dense thickets. This area was further characterized by high woody cover as a result of high stem density and a significantly low grass cover.

Based on these findings, it can be concluded that the vegetation in the broader conservancy (represented by outside area) is being negatively impacted by human activities. There is clear evidence of overgrazing in the outside area (significantly low grass cover and high occurrence of increaser II grass species). Wood harvesting

and land clearing for cultivation clearly altered the structure of the vegetation in the outside area and could lead to bush thickening, which is a threat to biodiversity. The relatively low plant species diversity recorded during this study in the outside area demonstrates the overall negative impact of anthropogenic activities on the vegetation structure and biodiversity of woodland ecosystems. It can also be concluded that the vegetation in the Salambala conservancy has not fully recovered from effects of past land use types, as evident from the vegetation structural attributes such as density, total basal areas, basal area and height frequency distributions. This study has clearly demonstrated the negative effects of different land use types on species diversity, richness and vegetation structure, especially at a localized level. Despite the overriding effects of variable and unpredictable climatic conditions on the vegetation of arid to semi-arid ecosystems, this study has shown that land use patterns still play an important role in altering vegetation attributes, particularly at a local scale.

## **6.2 Recommendations**

- a) The Kalahari and Mopane woodlands vegetation mosaic of the Salambala conservancy presents a unique ecosystem that not only serves an important source of a vast variety of goods and services for the community, but also for the components of biodiversity in the area. There is therefore a need to step up conservation measures, especially in the broader conservancy area, where most of this unique vegetation mosaic is situated.

- a) The establishment of communal area conservancies in Namibia and elsewhere is clearly seen as one of the strategies that can rescue the biodiversity not catered for within conventional protection strategies, such as protected area networks. Therefore, zonation of conservancies should be carried out with this important aspect in mind, if the experience of protected areas, which had their main focus on the protection of wildlife, especially large mammals, is to be avoided.
- b) It is further recommended that the state of vegetation and other aspects of biodiversity should become a focus of studies and research programmes on communal conservancies, as:
- Lack of information on the state of vegetation could be detrimental to wildlife productivity and sustainability.
  - Vegetation, especially woodlands are important repositories of most terrestrial biodiversity and lack of information on their state could undermine the ecological sustainability of communal area conservancies.
  - Wildlife re- or introduction is one of the main focus in communal conservancies, therefore is it imperative to assess the impact of increasing wildlife populations on vegetation, especially large herbivores such as elephants in order to determine whether further introductions are needed or not.
- d) Although assessment of carrying capacity was not the focus of the current study, it is highly recommended that the ecological carrying capacities of the different

zones should be determined to inform on stocking rates that would not be detrimental to vegetation characteristics such as structure, composition, richness and diversity.

- e) It is also recommended that detailed, small-scale vegetation descriptions be done before the establishment of conservancies and other CBNRM areas such as community forests, so that the information can serve as baseline data for future monitoring of these areas.

## REFERENCES

1. Abd-El-Ghani, M.M. 1998. Environmental correlates of species distribution on arid desert ecosystems of eastern Egypt. *Journal of Arid Environments* 38:297-313.
2. Anderson, G.D. and Walker, B.H. 1974. Vegetation composition and elephant damage in the Sengwa Wildlife Research Area, Rhodesia. *Journal of South African Wildlife Management Association* 4: 1-14
3. Archibald, O.W. 1995. Ecology of woodland vegetation, Chapman and Hall, London. pp. 510
4. Ashley, C. 1997. Incentives Affecting Biodiversity Conservation and Sustainable Use: the Case of Land Use Options in Namibia, DEA, Research Discussion Paper no.13, Windhoek
5. Banda, T., Schartz, M.W. and Caro, T. 2006. Woody vegetation structure and composition along a protection gradient in a Miombo ecosystem of Western Tanzania, *Forest Ecology and Management* 230: 179-185
6. Barbour, M.G., Burk, J.H., Pitts, W.D., Gilliam, F.S. and Schwartz, M.W. 1999. *Terrestrial Plant Ecology*. 3<sup>rd</sup> ed. New York: Benjamin Cummings.
7. Barnard, P. (ed.). 1998. *Biological Diversity In Namibia: a country study*. Windhoek, Namibia National Biodiversity Task Force.
8. Beaumont, P. 1993. *Drylands environmental management and development*. United Kingdom, MacKay's of Chatlam.
9. Beeby, A. 1993. *Applying Ecology*. London, Chapman & Hall.
10. Ben-Shahar, R. 1996. Do elephants over-utilise mopane woodlands in northern-Botswana. *Journal of Tropical Ecology* 12: 505-515

