THE EFFECT OF BUSH ENCROACHMENT ON THE FAMILY DIVERSITY AND COMPOSITION OF GROUND-DWELLING INVERTEBRATES IN SELECTED SITES IN OMAHEKE REGION, NAMIBIA.

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE
IN BIODIVERSITY MANAGEMENT AND RESEARCH

OF
THE UNIVERSITY OF NAMIBIA and HUMBOLDT-UNIVERSITÄT ZU BERLIN

The Department of Biological Sciences
BY

Margaret Mkandawire
(200946536)

March 2013

Main Supervisor: **Dr J.K Mfune (University of Namibia)**

Co-Supervisor: **Prof. I Mapaure (University of Namibia)**

ABSTRACT

Bush encroachment, characterized by increase in woody plants in ecosystems, is one of the manifestations of environmental degradation that is prevalent in many parts of Namibia. The present study was conducted in Ben Hur area in the Omaheke Region, about 60 km South-East of Gobabis with the objectives of comparing family diversity, abundance and composition of ground dwelling invertebrates in habitats that are at different levels of bush encroachment and determining their seasonal variation. Data on the seasonal variation in family diversity, abundance and composition of ground dwelling invertebrates were collected at three sites with vegetation that was denoted normal savanna (NSV) site, intermediate bush encroached (IBE) site and a highly bush encroached (HBE) site. Statistical test using One way ANOVA confirmed that there was a significant difference in the woody plants densities among the three study sites ($F= 37.79$, $df=2$ and $p<0.001$).

In each 100m x 50m treatments, 6 quadrats measuring 10m x 10m were systematically demarcated. In each of these 10 plots, 5 plastic pitfall traps were set (making it 30 wet pitfall traps at each site). Invertebrates were collected in September, 2011 (hot dry season); March, 2012 (hot wet season); and in June, 2012 (cold dry season). This was done to determine how seasonal variation in vegetation structure affects abundance, diversity, richness and composition of invertebrates.

During the cold dry and hot dry season, there was no significant difference in Family diversity and relative abundance of invertebrates among the three sites ($H=3.67$, $df=2$, $p>0.05$; $H=4.2$, $df=2$, $p>0.05$); but there was significant difference in invertebrates Family diversity during the hot wet season ($F=3.12$, $df=2$, $p<0.05$). During the hot wet season, invertebrates Family diversity was highest in the high bush encroached site because of more shade which make the microclimatic conditions than in more open sites. In the normal savanna and the intermediate bush encroached sites, there was significant difference in Family diversity across the seasons, with highest diversity recorded in the cold dry season. There was no significant difference in invertebrates' Family diversity across the seasons for the high bush encroached site.

There was significant difference in Family richness among the three sites during the cold dry season ($H=6.5$, $df=2$ and $p<0.05$), with the highest richness in the intermediate bush encroached site. During the cold dry season, there was significant difference in invertebrates Family richness ($H=9.2$, $df=2$, $p<0.05$), and the highest richness was in the normal savanna site. There was no difference in invertebrates' Family richness among the three sites during the hot dry season.

Abundance of captured invertebrates was highest in the intermediate bush encroached site ($n=1776$) and lowest in the high bush encroached ($n=1161$) site. However, the overall Family richness was highest in the normal savanna followed by the bush encroached site and lowest in the highly bush encroached sites. Hierarchical Cluster Analysis revealed that there was significant difference in invertebrates' Family composition among the

three sites during the cold dry and hot dry seasons but there was no difference in invertebrate Family composition during the hot wet season. In general, bush encroachment impacts diversity, richness, composition and abundance of invertebrates differently in different seasons.

Key words: Environmental degradation, Bush encroachment, ground-dwelling invertebrates, abundance, diversity, richness and composition.

DEDICATION

This thesis is dedicated to my husband, Charles and our children, Zinyengo, Wongani, Masozi and Charles Junior for their unconditional love, encouragement and support provided. They were my inspiration during the whole study period.

ACKNOWLEDGEMENTS

I would like to thank the Almighty God for his mercy and grace for being with me throughout. I thank especially my two wonderful supervisors Dr John Mfune and Prof. Dr Isaac Mapaure for their academic guidance and constructive criticisms during the research and write up of my thesis. You have been great mentors. Special thanks go to Prof. L. Kazembe for assisting in data analysis using “BiodiversityR” package and also proof reading the thesis for me.

My sincere gratitude to my husband, Charles Senior and our children, Zinyengo, Wongani, Masozi and Charles Junior for their unconditional love, encouragement, moral support, and patience. I would also like to thank my parents Mr. Fremont and Mrs. Staphel Mwale for their prayers.

I sincerely thank all the people who assisted me in data collection and sorting invertebrates: Emilia Haimbili, Micheal Mogotsi, John Kagwe, Matilda Mkandawire, Francis Mkandawire, Kikolo Mwakasungula, Tatuna Ngwira, Tamala Nyirenda and Hilen Amadhila- thanks for all your effort and time in this work.

My gratitude goes to the many people who spared their valuable time during my internship at the Museum fur Naturkunde in Berlin, Prof. Dr Zeller, Ms Nicole Stalik, and Dr Thomas Goettert, for making my stay in Germany comfortable. Dr Manfred Uhlig, you will always be remembered as a father, a lecturer and a friend. Your personality distinguishes you. Dr Frank Koch and Dr J Deckert for that precious time you accorded to me to gain some technical skills which have been very useful in this research.

I would also like to thank the staff at the National Museum in Namibia. Mr. Vincent Mughongora, Mr. Benson Muramba, Mr. Walter Hauwanga and Mr. Corris Kaapehi for your support with the verification of identified and actual identification for some of the many invertebrate specimens brought to the Museum. The same appreciation goes to the staff at the National Herbarium and Botanic Gardens of Namibia in Windhoek; Ms Quanita Daniels, Mr. Levi Nanyeni, Ms Hendrina Hasheela, and all the staff for the skills gained in plant specimen identification in my project. You made me feel as part of you and I will always remember you for that. I would also like to thank the Ministry of Environment and Tourism for granting a research permit (MET research and collecting Permit number 1609/2011) that enabled me to conduct my research.

To all my classmates, Mandene Morkel, Tabitha Dumba, Caroline Tischtau and Saskia Weid for your encouragement and support during my studies and writing of this thesis.

DECLARATION

I, Margaret Masida Faith Mkandawire, declare that this study is a true reflection of my own research and that this work or part thereof has not been submitted for a degree in any institution of higher education.

I, Margaret Masida Faith Mkandawire, 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; providing 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.

………………………………………… Date……………………………………

Margaret Masida Faith Mkandawire.

ACRONYMS

ANOVA	Analysis of variance
CEC	Cation exchange capacity
DEA	Department of Environmental Affairs
DEES	Directorate of Extension & Engineering Services
DRWS	Directorate of Rural Water Supply
FAO	Food and Agriculture Organisation of the United Nations
GoRN	Government of the Republic of Namibia
HBE	High bush encroachment
HCA	Hierarchical Cluster Analysis
IBE	Intermediate bush encroachment
IDH	Intermediate disturbance hypothesis
KS	Kolmogorov–Smirnov
MoET	Ministry of Environment and Tourism
NEPAD	New Partnership for Africa Development
NSV	Normal savanna
OM	Organic matter
RoN	Republic of Namibia
SPSS	Statistical Package for Social Sciences

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

TABLE OF CONTENTS

CHAPTER 1

1.0 INTRODUCTION

1.1 General Introduction

The loss of biodiversity and a loss of natural resources in an ecosystem which cannot be replaced (Chrisholm and Dumsday, 1987) commonly referred to as environmental degradation, is one of the major outcomes of anthropogenic activities that threaten ecosystem and socio-economic benefits which humans derive from the environment.

It is aggravated by many factors including, but not limited to inappropriate land use, over cultivation, over grazing, pollution and poverty (Zeleke, 2009). It is manifested through a wide range of ways including soil erosion, deforestation, desertification, salinization and bush encroachment (de Klerk, 2004; Zeleke, 2009.

Bush encroachment is defined as the increase in the density of woody or shrubby plants (Scholes and Archer, 1997; Smit, 2004; Britz and Ward, 2007; Van Auken, 2009). In turn, grasses, especially palatable ones, are suppressed giving rise to habitats that are dominated by woody plants (trees and shrubs) (Ward, 2005). Therefore bush encroachment decreases the diversity of species and habitats, and results in reduction in biodiversity of such habitats and ecosystems (Meik *et al*., 2002). It is thus evident that when it occurs in productive arable land, bush encroachment reduces availability of grasses for livestock and may reduce economic output from such rangelands (de Klerk, 2004). Bush encroachment therefore has ecological effects such as causing changes in the structure of habitats and ecosystems as well as causing economic impacts such as reducing the productivity of a rangeland through reduction of palatable grasses for livestock (Kraaij and Ward, 2006; Wiegand *et al*., 2006; Saltz and Ward, 2006). Bush encroachment has reduced the number of cattle on commercial farms by 47% over the last 30 years (de Klerk, 2004). According to Els (1995), bush encroachment remains the single most important factor that limits production of red meat in commercial farms in Namibia. At the national level, the country looses up to N$ 700 million in meat production annually, (de Klerk, 2004). It is common over much of the world`s arid and semiarid biomes (Eldridge *et al.*, 2011). In general, bush encroachment decreases the diversity of habitats, and this in turn decreases biodiversity as a whole (Meik *et al*., 2002), resulting in habitat degradation (de Klerk, 2004).

The main species causing bush encroachment in Namibia are *Acacia mellifera* subsp. *detinens* (Black thorn), *Dichrostachys cineria* (sickle bush), *Terminalia sericea* (Silver terminalia), *Terminalia prunioides* (Purple pod terminalia), *Acacia erubescens* (Blue thorn), *Acacia reficiens* (False umbrella thorn), *Rhigozum trichotomum* (three thorn) and *Colophospermum mopane* (mopane) (DEA, 2003; de Klerk, 2004).

Disturbances of habitats whether by physical or biological factors can affect richness and abundance of the ground-dwelling invertebrate communities (Ríos-Casanova *et al*., 2006). Disturbance is a natural phenomenon in many ecosystems and a source of much of the spatial and temporal heterogeneity across landscapes (Bass, 2003). The magnitude and frequency of disturbance are factors structuring many ecosystems (Beeby, 1993). Evidence of ecosystem response to specific scales and intensity of periodic disturbances is visible in the species traits, which reflect the likelihood of disturbance (Beeby, 1993).

Some species survive only in patches formed by disturbances. Wiegand *et al.*, *(*2006) hypothesized that any forms of disturbance (e.g. grazing or fire) create space, making water and nutrients available for plant germination. Under low soil nitrogen conditions, the nitrogen-fixing trees have a competitive advantage over other plants and, given enough rainfall, may germinate in large numbers in patches created by the disturbances.

Some disturbances such as bush encroachment provide ecologists with opportunities to test the intermediate disturbance theory by monitoring the short-term responses of individuals or the long-term adaptations of populations, as well as changes in the structure and composition of communities at a larger scale (Bass, 2003). The Intermediate Disturbance Hypothesis (IDH) states that species richness will be greatest in areas experiencing an intermediate level of disturbance (Pickett and White, 1985).

Invertebrates comprise an important component of many ecosystems and habitats and they inhabit all areas from the soil and litter layers, to herb and understory layers and even in forest canopy (Samways, 1994). A healthy and diverse community of ground dwelling invertebrates serves as an indicator of good ecological conditions within habitats, ecosystems and the environment in general (Samways, 1994). Invertebrates show different responses to disturbance hence are considered as good indicators of landscape change as they are abundant, widespread and species rich (Samways, 1994). The change in the structure and composition of habitats that have become bush encroached is likely to lead to changes on diversity and composition of communities of many plants and animals including small mammal and invertebrates and this provides a platform for testing the intermediate disturbance hypothesis (Sands *et.al*, 2009; Wu *et.al*, 2009).

1.2 Statement of the Problem

Bush encroachment is widespread in Namibia (de Klerk, 2004). Meik *et. al* (2002) reported that bush-encroachment influenced assemblages of diurnal lizard species in Central Namibia. Hoffmann & Zeller (2005) reported that changes in habitat structure and complexity due to overgrazing are associated with changes in the small mammal community structure and species richness in the Nama Karoo in southern Namibia. However, not much is known about how bush encroachment affects invertebrate assemblages in Namibia. The proposed research will generate information on how variation in vegetation structure due to bush encroachment affects the species composition, richness and diversity of ground-dwelling invertebrates at selected sites in Omaheke region in Namibia. This study will provide useful information for programmes in monitoring changes as a result of bush encroachment in Namibia

1.3 Objectives of the study

The objectives of this study were:

(a) To determine and compare family diversity of ground dwelling invertebrates at sites which differ in levels of bush encroachment over different seasons.

