



The study was carried out in Caprivi region situated in the North East of Namibia. The region was divided into three predominant vegetation types with substantial grazing potential. Nine (9) sites (three in each vegetation type) were randomly selected for data collection. The objective of the study was to estimate and compare the biomass production of the rangelands of the three vegetation types in the Caprivi. At each site 200m X 100m transect was laid down for collecting herbaceous vegetation using the conventional clipping method (using a 1m quadrat) and sorted into six categories (*Schmidtia pappophoroides*, Desirable perennial species, *Aristida* species, Annuals and Herbs and Forbs). The same site was used for assessing botanical composition and canopy cover (using a 2m iron rod) by using step point method. The mean total biomass production between the three vegetation types was significantly different ( $df = 10, P < 0.05$ ). The mean total biomass production for Kalahari woodlands was higher (1254.56kg/ha) in comparison to the other two vegetation types (Mopane woodlands and Floodplains). There was no significant difference ( $P = 0.641$ ) observed in the canopy cover between the tree vegetation types. The mean total cover for Caprivi region was calculated at 59.79%. The mean diameter and number of tufts for *Schmidtia pappophoroides* was not different ( $P = 0.922$  and  $p = 0.522$  respectively) between the vegetation types. The calculated grazing capacity (based on total herbaceous biomass production) was 9ha/LSU. This figure ignored other important factors such as palatability. The high biomass production of Herbs and Forbs in the Floodplains was caused by overgrazing resulting from high concentration of cattle during the critical seasons of the year, consequently desirable perennials are over utilized and replaced by annuals.

Biomass production, quadrat, grazing capacity, transect, overstocking, species

	Pages
ABSTRACT	ii
TABLE OF CONTENTS	...iii
LIST OF FIGURES	..vii
ACRONYMS	...viii
DEDICATION	x
ACKNOWLEDGEMENTS	xi
DECLARATION	xii

.....

INTRODUCTION	.1
1.1 Orientation of the study	...1
1.2 Statement of the problem	.3
1.3 Objectives of the study	.5
1.3.1 General objective	5
1.3.2 Specific objectives	..5
1.4 Significance of the study	..6
1.5 Limitations of the Research	.7

.....

LITERATURE REVIEW	..8
2.1 Introduction	....8



4.2 Biomass production of the six different classes	37
4.2.1 Total biomass production	37
4.2.2 <i>Schmidtia pappophoroides</i>	38
4.2.3 Desirable perennial species	39
4.2.4 <i>Aristida</i> species	40
4.2.5 Other Perennials	41
4.2.6 Annuals	42
4.2.7 Herbs and Forbs	43
4.2 Cover	44
4.3 Diameter of <i>Schmidtia pappophoroides</i> tufts	45
4.4 Number of <i>Schmidtia pappophoroides</i> tufts	46
4.5 Botanical Composition	47
4.6 Grazing capacity	48
í í	50
DISCUSSION	50
5.1 Determining the seasonal quality of herbaceous biomass by estimating the contribution of desirable perennials to the total biomass production	50
5.2 Determination of grazing capacity	52
5.3 Determination of herbaceous canopy cover	56
5.4 Determination and comparison of botanical composition	57

í ...59

CONCLUSION AND RECOMMENDATIONSí í í í í í í í í í í í í í í í í .59

6.1 Conclusioní .í 59

6.2 Recommendationsí .61

REFERENCESí 63

APPENDICESí .79

- Figure 4.1 Biplot showing distribution of species in relation to the three  
vegetation typesí .36
- Figure 4.2 Comparison of total mean biomass production among the three  
vegetation typesí .38
- Figure 4.3 Comparison of the mean difference in biomass of  
*Schmidtia pappophoroides* between the three vegetation typesí í .39
- Figure 4.4 Mean proportion of biomass production of Desirable  
species among the three vegetation types of Caprivi regioní í í ..40
- Figure 4.5 Mean of biomass production of *Aristida* species between  
the three vegetation types in Caprivi regioní í í í í í í í í .41
- Figure 4.6 Presents the comparison of means for biomass production  
of other perennial species among the three vegetation typesí í í í 42
- Figure 4.7 Biomass production of annuals species between the three  
vegetation typesí ...43
- Figure 4.8 Comparison of biomass production of Herbs and Forbs  
among the three vegetation types of Caprivi regioní í í í í í í 44
- Figure 4.9 Proportion of cover in the three vegetation types of Caprivií í í í 45
- Figure 4.10 Mean diameter of *Schmidtia pappophoroides* in different  
vegetation types of Caprivií í í í í í í í í í í í í í í í í 46
- Figure 4.11 Abundance of *Schmidtia pappophoroides* tufts in  
different vegetation typesí í í í í í í í í í í í í í í í í .47
- Figure 4.12 Mean percentage abundance of botanical composition in  
different vegetation typesí í í í í í í í í í í í í í í í í .48

Biomass Estimate From Canopy Volume

Biomass Production Estimate

Canonical Correspondence Analysis

Carrying Capacity

Carbon Dioxide

Dry Matter

Disc Pasture Meter

Dry Weight Rank

Food and Agricultural Organization

Grazing Capacity

Groupement Pour le Developement de la

Teledetection Aerospatale

Land Cover

Livestock Unit

Ministry of Agriculture Water and Forestry

Normalized Difference Vegetation Index

Near Infra ó red

Net Primary Productivity

Standard Error

Total Dry Matter

Tropical Livestock Unit

University of Namibia

Woodiness Accessibility and Palatability

## **DEDICATION**

This thesis is dedicated to one special person in my life, my late Father Mr. William Mulonda Kupindana who passed away on 17<sup>th</sup> of September 1997. He taught me important values in life, such as hard work, self discipline, commitment and perseverance. I salute him for instilling visionary wisdom that has made a person I am today. I further extend this dedication to my entire family and friends for their academic and inspirational support.

My greatest gratitude goes to my Heavenly Father, who is my source of strength and inspiration. Secondly I would greatly like to thank my supervisor Dr. Ndafuda Shiponeni for her professional support and guidance during the entire period of this study. The same special gratitude goes to Professor I. Mpofu, Head of Animal Science Department and Dr. P. Graz for their academic support and encouragement. My sincere acknowledgement also goes to Mr. Benester Buseko and Mr. Mufe Vulunzi who tirelessly assisted me during data collection. Special thanks go to Mr. Born-bright Muleke, Mr. Gallen Kachimine and Mr. Master Kaseba for their moral and financial support they provided to me. I am deeply indebted to my friends Mr. Vennety Mekalabi and Mr. Harry Bona for giving me courage and transport during data collection. A word of thanks goes to all the Headmen of Kasheshe, Gunkwe, Kabbe, Kaenda, Kaliyangile, Singalamwe, Linyanti, Masokotwani and Malengalenga for granting me permission to carry out my field study on their rangelands. Appreciations also go to my classmates and friends Mr. Absalom Kahumba, Mr. Oscar Mbango, Mr. Erastus Ngaruka, Mr. Nyalua Kapu, Mr. Morlu Korso Mr. Leslie Mapako and M<sup>rs</sup>. L. Andrews, thank you for availing your time and for going the extra mile when I needed assistance.

Last but not least to my family , wife Dinah my daughter Namasiku and all my sons, if it wasn't for your faith in me, and your constant reminders that I needed to finish the book, this thesis will not be a reality.

I, Oscar Mulonda, hereby declare that this study is a true reflection of my own research, and that this work has not been submitted for a degree in any other institution of higher education.

No part of this thesis may be reproduced, stored in any retrieval system, or transmitted in any form, or by means (e.g. electronic, mechanical, photocopying, recording or otherwise) without the prior permission of the author, or the University of Namibia on that behalf.

I, Oscar Mulonda, grant the University of Namibia the right to reproduce this thesis in whole or in part, in any manner or format, which the University of Namibia may deem fit, for any person or institution requiring it for study and research; provided that the University of Namibia shall waive this right if the whole thesis has been or is being published in a manner satisfactory to the University.

í í í í í í í í í í í í í í í í í  
Oscar Mulonda

í í í í í í í í í í  
Date

Poor nutrition caused by inadequate amounts and low quality of feed is one of the major causes of low livestock productivity in tropical areas (Kaitho, 1997) and more specifically in the Caprivi region of Namibia. Conventional feeds such as grains and oilseed cakes are not produced in sufficient amounts to meet the requirements of man and livestock in the tropical areas (Abule *et al.*, 2005a).

In the extensive communal arid and semi-arid rangeland, herbaceous plants are the major food source of grazers (Abule *et al.*, 2005b). Forage plants usually consumed by domestic animals and wildlife consist mainly of grasses and woody plant browses. Therefore, assessment of the condition of the vegetation utilized by grazing and browsing herbivores is fundamental for the sustainable utilization of the rangeland ecosystem.

When studying rangeland vegetation, scientists are often interested in knowing about plant productivity. Biomass is the amount (by weight) of vegetative material on a site, and is a function of the types of plants and site characteristics, such as soil type, precipitation, or solar input (Hankins and Launchbaugh, 2001). For example, in a very dry climate, the rangeland may only be able to produce 300 kilograms per hectare, but in a wetter climate, the rangeland may produce as much as 5,000 kilograms per hectare. However, the types of plants also make a difference. Many noxious weeds invade rangeland sites and displace the desired vegetation, reducing biodiversity and the amount of forage available for livestock and wildlife. When the biomass and the types of plants are known on a particular range site, this allows range

scientists to estimate the number and types of animals that the rangeland can support (Kaitho, 1997).

Estimates of above ground biomass are necessary for the management of wild and cultivated land. Biomass and standing crop are often used synonymously to refer to the dry weight of standing vegetation and litter. Biomass is one of the most important characteristics of range vegetation (Cook and Stubbendieck, 1986). It is a component that is used to determine stocking rates and match forage resources to appropriate levels of utilization, evaluate different management strategies, investigate forage or crop production, and quantify habitat characteristics.

There are a variety of methods, both direct and indirect in nature, to estimate standing crop (Cook and Stubbendieck, 1986; Catchpole and Wheeler, 1992). All of these methods have benefits and drawbacks and vary in their overall level of difficulty. The method of choice depends on: (1) research objectives, (2) vegetation structure and diversity (community heterogeneity), (3) research funding, (4) amount of time available and (5) the experience of the researcher.

Traditionally, direct methods such as hand or mechanical clipping have been the most widely used methods to determine biomass. Clipping is an accurate measure on individual plots but it is time and labor intensive and it may require numerous samples to obtain reliable pasture estimates. Extensive effort has been allocated to the development of indirect methods that rely on the relationship between specific vegetative attributes of the foliage and biomass as alternatives or supplements to direct samples. Generally, indirect methods are less tedious and faster to use than direct methods but they require some sort of direct measurement for

creation of new models, or calibration and validation of their estimates. In most range and wildlife studies, we were interested in estimating the biomass of a large area (i.e., pasture or management unit). Individual measurements recorded from quadrants or plots are used to estimate biomass of larger areas. Because the biomass of a large area truly is rarely known, measures of biomass get compared to sub-samples (i.e., clipped or mowed quadrants or plots).

## **1.2 Statement of the problem**

Namibia is a sparsely populated semi arid country of South West Africa that depends heavily on extensive livestock production for its economic wellbeing and food security (Routhauge *et al.* 2000). Managing the rangeland resource is therefore of great importance to the country, and rangeland managers possess few powerful tools to manipulate the stocking rate of their livestock to influence rangeland condition and prevent its degradation. In the Caprivi rangelands though, manipulation of stocking rate is a big challenge for livestock producers. However, to optimize stocking rate, information on the resource such as the seasonal herbaceous biomass production is required. This is because it directly determines the carrying capacity of the range.

Rangeland productivity, influenced primarily by rainfall and to a lesser extent by previous grazing treatment, is highly variable in time and space. It is very difficult to measure productivity accurately in the field since it requires a huge investment in manpower, time and skill. Consequently, it is seldom measured in practice. Small scale livestock farmers suffer from lack of this valuable information. In Namibia, carrying capacity of rangelands was last surveyed at national scale level more than three decades ago, using the conventional quadrant clipping methods.

The Ministry of Agriculture Water and Forestry (MAWF) with technical assistance from the Groupement pour le Development de la Teledetection Aerospatiale (GDTA) attempted to estimate the herbaceous biomass production from satellite imagery. The rangelands of the Caprivi region were only covered through extrapolation of results from similar geographical locations.

The Caprivi region has a present cattle population of 151,765 and 10,235 goats according to the latest official stock census of December 2010, compared to 125,927 cattle and 44,135 goats in the adjacent Kavango (MAWF, 2010). Despite the differences in area size, vegetation types and level of utilization of rangelands over the years between the two regions, they are categorized of having the carrying capacity of 12 Ha/LSU according to Lubbe and Espach, (2006). Therefore, the need for accurate and up-to date estimates of seasonal biomass production, on which pastoralists can base their stocking rate is urgent.

### **.3 Objectives of the study**

#### **1.3.1 General Objective**

The general objective of this study was to investigate the biomass production of the three major vegetation types of the rangelands of Caprivi region by using the conventional clipping (ground truthing) method.

1. Determine and compare the land cover in all the three vegetation types to assess the level of range degradation.
2. Determine and compare the vegetation composition to assess the range condition in which each of the vegetation type falls.
  - Determine the seasonal Biomass Production Estimate (BPE) by conventional clipping to determine the grass based BPE and
  - Determining the seasonal quality of herbaceous biomass by estimating the contribution of desirable perennials to the total biomass production.
3. Determine the health of rangelands by estimating the biomass production and average diameter of *Schmidtia pappophoroides* tufts.
4. Estimate the seasonal grazing capacity of the rangelands to provide information for proper regional planning and as tool for management aspect.

#### **1.4 Significance of the study**

The predominant land use in Namibia's northern communal areas is agriculture, where people depend directly on natural rangeland resources for their economic well-being and food security. Agriculture and many other human activities are severely limited by the shortages of moisture due to the variable and low rainfall. Much of Namibia is sparsely populated because of this harsh and arid environment where livestock farming is an extremely important activity, as about 70% of the population is directly or indirectly involved in this industry. More land is used for agriculture than for any other purpose: mostly for cattle, goat and sheep farming (Mendelson *et al*, 2002). In overgrazed areas, livestock are less productive than in well-managed areas, where they will grow faster and become more productive. Overstocked areas occur mainly in north-central Namibia, along the Okavango River, on the eastern floodplains in Caprivi, and typically around large settlements. Over stocking in these areas occurs due to the presence of large numbers of cattle and goats. In total, about 3.7% of the land (excluding protected areas) is overstocked at levels that are roughly double the accepted grazing capacity of the land (Mendelsohn *et al.*, 2002).

For sustainable utilization of any rangeland, it is imperative that proper inventory be carried out on a regular basis to keep track of the management strategies employed following the dynamic weather. Biomass production of Caprivi rangelands has never been critically assessed to draw some proper management strategies based on scientific studies. This study has managed to estimate the total biomass production of the rangelands of the Caprivi region, hence an estimated grazing capacity recommended. The study has also drawn some recommendation for proper planning and sustainable utilization of the rangeland resources.

## **1.5. Limitations of the Research**

The research project encountered some challenges that were serious impediments to the smooth implementation particularly during data collection and statistical analysis stage and they include;

- Funding; the student has not secured funding for the research project, making it difficult to acquire some necessary resources. Considering the vastness of the study area, the researcher found it hard to cope with transport to cover all the nine transects.
- Duration of the research; it was realized that the duration given for the successful completion of the project was not sufficient enough to adequately cover the whole region. However, the researcher had managed by employing some assistants for clipping the quadrants.
- It was also difficult to consult with supervisors since they were busy with other equally important and demanding assignments.
- The size of the area studied was huge and therefore resulted in sampling challenges.

## CHAPTER 2

### 2.1 Introduction

The rangeland ecosystem of tropical Africa corresponds to arid and semi-arid climates where agriculture is marginal due to climatic conditions insufficiently reliable for the development of reliable cultivated species (Ganzin, 2004). These ecosystems host wild and/or domestic herbivores that utilize the vegetation resources to face their nutritional needs. These herbivores represent for man a way of making use of the scarce resources according to various exploitation modes ranging from nomadic heading to sedentary animal farming in large ranches, transhumance herding or protected areas for wild life.