11. Ben-Shahar, R. 1998. Changes in structure of savanna woodland northern-Botswana following the impacts of elephants and fire. *Plant Ecology* 136: 189-194
12. Biodiversity Monitoring Transect Analysis in Africa (BIOTA). 2003. Structural and species diversity in semi-arid savannahs of southern Africa: impact of land use and climatic change. Subproject 09.
13. Bonham, C.D. 1989. Measurements for Terrestrial Vegetation. New York: Wiley-Interscience.
14. Bromilow, S. 2001. Problem plants of South Africa; a guide for identification and control of more than 300 invasive plants and other weeds. Briza Publications, South Africa.
15. Brown, L. and Bredenkamp, G.J. 2004. The use of structural size classes in the description of the woody vegetation of a Nature Reserve. *African Journal of Ecology* 42: 252-269.
16. Burke, A. 2006. The impact of large herbivores on floral composition and vegetation structure in the Naukluft Mountains, Namibia. *Biodiversity and Conservation* 6: 1203-1217
17. Cadotte, M.W., Franck, R., Reza, L. and Lovet-Doust, J. 2002. Tree and shrub diversity and abundance in fragmented littoral forest of southeastern Madagascar. *Biodiversity and Conservation* 11: 1417-1436
18. Campbell, B. (ed) 1996. The Miombo in transition: woodlands and wildlife
19. Chamberlin, E.A. and Aarssen, L.W. 1996. The cost of apical dominance in white pine (*Pinus strobes* L.) Growth in multi-stemmed versus single stemmed trees. *Bulleting of the Torrey Botanical Club* 123(4): 268-272

20. Curtis, B. and Mannheimer, C. 2005. Tree atlas of Namibia. National Botanical Research Institute, Windhoek.
21. Dalhberg, A. 1994. Contesting views and changing paradigms: the land degradation debate in Southern Africa. Representational HSC, Uppsala, Discussion paper no. 6.
22. Davis, M.A., Wrage, K.J., Reich, P.B., Tjoeker, M.G., Schaeffer, T. and Muermann, C. 1999. Survival, growth and photosynthesis of tree seedlings competing with herbaceous vegetation along a water-light-nitrogen gradient. *Plant Ecology* 145: 341-350
23. De Klerk, J. N. 2004. Bush Encroachment in Namibia. Report on phase 1 of the bush encroachment research, monitoring and management project. Windhoek: Ministry of Environment and Tourism.
24. Dembélé, F., Picard, N., Karembé, M. and Birnbaum, P. 2006. Tree vegetation patterns along a gradient of human disturbance in the Sahelian area of Mali. *Journal of Arid Environments* 64: 284-297.
25. Directorate of Veterinary Services (DVS) 2005. Annual report 2005. Ministry of Agriculture, Water and Forestry (MAWF), Windhoek, Namibia.
26. Dythan, C. 2003 (2<sup>nd</sup> edition). Choosing and using statistics, a biological guide. Blackwell Publishing, UK. pp. 248
27. Edwards, D. 1983. A broad scale classification of vegetation for practical purposes. *Bothalia* 114: 705-712
28. Evans, N.V., Avis, A.M. and Palmer, A.R. 1997. Changes in vegetation of the Mid-Fish River Valley, Eastern Cape, South Africa in response to land-use, as revealed by direct gradient analysis, *Journal of Range and Forage Science* 14: 68-74