(b) To determine and compare family richness of ground dwelling invertebrates in sites which differ in levels of bush encroachment over different seasons.

(c) To determine and compare family composition of ground dwelling invertebrates in sites which differ in levels of bush encroachment over different seasons.

(d) To determine seasonal variation of family abundance of ground dwelling invertebrates in sites which differ in levels of bush encroachment.

1.4 Research Hypotheses

(a) Family diversity and richness of ground dwelling invertebrates will be significantly high in the intermediate bush encroached area due to increased habitat heterogeneity.

(b) Family composition of ground dwelling invertebrates will be significantly different in the three sites due to differences in the vegetation cover and structure.

(c) Relative Family abundance of ground dwelling invertebrates will be significantly high at the intermediate bush encroached site than in the highly bush encroached site and normal savanna due to increased habitat heterogeneity.

(d) There is significant seasonal variation in Family diversity, richness, composition and abundance of ground dwelling invertebrates in habitats that differ in levels of bush encroachment due to habitat heterogeneity.

1.5 Significance of the study

Understanding impacts of bush encroachment on biodiversity will help balance between de-bushing to enhance economic benefits derived from rangelands and allowing a certain level of encroachment that will support biodiversity.

Since different levels of bush encroachment can be recognized, each with different degrees of bush density and vegetation structure, the intermediate disturbance hypothesis of family diversity was tested on ground dwelling invertebrates.

The study provided insight into the effects of bush encroachment on species diversity and abundance of invertebrates in the Omaheke Region. The results obtained in this study will contribute to further understanding the effects of bush encroachment on invertebrates biodiversity in the Omaheke Region and in Namibia.

The research results will also contribute to literature on the effects of bush encroachment on land and biodiversity and will be used as reference material for the monitoring of the Sustainable Land Management Programmes. There is little literature available focusing on the effects of bush encroachment on invertebrates diversity. Therefore this study is ecologically important and has application for conservation of biodiversity as well as management of bush encroached rangelands considering different land uses.

1.6 Limitation of the study

It was not possible to identify the trapped invertebrates to species level due to lack of Namibia specific identification references for invertebrates. The identification was therefore based on the identification keys for Southern Africa. Although the experts from the National Museum of Namibia verified some specimens identified to species level, most specimens could only be to Family level due to lack of Entomology taxonomy experts. This limitation hindered comparisons at species level.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 The Phenomenon of Bush Encroachment

Savannas are important as rangelands, and the consequences of bush encroachment for livestock productivity were assessed as early as the beginning of the 20th century (Ward, 2005; Lamprey, 1983). Bush encroachment has been acknowledged as the first step of a biome shift, potentially threatening savannas (Scheffer *et al*., 2001). Savannas are the most important ecosystems for raising livestock in Africa (Zeleke, 2009). The rapid and widespread woody cover increase results in a decrease of open savannas (Roques *et al.*, 2001). The encroachment of woody plants into grasslands, and the conversion of savannas and open woodlands into shrub lands have been widely reported during the past decade (Maestre *et al.*, 2009; Van Auken 2009). This change in vegetation structure has accelerated since the early 1900s due to a combination of effects including grazing (Archer *et al*., 1995).

Bush encroachment has severe impacts on biodiversity (Meik *et al.*, 2002). In general, bush encroachment decreases the diversity of habitats, and this in turn decreases biodiversity as a whole (Meik *et al.*, 2002). Decreased diversity of habitat structure in bush encroached habitats influenced native savanna diurnal lizard assemblages in central Namibia (Meik *et al.*, 2002). Blaum *et al*. (2007) reported that shrub encroachment due to overgrazing caused different responses in mammalian carnivore abundance and species richness in semiarid rangelands in Southern Kalahari.

In Namibia, bush encroachment is a serious environmental and economic problem (Meik *et al.*, 2002) as it results in the loss of resource productivity, loss of agricultural productivity and land degradation. Bush encroachment has adverse effects on livestock farming; it results in the decline of livestock production, due to the loss of grass production on grazing lands (Woiters, 1994). This in turn threatens livestock production particularly grazers (Kraaij and Ward, 2006) and livelihood of pastoral communities. Some of these species also tend to have very high levels of phenolic compounds (e.g. tannins) in their leaves, which reduce their digestibility to livestock and wildlife. Bush encroachment has also reduced the carrying capacity of Namibia's rangelands, which has resulted in the loss of income of more than N$700 million per annum in meat production (de Klerk, 2004). Bush encroachment continues to cause substantial losses in communal farms, resulting in lower food security and nutrition

2.2. Extent of bush encroachment in Namibia

Bush encroachment is widespread in Namibia affecting both communal as well as commercial farming communities (Woiters, 1994). According to Woiters (1994), more than 10 million hectares (12%) of Namibia's land is encroached. It is estimated that about 26 million hectares of land in Namibia is affected by bush encroachment (Zimmermann and Joubert, 2002). Savanna ecosystems with low carrying capacities are also more vulnerable to bush encroachment (Woiters, 1994).

There are different encroaching species occurring in different parts of the country because of differences in the abilities of their root systems to extract and intercept water from the different soil types in Namibia (de Klerk, 2004). The dominant species encroaching in the eastern parts of Namibia are *Acacia mellifera* and *Terminalia sericea*. The central northern parts of Namibia are mainly encroached by *Acacia reficiens* and *Acacia mellifera*; while far northern parts of the country are predominantly encroached by *Colophospermum mopane* and *Dichrostachys cinerea*. *Acacia mellifera* appears to be the major species encroaching the Khomas Region while the Southern Regions in Namibia are encroached by *Rhigozum trichotomum* (Joubert *et al*., 2003).

2.3 Bush encroachment in Omaheke Region

Bush encroachment has significant influence on vegetation composition in the communal areas as well as commercial areas of Omaheke Region. In some communal areas such as Otjinene, Epukiro and Talismanis, it is mainly *Terminalia sericea* and *Acacia mellifera* that have encroached (NEPAD/ FAO/GRoN, 2005).

These encroaching species in northern Omaheke fall into the height class of 2 to 4 meters tall. In contrast the Aminuis block and Corridor area have fewer acacias that are encroaching like the *Acacia reficiens* and *Acacia mellifera* (NEPAD/ FAO/GRoN, 2005).

2.4 Impacts of bush encroachment on agriculture

Bush encroachment has serious economic implications in the agricultural sector in Namibia because it results in the decline of livestock production following the loss of grass production on the grazing lands (de Klerk, 2004). Bush encroachment has reduced the number of cattle on commercial farms in Namibia by 47% over the last 30 years (Schneider, 1994). At the national level, bush encroachment has resulted in the loss of about N$ 700 million in lost meat production each year (de Klerk, 2004). According to Zimmermann and Joubert (2002), an estimated 26 million ha had been affected by bush encroachment in Namibia since (at that time) resulting in severe economic implications. In commercial farmer's view, bush encroachment results in a decline in livestock production which comes as a result of loss in grassland diversity (Quan *et al*. 1994).

2.5 Impact of bush encroachment on botanical diversity

Bush thickening is seen as a major threat to the botanical diversity in Namibia (Maggs *et al*., 1998). Bush encroaching species such as *Dichrostachys cinerea* usually displace other plant species, resulting in a decline in plant diversity (Joubert, 2003). Bush encroaching species have extensive and well developed tap roots and lateral root systems that reach deep into the soil to obtain water and nutrients (Walker,1985). The grass roots usually occur in the topsoil layer and are unable to penetrate deep further into the soil (de Klerk, 2004). Therefore grass-tree competition is greatly influenced by the amount of water retained in the upper soil layer and that which moves to the lower soil where tree roots predominate. When the grass layer is over-utilized, it loses its competitiveness against the woody species and bush encroachment results (de Klerk, 2004). As a result, fewer non-woody species occur in the bush encroachment vegetations (de Klerk, 2004) and species richness is not high in most of the vegetation types affected by bush thickening (Maggs *et al*., 1994).

However, there are some associations of herbaceous species with *Acacia* trees, for example, shade-loving grass species, such as the high yielding *Panicum maximum* (Guinea Grass), disappear with excessive clearing (Joubert, 2003). There have also been observations of some woody species such as *Boscia albitrunca* (Shepherd's Tree) growing through *Acacia mellifera* trees which act as protective nurseries (Joubert, 2003). However, competition for water between the herbaceous layer and the roots of trees limits grass productivity and, therefore, contradicts other findings in this respect (de Klerk, 2004). Although nitrogen content in the soil is high, inadequate phosphorus levels also serve as a limiting factor for increased grass production.

2.6 Impact of bush encroachment on soil properties

Soil texture is a crucial determinant of the tree-to-grass ratio because of its effects on plant growth, soil moisture, nutrient presence, and availability (Britz and Ward, 2007). Soil texture is of importance because it has a large effect on the ability of soil to retain moisture and withstand erosion (Britz and Ward, 2007). Teague and Smith (1992), in their research on relationship between woody and herbaceous components and the effects of bush-clearing in Southern African savannas found that mineralisable nitrogen and microbial biomass were significantly higher in soils from the canopy than those from the root and grassland zones, whereas organic matter, phosphorus and potassium declined in soils from the base of trees towards open grassland. Soils under canopies of trees in semi-arid environments are often more fertile than soils from the surrounding grassland. The increased nutrient status under canopies is attributed to tree roots gathering nutrients from soil below grass-root level or from horizontal gathering of nutrients by lateral roots (Dye and Spear, 1982).

In some cases, encroaching plants species create unfavorable growing conditions for native plants through allelopathy or by altering availability of soil nutrients (Christian and Wilson, 1999). Increased dominance of encroaching plant species may be associated with increased total root mass, increased soil moisture, and changes in soil nutrients (increases in nitrogen and decreases in calcium and potassium) (Kappes *et al*., 2007). Invasive plants also may alter soil salinity and pH, creating environments where native plants can no longer grow (Kappes *et al*., 2007).

2.7 Impact of bush encroachment on invertebrates

According to Joubert (2003), a huge diversity of insect species depends on trees in general, though it is not possible to list the species which inhabit bush thickets. For example, the larva of the Western Marbled Emperor Moth (*Heniocha dyops*) is dependent upon *Acacia mellifera*, *Acacia hereroensis* and *Acacia erubescens* for its food supply

(Oberprieler, 1995). Removal of *Acacia mellifera* from the area might negatively influence this species. The Topaz Spotted Blue Butterfly (*Azanus jesous*) feeds on the flowers and buds of *Dichrostachys cinerea* and the adults of this species and *Azanus ubaldu*s seem to be particularly associated with the flowers of *Acacias* in general (Williams, 1994). The bruchid weevils (Family Bruchidae) are closely associated with *Acacias* and other leguminous plants (Picker *et al*., 2002). These are just some examples of the so many associations which excessive removal of bush thickening species may affect.

Some invertebrate taxas are very sensitive to changes in vegetation structure. For example, Spiders and Carabid beetles are frequently used to assess habitat ‘quality’ in various forested ecosystems (Pearce and Venier, 2006) because these ground-dwelling invertebrates are relatively easily captured and identified, and their ecology and behaviour are well known compared with other invertebrate taxa. In addition, both Spiders and Carabid beetles are sensitive to changes in vegetation structure which is often dependent on canopy structure of the habitat (Sands *et al*., 2009). Barbaro *et al*. (2005) found that both spiders and Carabid beetles are very sensitive to disturbance hence good biodiversity indicators.

2.8 Importance of invertebrates in an ecosystem

Invertebrates form an integral part of ecosystems and occur at all levels of the food web (Seymour and Dean, 1999). They play important roles in ecosystems as pollinators of flowering plants, recycling of soil nutrients by decomposing organic matter and hence the alteration of structure and fertility of soil (Rivers-Moore and Samways, 1994). Invertebrates function as prey resources for many taxa, as important predators, and seed dispersers (Isaacs *et al.*, 2009). In agriculture, invertebrates, especially insects, perform important roles as pests, controllers of pests, prey and predators, and are major contributors to biodiversity and general indicators of ecosystem health (Holland and Reynolds, 2003). Invertebrates are found in all habitats and dominate the diversity of species, making up approximately 90% of all species (Duelli *et al.*, 1999; Pimentel *et al.*, 1992). Changes in vegetation and soil characteristics resulting from bush encroachment may have detrimental effects on invertebrates since they have relatively limited mobility and because many species have specific host plant requirements for food or as sites for reproduction (Tallamy 2004; Burghardt *et al.* 2008).