The rangeland resources are nevertheless vulnerable, and their exploitation has its risks, especially under arid climates where they are not only limited but also very unreliable. An equilibrium state exists between the rangeland and the herbivores, but this balance is unstable and can be broken by excessive utilization, often referred to as *overgrazing* (Ganzin, 2004). When this takes place degradation of the resources can occur, resulting in a reduction of the forage production potential and therefore in a loss of animal production potential. These degradations appear under two main forms. The first is the change in the rangeland vegetation, useful species disappearing to be replaced by lower forage quality plants. The second is a degradation of the soils which, when left bare after grazing, are not protected against rainfall and wind and are prone to phenomena of surface crust formation and erosion.

In order to limit degradations while keeping a variable level of production, a good management of the rangelands is indispensable. Management is a complex matter that involves, socio-economic and water resource aspects among others. The management of

forage resources is therefore one aspect of the management of the rangeland as the whole, but it is an essential one if rangelands are to be exploited a sustainable way. In this regard, the main action mode is commonly accepted the effort to adapt the intensity of exploitation to the capacity of the land. Therefore, reliable information on the recourses is useful in order to evaluate this capacity, especially when one considers large areas and requires a regular and global view that enables to judge the spatial variability and to take into account the temporal variability that characterizes arid lands (Ganzin, 2004).

Caprivi, one of the 13 regions of Namibia, forms the country's figure-like projection in the northeast, which extends Namibia's borders into the humid centre of southern Africa. The region lies about halfway between the equator and the southern tip of the continent and midway between the Atlantic and Indian Oceans. Attached to the rest of Namibia along a short border, Caprivi is bounded by four other countries: Botswana to the south, Angola and Zambia to the north, and Zimbabwe to the east. In broad terms, the Caprivi stretches 450km from east to west and ranges from 32 and 100 kilometres in width from north to south. It covers an area of about 14528 km<sup>2</sup> ( Mendelson *et. al.*, 2002).

In a country that is often characterised as hot and dry, Caprivi is distinctly more tropical than any of the other regions. It enjoys a higher rainfall, less evaporation and a warmer winter than the rest of Namibia, providing a home to many plants that are unable to survive elsewhere in Namibia. Even though Caprivi experiences the highest rainfalls in Namibia, it is still exposed to rains that is highly variable from year to year and from one place to another, to serious droughts from time to time (Mendelson *et. al.*, 1997). On average, the Caprivi annually receive rainfall ranging from 500mm in the west to 700mm in the east. In eastern Caprivi, rainfall is about 600-700mm while in the north-east around Katima Mulilo, average total

rainfall amounts to just under 700mm and modal values are about 550mm per year. In the southern-most parts of the region, averages are about 500 mm and modal totals are about 400mm. In the west of Caprivi, average rainfall is about 600mm and modal rainfall is about 550mm (Mendelsohn and Roberts, 1997).

There are six broad vegetation communities in the Caprivi: open water, floodplains, riverine woodlands, mopane woodlands, Kalahari woodlands and Impalila woodlands. There is a considerable variation within these categories such that certain plants are abundant and important in one area but absent in other areas or the trees may be tall and well grown in one but small and shrubby in another (Mendelson and Roberts, 1997).

Of all Namibia's regions, the Caprivi has the highest agricultural potential. It has been regarded to be the bread basket of Namibia yet the agricultural potential has never been exploited to date. Caprivi's communal farmers practice mixed farming, although crop production was the region's most farming enterprise up to the late 1990s. However, due to intensive extension activities and sensitization of self quarantine of livestock by other stakeholders, coupled with good cattle prices, farmers started realizing the economic advantage of livestock farming. Realising such enormous comparative advantages most farmers are switching from intensive crop production to livestock farming especially cattle rearing.

The biggest challenge that the region is facing is the low off-take rate of livestock from rangelands. The cattle off-take from the rangelands is less than 10% of the total cattle population annually. With this current scenario, aggravated by other disasters such as droughts, floods and anthropogenic fires, assessment of rangelands in this volatile region needs proper and urgent attention.

The Ministry of Agriculture Water and Forestry is currently in the process of fine tuning remote sensing methodologies in an effort to determine grazing capacities at farm, regional and national level. The approach involves the use of satellite derived total seasonal biomass production estimates (BPE), corrected for woody density and the accessibility and palatability of woody plants obtained by Woodiness, Accessibility and Palatability (WAP), and land cover (LC) mapping. Both BPE and LC mapping require ground truthing in terms of vegetation biomass production which forms the basis of grazing capacity to arrive at an accurate estimation (Lubbe, 2005).

It is known that such research has been intensified in commercial areas of Namibia and little if not none of such research have been carried out in the Caprivi. Ground truthing is bringing into line, with satellite generated data, the reality of what is going on in the veld. This study has managed to provide information on the biomass production of the region backed by scientific methodologies that can be used for fair land evaluation and be applied to ensure long term sustainable use of the grazing resources.

## **2.2 Botanical composition**

The botanical composition of grassland vegetation is a reflection of many factors, including past management. Changes in these factors will be reflected in changes in composition. There are many attributes of botanical composition that can be described or measured and the objective of the description or measurement dictates the methodology. Monitoring changes over time by repeated sampling is a commonly used approach to detect environmental or management effects (Whalley and Hardy, 2003).Vegetation description or measurement can be very labour intensive and time consuming. The resources invested depend on the purposes of the measurements and, essentially, the information collected is usually proportional to the

resources invested but there is wide variation in the cost effectiveness of the different methods available. Scale is also important and different methods must obviously be used for vegetation measurement on a global scale compared with a small replicated experiment.

Some form of sampling is always involved in measuring the botanical composition of grasslands. The number, size and location of sampling units and the timing of the sampling are critical. In small plot experiments, the whole population can sometimes be measured. The errors inherent in sampling vary enormously, depending not only on the spatial and temporal variation of the grassland attributes being measured but also on observer bias, and within and between the various sampling techniques. It is desirable to consult a statistician during the planning stages of any project involving grassland sampling to ensure that the sampling strategy is appropriate for the purpose and is statistically sound (Whalley and Hardy, 2003).

Suitable strategies depend on the characteristics of the grassland and the purposes of the measurements. The subsequent statistical analysis of the data is also governed by how samples are located in space and time. The distribution of individuals of the species present in the grassland can affect the sampling strategy and the subsequent statistical analysis of the results. Non-random distributions are common and may confound parametric methods of statistical analysis. In contrast, the dry-weight-rank (DWR) method of botanical analysis of grasslands (Mannetje and Haydock, 1963) may not be appropriate on grasslands with random distributions (Neuteboom *et al.*, 1998). It may therefore be desirable to determine the type of distribution that occurs before deciding on sampling strategy, sample size and the statistical analysis of the results. Some species tend to be clustered while others tend to be regularly dispersed.

Some of the commonest types of sampling device and the ways in which they have been used will provide an introduction to the wide range of sample types available for botanical composition. Different sampling methods are used for determination of botanical composition.

Currently, three methods of determining grazing capacity (GC) are being either applied or investigated by researchers in the Ministry of Agriculture Water and Forestry. These are: the quantitative yield method (measuring grass and animal biomass, and matching animal requirement to the amount of plant biomass available), remote sensing, and generating grazing index values for plants based on their biomass production nutritive value and palatability (Lubbe, 2005). Although the quantitative yield method or clipping of quadrats remains one of the most accurate methodologies available to determine grazing capacity in Namibia's heterogeneous rangelands, calculated GC values are still subject to a statistical error of 20% (Lubbe 2005).

Up until fairly recently grazing capacity in Namibia has been based primarily on estimations by experienced farmers and extension officers and was expressed as ha/Large Stock Unit (LSU) or Small Stock Unit (SSU). The subjective (but not necessarily totally incorrect) nature of this method was realized in the late 1980s and a more scientific approach based on the biomass principle was then developed by Namibian researchers. This approach is based on the objective measuring of plant and animal biomass. Plant biomass is determined by the clipping of quadrats, while animal biomass is determined through regular weighing of animals. By setting the daily Dry material (DM) intake of an animal at 3 % of live weight and

matching the amount of DM needed to the amount of available grass material, it is possible to determine the yearly grazing capacity of an area (Lubbe, 2005).

Simple quadrats of 50 cm × 50 cm or 1 m × 1 m are very commonly used for grassland studies but the size of the quadrats also depends on the vegetation type. In dense temperate grasslands, a commonly used size is 5 cm × 5 cm. These are easily constructed out of welded metal and are robust and useful in many situations. Quadrats made out of 10mm × 5 mm aluminium bar are light to carry and easy to see if mislaid. It is easier to make a square or rectangular quadrant to a precise size than it is to make a circular one. Rectangular quadrants should not be too long and thin as this increases errors associated with cutting or counting plants on the quadrant edge. A suitable size for a rectangular quadrant for many grassland situations is 1.0 m × 0.5 m (Whalley and Hardy, 2003).

Closed quadrats are often difficult to place in very tall vegetation without flattening the plants and making it difficult to determine which plants are included within the quadrat and which are not. Three-sided or open-ended quadrats are much easier to push into the grassland close to the ground with minimum disturbance of the vegetation. A more recent variation of simple quadrats is the use of nested quadrats. This arrangement overcomes the problems associated with requiring different quadrat sizes for sampling both rare and extremely common species within the one grassland community. Clusters of nested quadrats are set out in geometrically increasing areas and species are recorded individually within these nested quadrats. In dense grassland with many species present, the size of the quadrats would be reduced. The use of nested quadrats is increasing because they are very efficient in terms of time invested relative to the large amount of information obtained (Whalley and Hardy, 2003). A square shape is usually used and the corners of each sub-quadrat in the cluster are defined by marks on four diagonal cords leading outwards from a central peg.

An extension of a rectangular quadrat is a transect which may be tens of meters or even kilometers long. A transect may be either in the form of a Measuring Botanical Composition of Grasslands belt or a simple line. A belt transect usually consists of a tape or a string stretched across the vegetation, and species or individuals occurring within a specific distance perpendicular to the tape or string are recorded. A simple form of belt transect in large paddocks is to drive a vehicle across the vegetation and record species or individuals occurring between the tyre tracks. The vehicle must be driven along a predetermined course to avoid bias resulting from the driver avoiding difficult terrain (Whalley and Hardy, 2003).

With a line transect, individuals or species touching the tape or string are recorded. If changes in the sizes of the individual plants over time are to be followed, then the lengths of the intercepts occupied by individuals touching the line are recorded. Transects are very useful in detecting and quantifying vegetation patterns within grasslands. For example, a 1000 m transect may be divided into 50 m segments with segments overlapping by, say, 20 m. Data would be collected from the 32 segments of the transect, each 50 m long, and then used for pattern analysis (Whalley and Hardy, 2003). The transects can be laid out deliberately to intersect with patches of the grassland with different species composition and the edges of the patches can be precisely located. If these transects with the precise location of the edges are permanently marked, then changes in the size and/or species composition of the patches over time can be readily quantified.

The size of a quadrat can be reduced to a point so that it has a location but no area. Points can be located randomly throughout a sample site, or systematically to ensure even coverage (at any scale but usually within representative parts of the area being sampled) or along a transect. Whether each point hits leaves, a plant base, litter or bare ground can be recorded. If 100 points are recorded and if a particular species is recorded as a hit in ten of these points, then it can be assumed that it occupies 10% of the area sampled (Whalley and Hardy, 2003).

Many different devices have been constructed to locate points within the area to be sampled. Some of these involve frames where the points are a fixed distance apart and the points are slowly lowered through the vegetation (Levy and Madden, 1933; Brown, 1954). Hits on leaves (aerial cover) as well as plant bases (basal cover) or bare ground can be recorded. The points in these frames are often fairly close together and if the individual plants in the grassland are large then one hit of a species can mean that the adjacent points hit the same plant of the same species and the observations are not independent. In addition, because grassland vegetation tends to occur in aggregates or clumps (Crocker and Tiver, 1948), the use of a frame will lead to correlations within the points recorded each time the frame is located (Tidmarsh and Havenga, 1955) and the variance will be underestimated.

An approach to eliminate this autocorrelation is to distribute the points widely across the grassland being sampled (Tidmarsh and Havenga, 1955). Methods to achieve this include the wheel point apparatus, where the spokes of a wheel are used to locate points regularly across the grassland. Usually one spoke of the wheel is marked and the data are recorded each time (or multiples of each time) the marked point hits the ground. Other methods of regularly locating points along a transect include cutting a notch in the front of the operator's boot,

locating a small wire in the notch every predetermined number of paces, and recording the plant species that is hit (Mentis, 1981).

An important source of error in point quadrat data collected by different operators lies in the definition of a "hit", particularly when estimating basal cover. The point may descend within the perimeter of a living grass tussock, but if the point is very small it may only contact dead material. In addition, the tussocks of two separate species of grass may be interwoven and it can be extremely difficult to tell just which plant base has been contacted. Tidmarsh and Havenga (1955) provided detailed diagrams of hits and misses for grassland plants with different life forms. Theoretically points have location but no area and Goodall (1952) and Warren (1963) have investigated the relationship between area of the "point" and the bias introduced into the results with respect to the estimation of cover. The larger the area of the "point" the greater is the overestimation of cover. On the other hand, the smaller the area of the point, the more fragile the apparatus and the more difficult it is to use in the field.

Several methods have been devised using the distances from randomly distributed points to the nearest individual plant, or the nearest neighbor to randomly chosen individuals (Mueller and Ellenberg, 1974; Neuteboom *et. al.*, 1992). These plotless methods can be very rapid and are particularly useful in sparse vegetation but are very sensitive to whether the species are randomly dispersed or not (Lamacraft *et. al.*, 1983). In the nearest-individual method, points are randomly selected and the distance to the nearest individual of a particular species is measured. It should also be noted that the relative abundance of species may be

estimated by identifying the nearest plant to a randomly, or systematically, located point. The point to plant distance need not be measured. In the point-centered quadrat method, points are randomly chosen and axes are set up dividing the space around the point into four quadrants. The distance to the nearest individual in each of the four quadrants is measured, which decreases the number of points chosen and the time in making the measurements. In sparse shrub and, range-finding devices have been used to measure the distances to the nearest individuals.

### **2.3. Cover**

Cover means the projection of plants or plant parts on to the soil surface. Measurements of cover can be expressed either as the percentage of the soil surface covered by the plants or plant parts or can be broken down into the species or groups of species present. It can be measured as either canopy cover or basal cover. Land cover is one of the most important elements for describing and studying the environment, as it is the main source of primary production in terrestrial ecosystems. Land cover changes quickly over time and can be used as a simple indicator of human interventions on the environment; therefore, it can be an important parameter for environmental databases. The patterns that one sees on the earth's surface are products of many years of natural and human influences (Lillesand and Kiefer, 1994). With its geographic features, land cover can serve as a reference base for other environmental applications such as soil and vegetation.

The precision of estimates of cover by species when using point quadrats is a function of the actual cover of a species and the number of points observed. For example, in a grassland with 10% cover and where one of the species present contributes only 1% of that cover, there will be a 0.1% probability of striking the basal portion of that species, i.e. one chance in a

thousand of striking the plant. Point quadrats are therefore not suited to sampling for rare species. In semiarid grasslands with low cover it is often recommended that 3000 points should be observed when monitoring cover by species (Tidmarsh and Havenga, 1955).

The basal cover represents the proportion of the ground occupied by the bases (where they are rooted to the ground) of the individual species. Because all measurements are made at ground level, there cannot be any overlap and so the total basal cover cannot be more than 100%. Again, the percentage of the area occupied by bare ground, litter or stones can be estimated simultaneously. This may be particularly important in semi-arid and arid grasslands, where the percentage plant basal cover may be quite small. Basal cover is a more stable property of vegetation than canopy cover. It is less affected by prior grazing or seasonal conditions, particularly with perennial species. Sometimes the basal cover of stoloniferous species (mat-forming grasses) is difficult to measure because basal cover actually represents the projection of the stolons on the ground, which can be difficult to measure if they have a small diameter. In addition, a rosette component of grassland with radical leaves cause difficulties. Tussock grasses often have dead sections within the base and the difficult question then arises as to whether these sections should be included in the basal area or not.