29. Fox, J.H. 1985. Plant diversity in relation to plant production and disturbance by voles in Alaskan Tundra community. *Arctic and Alpine Research* 17:199-204.
30. Gauch, H.G. (Jr). 1982. *Multivariate Analysis in community ecology*. Cambridge, Cambridge University Press.
31. Geldenhuys, C.J. and Venter, S. 2002. Plant communities and biodiversity of the Limpopo Province forests: Relevance and management options. In Seydack, A.H.W., Vorster, T., Vermeulen, W.J. and van der Merwe, I.J. *Multiple use management of natural forests and woodlands: policy refinements and scientific progress*. Natural forests and savanna woodlands symposium III, 6-9<sup>th</sup> May 2002, Kruger National Park, South Africa.
32. Gondard, H., Romane, F., Grandjanny, M., Li, J. and Aronson, J. 2001. Plant species diversity changes in abandoned chestnut (*Castanea sativa*) groves in southern France. *Biodiversity and Conservation* 10: 189-207
33. Hickey, M. K. and King, C.C. 2000. *The Cambridge illustrated glossary of botanical terms*. Cambridge, Cambridge University Press.
34. Hiernaux, P. 1998. Effects of grazing on plant species composition and spatial distribution in rangelands of the Sahel. *Plant Ecology* 138: 191-202
35. Hipondoka, M.H.T., Aranibar, J.N., Chirara, C., Lihawha, M. and Macko, S.A. 2003. Vertical distribution of grass and tree roots in arid ecosystems of Southern Africa: niche differentiation or competition? *Journal of Arid Environments* 54:319-325.
36. Holm, L.G. 1977. *The world's worst weeds*. The University press of Hawaii, Honolulu.

37. Hunter, M.L. (Jr). 1996. *Fundamentals of Conservation Biology*, New York, Blackwell Science Inc.
38. Huntley, B.J. (Ed.). 1994. *Botanical Diversity in Southern Africa*. Cape Town, Creda Press.
39. Kadavul, K. and Parthasarathy, N. 1999. Plant biodiversity and conservation of tropical semi-evergreen forest in the Shervayan hills of Eastern Ghats, India. *Biodiversity and Conservation* 8:421-439.
40. Kaufmann, J.B. and Krueger, W. 1984. Livestock impacts on riparian ecosystems and stream side management implications: a review. *Journal of Range Management* 37(5): 430-437
41. Kraaij, T. and Milton S.J. 2006. Vegetation changes (1995-2004) in semi-arid Karoo shrubland, South Africa: Effects of rainfall, wild herbivores and change in land use. *Journal of Arid Environments* 64: 174-192.
42. Kent, M. and Coker, P. 1994. *Vegetation description and analysis*. England, Jon Wiley & Sons ltd.
43. Kreike, E.H.P.M. 1995. The ovambo agro-silvopastoral system: traditional land-use and indigenous natural resource management in North-central Namibia. Directorate of Forestry Publication no.4, Windhoek, Namibia.
44. Leggett, K., Fennessy, J. and Scheider, S. 2003. Seasonal vegetation changes in Hoanib River catchment, north-western Namibia: a study of a non-equilibrium system. *Journal of Arid Environments* 53:99-113.
45. Leggett, K., Fennessy, J. and Schneider, S. 2002. Does land use matter in an arid Environment? A case study from the Hoanib River catchment, north-western Namibia. Desert Research Foundation of Namibia.