Disturbances of habitats whether by physical or biological factors can affect richness and abundance of the ground-dwelling invertebrates' communities (Ríos-Casanova *et al.*, 2006). Invertebrates show different responses to disturbance hence are considered as good indicators of landscape change as they are abundant, widespread and species rich (Samways, 1994). They are used to reflect environmental quality and in many cases provide good basis for monitoring the changes that occur as habitats are degraded or restored with conservation management (Samways, 1994). Blaum *et al.* (2009) commended the use of invertebrates as indicators of habitat degradation due to bush encroachment because they followed the same response curves as did the higher taxonomic groups such as carnivores (Blaum *et al.*, 2007), rodents (Blaum and Wichmann, 2007) and birds (Seymour, 2006).

Seymour and Dean (1999) found grazing to affect abundances of ground-dwelling invertebrates and such effects were associated with changes in vegetation cover in grazed sites. These were attributed to the fact that ground-dwelling invertebrates have the ability to rapidly respond to environmental changes because of their short life cycles and specific habitat needs. Invertebrates also have the ability to respond to climatic conditions such as rainfall, humidity, wind speed, day length and sunlight (Netshilaphala *et al.*, 2005).

Seasonal fluctuations in temperature and rainfall are usually reflected in invertebrates' assemblages (Netshilaphala *et al.*, 2005). A number of studies have found that habitat temperature is of great importance in determining the distribution and activity of invertebrate's species (Ottesen, 1990). Some species of the Family Carabidae are more sensitive to temperature because they use bare ground patches to warm up before flight (Fry and Lonsdale, 1991). Vegetation type affects structural heterogeneity, food availability and also acts as an indicator of soil moisture (Hill *et al.*, 1999). Invertebrate communities will also be different on moist and completely free-draining soils because many species occur in a limited range of moisture conditions (Luff, 2007). Attignon *et al.* (2004) in a study on invertebrate diversity and the ecological role of decomposer assemblages in natural and plantation forests in southern Benin found that most invertebrate taxa are least active during the long dry season.

2.9 Possible factors that cause of bush encroachment

Factors causing bush encroachments are poorly understood (Ward, 2005). According to Sheuyange *et al.*, (2005) the causes of bush encroachments are elaborated by the background of two important models:

Walter's two-layer Model: The model explains that, if the grass layer is over utilized, it loses its competitive advantage and can no longer use water and nutrients effectively (Sheuyange *et al.*, 2005). This results in a higher water and infiltration rate into the subsoil benefiting trees and bushes and allowing them to dominate (Sheuyange *et al.*, (2005). According to Walter's two-layer hypothesis (1971), water is the limiting factor for both grassy and woody plants and grasses use only top soil moisture, while woody plants use the subsoil moisture (Wiegand *et al*., 2006). In this model the balance between grass and bush production is determined by the relative availability of soil water and nutrients in different rooting zones (Dougill and Cox, 2007). Savanna grasses out-compete woody species for water and nutrients in the top soil layers, while woody species have the competitive advantage in the sub-soil. According to the two-layer model, cattle grazing affect this balance by suppressing grass growth and promoting leaching to greater depth. This provides the opportunity for woody species to increase and for certain species to encroach (Britz and Ward, 2007) and, hence, the conclusion that bush encroachment is caused by the replacement of indigenous browsing animals by cattle and heavy livestock grazing (Britz and Ward, 2007).

The State-and-Transition Model: The model dwells on the dynamic nature of savanna ecosystems where rainfall and its variability play an important role in vegetation growth than the intensity of grazing (Ward, 2005). Higgins *et al*. (2000) hypothesized that grass-tree relationship in coexistence is driven by the limited opportunities for tree seedlings and saplings to escape drought and fire into the adult stage; therefore, bush encroachment occurs because of increased tree recruitment as a result of reductions in grass standing which reduces fire intensity.

Thus, according to Ward (2005) and Higgins *et al*. (2000), rainfall-driven variation in recruitment is more important in arid savannas, where fire is less intense and more frequent. The model is also supported by Langevelde *et al*. (2003) who suggested that there is a positive feedback between fuel load (grass biomass) and fire intensity. Increased levels of grazing reduce fuel load, making fires less intense and, thus, less damaging to trees. This leads to an increase in woody vegetation and a switch from an open type of vegetation (Sheuyange *et al.*, (2005). The state and transition model implies, therefore, that bush encroachment is not a permanent phenomenon and a savanna could be changed to its grass-dominated state by favorable management or environmental conditions.

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 Description of the study area

3.1 .1 Location and extent

The study was conducted in Ben Hur area, located at 22^0 47'S and 19^0 12' E in the Omaheke Region, eastern Namibia. It is located about 60 km South-East of Gobabis town, the economic headquarters of the Region. Gobabis is located 205 kilometers east of Windhoek, the capital city of Namibia (Figure 1). Omaheke is one of Namibia's 13 political Regions demarcated by the Second Delimitation Commission of 1998. The region derives its name from the Herero word for Sandveld and is commonly known as the "Cattle Country" (RoN, 2006). It covers a total land area of about 84,612 km^2, which translates to about 10.3 per cent of the country's total land surface.

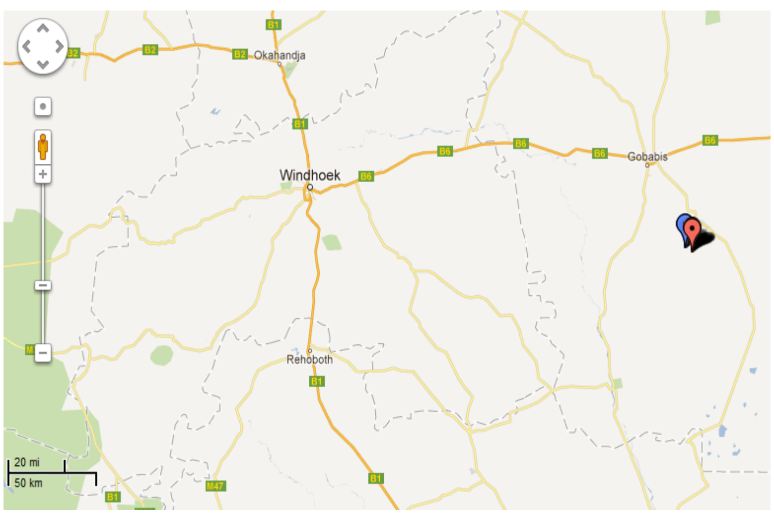

Figure 1. Location of the study area, Ben Hur in Omaheke Region (Google Earth).

3.1.2 Climate and rainfall

Omaheke experiences the hottest temperatures of just below 40 °C recorded during November and December, although the most representative daily temperature of the summer, ranging between 17 °C and 34 °C, are common in January. Lowest mean daily temperatures of about 2.5 °C to 6 °C during winter are recorded in July increasing from west to east (Mendelsohn *et al.,* 2002). Omaheke Region experiences summer rainfall during the months of December to April with the remaining seven months being dry (DEES, 2003). Mean precipitation range increases from south to north ranging from 400mm to 450mm per annum in southern Omaheke and it decreases to between 200 and 400 mm (DEES, 2003; Mendelsohn, *et al.,* 2002). An important aspect of the rainfall in this area is that it is sporadic and most of the times erratic within and between the rainfall season. Mean annual evaporation rate in the Region exceeds the mean annual rainfall, creating water deficits and consequently leading to dry climatic conditions (DEES, 2003).

3.1.3 Physical features, Geology and Soils of Omaheke Region

The topography of the Kalahari sand plains is almost flat (Strohbach *et.al.,* 2004). The soils consist of deep to very deep reddish, unconsolidated coarse-grained sedimentary sands of the ancient Kalahari (Strohbach *et.al,* 2004). The depth of the sand mantle of the Kalahari sandveld increases generally to the north and east. Well-defined high red dunes

(>20 m) occur mainly in the eastern expanses towards the Botswana border (Strohbach *et.al*, 2004).

3.1.4 Agriculture in Omaheke Region

The Omaheke region consists both of privately owned land (freehold) and communal land with about 72 percent of the total population of this sparsely populated Region living in rural areas on state owned communal areas (NEPAD, FAO and RoN, 2005). People in the Region are mainly cattle farmers, although farming systems which include game for meat production and hunting are common and there are several commercial conservancies (NEPAD, FAO and RoN, 2005).

Although the Region receives average rainfall of between 400-450mm, it is difficult to produce agricultural crops because the dominant sandy soils have low nutrient content and water percolates through them rapidly (Mendelssohn *et al*., 2002). Such conditions inhibit vegetation growth. As a result, crop cultivation is almost impossible in the region. Crop production does not play a major role because of the Region's climate, which is characterized by poorly distributed and unreliable precipitation (MoET, 2011).

Therefore the rural population exclusively depends on livestock production especially cattle production. The area is characterized by communal largely subsistence farming activities with settlements concentrated around water points under the jurisdiction of the Directorate of Rural Water Supply (DRWS) (NEPAD, FAO and RoN, 2005). Livestock farming is marginally viable as a profitable commercial enterprise (MoET, 2011). The

Region contributes about 20 percent to the national cattle production, 11 percent to sheep and 8 percent to goat (NEPAD, FAO and RoN, 2005). Therefore, the Region contributes significantly to livestock industry in Namibia, and by extension, makes significant contribution to the foreign exchange earnings of the country.

3.1.5 Vegetation and fauna of Omaheke Region

The key biomes found in the Region are the central Kalahari biome and southern Kalahari biome, characterised by sandy soils and acacia savanna (MoET, 2011). In the southern part of the Region, Camelthorn savanna vegetation is dominant with patches of Thorn Bush Savanna. The most predominant and widely distributed type of vegetation in the northern and north-eastern Omaheke Region is broad-leafed *Terminalia–Combretum* savanna, characterised by *Terminalia sericea* and *Combretum collinum* shrub land association (Strohbach *et al*. 2004). Western parts of Omaheke fall within the central highland shrub land dominated by *Acacia* shrubs intermixed with extensive herbaceous grass cover. Most areas of farmland in Omaheke are encroached by *Terminalia sericea* and *Acacia mellifera* trees, reducing its grazing potential and carrying capacity. The grass cover is dense and of good quantity in undisturbed areas but of poor quality due to poor soils. The areas are also characterised by dense grass stands of some of Namibia's best grazing species with isolated trees and mixed stands of shrubs (NEPAD, FAO and RoN, 2005).

There are low densities of wildlife in communal areas in the Omaheke Region due hunting, low levels of protection and the poor nutrient (MoET, 2011). However, a shift from livestock-based to wildlife-based production has been observed as there are a number of conservancies in the Omaheke Region (MoET, 2011).

3.2 Selection of the study site and experimental design

A preliminary field visit was conducted in the Ben Hur area to identify contrasting sites to test hypotheses. In order to assess the effect of bush encroachment on family richness, diversity and composition of ground dwelling invertebrates, it was necessary to select study sites that had significant differences in densities of woody vegetation. This therefore was the major criterion for site selection. It was decided at the outset to sample a normal savanna (which would serve as a control site); a site with intermediate density of woody plants or low bush encroachment (Intermediate bush encroachment site) and a site with high density of woody plant (High bush encroachment site). The design, therefore, had one control, normal savanna (NSV) site; intermediate bush encroachment (IBE) site as treatment one, and high bush encroachment (HBE) site as treatment two. According to de Klerk (2004) a savanna habitat is said to be bush encroached if it has a woody plant density of more than 1,000 woody plants (bushes) per hectare. The site is considered intermediated encroached if it has a density of between 1000 and 2500 woody plants per hectare; and highly bush encroached if it has more than 2500 woody plants per hectare.

For each of the treatments: control (NSV), intermediate bush encroachment (IBE) and highly bush encroachment (HBE), one 100m by 50m sampling plot was laid out. The three study sites selected had the following woody densities: a normal savanna site was represented with a woody plant density of 3,000 per hectare. The second site which represented intermediate bush encroachment as treatment one had a woody plant density of 11000/ha, while the third site which had a woody plant density of 23,500 per hectare was regarded as high bush encroachment area (treatment two). Thus the sites had far much higher bush densities compared to the literature cited (the IBE site had 4 times more bush while the HBE site had almost 8 times more bush than the stated figures in de Klerk, 2004). After the sites were selected, a field visit was undertaken to select sampling sites. For each of the treatments, a 100m × 50m grid was measured where smaller quadrats of 10m by 10m for data collection were laid down.