Point quadrats are commonly used to measure basal cover in grassland vegetation and the limits of error, whether partitioned into individual species or expressed as total cover; depend on the amount of cover and the number of points employed. It is important that the sampling points are farther apart than the diameter of the largest units or clusters of vegetation. In addition, the points must be adequately distributed over the area surveyed. If these conditions

are met, then the estimates obtained by point quadrats follow a binomial distribution. The number of points required to provide a given accuracy decreases as the percentage basal cover increases up to about 50% (Tidmarsh and Havenga, 1955).

Canopy cover is the projection of the plant canopies on to the soil surface, usually expressed as a percentage. The canopy cover of an area of grassland can change dramatically in a very short period of time, e.g. by grazing or fire, and re-growth may be slow or rapid, or may be stable, e.g. the canopy cover of the shrub component of semi-arid grass/shrub communities.

Because the canopies of different individuals and different species can overlap, the total can add up to more than 100% (Whalley and Hardy, 2003). The percentage of the area covered by bare ground, stones or litter can also be estimated at the same time. Measurement of canopy cover in grasslands can often be difficult because the grass leaves may have a vertical or near vertical orientation. The very act of walking about in the grassland can often cause these leaves to become horizontal and therefore effectively increase the canopy cover. Care must be taken that canopy cover is not substantially affected by sampling activities.

The usual method of estimating canopy cover is to use a point quadrat frame, such as the Levy bridge (Levy and Madden, 1933; Brown, 1954), where the points can be slowly lowered through the vegetation and hits of individual leaves recorded. Where the leaves of individual species can be identified from their morphology, the contribution of the leaves of different species to the canopy cover can be estimated. The use of point quadrats to estimate canopy cover in tall grassland is impossible in windy weather and when the height is more than 0.5 m (Whalley and Hardy, 2003).

Canopy cover in sparse grasslands can be estimated by measuring the intercept occupied by the canopies of individual species on a line or tape stretched across the grassland. The lengths of the intercepts occupied by the canopies of individual species are then added up and expressed as a percentage of the total length to give the percentage canopy cover of each species. This method will usually lead to higher estimates of canopy cover than the careful use of pins in a point quadrat frame (Brown, 1954).

Several techniques for the estimation of herbaceous biomass have been developed. The absolute gravimetric or direct harvest method applied to small sub-plots is generally too time-consuming for operational work. Visual estimation is rapid and reasonably accurate when carried out by local experts (Pieper, 1988). Wagenaar and de Ridder (1986) used a double sample of clipped and visually estimated samples in order to calibrate the visual estimation. The survey was carried out by two separate teams to check the consistency of the estimates. A combination of gravimetric and visual estimation using a regression relationship, was also applied by Garcia-Daguerre (1993). The method is fairly easy to implement but the calibration stage can be time consuming because each surveyor needs to be calibrated separately.

Mitchell (1982) described the use of a rising plate meter for estimating grass biomass in Australian pastures. The rising plate or disc meter needs to be calibrated against clipped quadrats. The disc is dropped from a standard height onto the grass and there is a strong relationship between the height above ground of the disc and the amount of dry biomass (Sannieret al. 1998). Scriveret al. (1986) used a rising plate meter to estimate forage production and utilisation on improved annual pastures in California and also found a linear

relationship. Trollope and Potgieter (1986) successfully used a Disc Pasture Meter (DPM) in the Kruger National Park in South Africa to estimate grass fuel loads. It has the advantage of being objective, rapid and easy to operate. However, judgement is required when making measurements in stony ground to avoid false readings. Previous work in Etosha by Kannenberg (1995) produced the DPM calibration curve using the same calibration procedure as Trollope and Potgieter (1986). The curve includes points from a wide range of locations and the single curve seems to be generally applicable for all Etosha grasses.

Traditionally, biomass estimation involved harvesting of the trees. As the forest cover decreased, there became the need for non-destructive methods for volume/biomass estimation. Methods were developed to relate the biomass with girth and height. Component-wise biomass equations were developed, which were used to estimate biomass at the plot level. In last couple of years satellite remote sensing has been successfully used for biomass and productivity estimation. The unique characteristic of plants is displayed by its reflectance in red and infrared region of electro-magnetic radiation.

The use of remote sensing techniques is particularly relevant as it provides the capability to cover large areas in near-to-real-time, which would be impossible to achieve with any other methods. Early work on biomass estimation with remote sensing concentrated on the investigation of a relationship between ground biomass measurements and vegetation indices derived from ground or airborne radiometer data (Pearson *et. al.* 1976, Wagenaar and de Ridder 1986, Lamprey and de Leeuw 1986, Franklin *et. al.* 1991, Hanan *et. al.* 1993, McCloy *et. al.* 1993).

Normalized Difference Vegetation Index (NDVI) is an indication of green leaf biomass and green leaf area derived from remote sensed imagery. It is produced by combining sensor

bands based on the principle that values vary with the absorption of red light by plant chlorophyll and the reflection of infrared radiation by water-filled leaf cells. In most cases NDVI is correlated with photosynthesis, and since photosynthesis occurs in the green parts of plant material, the NDVI is normally used to indicate green vegetation cover. NDVI is thus usually calculated as the product of the ratio of two electromagnetic wavelengths, such that  $NDVI = \frac{\text{Near Infrared} - \text{Red}}{\text{Near Infrared} + \text{Red}}$ . This ratio may thus be produced from a number of different sensors, including Landsat and SPOT. The most common use of vegetation indices to date, however, involves the Advanced Very High-Resolution Radiometer (AVHRR) sensors (Archer, 2003). The Normalised Difference Vegetation Index (NDVI) described by Tucker (1979) was the most commonly used vegetation index although the PVI (Perpendicular Vegetation Index) first described by Richardson and Wiegand (1977) was also used by Taylor *et al.* (1986) in Niger. The results from these studies all identified strong relationships between green biomass and vegetation indices and improved the understanding of the influence of various components in the vegetation. Some also attempted to relate airborne NDVI to satellite NDVI derived from the NOAA-AVHRR sensor (Taylor *et al.* 1986).

Prince (1991) and Franklin and Hiernaux (1991) used physical models of vegetation Productivity. Although this approach is useful to understand vegetation reflectance characteristics, it has been rarely applied because its operational use is hampered by the necessity to create an extensive network of field stations to calibrate the model. This is unrealistic in semi-arid Africa where resources are limited. As a consequence, empirical approaches based on regression relationships are often preferred. Most studies (Prince and Tucker 1986, Prince 1991, Wylie *et al.* 1991, Diallo *et al.* 1991) estimated the end-of-season biomass based on the integrated NDVI.

However, Kennedy (1989) and Garcia-Daguerre (1993) obtained good relationships between green biomass and NDVI for single date AVHRR images in Tunisia and Mexico respectively. Although encouraging results were obtained from early studies, they did not lead to operational applications mainly due to difficulties in image acquisition at that time and to the high cost of field calibration.

The terrestrial net primary productivity (NPP) is an interface between plants and other processes, as it describes the removal of CO<sub>2</sub> from the atmosphere and potential delivery of carbon to herbivores, decomposers or humans interested in food or fibre (Field *et al.* 1995). The biospheric carbon pools are surface related and their size depends on the amount of carbon per surface unit in the form of biomass and extension of related ecosystems (Kale *et al.* 2002). Although only a small amount of total energy that is reaching to the earth is fixed to organic matter by green plants, it is far higher than total primary energy consumed.

World per capita CO<sub>2</sub> emissions are about 4.21 metric tons. In Asia it is about 1.03 metric tons, as compared to Europe with about 8.20 metric tons (Kale *et al.* 2002). Estimates of per capita carbon concentration are higher in North and Central America i.e. 13.59 metric tons (Anonymous 1995). These are the estimates at global and continental level, which are not sufficient to confirm that whether the forest in general and tropical dry deciduous forest in particular is actually the source or sink of CO<sub>2</sub>. This has led a worldwide debate over the role of forest in global carbon cycle. Paucity of data base regarding the carbon estimates is one of the major reasons for debate to continue. The uncertainty in the carbon estimates is caused by high uncertainties in rates of land-use change, rates of forest degradation, the amount of carbon in vegetation and soil of the forests being cleared, and the allocation of carbon after clearing and burning (Brown & Iverson 1992). In Indian context as much as 86% of the

forested area is under tropical forest, of which 53% is dry deciduous, 37% moist deciduous and rest is wet evergreen (Kaul & Sharma 1971). These forests are very significant in terms of carbon balance. Attempts to understand the role of terrestrial ecosystem of India have been made for biomass and productivity using ecological methods (Chaturvedi & Singh 1987; Rawat & Singh 1988; Singh & Singh 1989; Singh & Singh 1991) and still the understanding on these forests is poor. Extensive work has been done for biomass related studies, using conventional methods but it is limited to small area only. Remote sensing is a promising tool for regional and global level estimations. Remote sensing provides a synoptic view of the object in consideration from a vantage point. The concept behind this is that different objects respond in different manner in different wavelength bands. Interaction of radiation with plant leaves is extremely complex. Gates *et al.* (1965) studied the spectral characteristics of leaf reflection, transmission and absorption. In Indian context Roy *et al.* (1986) studied grassland spectral properties and their relationship with biomass.

The relationship varied among parameters like composition, leaf orientation and soil background. Among different factors affecting the reflectance from forest canopy, leaves play a major role. The changes that occur in the spectral properties of plant leaves during the growing season are significant. The very young folded compact and under developed leaves exhibit lack of chlorophyll. Absorption in the visible range is due to the proto chlorophyll and anthocyanin (Kale *et al* 2002). Gradually the leaf becomes more and more green, which decreases the reflectance. Finally a fully open leaf shows the normal spectral characteristic with the green reflectance strong and the red blue spectral regions much absorbed (Roy, 1989). Reflectance from green leaves is higher in NIR (Near Infra Red) region than in visible part of the spectrum hence vegetation is clearly separable in NIR band (Roy, 1989). Sensors having different bands sense the reflectance coming from different objects and record their

values in respective bands. Different statistical and spectral response modelling techniques are used for predictions at regional and global level (Roy et al 1989).

Ever since colonial administrators and western trained scientists became involved in sub-Saharan Africa in the early 20<sup>th</sup> century and were faced with the task of governing countries where livestock production was a major economic enterprise, the proper utilization of rangelands became a concern (de Leeuw and Tohill, 1990). While during most of the colonial era devastating epidemics such as rinderpest and pleuropneumonia kept the growth of livestock populations in check and during the 1950s and 1960s regional campaigns of eradicating these major cattle diseases created a continuous increase in livestock numbers. It is estimated that between 1963 and 1970 annual growth of cattle populations averaged 2.8%, but slowed down to 1.25% per annum during 1970 to 1980 (Antenneh, 1984).

While up to the 1950s constraints of feed shortages for livestock were outweighed by those of disease, concern over looming imbalances between supply and demand of grazing resources led to large investments in projects of water development, many of which were financed by foreign aid. This provision of water to hitherto underutilized grazing lands further stimulated herd growth, but at the same time encouraged more settled modes of production and reduced mobility. While watering rights of man-made traditional wells were tightly enforced and served as a control on over-exploitation, water sources that were publicly financed were open to all, breaking the age-old equilibrium between water and rangeland use (Sandford 1983, Swift 1984). The need for establishing criteria and ways for determining the carrying capacity of African rangelands became more strongly felt when in the 1960s and 1970s

several regions were hit by droughts (1960 to 1961, 1973 to 1976 in East Africa; 1969 to 1973, 1979 in West Africa) causing enormous stock losses.

Meissner (undated) states that the term "carrying capacity" has different meanings for different people, and this is indeed illustrated by the number of different definitions that exist. In other papers, carrying and grazing capacity is understood to be as follows (after Trollope *et al.*, 1990): Carrying capacity: the potential of an area to support livestock through grazing and/or browsing and/or fodder production over an extended number of years without deterioration of the overall ecosystem. Grazing capacity: the productivity of the grazeable/browsable portion of a homogeneous unit of vegetation expressed as the area of land required to maintain a single animal unit over an extended number of years without deterioration to the soil.

Carrying capacity (CC) or grazing capacity (GC) can also be defined as the maximum possible stocking of herbivores that rangeland can support on a sustainable basis (FAO, 1988). Estimates of CC are commonly based on the assumption that livestock require a daily dry matter (DM) intake equivalent to 2.5% to 3.0% of their bodyweight. Thus, for a tropical livestock unit (TLU) of 250 kg of weight, 2.3 to 2.7 t of dry feed per annum is needed. To calculate an appropriate balance between forage supply and demand three multipliers are additionally required to adjust for: - grazing efficiency (the proportion of total herbage livestock can harvest

- forage loss (due to trampling, fouling and decomposition).
- proper use, which is the maximum proportion of forage that can be grazed without causing rangeland deterioration (FAO 1988).

Although each of these three factors needs consideration, most estimates have used a single multiplier that combines adjustments for all. For example, Le Houérou and Hoste (1977) assumed that, in the Sahel, total dry matter (TDM) contained 40% edible forage, while in South Ethiopia, Cossins and Upton (1987) stated that one TLU required 8 t DM per annum which converts to a utilization rate of about 30%. Van Wijngaarden (1985) proposed a proper use factor of 45% of TDM during the dry season based on his finding that when use was higher, perennial grass cover declined in the subsequent growing season.

Schmidt *et al.* (1995), stated that it is impossible to accurately determine the grazing capacity of an area because of the large number of influential variables. When one factor changes, grazing capacity also changes to a greater or lesser extent. A simple example is the effect of rainfall on grazing capacity especially in an arid country like Namibia. It remains essential to continue attempting to estimate grazing capacity, as it forms a strong basis for sustainable rangeland utilization (vander Westhuizen *et al.* 2001).

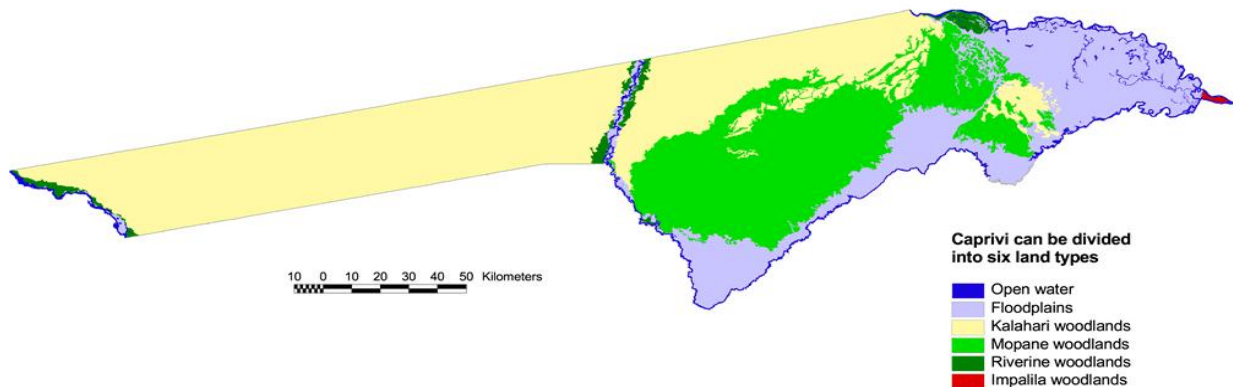
Reduction of herbaceous TDM due to woody cover has been discussed by several authors. In Kenya, van Wijngaarden (1985) found that for each 10% increase in woody cover, perennial herbaceous cover declined by 7% reaching zero cover when the woody canopy reached 90%. Rains and Kassam (1979) developed a non-linear relationship where at 20% woody cover TDM was reduced to 73%, and to a mere 17% when the ligneous stratum reached 60%.