46. Long, S.A. (ed.). 2004. Livelihoods and CBNRM in Namibia: the finding of the wild project, final technical report of the wildlife integration for livelihood diversification project (WILD). Prepared for the Directorates of Environment Affairs and Parks and Wildlife Management, the Ministry of Environment and Tourism, the Government of the Republic of Namibia. Windhoek, March 2004.
47. Loucougarg, G., Borris, A. and Barnard, J. 2004. Effects of grazing by horses and cattle on the diversity of coastland grasses in Western-Europe. *Conservation Biology* 116: 59-71.
48. Lykke, A.M. 1998. Assessment of species composition change in savanna vegetation by means of woody plants' size class distributions and local formation. *Biodiversity and Conservation* 7: 1261-1275
49. Mackey, R. L. and Currie D.J. 2001. The diversity-disturbance relationships: is it generally strong and peak. *Ecology* 12:3479-3492.
50. Mapaure, I. 2001. Small-scale variations in species composition of miombo-woodland in Sengwa, Zimbabwe: the influence of edaphic factors, fire and elephant herbivory. *Systematics and Geography of Plants* 71: 935-947.
51. Mapaure, I. 2006. The state of mopane woodlands in Omusati Region, Northern Namibia. A paper presented at a workshop on the management of mopane woodlands in Namibia and Zimbabwe. Africa Stadt Hans Hotel, Ongwediva. 19-21 September 2006.
52. Marguels, C. 2000. Biodiversity Planning and monitoring in Namibia. Directorate of Environmental Affairs. Research Discussion Paper no. 35, Windhoek, Namibia.

53. Mendelssohn, J.M., Jarvis, A., Roberts, C. and Robertson, T. 2002. Atlas of Namibia: A portrait of the land and its people. Cape Town: David Phillips.
54. Mendelssohn, A. and Roberts, C. 1997. An Environmental Profile and Atlas of the Caprivi. Directorate of Environmental Affairs, MET, Windhoek.
55. Metzger, K.L., Caughenour, M.B., Reich, R.M. and Boone, R.B. 2004. Effects of seasonal grazing on plant species diversity and vegetation structure in a semi-arid ecosystems. *Journal of Arid Environments* 61:147-160.
56. Midgley, J.J., Seydack, A.H.W. and Durrheim, G. 2002. What determines basal area in indigenous forests? Analysis of growth, mortality and basal area in the evergreen Knysna forest, South Africa. In: Seydack, A.H.W., Vorster, T., Vermeulen, W.J. and van der Merwe, I.J. Multiple use management of natural forests and woodlands: policy refinements and scientific progress. Natural forests and savanna woodlands symposium III, 6-9<sup>th</sup> May 2002, Kruger National Park, South Africa.
57. Ministry of Environment and Tourism 2006. Status and Facts of Conservancies.  
<http://www.gov.met.gov.na/programme/cbnrm/conservancies.htm>.
58. Namibia Association of CBNRM Support Organization. 2002. Namibia's communal conservancies: a review of progress and challenges. NACSO, Windhoek.
59. Namibia Bureau of Meteorology. 2006. Average temperatures for the Caprivi region, Windhoek, Namibia.
60. National Remote Sensing Centre 2003/2004. Fire Scar Maps for Eastern-Caprivi. Directorate of Forestry, Windhoek