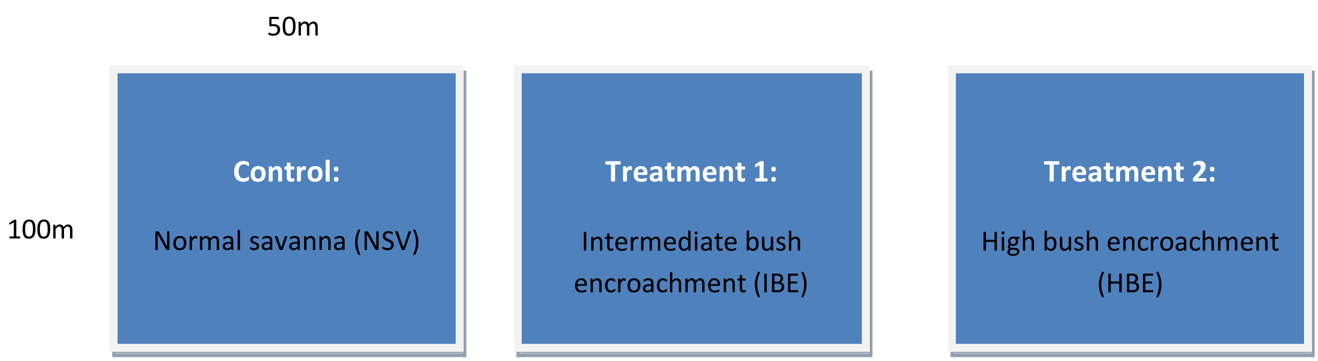

Figure 2. Layout of the three treatments (NSV=normal savanna, IBE=intermediate bush encroachment and HBE= high bush encroachment) of the study.

3.3 Measurement and estimation of woody and grass cover

To determine the density and diversity of woody vegetation for each treatment, three plots measuring 20m x 20m were systematically demarcated where all trees were identified to species level and counted. Within the 20m x 20m plots, 10m x10m plots were nested in which all shrubs and saplings were identified to species level and counted. Within the 10m x 10m plots, 1m by 1m plots were demarcated in which cover of forbs and grasses were assessed.

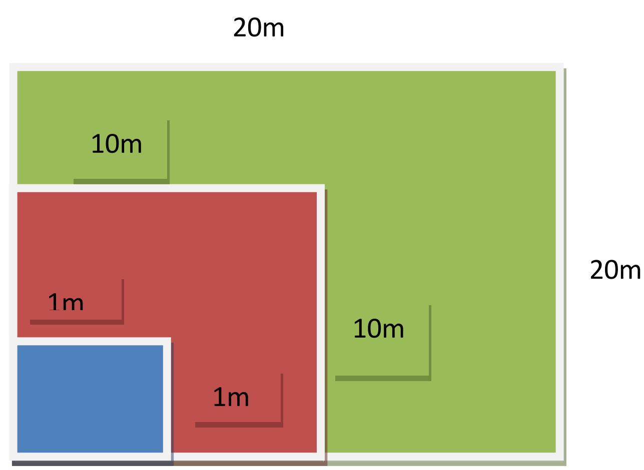

Figure 3. Field layout of the 20m x 20m quadrats where trees were assessed; within which are nested the 10m x 10m plots where shrubs were assessed and the 1m x 1m where grasses and forbs were assessed.

3.4 Vegetation Structure and plant species composition

All individual woody plants were identified to species level, counted and recorded in each plot. In each 20m x 20m quadrat, all trees were counted and the total number recorded. Any woody vegetation with >15cm stem basal circumference was considered a tree; any woody stem that had a stem basal circumference of <15cm was considered a shrub (Walker, 1976). The height of each tree was estimated using 2.5m range poles and recorded. In 10m by 10m quadrats which were nested in the 20m x 20m quadrats, the total number of shrubs was recorded and the height were estimated using 2.5m range poles. All woody plants were identified to species level in the field using a Guide to Trees and Shrubs of Namibia (Mannheimer and Curtis, 2009). Voucher specimens from the plants (a small branch with leaves, flowers, and pods or fruits, where applicable) that were not identified in the field were collected and put in plant press. They were taken to the National Botanical Research Institute for identification and verification. All the species for tree, shrubs, forbs and grasses were recorded.

Using the nested plot design, the percentage cover for herbaceous plants was visually estimated in $1m^2$ plots using the Blaun-Blaquet technique and recorded. Grasses and forbs were identified to species level using the relevant field guides (Mannheimer *et.al.*, 2008; Burke, 2006; Van Oudtshoorn, 2009). Voucher specimens for grasses and forbs that were not identified in the field were collected and put in the plant press. They were taken to the National Botanical Research Institute for identification and verification.

3.5 Soil Sampling

Soil samples were collected in the 20m x 20m quadrats where data for trees were collected. Five soil samples were collected in each quadrat (one soil sample from each corner of the quadrat, and one soil sample from the centre). The soil was collected using a garden shovel at a depth of 5cm after removing litter on the ground surface. These soil samples were then reconstituted into one composite sample by mixing the 5 samples in a basin. Three soil samples were collected from each treatment site. Composite samples were put in paper bags and sun-dried to stop biological activities before they were analyzed for texture (% sand, % clay and % silt), organic matter, conductivity, pH, cation exchange capacity(CEC), nitrogen, potassium and phosphorus.

3.6 Trapping of ground dwelling invertebrates

In each 100m x 50m treatments, 6 quadrats measuring 10m x 10m were systematically demarcated. In each of these 6 plots, 5 plastic pitfall traps were set. Four pitfall traps were set at the middle of each line of the quadrat; and one was set at the centre of the quadrat. Each pitfall trap measuring 11.5cm deep and 8.5cm in diameter was filled with soapy water when they were set. Therefore, in each treatment, 30 wet pitfall traps were set. Traps were made to flush with the edge of the ground and the position of each trap was marked to ease their location during inspection and emptying. Traps were left for 72 hours after which they were emptied and invertebrates put into vials using forceps (some invertebrates were sieved out from the traps and put in vials) and preserved in 70% ethanol. Trapping was always done on the same spots in September, 2011 (hot dry season), March, 2012 (hot wet season) and June, 2012 (cold dry season).

3.7 Processing and identification of invertebrates

The captured invertebrates were sorted according to morphological characteristics using the identification manuals such as the Field Guide to Insects of South Africa (Picker *et al*., 2004) in the laboratory at the University of Namibia. From each trap, invertebrates belonging to one family were placed in one vial and the vial was labeled with the following information: habitat, trap number, family of specimens, date collected and vial number. Families identified were confirmed at the National History section of the National Museum of Namibia.

3.8 Data analyses

3.8.1 Vegetation structure and plant species composition

Woody plant density was calculated as the sum of all the woody plants in a 20m × 20m ($400m^2$) plot, and extrapolated to density per hectare (10,000 m^2). Mean density and standard error for the mean for each site were calculated in BiodiversityR Statistical package for Biologists. The mean woody density data were tested for normality in BiodiversityR Statistical package for Biologists using Kolmogorov-Smirnov (KS) test. The data were found to be normally distributed ($W= 0.91$ and $p>0.05$). One way Analysis of variance (ANOVA) was used to test for significant differences of woody plant densities in the three sites.

To determine and compare plant species composition in the normal savanna, intermediate bush encroachment and high bush encroachment sites, binary data for woody plant species and herbaceous plant species were analysed using the Hierarchical Cluster Analysis (HCA) performed using Primer5.2.0 software. The Hierarchical Cluster

Analysis (HCA) is a multivariate procedure that groups observations by similarity and dissimilarity (Gauch, 1982).

3.8.2 Soil properties analysis

All the soil data were analyzed using SPSS version 16 for windows. Soil properties data were tested for normality using Kolmogorov-Smirnov test. All the data were normally distributed and one way Analysis of variance (ANOVA) was used to for significant differences in the soil properties among the three sampling sites, while Tukey's *post hoc* test was used to indicate sources of the differences.

3.8.3 Invertebrate richness, diversity and composition

The software BiodiversityR for windows was used to calculate diversity and richness for invertebrates. Each pitfall trap in a quadrat was considered as a sampling unit. Family diversity for each trap was calculated in the BiodiversityR for Biologists using the Shannon-Wiener. index of diversity (Shannon and Weaver, 1949).

$H = -\sum_{i-1}^{S} (pi)(Inpi)$ Where pi is the proportion of individuals found in the i^{th} species and ln is the natural logarithm. This Shannon-Wiener index takes into account richness as well as evenness, thus giving a good measure of family diversity (Krebs, 1994).

Mean Family diversity of ground-dwelling invertebrates and standard error of the mean for each quadrat were calculated from the diversity indices data from the five pitfall traps in a quadrat. From the mean family diversity indices of the six quadrats, mean family diversity indices for sites were calculated for each season. The mean diversity data for each site per season was tested for normality using the Kolmogorov-Smirnov (KS) test.

Family richness for each trap was calculated in the BiodiversityR for Biologists. Mean richness and standard error of the mean for each quadrat were calculated from the richness indices data from the five pitfall traps in a quadrat. From the mean richness indices of the six quadrats, mean richness indices for sites were calculated for each season. The mean richness data for each site per season was tested for normality using the Kolmogorov-Smirnov test.

For diversity and richness, when Kolmogorov-Smirnov test indicated normality of data distribution, a one way analysis of variance was used to test for differences while if the test indicated no normality, a Kruskal Wallis test was used to test for differences. When differences between means were indicated, a Tukey's test was conducted to reveal the source of the detected significant differences.

To determine and compare invertebrate Family composition in the normal savanna, intermediate bush encroachment and high bush encroachment sites, binary data for invertebrates' Families was analysed using the Hierarchical Cluster Analysis (HCA) performed using Primer5.2.0 software. The Hierarchical Cluster Analysis (HCA) is a multivariate procedure that groups observations by similarity and dissimilarity (Gauch, 1982).

The Bray-Curtis similarity analysis, the group average linkage method was performed on the invertebrate Family data in the three sites for each season. The cluster analysis was also used to generate dendrogram that showed similarities and dissimilarities of Families of invertebrates captured in the normal savanna, intermediate bush encroachment and high bush encroached sites during each season.

To determine seasonal variations in invertebrates abundances, all invertebrate Families trapped were ranked according to their relative abundances and proportional percentage contribution to the total number trapped were calculated for each site per season. Relative total abundances were then tested for using a two way analysis of variance (ANOVA) without replication with sites as treatments and seasons as blocks.

CHAPTER 4

4.0 RESULTS

4.1 Vegetation structure

4.1.1 Woody plants density

The mean densities of woody plants in the selected normal savanna site, intermediate bush encroached site and a highly bush encroached site are presented in Figure 4. The One way analysis of variance (ANOVA) test revealed significant differences in the mean woody densities among the three study sites ($F=37.79$, $df = 2$ and $p<0.001$). Tukey's test revealed that the density of woody plants were significantly different between the intermediate bush encroached site and the normal savanna site ($df=1$, $p<0.05$); between the high bush encroached site and the normal savanna site ($df=1$, $p<0.001$); and between the high bush encroached site and the intermediate bush encroached site ($df=1$, $p< 0.01$).

4.1.2 Herbaceous plant cover

Statistical test with Kruskal Wallis revealed that there was no significant difference in herbaceous plant cover among the three sites ($H=0.97$, $df=2$, $p>0.05$).

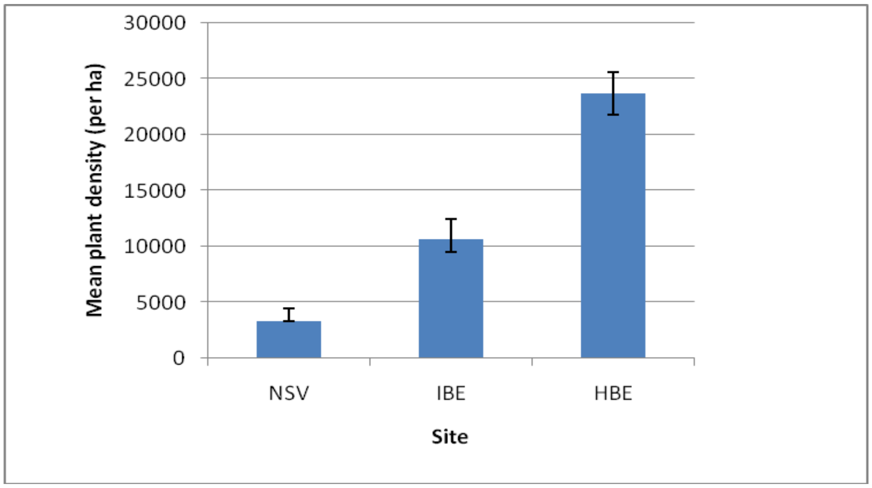

Figure 4. Comparison of mean density of woody plants among the three study sites (NSV= normal savanna, IBE= intermediate bush encroachment and HBE= high bush encroachment) in Omaheke Region. Error bars represent standard errors of the means**.**

4.1.2 Herbaceous plant cover

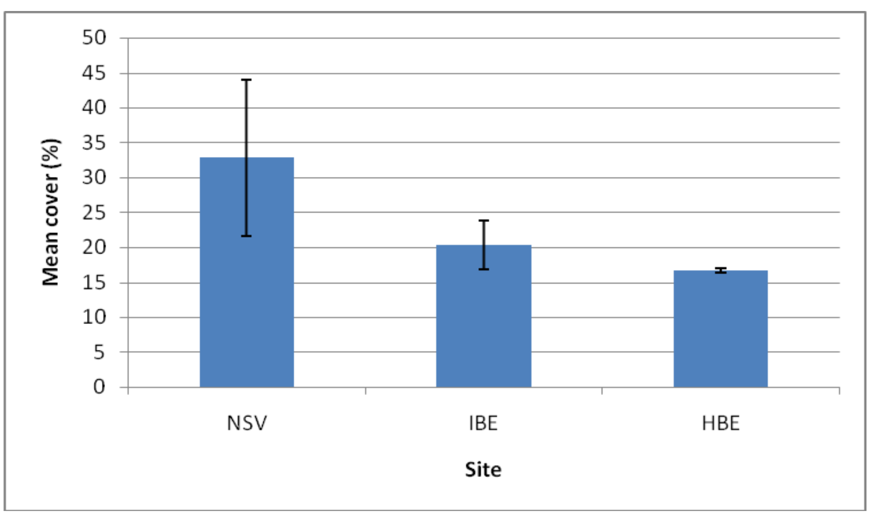

Figure 5. Comparison of mean grass and forbs cover among the three study sites (NSV=normal savanna, IBE=intermediate bush encroachment and HBE= high bush encroachment) in Omaheke Region. Error bars represent standard errors of the means**.**

4.2 Plant species composition

4.2.1 Woody plants

Hierarchical Cluster Analysis was undertaken to test the hypothesis that there would be no significant difference in the composition of plant species amongst the normal savanna, intermediate bush encroached and high bush encroached sites. Presented in Figure 6 is a dendrogram showing clusters generated by the Hierarchical Cluster Analysis (HCA).