Timberlake and Reddy (1986) used this relationship to adjust their estimates of CC for razing lands of Mozambique. An even large effect of the tree strata on herbaceous TDM was reported in the sub humid zone in Mali with a mean rainfall of 1,100 mm. Without tree cover,

recorded yields were 5 t DM ha<sup>-1</sup> which dropped linearly to 1 t when tree cover increased to 40% (Penning de Vries and Djiteye 1982). Rutherford (1978) confirmed the inverse relations between herbaceous production and wood cover in Southern Africa, and for his carrying capacity map in Botswana. Field (1978) assumed reduction of 5% in CC per every 100 units of trees/shrubs ha<sup>-1</sup>. However, decline of herbaceous biomass due to woody cover is offset somewhat by increased browse production, the magnitude of which depends on species composition and degree of woody cover.

The research study was conducted in the Caprivi region, located in the north east of Namibia. The population of six vegetation types of Caprivi region have were studied by purposively sampling three vegetation types that have most grazing potential; flood plains, mopane and Kalahari woodlands. The other vegetation types namely, open water, riverine woodlands and Impalila woodlands are of insignificant value to foraging animals and therefore have been excluded in the study.

### Vegetation types of Caprivi



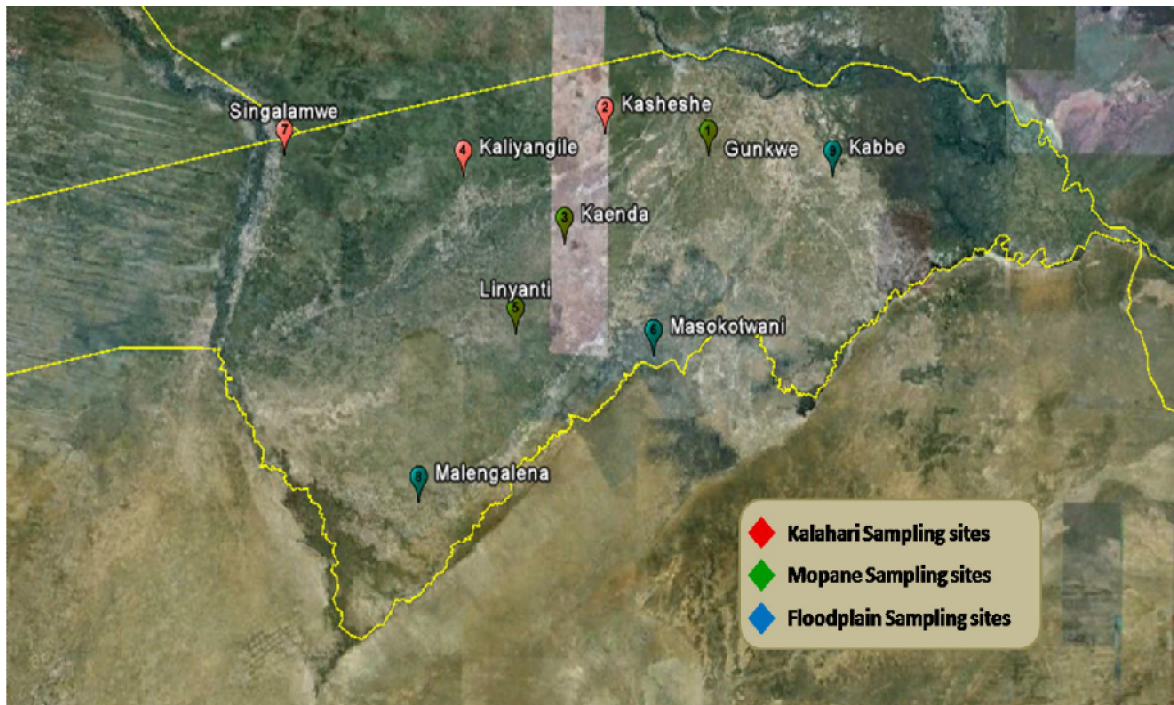
Source: IRDNC & Saving planet Earth

In each of the three considered vegetation type, three transects were established, one each in degraded, moderate and good rangelands sites.

All different areas that belong to each of the three vegetation types were subjected to a complete randomisation to determine the areas under which the study was conducted. Agricultural Extension Technicians responsible for sampled areas were consulted together with local farmers in determining the condition of the rangelands in various sites of the area. Stratified sampling method was employed at this level to figure out degraded, moderately grazed and good sites resulting in fairly representative outlook of the whole vegetation category. This was done by way of touring the sampled areas to verify the class under which the transect falls. In the Kalahari woodland vegetation type, nineteen (19) areas were subjected to a complete randomisation using random digits and three areas namely; Kasheshe, Kaliyangile and Singalamwe were sampled out for verification of rangeland condition.

A similar method was used for Mopane woodlands and floodplains. Three areas out of a total of twenty nine (29) areas were sampled under Mopane woodland namely Gunkwe, Kaenda and Linyanti. Out of the thirty five (35) areas under flood plains the three sampled areas were Masokotwani, Kabbe and Malengalenga.

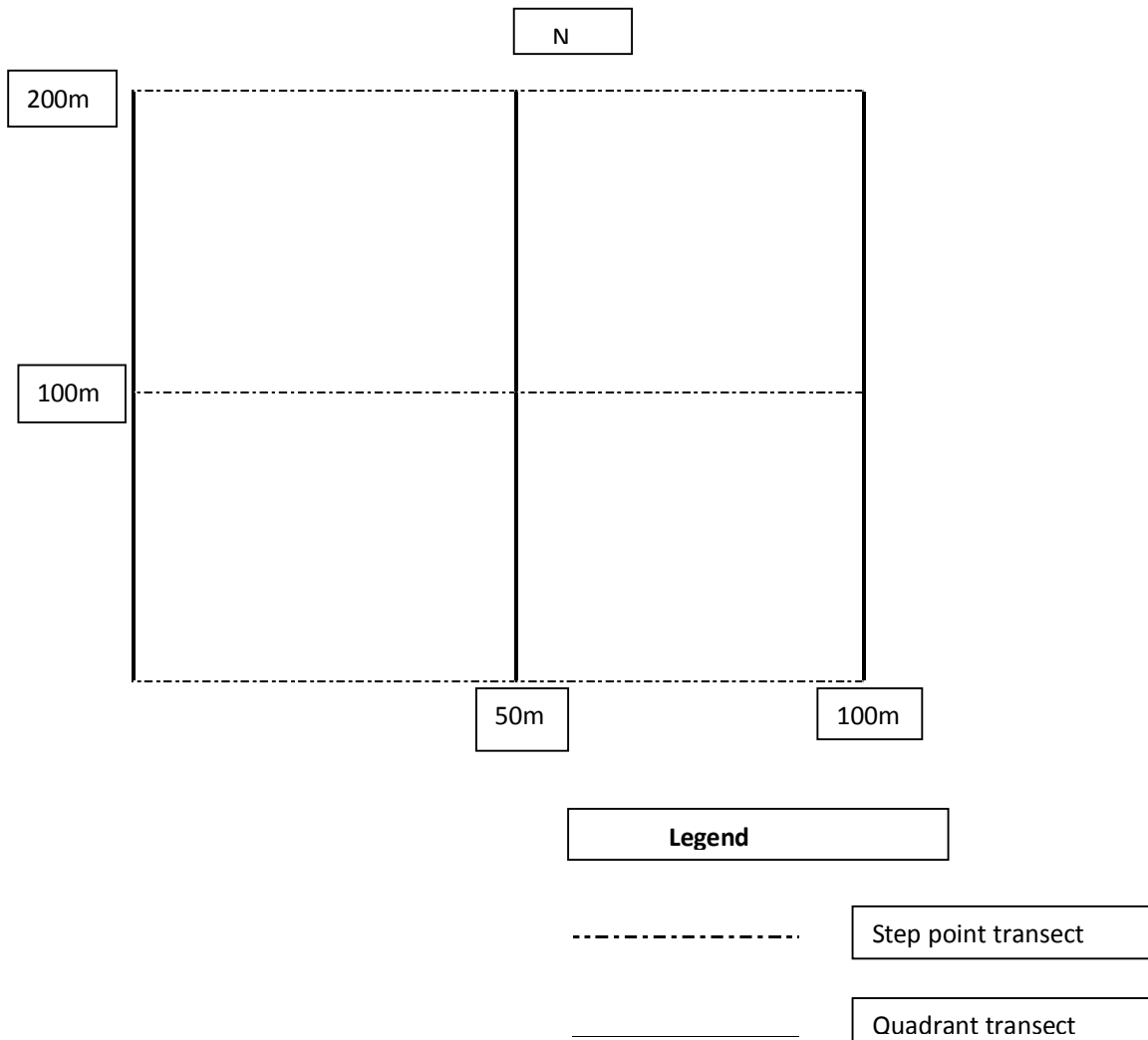
Caprivi map showing study sites



Source: Espach, 2011.

A transect of 200m was laid down for clipping of grasses using 1m<sup>2</sup> quadrant and 20m between quadrants. Each transect was replicated twice with 50m between replicates. That equates to about 33 quadrates per clipped sites. The same site was used for botanical composition. The transect for determining botanical composition and land cover was laid perpendicular to the quadrant transect and measured about 100m long with two replicates of 100m apart.

Graphically the research design is shown below.



In order to assess the different parameters, the research project employed a number of methodologies which are given below:

Clipping was carried out in March and April 2011 to coincide with the herbaceous vegetation maturity. At every clipping site, a sub-transect of eleven, 1m<sup>2</sup> quadrant (20 paces apart) were

clipped. All herbaceous matter from the quadrant were clipped off at ground level (representing maximum standing biomass) and sorted into six categories.

1. All *Schmidtia pappophoroides* tufts were clipped separately and the number of tufts clipped counted. In this manner, the density (tufts/m<sup>2</sup>) and biomass (grams DM/tuft) of this valuable indicator grass was established, as well as its relative contribution to total herbaceous yield.
2. All other desirable perennial forage grasses besides *Schmidtia pappophoroides*, viz. *Antephora pubescens*, *Brachiaria nigropedata* and *Panicum* spp. were clipped separately, without counting tufts, to establish the relative contribution of desirable perennial grasses to total herbaceous yield.
3. All annual and perennial *Aristida* spp, commonly indicative of rangeland degradation, were clipped separately, without counting tufts, to establish the relative contribution of degradation indicator grasses to total herbaceous yield.
4. All other perennial grasses besides those already mentioned, were clipped separately, without counting tufts, to establish the relative contribution of all perennial grasses to total herbaceous yield.
5. All other annual grasses besides the annual *Aristida* spp. were clipped separately, without counting tufts, to establish the relative contribution of annual grasses to total herbaceous yield.
6. All dicotyledonous herbs and forbs were clipped separately, without counting plants, to establish the relative contribution of dicotyledonous herbs and forbs to total herbaceous yield.

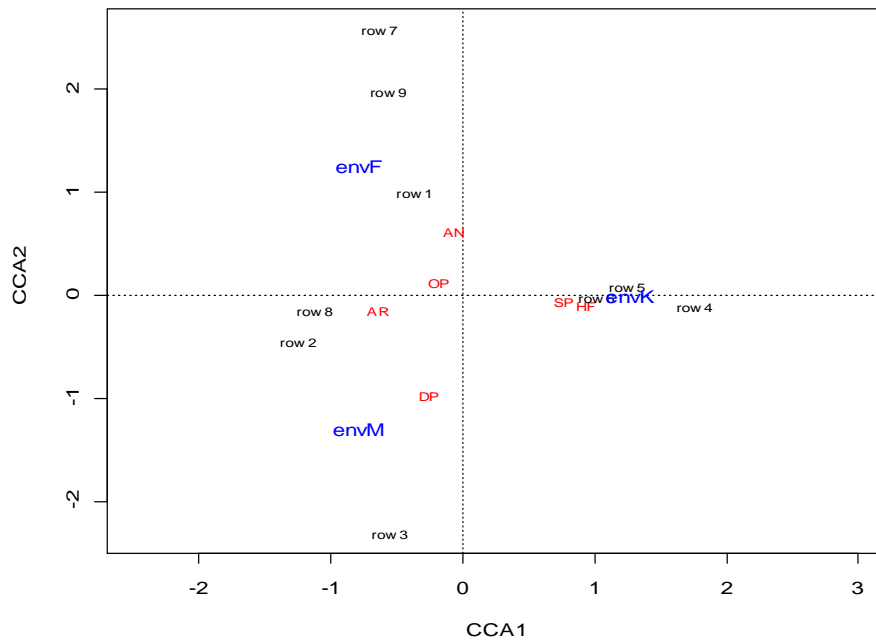
Sub transects were laid down 50 paces between clipping opportunities. The six separate bags of clippings derived from every sub-transect was weighed wet and a sample taken, weighed and placed in the drying oven at 70<sup>0</sup>C for 24 hours. The dried sample was removed from the

oven and weighed for calculation of the percentage dry matter content. The data were statistically analysed using the Chi square and the Analysis of variance (ANOVA) methods.

After clipping the quadrants, vegetation was assessed in terms of its botanical composition and canopy cover of the soils. These were derived from the systematic step point method perpendicular to the direction of the sub-transect using a two meter (2m) falling rod. Three sub- transects of 100m apart were assessed maintaining a west east direction.

Botanical composition was calculated as the abundance of species (strikes on a plant species divided by total strikes X 100) and canopy cover of the soil as the percentage of total strikes that fell on or beneath a plant canopy.

Figure 4.1 shows the distribution of vegetation categories within the three vegetation types. *Schmidtia pappophoroides* and herbs and forbs were found to be more abundant in Kalahari woodlands (K). In Mopane (M) woodlands, it was found to be dominated by desirable perennials and also edging the floodplains (F) slightly in the abundance of *Aristida* species. Annuals were more predominant in floodplains while other perennials were recorded in all vegetation types but slightly more in floodplains.

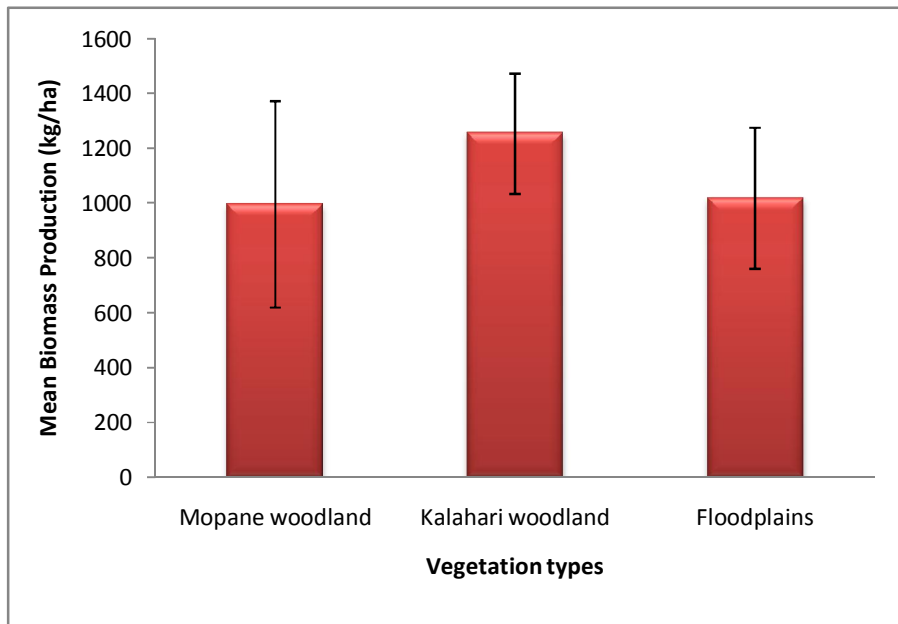


: Biplot showing distribution of species in relation to the three vegetation types

4.2

Alpha	0.05
degrees of freedom	10
Calculated Chi-square	3564.836
Critical value of Chi-square	18.30704
Probability of observed Chi-square	0

Figure 4.2 indicates that there are deviations in the mean biomass production of different classes of the three vegetation types. However, Kalahari woodlands showed the highest mean total biomass production (1254.56kg/ha) as compared to Mopane woodlands (996.03kg/ha) and Floodplains (1018.4kg/ha). Statistically there was a significant difference (df = 10,  $P < 0.05$ ) in the mean biomass production of the herbaceous plants among the three vegetation types of Caprivi.