61. Neke, K.S. 2002. Patterns on woody plant population in relation to human use in a South African savanna. In: Seydack, A.H.W., Vorster, T., Vermeulen, W.J. and van der Merwe, I.J. Multiple use management of natural forests and woodlands: policy refinements and scientific progress. Natural forests and savanna woodlands symposium III, 6-9<sup>th</sup> May 2002, Kruger National Park, South Africa.
62. Norusis, M. 2004. SPSS 13.0 Guide to Analysis. New York, Prentice Hall.
63. Omeja, P., Obua, J. and Cunningham, A.B. 2004. Regeneration, density and size class distribution of tree species used for drum making in central Uganda. *African Journal of Ecology* 42: 129-136
64. Owen-Smith, N. 2002. Facilitation versus competition in grazing herbivore assemblages, *Oikos* 97 (3): 313-318
65. Parsons, D.A.B., Shackleton, C.M. and Scholes, R.J. 1997. Changes in herbaceous layer condition under contrasting land use systems in the semi-arid lowveld, South Africa. *Journal of Arid Environments* 37:319-329.
66. Pettit, N.E., Froend, R.H. and Ladd P.G. 1995. Grazing remnant woodland vegetation, changes in species composition and life form groups. *Journal of Vegetation Science* 6: 121-130.
67. Ramirez-Marcial, N., Gonzalez-Espinosa, M. and Williams-Linera, G. 2000. Anthropogenic disturbance and tree diversity in Montane rainforests in Chiapas, Mexico. *Journal of Ecology* 8: 345-354.
68. Relva, M.A. and Veblen, T.T. 1998. Impacts o introduced large herbivores on *Austrocedus chilensis* forests in Northern Patagonia, Argentina. *Forest Ecology and Management*: 108: 27-40

69. Sala, O.E. 1988. The effect of herbivory on vegetation structure. In Werger, M.J.A., Van der Aart, H.J. and Verhoeven, J.T.A. 1988. Plant form and vegetation structure. SPB Academic Publishing, The Hague.
70. Scholes, R.J. and Archer, S.R. 1997. Tree-grass interactions in savannas. *Annual Review of Ecology and Systematics* 28: 517-544.
71. Scoones, I. (ed.). 1995. Living with Uncertainty: new direction in pastoral development in Africa. Intermediate Technology Publications Ltd., UK.
72. Sekhwela, M.B.M. 2003. Woody vegetation resource changes around selected settlements along aridity gradient in the Kalahari, Botswana. *Journal of Arid Environments* 54:469-482.
73. Sheuyange, A. 2002. Landscape level vegetation changes in relation to fire history in Eastern Ohangwena region, Namibia. Msc thesis, Norwegian University of Life Sciences, Norway.
74. Sisay, A. and Baars, R.M.T. 2002. Grass composition and rangeland condition of the major grazing areas in the Mid-Rift Valley, Ethiopia. *Journal of Range Management* 40: 18-26
75. Smit, G.N., Rethman, N.F.G. and Moore, A. 1996. Vegetative growth, reproduction, browses production and response to tree clearing of woody plant in African savanna. *Journal of Range and Forage Science* 13 (2):78-88.
76. Straede, S., Nebel, G. and Rijal, A. 2002. Structure and floristic composition of community forest and their compatibility with villager's traditional needs for forest products. *Biodiversity and Conservation* 11:487-508.

77. Sullivan, S. 1999. The impacts of people and livestock on topographically diverse open wood and shrub-lands I arid North West Namibia. *Global Ecology and Biogeography* 8: 257-277
78. Svenning, J.C. 1998. The effect of land-use on the local disturbance of Palm species in an Andean rain forest fragment in North-western Ecuador, *Biodiversity and Conservation* 7: 1529-1537
79. Ter Braak, C.J.F. and Prentice, I.C. 1988. A theory of Gradient Analysis. *Advances in Ecological Research* 18: 271-317.
80. Ter Braak, C.J.F and Smilauer, P. 2002. CANOCO Reference manual and CanoDraw for Windows User's guide: Software for Canonical Community Ordination (version 4.5). Microcomputer Power (Ithaca, NY, USA).
81. Trollope, W.S.W., Hines, C.J.H. and Trollope, L.A. 2000. Simplified Techniques for assessing range condition in the east Caprivi region of Namibia. Directorate of Forestry, Windhoek, Namibia.
82. Van den Berg, L. and Kellner, K. 2005. Restoring degraded patches in semi-arid rangeland of South Africa. *Journal of Arid Environments* 61:497-511.
83. Veach, R., Lee, D. and Philippi, T. 2003. Human disturbance and forest diversity in the Tansa Valley, India. *Biodiversity and Conservation* 12: 1051-1072
84. Verlinden, A. and Dayot, B. 2004. A comparison between indigenous environmental and a conventional vegetation analysis in north-central Namibia. *Journal of Arid Environments* 62:143-175.
85. Vetter, S. 2005. Rangeland at equilibrium and non-equilibrium: recent developments in the debate. *Journal of Arid Environments* 65: 321-341