Hierarchical Cluster Analysis separated the plots into 4 main clusters based on woody plant species composition (Figure 6). Cluster 1 had only one plot from intermediate bush encroached site. This plot had about 10% similarity level to the rest of the plots and *Grewia flava* as the main species in the cluster. Cluster 2 had plots only from the high bush encroached sites and the main species is *Tarchonanthus camphoratus.* Cluster 3 was composed of plots from the normal savanna site only, and the main species for the cluster is *Terminalia sericea* and *Grewia bicolor.* The last cluster (Cluster4) had plots from all the three sites and the common plant species were *Acacia leuderitzii* and *Acacia mellifera.* Overall, plots from the normal savanna were separated from the bush encroached ones.

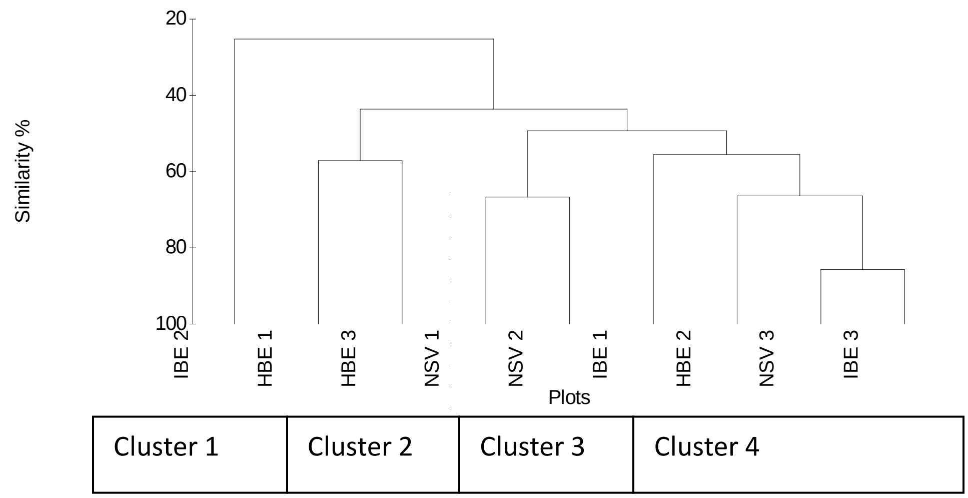

Figure 6. Hierarchical Clusters Analysis dendrogram showing differences in woody plant species composition among three sites (NSV=normal savanna, IBE= intermediate bush encroachment and HBE=high bush encroachment) with different bush densities in Omaheke Region.

4.2.2 Herbaceous plants

Hierarchical Cluster Analysis separated the plots into 3 main clusters (Figure 7) based on the presence / absence of herbaceous plants species. Cluster 1 comprised 2 plots from the highly bush encroached site with zero percent similarity to any other plots (but share 50% similarity between themselves) The common species in the cluster was *Eragrostis biflora*.

Cluster 2 comprised all the plots from the normal savanna site mixed with 2 plots from the intermediate bush encroached site and the common species for the cluster were *Panicum fluviicola, Aristida stipitata* and *Pogonarthria squarrosa.*

Cluster 3 comprised 2 plots, one from the high bush encroached site and the other from the intermediate bush encroached site and the common species in the cluster was *Pollichia campestris*. (Clusters 2 and 3 share only 10% similarity).

In general, normal savanna sites were separated from the highly bush encroached site.

Figure 7. Hierarchical Clusters Analysis dendrogram showing differences in grasses and forbs species composition among three sites (NSV=normal savanna, IBE=intermediate bush encroached and HBE= high bush encroached) with different bush densities in Omaheke Region.

4.3 Soil chemical and physical properties

The present study characterized soil chemical and physical properties in order to obtain environmental variable for each study site that would be valuable to explain mechanisms of influence of bush encroached on the family diversity of ground dwelling invertebrates.

One way analysis of variance (ANOVA) revealed that there was significant difference in the pH among the three sampling sites ($F= 8.14$, $df =2$ $p<0.05$). Tukey's test revealed that the significant difference was found between highly bush encroached site and normal savanna site ($df=1$, $p<0.05$).

Table 1. Comparison of soil chemical and physical properties at 5cm depth in the three sites that differed in levels of bush encroached in Omaheke Region. Where the letters are the same in a comparison by soil variable in different sites, it means there was no significant difference and vice versa. (OM = organic matter, CEC = Cation exchange capacity).

Soils Variable/site	**Normal Savanna**	**Intermediate Bush encroached**	**Highly Bush encroached**
pH(w)	6.53^{a}	6.73^{a}	7.03^{b}
OM (%)	0.55^{a}	0.69^{b}	1.18^{c}
CEC(meq/100g)	2.75^{a}	3.3^{a}	3.47^{a}
Conductivity (mS/m)	1.67^{a}	2.0^{b}	4.9^{c}
Nitrogen (%N m/m)	0.04^{a}	0.03^{b}	0.06^{c}
Phosphorus (mgP/kg)	2.01^{a}	1.57^{b}	4.88^{c}
Potassium (mgK/kg)	50.00^{a}	48.67^{a}	67.6^{a}
Sand (%)	94.19^{a}	93.62^{b}	92.48^{c}
Clay (%)	3.8^{a}	3.76^{a}	3.82^{a}
Silt (%)	1.95^{a}	2.61^{a}	3.68^{b}

There was significant difference in the organic matter content among the three sampling sites ($F= 15.9$, $df =2$ $p<0.05$). Tukey's test revealed that the significant difference was found between highly bush encroached site and normal savanna site ($df=1$, $p<0.05$); and between highly bush encroached site and the intermediate bush encroached site ($df=1$, $p<0.05$). Organic matter was highest in high bush encroached site followed by intermediate bush encroached site and was lowest in the normal savanna site (Table 1).

There was no significant difference ($F= 2.39$, $df =2$ $p>0.05$) in the cation exchange capacity among the three sampling sites (Table 1).There was significant difference in the conductivity among the three sampling sites ($F= 14.63$, $df =2$ $p<0.05$). Tukey's test revealed that the significant difference was found between highly bush encroached site and normal savanna site ($df=1$, $p<0.01$); and between highly bush encroached site and the intermediate bush encroached site ($df=1$, $p<0.01$). Organic matter was highest in high bush encroached site followed by intermediate bush encroached site and was lowest in the normal savanna site (Table 1).

There was significant difference in the nitrogen content among the three sampling sites ($F= 13.0$, $df =2$ $p<0.05$). Tukey's test revealed that the significant difference was found between highly bush encroached site and normal savanna site ($df=1$, $p<0.05$); and between highly bush encroached site and the intermediate bush encroached site ($df=1$, $p<0.01$). Nitrogen was highest in high bush encroached site followed by normal savanna site and was lowest in the intermediate bush encroached site (Table 1).

There was significant difference in the phosphorus content among the three sampling sites ($F= 13.0$, $df =2$ $p<0.05$). Tukey's test revealed that the significant difference was found between highly bush encroached site and normal savanna site ($df=1$, $p<0.05$); and between highly bush encroached site and the intermediate bush encroached site ($df=1$, $p<0.01$). Phosphorus was highest in high bush encroached site followed by normal savanna site and was lowest in the intermediate bush encroached site (Table 1).

There was significant difference in the potassium content among the three sampling sites ($F= 5.98$, $df =2$ $p<0.05$). Tukey's test revealed that the significant difference was found between the highly bush encroached site and the intermediate bush encroached site ($df=1$, $p<0.05$). Potassium was highest in high bush encroached site followed by normal savanna site and was lowest in the intermediate bush encroached site (Table 1).

There was significant difference in the sand content among the three sampling sites ($F= 14.38$, $df =2$ $p<0.01$). Tukey's test revealed that the significant difference was found between the highly bush encroached site and the normal savanna site ($df=1$, $p<0.05$); and between the highly bush encroached site and the intermediate bush encroached site ($df=1$, $p<0.05$). Sand was highest in normal savanna site followed by intermediate bush encroached site and was lowest in the HBE site (Table 1).

There was significant difference in the silt content among the three sampling sites ($F= 4.9$, $df =2$ $p<0.05$). Tukey's test revealed that the significant difference was found between the highly bush encroached site and the normal savanna site ($df=1$, $p<0.05$). Silt was highest in high bush encroached site followed by intermediate bush encroached site and was lowest in the normal savanna site (Table1). There was no significant difference in the clay content among the three sampling sites ($F= 0.016$, $df =2$ $p>0.05$).

4.4 Invertebrates

4.4.1 Site variation in Family diversity of ground dwelling invertebrates.

In this study, determination of the variation in the Family diversity of ground dwelling invertebrates between seasons and the extent of bush encroached was the main focus of investigation. The seasonal variation in the Family diversity of invertebrates in the three sampling sites is presented in Figure 8.

Kruskal Wallis test revealed that there was significant difference in the mean diversity of invertebrates in the normal savanna site across the three seasons ($H= 7.6$, $df=2$, $p<0.05$). Tukey's *post hoc* test revealed that the significant difference was between the hot wet season and the cold dry seasons ($df=1$, $p<0.05$). The highest mean diversity was during the cold dry season (June) followed by the hot dry season (September) and was lowest in the hot wet season (March) (Figure 8).

Kruskal Wallis test revealed significant differences in mean diversity ($H = 25.69$, df=2, $p<0.001$) in the intermediate bush encroached site across the seasons. Tukey's *post hoc* test revealed that the significant difference was between hot wet season and cold dry season, (df=1, $p<0.001$); and the hot dry and cold dry season (df=1, $p<0.001$). The highest mean diversity in the cold dry season followed by the hot dry season (Figure 8). The lowest diversity mean was recorded in the hot wet season.

There was no difference in invertebrates Family diversity for the high bush encroached site across the seasons ($F=0.76$, df=2 and $p>0.05$).