Comparison of total mean biomass production among the three vegetation types.

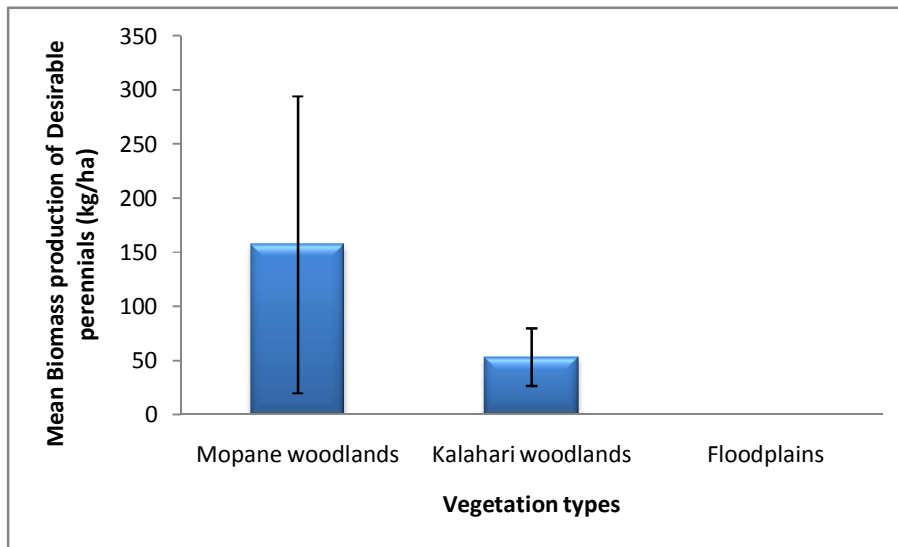
Bars indicate SEs.

#### 4.2.2 *Schmidtia pappophoroides*

The mean biomass production of *Schmidtia pappophoroides* was different between the three vegetation types. Mopane woodland and Floodplain were slightly similar (70.6 kg/ha and 49 kg/ha respectively) but the huge difference was observed with Kalahari woodlands (363 kg/ha). The analysis presented above indicates a significant difference with the chi-square contribution of 205.0403, 512.036 and 119.096 for Floodplains, Kalahari and Mopane vegetation types, respectively

Comparison of the mean difference in biomass of *Schmidtia pappophoroides* between the three vegetation types. Bars indicate SEs

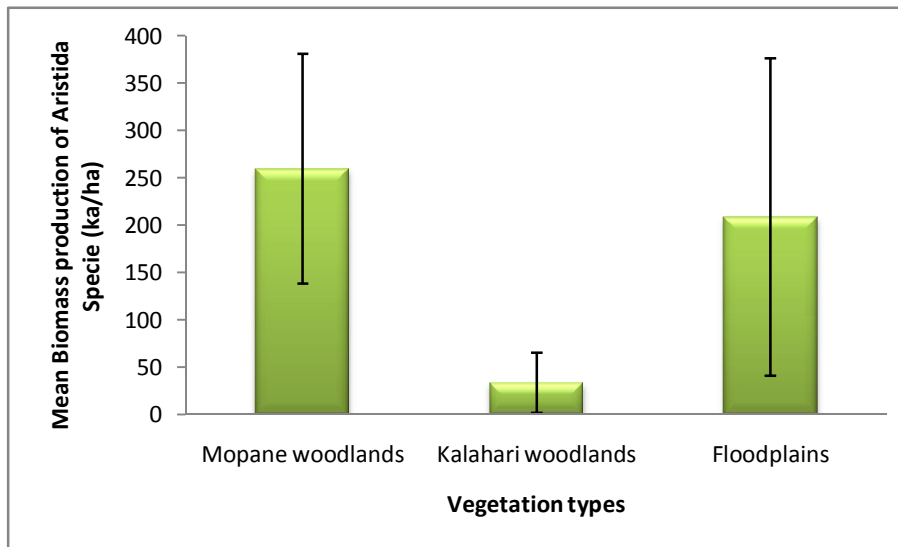
Three species were classified under *Desirable* perennials namely; *Panicum* species, *Antephora pubescens* and *Brachiaria nigropedata*. The mean biomass production (kg/ha) of *Desirable* perennial species indicates differences among the three vegetation types. This study has discovered that none of the desirable species was recorded in the Flood plains.



Mean proportion of biomass production of Desirable species (*Antephora pubescens*, *Brachiaria nigropedata*, *Panicum* Species) among the three vegetation types of Caprivi region. Bars indicate SEs

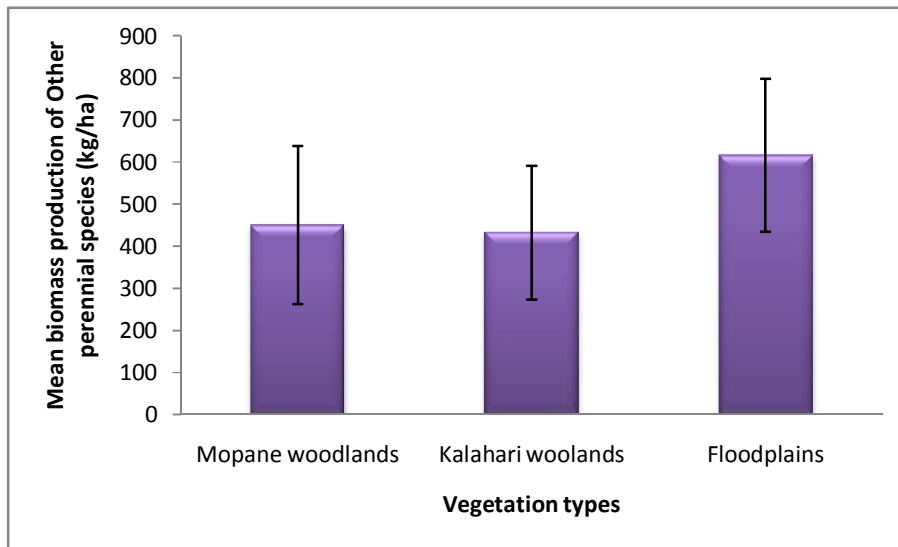
### *Aristida*

All *Aristida* species (annuals and perennials) were classified into one group. Unlike *Schmidtia pappophoroides* and desirable species that fell short in the Floodplains, *Aristida* species marked its abundance in this vegetation type. The *Aristida* species (Figure 4.4) were relatively high in Mopane and Floodplains (259.53 and 208.66 respectively) while low in Kalahari woodlands (33.93). *Aristida* species was significantly different ( $P < 0.05$ ).



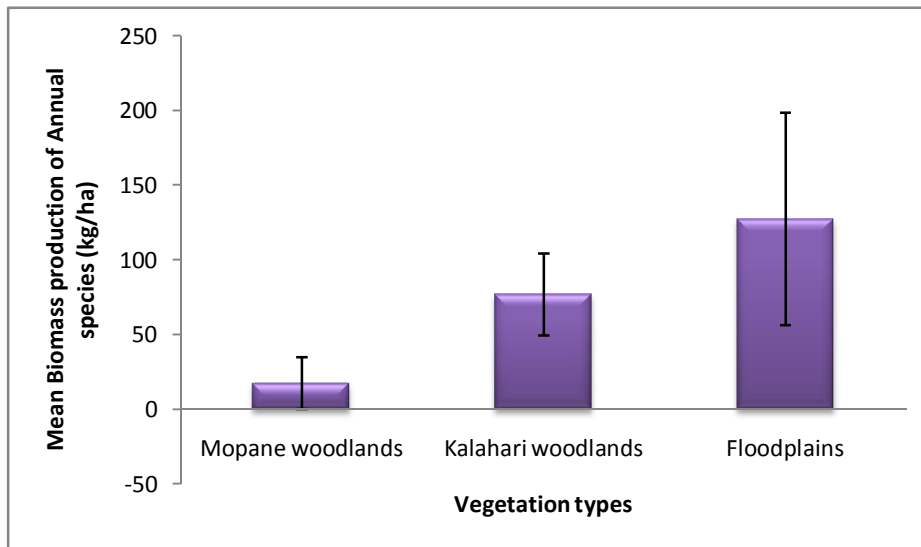
Mean of biomass production of *Aristida* species between the three vegetation types in Caprivi region. Bars indicate SEs

This category was inclusive of all perennial herbaceous species other than *Schmidtia pappophoroides*, desirable species as indicated above and perennial *Aristida* species. The mean differences of other perennials species among the three vegetation types was not relatively low (450.66, 432.8 and 616.66 for Mopane, Kalahari and Floodplains respectively) as compared to the above three classes. There was no significant difference ( $P = 0.265$ ) observed between the three vegetation types.



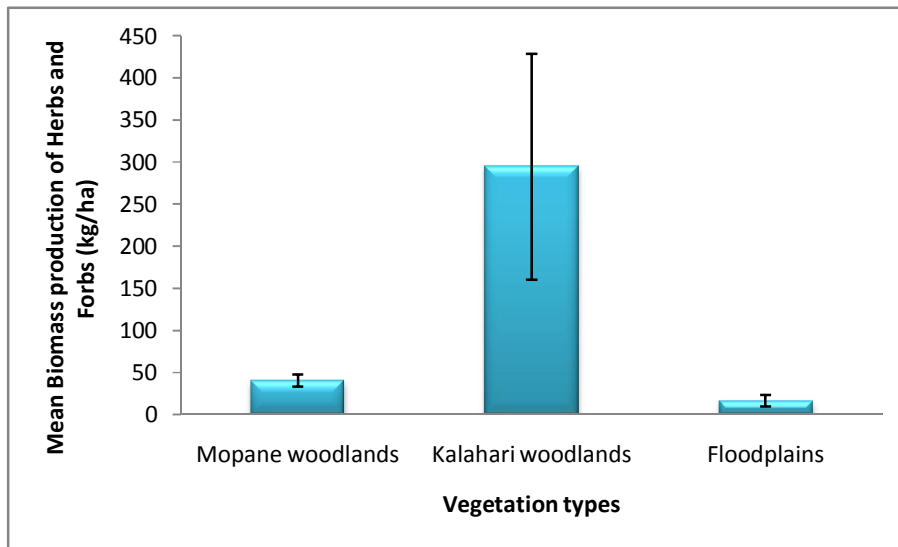
Comparison of means for biomass production of other perennial species among the three vegetation types. Bars indicate SEs

In this category, all the annual herbaceous plants other than *Aristida* species were considered. Like *Aristida*, means of Annual herbaceous species indicated to be high in Floodplain vegetation type (127.4) as compared to Mopane and Kalahari woodlands (17.33 and 76.76 respectively). The Annual species also contributed to the significant difference of the total biomass production with chi-square contribution of 148.2021, 2.3884 and 111.8414 for Floodplains, Kalahari and Mopane respectively.



Biomass production of annuals species between the three vegetation types. Bars indicate standard errors (SEs)

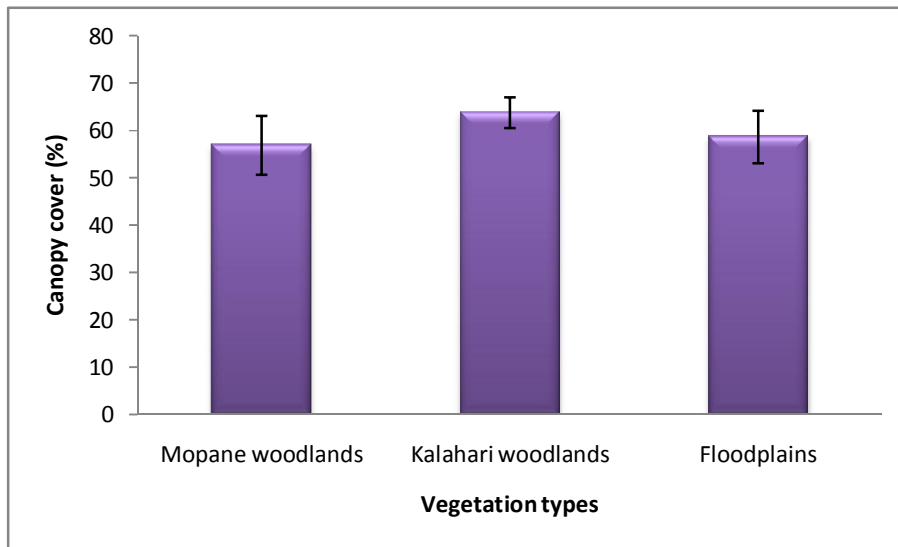
This category encompassed all the dicotyledonous herbs and forbs into one class. This category (Figure 4.7) indicated low biomass in Floodplains and Mopane woodlands (40.83 and 17 respectively) while the biomass in Kalahari was high (294.4). Herbs and Forbs also contributed positively to the overall significant difference ( $P=0$ ) of total biomass production of the three vegetation types in Caprivi.



Comparison of biomass production of Herbs and Forbs among the three vegetation types of Caprivi region. Bars indicate SEs.

The Shapiro-Wilk test was used to determine if the data was normally distributed, and an ANOVA was used to determine potential differences in the percentage cover between the vegetation types.

There was no significant difference ( $P=0.641$ ) in the mean percentage canopy cover between the three different vegetation types in Caprivi region. A higher proportion (63.73%) of cover was recorded in the Kalahari woodlands (Figure 4.8). The proportion of cover in the other two vegetation types (Mopane woodlands and Floodplains) was relatively similar (56.86% and 58.66 % respectively).

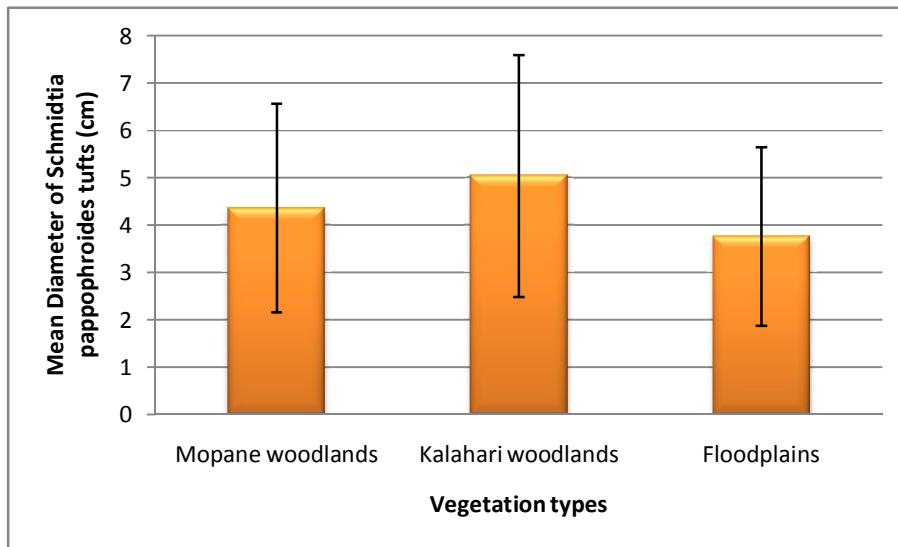


Proportion of cover in the three vegetation types of Caprivi. Bars indicate SEs.

### *Schmidtia pappophoroides*

The data was transformed using the square transformation to achieve normality, and an ANOVA was used to determine potential differences in the diameter of Sp tufts between the three vegetation types.