86. Walpole, M.J., Nabaala, M. and Matankory, C. 2004. Status of the Mara Woodlands in Kenya. *African Journal of Ecology* 42:180-188.
87. Walter, D.W., Smollak, S. and Dormaar, J.F. 1990. Vegetation response to time-controlled grazing on mixed and Forsue Priare. *Journal of Range Management* 43: 513-517
88. Ward, D. 2002. Do we understand the causes of bush encroachment in African Savannas? In: Seydack, A.H.W., Voster, T., Vermeleun, W.J. and van der Merwe, I.J. Multiple-use management of natural forests and woodlands: policy refinements and scientific progress. Natural forests and savanna woodlands symposium III, 6-9<sup>th</sup> May 2002, Kruger National Park, South Africa
89. Werger, M.J.A. 1972. Species-Area relationship and plot sizes: with some examples from South Africa. *Bothalia* 10: 583-592.
90. Werger, M.J.A., Van der Aart, H.J. and Verhoeven, J.T.A. 1988. Plant form and vegetation structure. SPB Academic Publishing, The Hague.
91. Zapfack, L., Engwald, S., Sonke, B., Achoundong, G. and Madong, B.A. 2002. The impact of land conversion on plant biodiversity in the forest zone of Cameroon. *Biodiversity and Conservation* 11: 2047-2061
92. Zhang, W. 1998. Changes in species diversity and canopy cover in steppe vegetation in Inner Mongolia under protection from grazing. *Biodiversity and Conservation* 7:1365-1381.
93. Ziedler, J., Hanrahan, S. and Scholes, M. 2002. Land-use intensity affects range condition in arid to semi-arid Namibia. *Journal of Arid Environments* 52:389-403.

94. Zolho, R. 2005. Effects of fire frequency on regeneration of miombo woodlands in Nhambita, Mozambique. In: Campbell, B. 2006 (ed) The Miombo Woodlands in transition: woodlands and welfare in Africa, Bogor, CIFOR. Pp. 59-71

## APPENDICES

**Appendix 1:** The grass species and other herbaceous plants identified as key species for assessing range condition in the Kalahari woodlands, Mopane woodlands and Floodplains in

No	Grass species	Ecological status	Kalahari Woodland	Mopane Woodlands	Floodplains
1	<i>Brachiaria nigropedata</i>	Decreaser			+
2	<i>Digitaria</i> -perennials	Decreaser		+	+
3	<i>Panicum coloratum</i>	Decreaser		+	+
4	<i>Panicum maximum</i>	Decreaser	+		
5	<i>Themeda triandra</i>	Decreaser	+		
6	<i>Aristida pilgeri</i>	Increaser I		+	
7	<i>Aristida stipitata</i> *	Increaser I	+	+	
8	<i>Brachiaria dura</i>	Increaser I			+
9	<i>Eragrostis pallens</i> *	Increaser I	+		
10	<i>Tristachya superba</i>	Increaser I		+	
11	<i>Vetivera nigritana</i>	Increaser I			+
12	<i>Aristida</i> annual species*	Increaser II			+
13	<i>Cynodon dactylon</i>	Increaser II			
14	<i>Dactyloctenium giganteum</i> *	Increaser II	+		

the East Caprivi region of Namibia and used for the assessment of the range condition in the Kalahari woodlands of the Salambala conservancy, northeast Namibia.