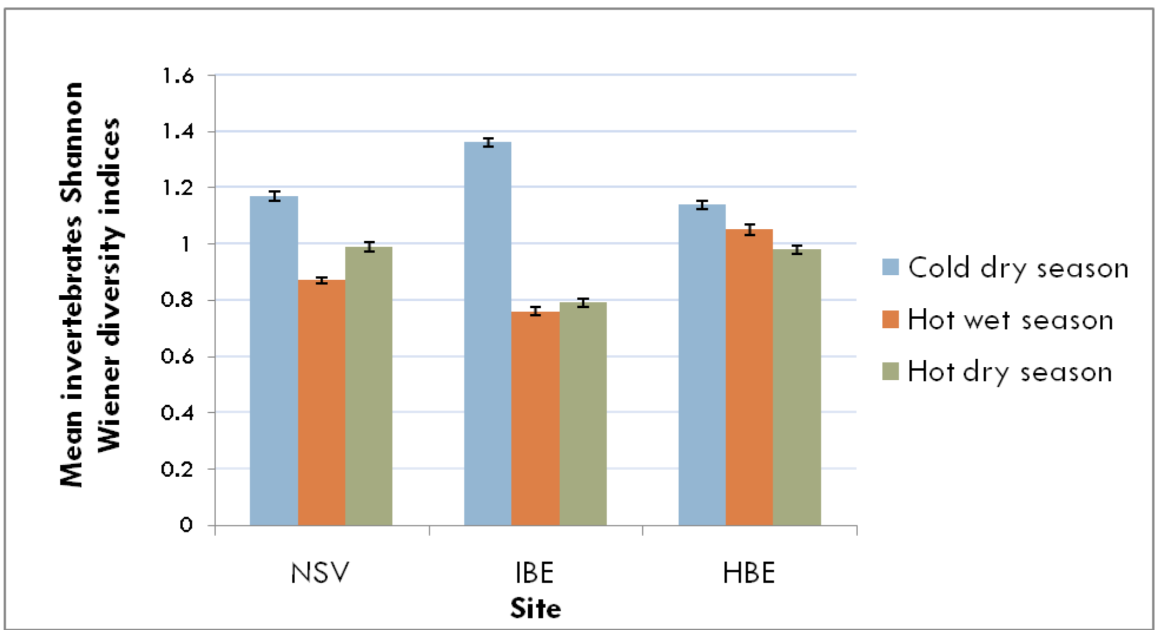

Figure 8. Site variation of the Shannon Wiener Family diversity indices in three sites (NSV=normal savanna, IBE=intermediate bush encroached and HBE= high bush encroached) that differ in levels of bush encroachment in Omaheke Region across the seasons. Bars indicate standard error of the means**.**

4.4.2 Seasonal variation of invertebrate Family diversity in the three sites.

Since the focus of the study was to determine variation in the Family diversity of ground dwelling invertebrates due to bush encroached, spatial analysis was also done. Spatial variation in the Family diversity of invertebrates in the three sampling sites is presented in Figure 9**.**

During the cold dry season, there was no significant difference in the mean Family diversity of invertebrates ($H = 3.67$, $df=2$, $p>0.05$) among the three sites (normal savanna, intermediate bush encroached and high bush encroached) (Figure9).

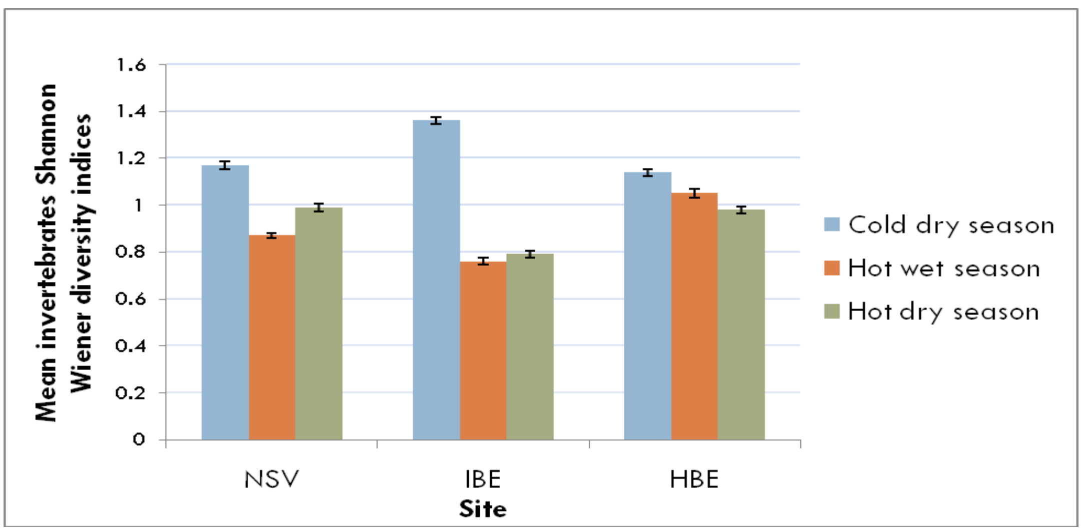

Figure 9. Seasonal variation in invertebrate Shannon Wiener Family diversity indices among the three sites (NSV=normal savanna, IBE=intermediate bush encroached and HBE= high bush encroached) that differ in levels of bush encroached in Omaheke Region in each season. Bars indicate standard errors of the means.

One way analysis of variance (ANOVA) revealed significant differences in Family diversity among the three sites ($F=3.12$, $df=2$, $p<0.05$) during the hot wet season. Tukey's test revealed a significant difference between intermediate bush encroached and highly bush encroached sites ($df= 1$, $p<0.05$). During the hot wet season, the mean Family diversity of invertebrates was highest in the high bush encroached site followed by the normal savanna site and the lowest was in the intermediate bush encroached site (Figure 9). During the hot dry season, Kruskal Wallis test revealed that there was no significant difference in mean diversity ($H= 4.2$, $d=2$, $p>0.05$) among the three sites.

4.5 Invertebrate Family richness

4.5.1 Site variation in Family richness in the three seasons

In this study, variation in the numbers of Families (Richness) of ground dwelling invertebrates by season and level of bush encroachment was investigated. The seasonal variation of Family richness in the three sampling sites is presented in Figure 10.

In the normal savanna site, Kruskal Wallis test revealed that there was a significant difference in Family richness of invertebrates among the three seasons ($H = 19.5$, $df=2$, $p<0.001$). Tukey's *post hoc* test revealed that the difference was between hot wet and cold dry seasons ($df=1$, $p<0.001$) and between the hot dry and hot wet seasons ($df=1$, $p<0.001$). The highest mean Family richness was during the hot wet season followed by the cold dry and the hot dry seasons (Figure 10).

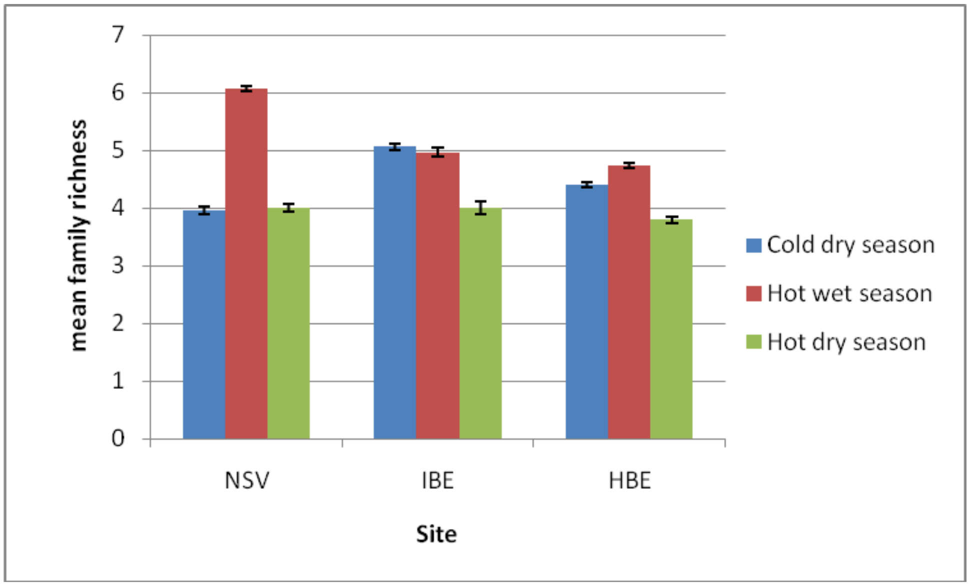

Figure 10. Site variations in mean Family richness of invertebrates at three sites (NSV= normal savanna, IBE= intermediate bush encroached and HBE= high bush encroached) that differ in levels of bush encroached in Omaheke Region. Bars indicate standard error of the means**.**

In the intermediate bush encroached site, Kruskal Wallis test revealed that there was a significant difference in the mean Family richness of invertebrates among the three seasons ($H = 7.16$, $df=2$, $p<0.05$). Tukey's test revealed that the significant difference was between hot dry and hot wet seasons ($df=1$, $p<0.01$). The mean Family richness of invertebrates was high during the cold dry season followed by the hot wet season (Figure 10).

In the high bush encroached site, Kruskal Wallis test revealed that there was no significant difference in the richness of invertebrates among the three seasons ($H=1.22$, $df=2$, $p>0.05$) (Figure 10).

4.5.2 Seasonal variations in invertebrate Family richness in the three sites

During the cold dry season, Kruskal Wallis test revealed that there was significant difference in Family richness of invertebrates among the three sites (H= 6.5, df=2, p<0.05). Tukey's *post hoc* test revealed that the significant difference was between normal savanna and the intermediate bush encroached sites (df=1, p< 0.05). Family richness for invertebrates was highest in the intermediate bush encroached site followed by the high bush encroached site and lowest in the normal savanna site (Figure 11).

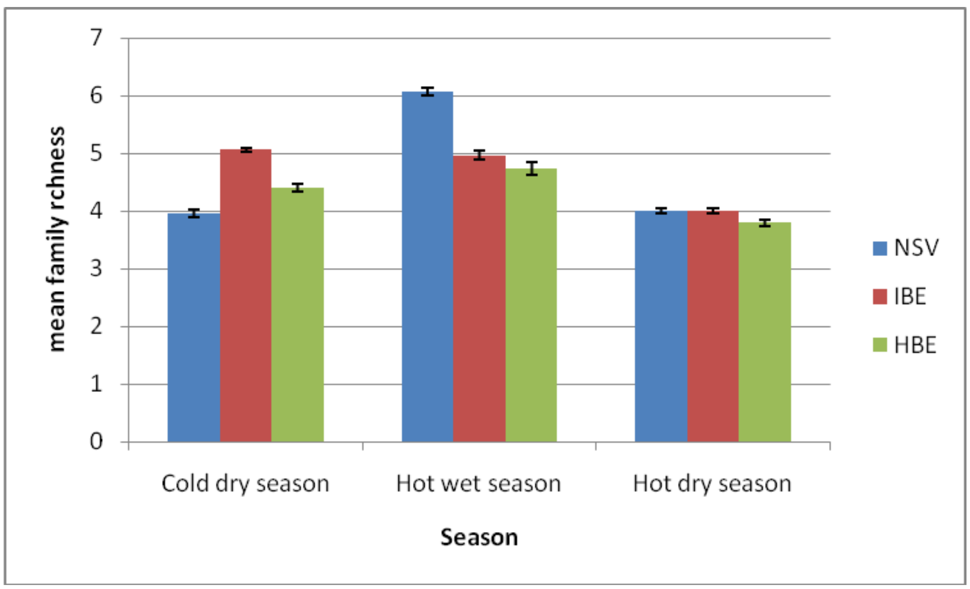

Figure 11. Seasonal variation in mean Family richness of invertebrates in the three sites (NSV=normal savanna, IBE= intermediate bush encroached and HBE= high bush encroached) that differ in levels of bush encroachment. Bars indicate standard error of the means.

During the hot wet season, Kruskal Wallis test revealed that there were significant differences in the mean Family richness of invertebrates among the three sites ($H = 9.28$, $df = 2$, $p < 0.05$). Tukey's *post hoc* test revealed that the significant differences were between the normal savanna and the high bush encroached sites ($df=1$, $p<0.05$), and between normal savanna and intermediate bush encroached site ($df=1$, $p<0.05$). The highest mean richness was in the normal savanna site followed by the intermediate bush encroached site and lowest in the high bush encroached site (Figure 11). During the hot dry season, Kruskal Wallis test revealed no significant differences in Family richness of invertebrates among the three sites ($H = 0.55$, $df=2$, $p > 0.05$).

4.5.3 Comparison of Family composition of invertebrates

4.5.3.1 Hot dry season

Hierarchical Cluster Analysis that was used to compare the Family composition of invertebrates in the three sampling sites separated the sampling units into 2 clusters, one of which has 2 sub clusters (Figure 12).

At 50% similarity level, plot 2 in the high bush encroached site was clearly separated from the rest of the plots forming its own cluster. The main Families found in this plot were the Myriapoda (Millipedes) and Gyrnidae (Whirligig beetle). At about 70% similarity level, there were 2 clusters formed (one with three sub clusters) (Figure 12).

Figure 12. Hierarchical Cluster Analysis (HCA) dendrogram showing differences in family composition among the sites with different bush encroachment densities in Omaheke Region during the hot dry season. (IBE=intermediate bush encroached site, HBE= high bush encroached site and NSV=normal savanna site).

Sub cluster 2a is composed of plots from the intermediate bush encroached and high bush encroached sites. The common Families for these plots were Ceratopogonidae (Biting midges) and Meloidae (Blister beetles). The sub cluster shared about 68% similarity with sub cluster 2b.

Sub cluster 2b was composed of plots from the normal savanna and high bush encroached sites. The common Family in the cluster was the Athericidae (flies). Sub cluster 2c was composed of plots from the intermediate bush encroached site sharing about 65% similarity with sub clusters 2a and 2b. The common Family in the sub cluster was the Gnaphosidae (stealthy spiders).

Cluster 3 was composed of only plots from the normal savanna sites. The common Families were Agoanidae (wasps), Formicidae (ants), Salticidae (jumping spiders) and Tenebrionidae (beetles). Generally, plots from normal savanna site were separated from the rest of the bush encroached site.