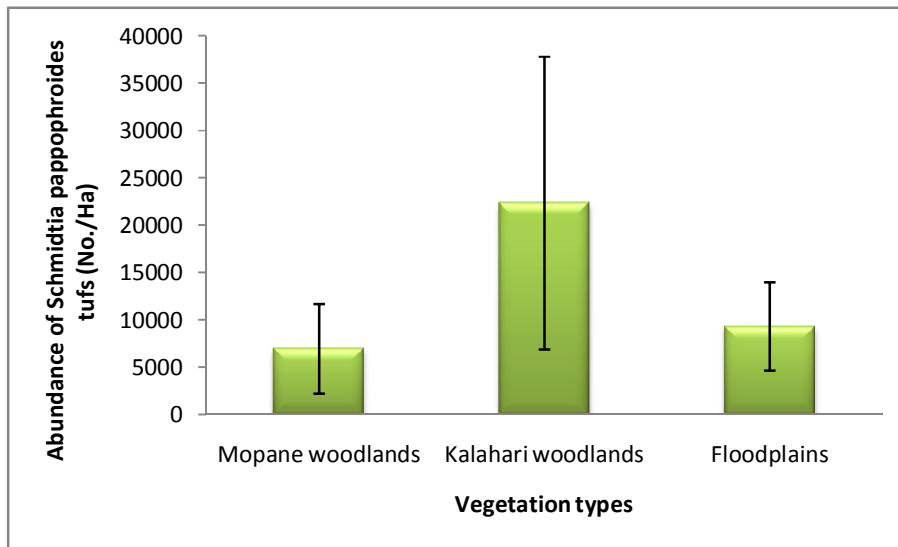
There was no significant difference ( $P=0.922$ ) in the mean diameter of *Schmidtia pappophoroides* between three vegetation types. However, *Schmidtia pappophoroides* tufts in Kalahari woodland (Figure 4.9) were bigger (5.04 cm) than those of Mopane (4.36 cm) and Floodplains (3.76 cm).



Mean diameter of *Schmidtia pappophoroides* in different vegetation types of Caprivi. Bars indicate SEs.

### *Schmidtia pappophoroides*

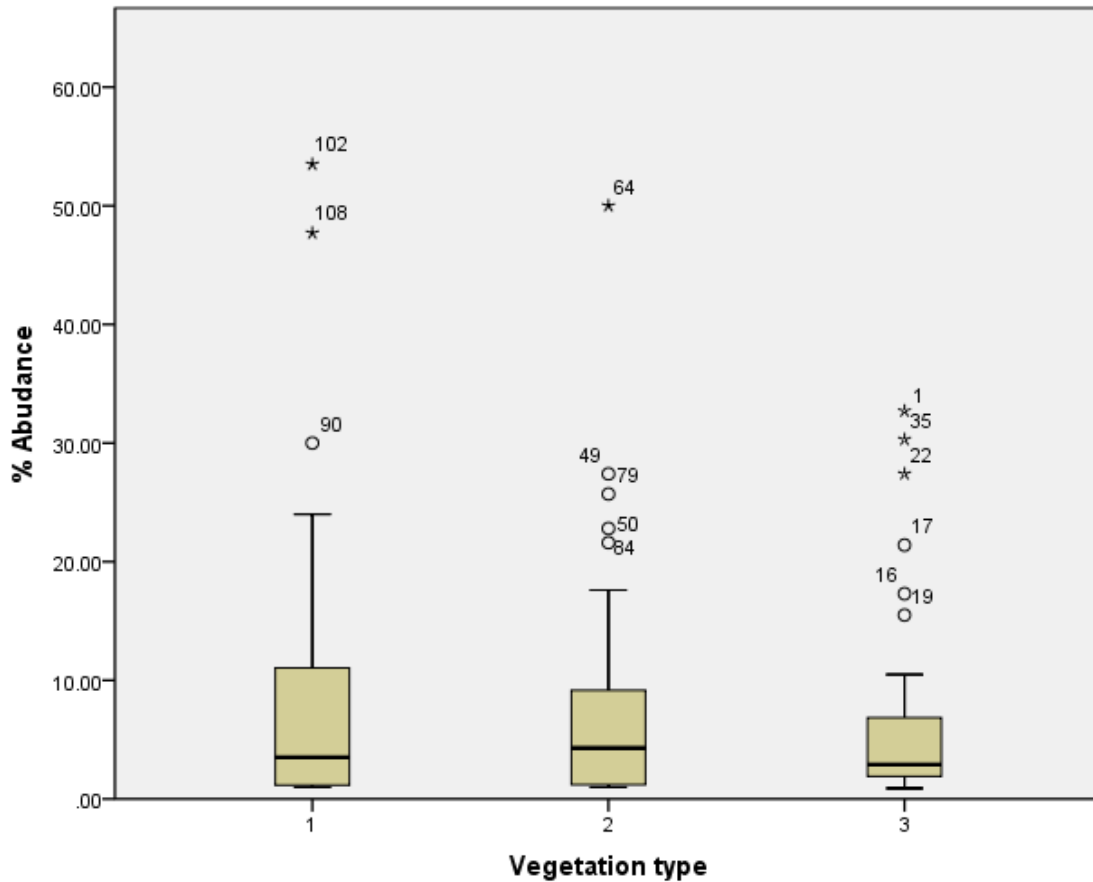
There was no significant difference ( $P = 0.522$ ) in abundance of *Schmidtia pappophoroides* between the three vegetation types in Caprivi region. Kalahari woodlands was better off in terms of abundance of this specie (22333.3/ha) as compared to Mopane woodlands (7000/ha) and Floodplains (933.33/ha).



Abundance of *Schmidtia pappophoroides* tufts in different vegetation types.

Bars indicate SEs

There was a significant difference ( $P = 0.023$ ) between the means of different vegetation types. The mean abundance for Mopane woodlands is higher (9.379) than Kalahari woodlands (7.694) and Floodplains (6.376). The result assumes a significant quantity of outliers as shown in Figure 4.11.



Mean percentage abundance of botanical composition in different vegetation types (1 = Mopane woodlands, 2 = Kalahari woodlands, 3 = Floodplains). Bars indicate SEs.

#### 4.6 Grazing Capacity

The total grazing capacity based on herbaceous biomass production for the rangelands of Caprivi has been determined as follow;

Total Ha: 1452800

Total Biomass production (DM): Mopane = 996.03 kg/ha

Kalahari = 1254.56 kg/ha

Floodplains = 1018.4 kg/ha

Average biomass production: 1089.66 kg/ha.

It is known from literature that a kilogram of animal biomass needs 3% per day in DM to sustain itself (Espach *et al*, 2006). The average weight of cattle (referred to as Large Stock Unit) in Namibia is 450 kg (de Leeuw and Tothill, 1990). It is a requirement when determining grazing capacity that only 50% of total biomass is allowed to be usable to maintain vigor and allow for other losses such as trampling and termite activities (FAO, 1988).

Total grazable biomass production = 544.83 kg/ha X 1452800 (DM) ha = 791529024

3% of 450 kg = 13.5 kg

For one Large stock Unit (LU) it will require 13.5 kg X 365 days = 4927.5 DM kg per season.

The total number of Large stock Unit (LU) to be carried by the Caprivi rangelands (based on the Total Herbaceous production) during the 2010/2011 grazable period of one year was estimated to be 160635.

The above total grazing capacity equates to approximately nine ha per Large stock Unit.

The focus of the degradation debate is grazing and as a result forage quality has been used as the major indicator of degradation (*e.g.* van Vegten 1983; Ringrose *et al.* 1990; de Queiroz 1993). This study indicated that in Kalahari woodlands, the contribution of *Schmidtia pappophoroides* and herbs and forbs are higher than in other vegetation types (Figure 4.1). Desirable perennial species and other perennial (Figure 4.3 and 4.5 respectively) species also occur in acceptable amounts. It is a reflection of a good rangeland in comparison to the other two vegetation types. FAO, 2001 classified rangelands as "excellent" if 76-100 percent of desirable indicator species are present, "good" for 51-75 percent, "fair" for 26-50 percent, and "poor" for 0-25 percent.

Most of Namibia's ranching products are obtained from grazing livestock species such as sheep, cattle and ostriches (MAWF, 2006). Goats, also grazers, are of much smaller significance economically although they are very valuable to the impoverished farmers in communal areas. Most wild game species are mixed feeders, utilizing both grass and bush. When plants which animals prefer to eat are known, then the rangeland can be manipulated, so that it consists of a balance of grass and bush, to contain more of the preferred forage species than of the less- and un-preferred forages.

In the central, northern, eastern and north-eastern savannas of Namibia, all of them based on aeolian Kalahari sands, cattle prefer two perennial grasses, *Antephora pubescens* and

*Schmidtia pappophoroides* (Rothauge, 2007). These can constitute as much as 70 % of their diet (if they are plentiful in the rangeland) (Rothauge, 2006). These preferred grasses are very abundant in a savanna rangeland in good condition (Rothauge, 2005; 2006) and can indicate to the rancher whether or not the savanna can withstand the applied grazing pressure (Rothauge, 2006).

In the Floodplains, it has been discovered by this study to have abundance in annual grass species, an indication of poor rangeland (Figure 4.6) and other perennial grass species (Figure 4.5). *Aristida* species (Figure 4.4) was discovered to be more pronounced in Mopane woodlands and Flood plains and very low in Kalahari woodlands. These results clearly indicate signs of poor rangelands in the Floodplains in comparison to Kalahari and Mopane which harbours abundance of *Schmidtia pappophoroides* and Desirable perennial species respectively.

It is clearly evident that Kalahari woodland was discovered by this study to be in good condition. Figure 4.9 showed the mean diameter of *Schmidtia pappophoroides* in different vegetation types of Caprivi. With the mean diameter of 5.04, Kalahari woodland had the biggest *Schmidtia pappophoroides* tufts. The mean total number of *Schmidtia pappophoroides* tufts was also higher in Kalahari woodlands in comparison to the Mopani and Floodplains. With these results, Kalahari woodlands could be regarded to be the most preferable grazing vegetation type of all rangelands in Caprivi.

The study shows that the rangelands of Caprivi have a grazing capacity of nine ha per Livestock Unit. Such results will indicate high productivity to any Namibian farmer considering the fact that the best rangelands in Namibia have the grazing capacity of 12 ha per Large stock Unit (Lubbe *et al*, 2005). However, the study did not consider other factors such as palatability of species. Different palatability factors are allocated to different grass species encountered during surveys. The palatability factors for all grass species occurring in the survey are added together to arrive at a total palatability factor for the herbaceous component of that particular land cover unit (Espach *et al*, 2006). This could have lowered the grazing capacity to a certain extent because some species have low palatability factors.

A common rule of thumb for planning an appropriate level of pasture utilization is 'take half, leave half,' or a 50 percent use of annual available forage production. This degree of forage utilization includes not only herbage actually consumed by the animal but also damage to the plants caused by trampling, loafing, and losses owing to other, non-livestock factors (e.g., loss to insects or wildlife). Some experts estimate that up to approximately 25 percent of total annual forage production is lost to livestock damage and competitive uses under continuous or set-stock grazing programs (Lyons and Machen, 2001).

Overstocked areas occur mainly in north-central Namibia, along the Okavango River, on the eastern floodplains in Caprivi, and typically around large settlements. Overstocking in these areas occurs due to the presence of large numbers of cattle and goats (Rothauge, 2007).

The concept of grazing capacity assumes that livestock are kept within fixed areas of land with recognized boundaries. Such conditions rarely prevail in communal rangelands of

Namibia particularly in the Caprivi Region. Mobility of stock together with communal land tenure and fluid rights of access to grazing and water do not facilitate the computation of meaningful carrying capacities. In both transhumant and agro-pastoral systems, stock rely on several niches within the ecosystem, while in areas with cropping, residues from crops are an important source of feed. The contributions of these different sources of feed to the annual diet are difficult to quantify nor is it easy to determine how much land is utilized by each herd.

The scale of the grazing capacity assessment has an important bearing on its validity and usefulness. If direct interrelationships between animal output and feed supplies are aimed at, resources within the grazing orbit of the individual producer need to be determined. This is more easily achieved for individual mixed farmers than for nomadic or transhumant pastoralists. For these latter groups, communal use of grazing resources implies that only aggregate values of carrying capacity are meaningful, the size of the area being dependent on the boundaries of common use. These boundaries are still not defined in Caprivi apart from few communities where conservancies have been established. In most of Southern Africa, stock-owning farmers have stable usufructury rights to the land they cultivate, while communal grazing lands are shared with many owners. This implies that the scale at which grazing capacity must be estimated is that of the entire village area. (de Leeu and Tothill, 1990)

In developed countries, multi-species exploitation of rangelands is rather uncommon. Even if more than one species of livestock are kept, they are often allocated separate areas of grazing land. In Namibia, multi-species enterprises are the rule. In the more arid south, sheep, goats and game predominate, while in the central and northern areas, cattle and small stock are kept

by smallholder farmers and wild life also does exist. Consequently, several livestock enterprises are combined within the same management unit. As feed preferences between species differ, assessing the fraction of edible feed becomes more complicated, in particular where browse from woody species is an important component.

In the developed world, the concept of grazing capacity has been applied mostly to cattle production enterprises and as a consequence, graminoid herbage chosen by cattle has become the norm for identifying desirable species. Herbs, dwarf shrubs and taller woody species are classed as undesirable and would decrease grazing capacity in proportion to their abundance. In multi-species enterprises, emphasis on graminoid herbage would underestimate grazing capacity if the grazing value of herbs and woody species is negatively assessed (de Leeu and Tothill, 1990).

Although proven to be relatively accurate in grass dominated veld, there are still a number of shortcomings in the quantitative yield method of determining grazing capacity. Probably the most important one is that it measures only grass production while the vegetative production of herbs, dwarf shrubs, tall shrubs and trees is excluded. Currently the occurrence of these components in the veld is treated as a "bonus" additional to the calculated grazing capacity on grass. This brings about a degree of conservativeness in the final calculated grazing capacity figures. Although it is possible to determine the yield of these vegetative components the appropriate methodologies are time and labour consuming and therefore expensive.

Secondly, the figure of 3% of live weight is a very rough estimate and considered by Meissner (1995) to be not scientifically justifiable. He points out that where as a 200 kg calf may eat 6 kg of DM/day, an 800 kg bull will not eat 24 kg of DM/day. It is shown that the

intake for cattle could be much less (2.2- 2.3% of live weight) while the intake for sheep may vary from 2.9- 3.5% of live weight. This may bring about conservative stocking rates when applied on a cattle farm, while a sheep farm may be somehow overstocked.

After clipping and drying, the total grass biomass yield is decreased by 50%. This stems from the fact that where more than 50% of the foliage of a grass plant is removed, prolonged or complete root growth stoppage follows, which is reflected in poor shoot development (Crider,1955; Dahl,1995). It is a fact that animals select different plants when grazing and that plants will be defoliated to different levels in the same sward when grazed. In order to more accurately determine the grazing capacity one should therefore not use 50% across the board for all species but include utilization factors in the grass biomass yield calculation process. For example, Bester *et al.* (1985) found that where a stocking rate of six ha/LSU was applied, defoliation at the end of the grazing period for *Schmidtia pappophoroides*, *Stipagrotis uniplumis* and *Eragrostis rigidior* was 60%, 33% and 17% respectively. Higher stocking rates would bring about higher levels of utilization of the less palatable species, but such stocking rates would invariably exceed the acceptable level of utilization of the palatable species.

This indicates that the inclusion of utilization factors will contribute towards more accurate calculation of grazing capacity if sustainability is to be the underlying objective. Although it is quite possible to clip grass on a species basis and apply utilization factors when calculating grazing capacity it requires special knowledge on palatability and the diet selection patterns of domesticated animals.

Cover is an important ecological characteristic and is generally calculated as the percentage of ground surface covered by vegetation. Cover can be expressed in absolute terms (square meters/hectares) but is most often expressed simply as a percentage. Researchers use several types of cover to classify erosion potential, but the most common examples are foliar, canopy, ground, and basal covers. Foliar cover is the area covered by the aerial portions of plants, canopy cover is the area covered by the outer perimeter of foliage, ground cover is the percentage of ground covered by plants, litter, rocks and gravel at a site, and, basal cover is the area of ground covered by the basal (new growth) portion of the plants (National Applied Resource Science Center 1996). The cover types that are most relevant to erosion potential are ground cover and basal cover, since these estimates reflect the amount of plant materials situated directly on the soil surface.

Rangeland health assessments are needed to evaluate the state of the component ecosystems of the rangelands. Monitoring systems are needed to detect changes that are related to the probability of degradation (i.e. risk of crossing threshold to an alternate but less desirable state) (Westoby *et.al*, 1989). Monitoring is also needed to track the success or failure of restoration efforts. For both assessment and monitoring, it is necessary to have a suite of indicators that are sensitive to environmental stress, that focus on risk of degradation, and that are related to ecosystem function (Herrick *et al*, 1995). For rangeland health, the indicators must provide information which can be used to evaluate the capacity of the system to conserve and efficiently use water and nutrients and to support biodiversity, economic production and recreational uses.