**Adapted and modified from: Trollope *et al*; 2002**

\*: Species used in the study

**Appendix 2a-d:** Chi-square distribution tables for the core, transitional and outside areas in the Kalahari woodlands of the Salambala conservancy, northeast Namibia

a) Basal area frequency distributions

	≤70.99	71 - 140.99	141 - 210.99	211 - 280.99	281 - 350.99	351 - 420.99	421 - 490.99	≥491
Observed ( C )	<b>8</b>	29	17	8	6	5	5	<b>17</b>
Expected ( C )	<b>17</b>	26	18	13	6	4	3	<b>7</b>
Observed ( T )	<b>85</b>	76	<b>33</b>	<b>23</b>	9	8	5	17
Expected ( T )	<b>47</b>	70	<b>49</b>	<b>36</b>	16	11	7	20
Observed ( O )	<b>10</b>	48	58	47	20	11	6	9
Expected ( O )	<b>38</b>	57	40	29	13	9	6	16

b) Height frequency distributions (Trees)

Classes (m)	<2.5	2.51-3.5	3.51-4.5	4.51-5.5	5.51-6.5	6.51-7.5	>7.5
Observed ( C )	6	<b>18</b>	13	15	15	6	<b>19</b>
Expected ( C )	9	<b>28</b>	22	12	8	6	<b>8</b>
Observed ( T )	35	<b>48</b>	51	38	30	26	22
Expected ( T )	25	<b>76</b>	59	32	23	15	20
Observed ( O )	15	<b>101</b>	66	17	<b>5</b>	<b>1</b>	<b>4</b>
Expected ( O )	21	<b>63</b>	49	27	<b>19</b>	<b>13</b>	<b>17</b>

c) Height frequency distributions (Shrubs)

Classes (m)	<1	1.1-1.5	1.6-2.0	2.1-2.5	2.6-3.0	3.1-3.5	>3.5
Observed ( C )	<b>1</b>	1	15	5	0	1	2
Expected ( C )	<b>8</b>	6	7	3	1	0	0
Observed ( T )	26	<b>29</b>	17	2	3	0	0
Expected ( T )	24	<b>19</b>	22	8	3	0	1
Observed ( O )	30	15	22	12	4	0	0
Expected ( O )	26	20	24	9	3	0	1

d) Frequency of occurrence of increaser I and increaser II grass species

	Increaser I	Increaser II	Total
Observed ( C )	16	<b>12</b>	28
Expected ( C )	6.59	<b>21.41</b>	
Observed ( T )	14	29	43
Expected ( T )	10.12	32.88	
Observed ( O )	<b>3</b>	<b>63</b>	66
Expected ( O )	<b>15.29</b>	<b>49.71</b>	

**Appendix 3:** The geographical location of plots in the Kalahari woodlands of the Salambala conservancy, northeast Namibia.

Plot	Longitude	Latitude
1	24.6070	-17.8380
2	24.6067	-17.8383
3	24.6066	-17.8389
4	24.6066	-17.8394
5	24.6065	-17.8398
6	24.6090	-17.8383
7	24.6063	-17.8107
8	24.6063	-17.8103
9	24.6061	-17.8106
10	24.6061	-17.8102
11	24.6061	-17.0811
12	24.6059	-17.8105
13	24.5497	-17.8091
14	24.5496	-17.8093
15	24.5496	-17.8096
16	24.5496	-17.8094
17	24.5486	-17.8083
18	24.5486	-17.8081
19	24.5482	-17.8081
20	24.5484	-17.8080
21	24.5480	-17.8078
22	24.5482	-17.8077
23	24.5478	-17.8079
24	24.5482	-17.8078
25	24.5496	-17.8098
26	24.5484	-17.8082
27	24.5480	-17.8080
28	24.5482	-17.8079
29	24.5482	-17.8076
30	24.5477	-17.8078
31	24.5486	-17.8079
32	24.5487	-17.8080

**Appendix 4:** List of recorded species at three sites in the Kalahari woodlands of the Salambala conservancy, northeast Namibia