4.5.3.2 Hot wet season

At 30% similarity level, Cluster 1 which comprises only one plot from the high bush encroached was clearly formed. The main Family that isolated this cluster was Curculionidae (true weevils) of the Order Coleoptera (Figure 13).

At 60% similarity level, two clusters were formed from the group. These clusters were composed of plots from all the three sites (normal savanna, intermediate bush encroached and high bush encroached). The main Families in the cluster 2 were Meloidae (Blister beetles), Gnaphosidae (Stealthy spiders), Formicidae (Ants), Salticidae (Jumping spiders) and Tenebrionidae (Beetles). The common Families in cluster 3 were the Formicidae (Ants), Meloidae (Blister beetles) and Tenebrionidae (Beetles).

During the hot wet season, the Hierarchical Cluster Analysis did not separate plots according to sites meaning the invertebrates Family composition was not influenced by differences in the level of bush encroached (Figure 13).

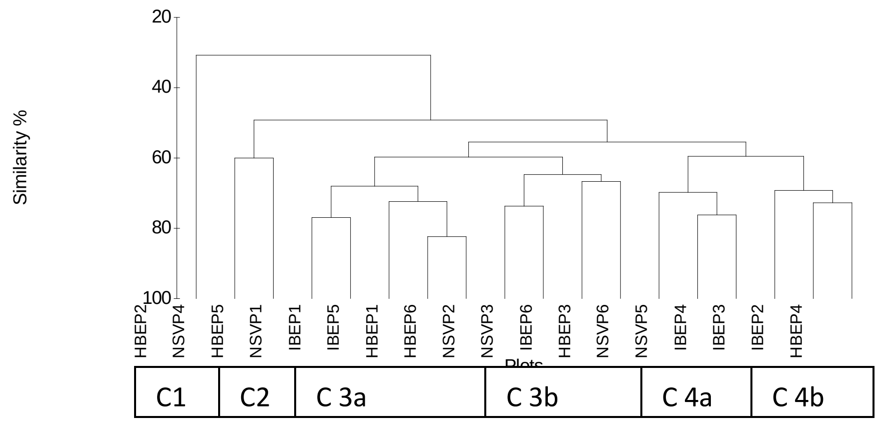

Figure 13. Hierarchical Cluster Analysis (HCA) dendrogram showing differences in Family composition of invertebrates among sites with different levels of bush encroachment densities in Omaheke Region during the hot wet season. (IBE=intermediate bush encroached site, HBE= high bush encroached site and NSV=normal savanna site).

4.5.3.3 Cold dry season

For data of Family composition of invertebrates, Hierarchical Cluster Analysis separated the sampling units into 2 clusters, one of which has 2 sub clusters (Figure 14).

At 50% similarity level, there were two main clusters formed. Cluster 1 comprised of more plots from the high bush encroached site and one from the normal savanna site. The main Families for the cluster were the Agoanidae (Fig wasp), Athericidae (Flies), Formicidae (Ants), and the Order Hemiptera, Suborder Heteroptera, Blattelidae (Cockroaches), Salticidae (Jumping spiders) and Tenebrionidae (Beetles).

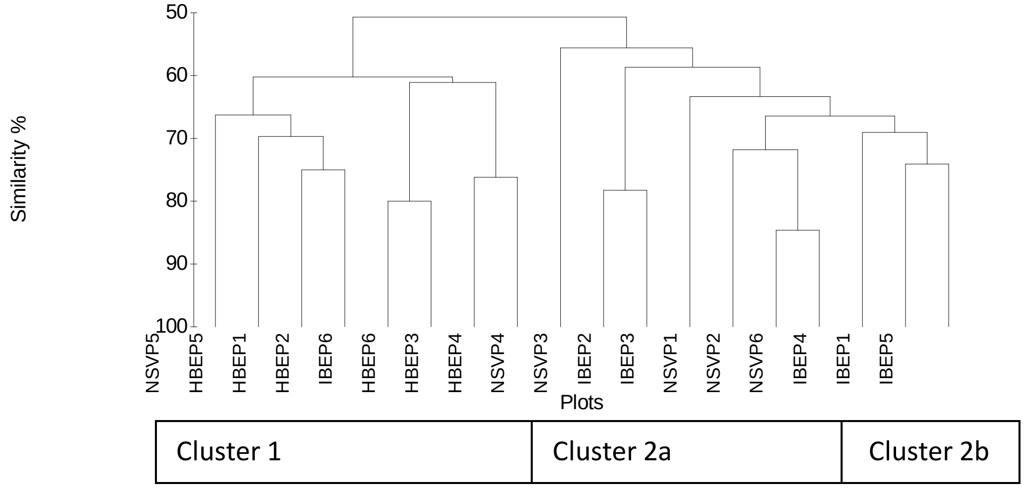

Figure 14. Hierarchical Cluster Analysis (HCA) dendrogram showing differences in family composition among the sites with different bush encroachment densities in Omaheke Region during the cold dry season. (IBE=intermediate bush encroached site, HBE= high bush encroached site and NSV=normal savanna site).

Cluster 2 comprised of plots from the normal savanna and intermediate bush encroached sites. The cluster was further subdivided into two sub clusters with sub cluster 2a comprising mostly plots from normal savanna sites and two plots from the intermediate bush encroached sites. The main Families in sub cluster 2a were Agoanidae (Fig wasps), Blattellidae (Cockroaches), Formicidae (Ants), Tenebrionidae (Beetles), Athericidae (Flies) and Bombylidae (Bee flies).

Sub cluster 2b had only plots from the intermediate bush encroached sites. The main Families in sub cluster 2b were Correidae (Leaf footed bug), Ichneumonidae (Wasps) and

Megachillidae (Bees). The clusters indicate differences in Family composition of invertebrates among the three sites.

4.5.4 Family abundance of invertebrates in each site across the three seasons

4.5.4.1 Hot dry season

In the hot dry season, for the normal savanna site, a total of 386 individuals belonging to 19 Families and 8 Orders were captured (Table 2). The dominant Family was the Formicidae (Ants) of the Order Hymenoptera (n=218) contributing 55.6% of the total capture. The other dominant Families were the Meloidae (Blister beetles) of the Order Coleoptera (n=23, 6 %), Salticidae (Jumping spiders) of the Order Araneae (n=19, 4.9%) and Gryllidae (Cricket) of the Order Orthoptera (n=11 2.8%). The rare Families were the Polyphargidae (Arid area cockroaches) of the Order Blattodea, the Pteromalidae (Pteromalid wasps) of the Order Hymenoptera, the Hymenopodidae (Orchid mantids) of the Order Mantodea and the Mutilidae (Velvet ants) of the Order Hymenoptera, each with one individual and contributing < 1% of the total capture each (Table 3a).

Table 2. Relative abundance of invertebrates captured in each site per season (NSV= normal savanna site, IBE= Intermediate bush encroached site and HBE= High bush encroached site).

Season	**Site**	**Number of Orders**	**Number of Families**	**Number of invertebrates**	**Proportion (%)**
Cold dry	NSV	7	25	175	**21.16**
	IBE	8	27	320	38.70
	HBE	9	25	332	40.14
	Total			**827**	**100**
Hot dry	NSV	8	19	386	30.73
	IBE	7	17	554	44.11
	HBE	8	18	316	25.16
	Total			**1256**	**100**
Hot wet	NSV	10	28	1215	43.38
	IBE	9	27	1073	38.31
	HBE	11	27	513	18.31
	Total			**2801**	**100**

The dominant Family was the Formicidae (Ants) of the Order Hymenoptera (n=218) contributing 55.6% of the total capture. The other dominant Families were the Meloidae (Blister beetles) of the Order Coleoptera (n=23, 6 %), Salticidae (Jumping spiders) of the Order Araneae (n=19, 4.9%) and Gryllidae (Cricket) of the Order Orthoptera (n=11 2.8%). The rare Families were the Polyphargidae (Arid area cockroaches) of the Order Blattodea, the Pteromalidae (Pteromalid wasps) of the Order Hymenoptera, the Hymenopodidae (Orchid mantids) of the Order Mantodea and the Mutilidae (Velvet ants) of the Order Hymenoptera, each with one individual and contributing < 1% of the total capture each (Table 3a).

For the intermediate bush encroached site, a total of 554 individuals were captured belonging to 17 Families and 7 Orders in the hot dry season (Table 2). The dominant Family was the Formicidae (Ants) of the Order Hymenoptera (n=435) and contributing 78.5% of the total capture. The rare Families were the Mutilidae (Velvet ants) of the Order Hymenoptera, Blattellidae (Cockroaches) of the Order Blattodea and Acrididae (Locusts) of the Order Orthoptera; each with one individual and contributing < 1% to the total site capture for the season (Table 3a).

In the high bush encroached site, a total of 316 individuals were captured belonging to 18 Families and 8 Orders (Table 2). The dominant Families were the Salticidae (Jumping spiders) of the Aranea Order (n=177). The rare Families were the Gryllidae (Crickets) of the Order Orthoptera, Mutilidae (Velvet ants) of the Order Hymenoptera, Ichneumonidae (Wasps) of the Order Hymenoptera and the Colletidae (Bees) also of the Order Hymenoptera each with one individual and contributing < 1% to the total invertebrates captured in the high bush encroached site for the hot wet season (Table 3a).

Table 3a. Dominant and rare Families (dominant contributing above 10% and rare less than 0.5%) of the proportion captured based on numerical relative abundance in the three sites (NSV=normal savanna, IBE= intermediate bush encroached and HBE =high bush encroached sites) in the hot dry season.

Site	**Family Name**	**Common name**	**Relative abundance**	**Proportion (%)**
NSV				
Dominant Family	Formicidae	Ants	218	55.6
	Suborder Homoptera	Bugs	67	17.4
Rare Families	Mutildae	Velvet ants	1	0.3
	Hymenopodidae	Orchid mantis	1	0.3
	Pteromalidae	Pteromalid wasp	1	0.3
	Polyphargidae	Sand cockroach	1	0.3
	Suborder Heteroptera	Stink bugs	1	0.3
IBE site				
Dominant Family	Formicidae	Ants	435	78.5
Rare Families	Acrididae	Locusts	1	0.2

	Blattelidae	Cockroach	1	0.2
	Mutilidae	Velvet ants	1	0.2
	Suborder Heteroptera	Stink bugs	1	0.2
HBE site				
Dominant Families	Formicidae	Ants	177	56
	Athericidae	Flies	32	10.1
Rare Families	Blattelidae	Cockroach	1	0.3
	Grynidae	Whirligig beetle	1	0.3
	Ichneumonidae	Wasp	1	0.3
	Myriapoda	Millipeds	1	0.3
	Mutilidae	Velvet ants	1	0.3

4.5.4.2 Hot wet season

In the normal savanna site, a total of 1,215 individuals belonging to 28 Families and 10 Orders were captured (Table 2). The dominant Families were the Formicidae (Ants) of the Order Hymenoptera (n=962) contributing 79.2% of the total capture. The rare Families were the Mantidae (Mantids) of the Order Mantodea, the Pyrogomorphidae (Foam grasshoppers) of the Order Orthoptera, the Leptophlebidae (Mayfies) Family of the Order Ephemeroptera and the Myriapoda (Millipede) each of which had one individual < 1% of the total capture from the normal savanna site for the hot wet season (Table 3b).

In the intermediate bush encroached site, a total of 1073 individuals were captured belonging to 27 Families and 9 Orders in the hot wet season (Table 2). The dominant Family was the Formicidae (Ants) of the Hymenoptera Order (n=879) contributing 81.2% of the total capture. The rare Families were the Trogossitidae (Bark gnawing beetles) of the Order Coleoptera, Tingidae (Lace bugs) of the Order Hemiptera, Theraphosidae (Spiders) of the Order Aranea, Pyrogomorphidae (Foam grasshoppers) of the Order Coleoptera and Drillidae of the Order Coleoptera; each with one individual and contributing < 1% to the total capture from the intermediate bush encroached site for the hot wet season (Table 3b).

In the high bush encroached site, a total of 513 individuals were captured belonging to 27 Families and 11 Orders (Table 2). The dominant Families were the Formicidae (Ants) of the Order Hymenoptera (n=278) contributing 54.2% of the total capture, Athericidae (Flies) of the Order Diptera (n=88) representing 17.2%. The rare Families were the Termittidae (Termites) of the Order Isoptera, Caenidae (Caenflies) of the Order Ephemeroptera, Chrysomelidae of the Order Coleoptera and the Sphecidae (Leaf footed bug) of the Order Hymenoptera, each with (n=1) and contributing < 1% to the total invertebrates captured in the high bush encroached site for the season (Table 3b).