This study has shown that canopy cover of herbaceous plants was more than 50% (Figure 4.8) in all vegetation types, an indication of good biomass productivity and consequently

grazing capacity considering other factors such as palatability to be constant. In areas of low quality and unpredictable rainfalls such as Namibia, rain fed crops is not preferable. Thus most of the arid and semi arid lands of the world are referred to as rangelands where livestock production is virtually the only suitable industry. The productivity measure chosen to be investigated is one that relates directly to livestock production and that is cover of vegetation particularly of preferred species.

A high number of species was recorded in the Floodplains (47) in comparison with Kalahari and Mopane (39 and 32 respectively). This is an indication of specie richness in these vegetation types. The setback of the floodplains vegetation type however is its abundance in annual species (Figure 4.6). which are not desirable to livestock. Literature reveals that botanical composition is subject to grazing management employed by the farm manager or community members. It is argued that grazing animals are powerful tool for a rangeland manager to use to either retain or alter species composition of grassland, (Whalley, 2000).

The consequences of open grazing were tested by Heady (1975) who mentioned that too many poorly managed animals will cause overgrazing and vegetation deterioration through several commonly accepted stages. The most palatable species selected first and the continuous of the practice reduce the vigor of the plants. The space vacated by desirable species became the expanded home of less desirable species, and annual invaders.

The drawback of open grazing in relation to time of use and damage was mentioned by Suleiman and Darrag (1982), that the nomads in the Sudan do not take into consideration the proper time of grazing. In most cases they graze an area when the plants are not ready for grazing. sometimes they graze when the soil is too wet, and this eventually cause damage to

both plants and soils. Ibrahim (1962) mentioned the consequences and the degradation related to nomadism under open grazing system and stated that the major causes of ecological degradation is overstocking which led to overgrazing damages, subsequent depletion of palatable grasses and tree species and the destruction of soil- water balance and causing microclimate changes.

To a certain extent this can justify the higher botanical composition of poor quality in the Floodplain vegetation types. High concentration of cattle numbers in close proximity to water has partially resulted in the desirable perennial species being replaced by annual species. Annual grasses are not persistent, therefore less reliable, generally less productive and less nutritious than perennial grasses; thus, animal production on an annual grass sward is less sustainable and the risks are greater.

## 6.1. Conclusion

The study was carried out in the North East region of Namibia, specifically the Caprivi region. The region was divided into three vegetation types with grazing potential. The objective of the study was to estimate the biomass production of the rangelands of Caprivi and subsequently determine the grass based grazing capacity.

A total of nine sites (three in each vegetation type) were randomly selected by sampling all areas found in each vegetation type. At each site three sub-transects were laid down in the South ó North direction (200m long and 50m wide) for clipping of quadrants. At each clipping opportunity, all herbaceous materials were clipped and placed in bags classified into six categories as follow; all *Schmidtia pappophoroides*, all desirable perennials, all *Aristida* species, all other perennials, all annual species other than annual *Aristida* and all herbs and forbs. This was done to determine herbaceous biomass production. All *Schmidtia pappophoroides* tufts were also counted and measured to determine the vigor of *Schmidtia pappophoroides* and subsequently rangeland condition.

At the same sites, three sub- transects were laid down (100m long and 100m between sub-transects) perpendicular to the quadrant sub-transects. Using a two meter falling rod (step point method), botanical composition and herbaceous canopy cover were determined.

Results showed that there was a significant difference ( $df = 10, P < 0.05$ ) in the total biomass production between the three vegetation types of Caprivi. Kalahari woodlands showed higher

mean biomass production (1254.56kg, DM/ha) in comparison to Mopane woodlands (996.03 kg, DM/ha) and Floodplains (1018.4 kg, DM/ha). However the study shows that there was no significant difference in herbaceous canopy cover ( $P = 0.642$ ) between the three vegetation types.

Similar results were encountered in the mean diameter of *Schmidtia pappophoroides* which was not significantly different ( $P = 0.522$ ) between the vegetation types. Equally there was no significant difference ( $P = 0.922$ ) observed in the mean number of *Schmidtia pappophoroides* tufts between the vegetation types. Botanical composition however showed a significant difference ( $P = 0.023$ ) between the three vegetation types.

This study also estimated the grazing capacity (nine ha/LSU) for the total rangelands of Caprivi based on herbaceous biomass production for the year the study was carried out. The concept of grazing capacity is useful for planning purposes, calculations of the average productivity of land in terms of feed resources, and expected output of livestock. While long term averages may be required for general forward projections, the limitations of such data should be fully recognised in the light of sharp fluctuations over time and space.

The ultimate validity of the grazing capacity concept rests on the recognition that feed resources are governed by an interlinked set of environmental factors, which determine the upper and lower limits of primary as well as secondary productivity in the short term but even more so in the long term perspective.

- a) This study has discovered that there are more annual species in the Floodplains in comparison to other vegetation types. This could be justification of a situation where desirable perennials species were overgrazed and subsequently replaced by annuals. It is recommended that provision of water in areas that are not grazed during the dry periods is crucial. This will reduce the concentration of livestock, including game in the floodplain areas during the dry season.
- b) The study has also revealed that the rangeland condition of Kalahari woodlands is better than Mopane woodlands in terms of measured indicators such as mean number and diameter and *Schmidtia pappophoroides*. This could be the result of grazing system employed by communities found in these vegetation types. Continuous grazing of under stocked rangelands results in desirable species being sacrificed while the less desirable remain under utilized. It is recommended that sedentary grazing system as practiced by some communities be encouraged to limit selective grazing to a certain extent.
- c) An important principle of rangeland management is that herbaceous plants (grasses) need time to recover from previous grazing or after fire to enable sustainability by way of photosynthesis and seed formation. It is recommended that communities form committees that will be responsible for developing and implementing the grazing plans to ensure simple rotation of cattle even by sedentary management.
- d) The Ministry of Agriculture (Directorate of Research) should assist communities with proper boundary demarcations in determining grazing capacity to be used as benchmarks for stocking rate control.

- e) Further studies need to be carried out that will take into consideration the browse contribution to the total biomass production which this study could not incorporate by using the Biomass Estimate from Canopy Volume (BECVol) model.
- f) Considering the time factor for carrying out such studies using the conventional clipping method, the use of remote sensing should be encouraged for better efficiency.

Abule, E., Snyman, H.A., Smit, G.N., (2005a). *Comparisons of pastoralists perceptions about rangeland resource utilization in the Middle Awash Valley of Ethiopia. Journal of Environmental Management* 75, 21635.

Abule, E., Snyman, H.A., Smit, G.N., (2005b). *The influence of woody plants and livestock grazing on grass species composition, yield and soil nutrients in the Middle Awash Valley of Ethiopia. Journal of Arid Environments* , 3436358.

Anonymous (1995). *A Report by the World Resources Institute in Collaboration with the United Nations Environmental Program and The United Nations Development Program.* Oxford University Press, New York.

Antenneh, A (1984) -Trends in sub-Saharan Africa's livestock industriesø *ILCA Bulletin* 18: 7-15.

Archer R.M. (2004). Beyond the ÷climate versus grazingö impasse: Using remote sensing to investigate the effects of grazing system choice on vegetation cover in eastern Karoo. *Journal of Arid environments* , 381 ó 408.

Bester F.V .Van Eck,J .A. and Steyn A.,J.(1985). Benutting van veld by verskillende produksiepeile en botaniese samestelling in die doringbos savanna .*Agricola*1. pp 69 - 72.

Brown, S. & L.R. Iverson. (1992). Biomass estimates for tropical forests. *World Resource Review* : 366-384.

Brown D. (1954). *Methods of surveying and measuring vegetation*. Bulletin number 42, Commonwealth Agriculture Bureau of pasture and field crops, Hurley, UK, pp 223.

Catchpole, W. R., and C. J. Wheeler. (1992). Estimating plant biomass: a review of techniques. *Australian J. of Ecol.* 17:121-131.

Chaturvedi, O.P. & J.S. Singh.(1987). The structure and function of pine forest in central Himalayas. Dry matter dynamics. *Annals of Botany* :237-252.

Cook, W. C, and J. Stubbendieck. (1986). *Range research: basic problems and techniques*. Society for Range Management. Denver, CO.

Cook W. C, and J. Stubbendieck. 1986. *Range research: basic problems and techniques*. Society for Range Management. Denver, CO.

Coppock, D.L., Reed, J.D., (1992). *Cultivated and native browse legumes as calf supplements in Ethiopia*. *Journal of Range Management* (3), 231-237.

Cossins, N J and M Upton (1987). The Borana Pastoral System of Southern Ethiopia. *Agricultural Systems* : 199-218.

Crider, F. J.(1955). Root growth stoppage resulting from defoliation of grass. U.S Dept. Agr. Tech. Bull. 1102. p23.

Crocker R.L. and Tiver N.S. (1948). Survey methods in grassland ecology. *Journal of the British Grassland Society* 3, 1 – 26.

Dahl, B. E. (1995). Developmental Morphology of Plants. In: D.J. BEDUNAH and R.E. SOSEBEE (Editors) Wild land Plants. Physiological Ecology and Developmental Morphology. Society for Range Management. 1938 York Street Denver Colorado 80206.

deQueiroz, J.S. (1993). Range degradation in Botswana: Myth or reality? *Pastoral Development Network Paper 35b*. Overseas Development Institute, London.

Diallo, O., Doiuf, A., Hanan, N. P., Ndiaye, A., and Prevost, Y., (1991). AVHRR Monitoring of Savanna Primary Production in Senegal, West Africa: 1987-1988. *International Journal of Remote Sensing*, 12, 1259-1279.

Espach C. (2011). (unpublished) *Google map*. Windhoek, Namibia.

Espach C. Lubbe L G. and Ganzin N., (2006). Determining grazing capacity in Namibia: *Approaches and methodologies*. Ministry of Agriculture Water and Forestry, Windhoek, Namibia.

FAO (2001). Interactions between livestock production systems and the environmental impact. Agriculture and Consumer Protection. Bulletin No. 45, Rome.

FAO (1988). *Guidelines: land evaluation for extensive grazing* 'FAO Soil Bulletin No 58 Rome.

Field, Christopher B., James T. Randerson & Carolyn M. Malmstrom. (1995). Global net primary production: combining ecology and remote sensing. *Remote Sensing of Environment* :74-88.

Field, D I (1978). *Potential carrying capacity of rangeland of Botswana* Ministry of Agriculture, Gaborone, Botswana.

Franklin, J., and Hiernaux, P. H. Y., (1991<sub>a</sub>). Estimating foliate and woody biomass in Sahelian and Sudanian woodlands using a remote sensing model. *International Journal of Remote Sensing*, , 1387-1404.

Franklin, J., Prince, S. D., Strahler, A. H., Hanan, N. P., and Simonett, D. S., (1991<sub>b</sub>). Reflectance and transmission properties of West African Savanna trees from ground radiometer measurements. *International Journal of Remote Sensing*, , 1369-1385.

Ganzin N. (2004). *Contribution of wide field satellite data to assist rangeland resources management in the arid environments of Kenya and Namibia*. Doctorate Thesis, University of Orleans, France.

Garcia-Daguerre, R. R., (1993). *Coarse Resolution Remote Sensing for Rangeland Monitoring in North-Central Mexico*, PhD thesis, Silsoe College.

Gates, D.M., H.J. Keegan, Shceleter & V.R. Weidner (1965). Spectral properties of plants. *Applied Optics* :11-20.

Goodall D.W. (1952). Some considerations in the use of point quadrants for the analysis of vegetation. *Australian Journal of Science* 1- -41.

Hanan, N. P., Prince, S. D., and Franklin, J., (1993). Reflectance properties of West African Savanna trees from ground radiometer measurements. II. Classification of components. *International Journal of Remote Sensing*, , 108161097.

Hankins J. And Launchbaugh H. (2001). *Range vegetation Inventory*, Idaho Rangeland Resource Commission, Moscow, Russia.

Heady H F (1975). Range Management. McGraw-Hill, New York pp. 460.

Suleiman MM and Darrag A (1982). Desertification with special emphasis on carrying capacity and pasture resources, present assets of Natural Resources Issue in Sudan, Institute of environmental studies, University of Khartoum Sudan.

Herrick J. E., Whitford W.G., deSoyza A. G., Van Zee J. (1995). Soil and vegetation indicators for assessment of rangeland ecological condition. (pp 157 ó 166). In: Celedonio A. G. ed. *North American Workshop on Monitoring for Ecological assessment of Terrestrial and Aquatic Ecosystems. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station*. 305 p.

Holechek J, L., Pieper R, .D. and Herbel C, H , (1998). Range Inventory and Monitoring In: *Range Management Principles and Practices*. 3<sup>rd</sup> Edition Prentice - Hall, Upper Saddle River, New Jersey.

Ibrahim F (1962). Ecological and Human possibilities and Constraints of development of traditional pastoralists of the nomads of western Sudan, In: IFO, Munchen Intress.

IRDNC & Saving planet (Earth 2004). *Vegetation Types of Caprivi region*. IRDNC, Windhoek.

Jahnke, H.E., (1982). *Livestock Production Systems and Livestock Development in Tropical Africa*. Kieler Wissenschaftsverlag Vauk, Kiel, 45680pp.

Kaitho, R.J., (1997). *Nutritive value of browses as protein supplement(s) to poor quality roughages*. PhD Thesis. Wageningen Agricultural University, Netherlands.

Kale M.P., Singh S. and Roy P.S., (2002). Biomass and productivity estimation using aerospace data and geographic Information System. *International Society for Tropical Ecology*. (1) 123 ó 136.

Kannenbergh, N., (1995). *Grass-biomasse in Savannenbiomen des Etosha National Park: Anwendung des Disc Pasture Meter (DPM)*.

Kaul, O.N & D.C. Sharma. (1971). Forest type statistics: *Indian Forester* : 435-436.

Kennedy, P., (1989). Monitoring the vegetation of Tunisian grazing lands using the normalized Difference Vegetation Index. *Ambio*, , 1196123.

Lamacraft, R.R., Friedel, M.H. and Chewings, V.H. (1983). Comparison of distance based density estimates for some arid rangeland vegetation. *Australian Journal of Ecology* , 1816187.

Lamprey, R. H., and De Leeuw, P. N., (1986). *IL CA/UNEP-AVHRR calibration project, methodology and results for June 1985* (Nairobi: ILCA).

deLeeuw P. N. and Tohill J.C. (1990). *The concept of rangeland carrying capacity in sub-Saharan Africa - myth or reality*, ISSN, Addis Ababa, Ethiopia.

Le Houérou, H N and C H Hoste (1977). "Rangeland production and annual rainfall relations in the Mediterranean Basin and in the African Sahelo-Sudanian zone" *Journal of Rangeland Management* : 183-189.

Levey E.B. and Maden E.A. (1933).The point method of pasture analysis. *New Zealand journal of Agriculture* **46**, 267 – 279.

Lillesand T.M.&Kiefer R.W., (1994). *Remote sensing and image interpretation* (3rd Edition). Chichester: John Wiley & Sons.

Lyons, R.K., and R.V. Machen.(2001). Stocking rate: The key grazing management decision. Texas Agricultural Extension Service, L-5400. Available at <http://rangeweb.tamu.edu/extension/rangedetect/index.Htm>arvest.

Lubbe L.G. (2005). Towards an updated carrying capacity map for Namibia: *A review of the methodologies currently used to determine carrying capacity in Namibia* .MAWF, Windhoek, Namibia.

Lubbe L.G., Espach C. (2006).*Using remote sensing in search of grazing capacity*, Directorate of Agricultural Research and Training, Ministry of Agriculture Water and Forestry.

Mannetje L.T and Haydock K.P (1963).The dry rank-weight rank method for the botanical analysis of pasture, *Journal of British Grassland Society* **18**, 268 – 275.

MAWF, (2006). *Agricultural Statistics Bulletin* (1992ó2004). Directorate of Planning, Ministry of Agriculture, Water and Forestry, Windhoek, Namibia.