1. *Acacia erioloba*
2. *Albizia harveyi*
3. *Amblygonocarpus andongensis*
4. *Aristida stipitata* subsp. *graciflora*
5. *Bidens biternata*
6. *Blepharis maderaspatensis*
7. *Burkea africana*
8. *Citrulus lanatus*
9. *Colophospermum mopane*
10. *Combretum collinum*
11. *Combretum engleri*
12. *Combretum mossambicense*
13. *Combretum zeyheri*
14. *Commiphora angolensis*
15. *Dactyloctenium giganteum*
16. *Dicrostachys cinerea*
17. *Eragrostis pallens*
18. *Erythrophleum africanum*
19. *Euphorbia crotonoides*
20. *Grewia flavescens*
21. *Grewia retinervis*
22. *Guibortia coleosperma*
23. *Hemizygia bracteosa*
24. *Markhamia obtusifolia*
25. *Markhamia zanzibarica*
26. Namunyati (Subiya<sup>2</sup>)
27. *Ochna pulchra*
28. *Perotis patens*
29. *Philenoptera nelsii*

30. *Pogonarthria fleckii*
31. *Polycarpaea carymbosa*
32. *Stipagrostis spp.*
33. *Syzygium guineense* subsp. *guineense*
34. *Terminalia brachystemma*
35. *Terminalia sericea*
36. *Trephrosia lupinifolia*
37. *Tricholaena monachne*
38. *Vernonia poskeana*
39. *Ximenia caffra*

---

<sup>2</sup> A local vernacular spoken in the Salambala conservancy

**Appendix 5:** Matrix based on presence/absence of species at three sites in the Kalahari woodlands of the Salambala conservancy, northeast Namibia

Species	Plots: 1-7 (Core area); 8-17 (Transitional area); 18-32 (Outside area)																																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32		
<i>A. erioloba</i>	1	0	1	1	0	1	1	0	0	0	1	0	0	1	0	0	1	0	1	1	1	0	1	1	1	0	1	0	1	1	1	1		
<i>A. harveyi</i>	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
<i>A. andongensis</i>	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
<i>A. stipitata</i>	1	1	0	1	0	0	0	0	0	0	1	1	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	
<i>B. biternata</i>	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0		
<i>B. maderaspatensis</i>	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
<i>B. africana</i>	1	1	0	1	1	1	0	1	0	1	1	1	1	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	1	
<i>C. lanatus</i>	0	0	1	1	1	1	1	1	0	1	1	1	0	1	0	1	1	0	0	0	1	0	1	1	0	0	1	0	1	0	0	0		
<i>C. mopane</i>	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
<i>C. collinum</i>	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1		
<i>C. engleri</i>	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0		
<i>C. mossabicense</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0	0	1	0	1	1	1	0	1	0		
<i>C. zeyheri</i>	0	0	0	0	0	0	0	0	1	1	1	1	1	0	1	0	1	1	0	0	1	0	1	1	0	0	0	0	1	0	0	0		
<i>C. angolensis</i>	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	
<i>D. giganteum</i>	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	
<i>D. cinerea</i>	0	0	1	1	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	
<i>E. pallens</i>	0	1	1	0	0	1	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
<i>E. africanum</i>	0	0	0	0	0	0	0	1	1	0	1	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	
<i>E. crotonoides</i>	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
<i>G. flavescens</i>	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
<i>G. retinervis</i>	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	1	1	1	
<i>G. coleosperma</i>	1	1	0	1	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
<i>H. bracteosa</i>	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>M. obtusifolia</i>	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	1	1	1	1	0	1	1	1	1	1	1	1	0	1	
<i>M. zanzibarica</i>	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Namunyati (Subiya <sup>1</sup> )	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	
<i>O. pulchra</i>	0	1	0	1	0	0	0	1	1	1	1	0	0	1	0	1	1	1	0	1	1	1	1	0	0	0	1	1	0	0	1	0	0	

<sup>1</sup> Local vernacular spoken in the Salambala Conservancy