McCloy, K. R., Schoneveld, R., and Kemp, D., (1993). Measurement of pasture parameters from reflectance data. *International Journal of Remote Sensing*, , 1107ó1118.

Meissner H.,H. (1995).Carrying capacity as estimated by the animal unit and biomass methods: *Pros and cons*. Sand veld Farmers Day.

Meissner H, H. (1997). Animal related information required and amore comprehensive approach to improve estimates of carrying capacity. *Proceedings of the symposium on the science of free ranging ruminants* ó Fort Hare.

Mendelson J., Roberts A.C.& Robertson T. (2002). *Atlas of Namibia: A portrait of the land and its people*. David Philip Publishers, Cape Town.

Mendelson J., Roberts C. (1997). *An Environmental profile and Atlas of Caprivi*. Directorate of Environment and Tourism, Windhoek, Namibia.

Mentis M.T. (1981). Evaluation of the wheel point and step point methods of veld condition assessment. *Proceedings of the Grassland Society of Southern Africa* , 89 ó 94.

Ministry of Agriculture Water and Forestry (2010). *Livestock census report*, Directorate of Veterinary Services, Windhoek, Namibia.

Mitchell, P., (1982). Value of a rising-plate meter for estimating herbage mass of grazed perennial ryegrassó white clover swards. *Grass and Forage Science*, , 81ó87.

Mueller M.D. and Ellenberg H. (1974). *Aims and methods of vegetation ecology*. John Wiley and Sons, New York, pp 547.

National Applied Resource Science Center (NARSC). (1996). Sampling vegetation attributes.

Interagency Technical. Reference:

<http://ecore restoration.montana.edu/mineland/guide/sampling/vegetation>.

Neuteboom, J.H., Lantinga, E.A. and Loo, E.N. van (1992). The use of frequency estimates in studying sward structure. *Grass and Forage Science* , 3586365.

Neuteboom J.H., Lantinga E. A. And Struik P.C., (1998). Evaluation of the dry weight rank method for botanical analysis method of grassland by means of simulation. *Netherlands journal of Agricultural Science* **46**, 285 – 304.

Pearson, R. L., Tucker, C. J., and Miller, L. D., (1976). Spectral mapping of short grass prairie biomass. *Photogrammetric Engineering and Remote Sensing* , 3176323.

Penning de Vries, F W T and M Adjiteye (eds) (1982). *La Productivité desPâturages Sahéliens* Centre for Agricultural Publishing and Documentation Wageningen, Netherlands.

Pieper, R. D., (1988).Rangeland vegetation productivity and biomass. *Handbook of vegetation science vol. 14. Vegetation science applications for rangeland analysis and management*, edited by P. T. Tueller (Dordrecht: Kluwer Academic Publishing).

Prince, S. D., and Tucker, C. J., (1986).Satellite remote sensing of rangelands in Botswana.

II. NOAA-AVHRR and herbaceous vegetation. *International Journal of Remote Sensing*, 7, 1555-1570.

Prince, S. D., (1991). A model of regional primary production for use with coarse resolution satellite data. *International Journal of Remote Sensing*, , 1313-1330.

Rains, A B and Kassam A. H (1979). *Land resources and animal production*. Consultants' working paper No 8 FAO/UNFPA Project INT/75/P13 AGLSFAO, Rome 28p.

Rawat, Y.S. & J.S. Singh.(1988). Structure and function of oak forest in Central Himalaya. Dry matter dynamics. *Annals of Botany* : 327-411.

Richardson, A. J., and Wiegand, C. L., (1977). Distinguishing vegetation from soil background information. *Photogrammetric Engineering and Remote Sensing*, , 1541-1552.

Ringrose, S., Matheson, W., Tempest, F. and Boyle, T. (1990). The development and causes of range degradation features in southeast Botswana using multi temporal Landsat MSS imagery. *Photogrammetric Engineering and Remote Sensing* , 1252-1262.

Rothauge A. (2007). *Some principles of sustainable rangeland management in Namibia*, Neudamm Agricultural College, Windhoek, Namibia.

Rothauge, A., (2006). The Effect of Frame Size and Stocking Rate on Diet Selection of Cattle and Range Condition in the Camelthorn Savanna of East-Central Namibia. *Ph.D. thesis*.

University of Namibia, Windhoek, Namibia.

Rothauge, A., (2005). Long-term ecological monitoring of the central Highland savanna of Namibia. *Unpublished report*. Neudamm Agricultural College, Windhoek, Namibia.

Routhauge A, Ganzin N, and Coetzee M. (2000). *A case study of the application of satellite imagery to estimate biomass production of a semi arid rangeland in Namibia*, Neudamm Agricultural College, Windhoek, Namibia.

Roy, P.S., K.G. Saxena & D.S. Kamat. (1986). Biomass estimation through remote sensing. *IIRS Technical Report 1-78*.

Roy, P.S. (1989). Spectral reflectance characteristics of vegetation and their use in estimating productive potential. *Indian Academy of Science Plant Science* : 59-81.

Rutherford, M C (1978) Primary production ecology in Southern Africa in Wager, M J A (ed) *Bio-geography and ecology of Southern Africa*: 623-652 Junk The Hague, Netherlands.

Sandford, S (1983). Organization and management of water supplies in tropical Africa *ILCA Research Report No 8* Addis Ababa, Ethiopia.

Sannier, C. A. D., Taylor, J. C., Du Plessis, W., and Campbell, K., (1998). Real-time vegetation monitoring with NOAA-AVHRR in Southern Africa for wildlife management

and food security assessment. *International Journal of Remote Sensing*, , 6216  
639.

Schmidt A, G., Theron, G .K. and Van Hoven, W., (1995). *A comparison of some methods used to estimate the grazing capacity of a game ranch in Northern Province, South Africa.* Koedoe, 38/2:pp 1 ó 6.

Scrivner, J. H., Center, M., and Jones, M. B., (1986). A rising plate meter for estimating production and utilization. *Journal of Range Management*, , 4756477.

Singh, S.P. & J.S. Singh.(1989). Ecology of central Himalayan forest with special emphasis on sal forest ecosystem. pp. 193-222. *In: J.S. Singh & B. Gopal (eds.). Perspective of Ecology*, Professor S.C. Pandeya Commemoration Volume, M/S Jagmander Book Agency, New Delhi.

Singh, L. & J.S. Singh.(1991). Species structure, dry matter dynamics and carbon flux of a dry tropical forest in India. *Annals of Botany* : 263-273

Suleiman M.M. and Darrag A (1982). Desertification with special emphasis on carrying capacity and pasture resources, present assets of Natural Resources Issue in Sudan, Institute of environmental studies, University of Khartoum Sudan.

Swift, J, (ed) (1984).*Pastoral Development in Central Niger* Ministère du  
Development Rural USAID Niamey, Niger.

Taylor, J. C., Belward, A. S., Hewett, D. G., and Wyatt, B. K., (1986). Mapping of vegetation and soils and estimation of biomass in the Sahel. *Final report to the Commission of the European Communities on Monitoring of pastureland ecosystems in the Sahel and mapping of cloud cover and rainfall.*

Tidmarsh C.E. M. and Havenga C.M. (1955). *The wheel point method of survey and measurement of open grassland and karoo vegetation in South Africa.* (Memior No. 29). Botanical survey of South Africa, The Government printer, Pretoria, pp 49.

Timberlake, J R and S J Reddy (1986). *Potential pasture productivity and livestock carrying capacity over Mozambique.* InstNac Invest Agronl Publ No 49, Maputo, Mozambique.

Trollope, W. S. W., and Potgieter, A. L. F., (1986). Estimating grass fuel loads with a disc pasture meter in the Kruger National Park. *Journal of the Grassland Society of South Africa,* , 1486152.

Trollope, W.S.W., Trollope, L.L., & Bosch, O.J.H., (1990). Veld and pasture management terminology in southern Africa. *Tydskrif van die Weidingsvereniging van Suidelike Afrika,* 7(1).www.iwmi.org; September 2006.www.spotimage.fr; September 2006.

Tucker, C. J., (1979). Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing of Environment,* , 1276150.

van der Westhuizen H.C.,Snyman H.A.,VanRensburg W. L. and PotgieterJ.H., (2001). The quantification of grazing capacity from grazing and production values of forage species in semi-arid grasslands of Southern Africa *In: African Journal of Range and Forage Science*. 18: pp 43-52.

vanVegten, J.A. (1983).Thornbush invasion in a savanna ecosystem in eastern Botswana.*Vegetatio* , 367.

Wagenaar, K. T., and de Ridder, N., (1986). *Estimates of biomass production and distribution in the I L P Project Zone in 1985, based on satellite NDVI values* (Addis Ababa: ILCA).

Warren W.J. (1963). Errors resulting from thickness of point quadrants. *Australia Journal of Botany* , 178 ó 188.

Westoby M., Walker B., Noy ó Meir I., (1989). Opportunistic management for rangelands not at equilibrium. *J. Range manage* :266 ó 274.

Whalley R.B.D and Hardy M.B. (2003). *Measuring botanical composition of grassland* , Botany Department, University of New England, Armidale, New South Wales, Australia.

Whalley RDB (2000). Grasslands, grazing animals and people. How do they fit together. *Tropical grasslands*, : 192-198.

Wylie, B. K., Harrington, J. A. Jr., Prince, S. D., and Denda, I., (1991). Satellite and ground-based pasture production assessment in Niger: 1986-1988. *International Journal of Remote Sensing*, , 1281-1300.

Wijngaarden, W van (1985). *Elephants-Trees-Grass-Grazers: Relationships between climate, soils, vegetation and large herbivores in a semi-arid ecosystem (Tsavo, Kenya)* ITC Publ No. 4 Enschede, Netherlands.

		Vegetation type		
		1	2	3
		Count	Count	Count
Specie Name	<i>Anthephora pubensces</i>	0	1	0
	<i>Anthephora pubescens</i>	1	0	0
	<i>Arastida adscensionis</i>	0	1	0
	<i>Aristida adscensionis</i>	0	0	1
	<i>Aristida congesta</i>	1	0	0
	<i>Aristida sciurus</i>	0	2	2
	<i>Aristida stipitata</i>	1	1	0
	<i>Brachiaria brizantha</i>	0	0	1
	<i>Brachiaria nigropedata</i>	3	1	0
	<i>Brachiaria xantholeuca</i>	1	1	0
	<i>Chloris virgata</i>	0	1	1
	<i>Cymbopogon excuvatus</i>	0	0	1
	<i>Cynodon dactylon</i>	0	1	3
	<i>Dactyloctenium giganteum</i>	1	0	0
	<i>Dactyloctenium giganteum</i>	1	0	0
	<i>Dactyloctenium giganteum</i>	1	0	0
	<i>Digitaria eriantha</i>	3	2	1
	<i>Digitaria eriantha</i>	0	0	1

<i>Digitaria eriatha</i>	0	1	0
<i>Digitaria sanguinalis</i>	2	0	1
<i>Digitaria eriantha</i>	0	0	1
<i>Eragrostis aethiopica</i>	1	0	0
<i>Eragrostis caesia</i>	0	1	0
<i>Eragrostis cilianensis</i>	0	0	1
<i>Eragrostis cylindriflora</i>	0	1	1
<i>Eragrostis echinocloidea</i>	0	0	1
<i>Eragrostis lehmanniana</i>	0	1	1
<i>Eragrostis lemahnniana</i>	1	0	0
<i>Eragrostis micrantha</i>	0	0	1
<i>Eragrostis nindensis</i>	0	1	0
<i>Eragrostis nindesis</i>	1	2	1
<i>Eragrostis pallens</i>	0	0	1
<i>Eragrostis planiculmis</i>	0	0	1
<i>Eragrostis rigidior</i>	3	2	3
<i>Eragrostis rotifer</i>	0	2	0
<i>Eragrostis superba</i>	0	1	2
<i>Eragrostis trichophora</i>	0	0	1
<i>Eragrostis x-pseudo obtusa</i>	0	0	1
<i>Forbs</i>	2	2	3
<i>Fuirena obcordata</i>	0	0	1
<i>Heteropogon contortus</i>	0	1	1
<i>Heteropogon cotortus</i>	0	0	2

<i>Hypertherlia dissoluta</i>	0	1	0
<i>Hypertherlia dissoluta</i>	0	0	1
<i>Monelitrrium luderisiana</i>	0	1	0
<i>Panicum coloratum</i>	0	1	0
<i>Panicum maximum</i>	1	0	0
<i>Pogonarthria squarrosa</i>	2	0	1
<i>Pogonathria squarrosa</i>	0	0	1
<i>Schizachyrium jeffreysii</i>	0	1	0
<i>Schmidtia pappophoroides</i>	1	0	0
<i>Schmidtia pappophoroides</i>	1	2	2
<i>Setaria nigrirostris</i>	0	1	0
<i>Setaria sphacelata-sericea</i>	0	0	1
<i>Setaria ustilata</i>	1	0	1
<i>Sorghum versicolor</i>	0	0	1
<i>Sporobolus festivus</i>	0	0	1
<i>Sporobolus fimbriatus</i>	0	1	0
<i>Sporobolus ioclados</i>	0	2	0
<i>Sporobolus panicoides</i>	1	0	0
<i>Sporobolus stapfianus</i>	1	0	0
<i>Stipagrostis hirtingluma</i>	0	0	1
<i>Stipagrostis uniplumis</i>	0	1	0
<i>Trachypogon spicatus</i>	0	0	1
<i>Tricolaena monachne</i>	0	0	1
<i>Tristachya superba</i>	1	1	0

<i>Urochloa mosambicensis</i>	0	1	0
-------------------------------	---	---	---

An	382.2	230.3	52
Ar	626	101.8	778.6
DP	0	160	471
HF	51	883.2	122.5
OP	1849	1298.4	1352
SP	147	1089	212

An	207.0345	254.978	202.4875
Ar	469.3405	578.0268	459.0326
DP	196.5971	242.1236	192.2793
HF	329.23	405.4706	321.9993
OP	1401.853	1726.483	1371.064
SP	451.1452	555.6179	441.2369

An	148.2021	2.388454	111.8414
Ar	52.29079	392.3555	222.4751
DP	196.5971	27.8547	404.0227
HF	235.1303	562.8653	123.6027
OP	142.6261	106.1436	0.265086
SP	205.0433	512.036	119.096

Column1	Column2	Column3	Column4	Column5	Column6	Column7
Herbaceous category	Mean quadrants	Mean wet yield	Mean Sample wet mass	Mean dry matter	Dry Matter %	DM yield G/M2
<i>Schmidtia pappophoroides</i>	33	2190	190	107	56.3	37.4
Desirable perennials	33	351	171	83	48.5	5.2
<i>Aristida spp</i>	33	192	156.5	91.5	58.4	3.4
Other perennials	33	3102	245	113.6	46.4	43.6
Annuals	33	587	192.6	84	43.6	7.7
Herbs and forbs	33	2476	323.3	82.6	25.5	19.1

Herbaceous category	Mean No. of quadrants	Mean Wet yield	Mean Sample wet mass	Mean Dry mass	DM %	DM yield g/m2
<i>Schmidtia pappophoroides</i>	33	380	163	100	61.3	7.1
Desirable perennials	33	1171	211	106.5	50.4	18
<i>Aristida spp.</i>	33	1401	230	142.6	62	26.3

Other perennials	33	3364	204	98.3	48.2	49.1
Annuals	33	125	183	84	45.9	1.7
Herbs and forbs	33	381	252.6	94.6	37.4	4.3

Herbaceous category	Mean quadrants	Mean wet yield	Mean Sample wet mass	Mean dry matter	Dry Matter %	DM yield G/M2
<i>Schmidtia pappophoroides</i>	33	2190	190	107	56.3	37.4
Desirable perennials	33	351	171	83	48.5	5.2
<i>Aristida spp</i>	33	192	156.5	91.5	58.4	3.4
Other perennials	33	3102	245	113.6	46.4	43.6
Annuals	33	587	192.6	84	43.6	7.7
Herbs and forbs	33	2476	323.3	82.6	25.5	19.1