Table 3b. Dominant and rare Families (dominant contributing above 10% and rare less than 0.5%) of the proportion captured based on numerical relative abundance in the three sites (NSV=normal savanna, IBE= intermediate bush encroached and HBE =high bush encroached sites) in the in the hot wet season.

Site	**Family Name**	**Common name**	**Relative abundance**	**Proportion %**
NSV				
Dominant Family	Formicidae	Ants	962	79.2
Rare Families	Ceratopogonidae	Bitting midges	1	0.1
	Eumenidae	Potter wasp	1	0.1
	Leptopogonidae	Mayflies	1	0.1
	Myriapoda	Millipeds	1	0.1
	Pyrogomorphidae	Foam grasshoppers	1	0.1
	Mantidae	Mantid	1	0.1
IBE site				
Dominant Family	Formicidae	Ants	879	81.9
Rare Families	Anthophoridae	Bees	1	0.1
	Drillidae	Drillid beetles	1	0.1
	Hymenopodidae	Orchid mantis	1	0.1
	Pyrogomorphidae	Stick grasshopper	1	0.1
	Therophosidae	Spiders	1	0.1
	Tingidae	Lace bugs	1	0.1
	Trogossitidae	Bark gnawing beetle	1	0.1

HBE site				
Dominant Families	Formicidae	Ants	278	54.2
	Athericidae	Flies	88	17.2
Rare Familes	Anastostomatidae	King cricket	1	0.2
	Curculionidae	Weevils	1	0.2
	Japygidae	Diplurans	1	0.2
	Sphecidae	Sand wasps	1	0.2
	Chrysomelidae	Leaf beetles	1	0.2
	Caenidae	Caen flies	1	0.2
	Termittidae	Termites	1	0.2

4.5.4.3 Cold dry season

In the hot dry season, for the normal savanna site, a total of 175 individuals belonging to 25 Families and 7 Orders were captured (Table 2). The dominant Families were the Tenebrionidae (Beetles) of the Order Coleoptera (n=44) contributing 25.1% of the total capture, Formicidae (Ants) of the Order Hymenoptera (n=22, 12.6%) the Blattellidae (Cockroaches) of the Order Blattodea (n=22) contributing 12 % of the total capture from the normal savanna site in the cold dry season. The rare Families were Gryllidae (Crickets) of the Order Orthoptera, Drilidae (Drill beetles) of Order Coleoptera and the Alydidae (Broad headed bugs) of the Order Hemiptera, Gnaphosidae of the Order Aranea, Tingidae (Lace bugs) of the Order Hemiptera, Drillidae (Drilid beetle) of the

Order Coleoptera, each with one individual and contributing <1% of the total capture (Table 3c).

For the intermediate bush encroached site, a total of 320 individuals were captured belonging to 27 Families and 8 Orders in the hot dry season (Table 2). The dominant invertebrates were the sub order Heteroptera (Stink bugs) of the Order Hemiptera (n=96) contributing 30% of the total capture, the Formicidae (Ants) (n=55) of the Order Hymenoptera contributing 17.2%, Blattodea (Cockroaches) (n=43) of the Order Blattodea contributing 13.4% of the total capture and the Tenebrionidae (Beetles) (n=36) of the Order Coleoptera contributing 11.2% of the total capture from the intermediate bush encroached site in the season. The rare Families were the Drillidae (Drilid beetle) of the Order Coleoptera, Grynidae (Whirligig beetle) of the Order Coleoptera and the Pompilidae of the Order Hymenoptera, Mutilidae of the Order Hymenoptera, Hymenopodidae of the Order Mantodea, and Sciaridae of the Order Diptera each with one individual and contributing <1% to the total capture (Table 3c).

In the high bush encroached site, a total of 332 individuals were captured belonging to 25 Families and Orders (Table 2). The dominant invertebrates were the sub order Heteroptera (Stink bugs) of the Order Hemiptera (n=123) contributing 37% of the total capture, Formicidae (Ants) (n=59) of the Order Hymenoptera contributing 17.8%. The rare Families were the Gryllidae (Crickets) of the Order Orthoptera, Solifugae (Sun spiders) of the Order Aranea, Elateridae (Fireflies) of the Order Coleoptera, Braconidae (Braconid wasp) of the Order Hymenoptera, Chrysomelidae (Leaf beetles) of the Order

Coleoptera, Myrmeleontide (Ant lion) of the Order Neuroptera and Gnaphosidae (Stealthy ground beetles) of the Order Coleoptera each with one individual and contributing <1% of the total capture in the high bush encroached site.

Statistical test using two way analysis of variance (ANOVA) with sites as treatments and seasons as blocks revealed that there was no significant difference in the abundance of invertebrates captured among the three sites in each season ($F=1.10$, $df=2$ and $p>0.05$) but there was significant difference in abundance across seasons in each site ($F=6.95$, $df=2$ and $p<0.05$).

Table 3c. Dominant and rare Families (dominant contributing above 10% and rare less than 0.5%) of the proportion captured based on numerical relative abundance in the three sites (NSV=normal savanna, IBE= intermediate bush encroached and HBE =high bush encroached sites) in the in the cold dry season**.**

Site	**Family Name**	**Common name**	**Relative abundance**	**Proportion %**
NSV				
Dominant Family	Tenebrionidae	Beetles	44	25.1
	Blattelidae	Cockroaches	22	12.6
	Formicidae	Ants	22	12.6
Rare Families	Alydidae	Broad headed beetle	1	0.6
	Drillidae	Drilid beetle	1	0.6
	Gnaphosidae	Jumping ground spiders	1	0.6
IBE site				

Dominant Family	Suborder Heteroptera	Stink bugs	96	30
	Formicidae	Ants	55	17.2
Rare Families	Drillidae	Drilid beetle	1	0.3
	Grynidae	Whirligig beetle	1	0.3
	Mutilidae	Velvet ants	1	0.3
	Pompilidae	Wasp	1	0.3
HBE site				
Dominant Families	Suborder Heteroptera	Stink bugs	123	37
	Formicidae	Ants	59	17.8
Rare Families	Gryllidae	Cricket	1	0.3
	Solifugae	Sun spider	1	0.3
	Elateridae	Fireflies	1	0.3
	Braconidae	Braconid wasp	1	0.3
	Chrysomelidae	Leaf beetles	1	0.3
	Myrmeleontidae	Ant lion	1	0.3
	Gnaphosidae	Jumping ground spiders	1	0.3

CHAPTER 5

5.0 DISCUSSION

5.1 Differences in vegetation structure

The study sites provided suitable habitats where the impact of bush encroached can be studied because the three sites have significantly different bush densities. Statistical tests in this study revealed that there was a significant difference in the density of woody plants among the three sites, with the normal savanna (NSV) having the lowest density and high bush encroached (HBE) site having the highest density (Figure 4). The differences in bush densities in this area between the normal savanna and the other two sites indicate that bush encroachment as a concept is better expressed in relative terms. An encroached site is generally considered to have > 1,000 bushes per hectare (de Klerk, 2004) but in this region, a normal savanna had an average of 3,000 bushes per hectare and there was no evidence that the normal savanna had been encroached. Despite observed differences in herbaceous plant cover (Figure 5), statistical test revealed no significant difference in herbaceous plant cover among the three sites. This observation is contrary to expectation since there should be an inverse relationship between woody density and plant cover as predicted by Walter' Hypothesis (Walter, 1971). However, the trend in herbaceous cover still conformed to the expectation but the high variability in cover at the normal savanna (NSV) site led to the no significant difference in the results.

Therefore, one would expect the differences in herbaceous cover to have an impact on the ecology of invertebrates communities in the area.

Species composition of woody and herbaceous plants differed significantly among the three sites (Figures 7 and 8). In both cases, the normal savanna site was more distinctly separated from the bush encroached sites. This is because the plant species in the normal savanna site were different from the species in the intermediate bush encroached and the high bush encroached species. Changes in woody density alter competitive interactions among plant species such that species composition changes (Scholes and Walker, 1993). In an encroached state, only one or two species dominate whereas in a “normal” state, dominance is shared among several species. The differences in composition and dominance lead to differences in species richness and diversity due to lower evenness in bush encroached sites compared to normal savanna.

5.2 Soil chemical and physical properties

Soil chemical and physical properties were analysed in this study to check if the three sites had major differences in soil properties apart from the bush encroachment. Although statistics show significant difference in sand % among the sites, the soil texture in all the three sites (normal savanna, intermediate bush encroached and high bush encroached) is classified as sandy because the sand content is above 90% (Table 1). There was no significant difference in cation exchange capacity, clay content and Potassium content among the three sites (Table 1). These factors then confirm that the differences in vegetation structure and plant species composition were as a result of bush encroachment and not due to differences in soil textural properties. According to Britz and Ward (2007), soil texture is a crucial determinant of the tree to grass ratio because of its effects on plant growth, soil moisture, nutrient presence and availability. Soil texture is important because it impacts on soil structure (Nichols *et al.,* 2004). This in turn affects the ability of the soil to retain moisture and withstand erosion (Britz and Ward, (2007). Soil organic matter and conductivity were significantly higher in high bush encroached site followed by the intermediate bush encroached site (Table 1). The increase in organic matter content was due to increase in leaf litter from the encroaching woody plants. The organic matter has positive influence on soil conductivity (Auerswald, 1995). Nitrogen and Phosphorus were significantly higher in high bush encroached site followed by the intermediate bush encroached site and lowest in the normal savanna site (Table 1). This is due to the ability of woody plants to tap nutrients from the lower levels of the soil compared to grasses in the normal savanna site which are only able to tap nutrients from the upper layer of the soil. Similar results were reported by Dye and Spear (1982), and also Teague and Smith (1992).

5.3 Spatial variation in invertebrate family abundance, richness, diversity, and composition

During the cold dry and hot dry seasons, there was no significant difference in Family diversity and relative abundance of invertebrates among the three sites (Figure 9 and Table 2). During the two seasons, there was no supporting evidence for the hypothesis that suggested that the diversity of invertebrates would be higher in the intermediate bush encroached site than in the normal savanna site and the high bush encroached sites. The study revealed that differences in bush density and herbaceous cover in the different sites did not have a significant effect on relative abundance and Family diversity among the normal savanna, intermediate bush encroached and high bush encroached sites (Figure 9). This may be so because all the three sites are located in the same ecological area and are exposed to similar climatic variables (moisture, temperature and sunlight). These sites provided the invertebrates with similar niche opportunities to exploit (Krebs, 1994). Niche availability is a function of habitat heterogeneity or complexity; the more complex the habitat, the greater the diversity of species or Families of organisms (Rosenzweig and Winakur, 1969; Hatley and MacMahon, 1980). According to Krebs (1994), abiotic factors such as temperature, moisture and radiation shape the biological structure of communities and therefore determine the type of organisms that will be supported. During the two seasons (cold dry and hot dry), leaf and herbaceous cover is basically the same at all sites due to deciduousness of the plants resulting in all habitats being open.

However, diversity was highest in the bush encroached site during the hot wet season. This is because closed woodland areas such as the high bush encroached site offer more shade during the hot season, thereby making the microclimatic conditions better than more open sites. Invertebrates being ectotherms are very sensitive to fluctuations in temperature and are expected to be more in cooler areas during the hot wet season. Thus bush encroached increases habitat heterogeneity (Blaum *et al*, 2009) and provides diverse physical habitat structure that supports diverse vegetation and associated plant and animal communities including invertebrates. The wet conditions during the hot wet season (compared to hot dry season) bring an abundance of food at all sites. Therefore, one would suggest that it is the interactive effect of moisture and temperature that ultimately influences invertebrate diversity.

During the cold dry season, there was significant difference in Family richness of invertebrates with the highest richness in the intermediate bush encroached site followed by the high bush encroached site and was lowest in the normal savanna site. These results provide evidence to support the hypothesis that Family richness of ground dwelling invertebrates would significantly differ among the sites that differ in levels of bush density. The increase in richness at the intermediate bush encroached and high bush encroached sites is attributed to increased habitat heterogeneity as proposed by the intermediate disturbance hypothesis which suggest that diversity will be at the highest levels when the patterns of disturbance which impact the area are intermediate ((Skowno *et al.*, 1999; Pickett and White, 1985). This is because at high levels of disturbance, the species present will be those that are hardened under disturbed conditions, or which spread and grow quickly and invade an area in between disturbances. This represents a small subset of the species that could potentially exist in that area if disturbances did not occur (Pickett and White, 1985). At low levels of disturbance, the competitive exclusion principle suggests that each available niche in the area will be dominated by a single species that is the best competitor given that it has had the time to out-compete all other species which might occupy that niche (Pickett and White, 1985). This too represents a small sub-set of the species that could fill that niche if competition were not present. However, at intermediate disturbance level, the good competitors will have an opportunity to gain a foothold without being destroyed by disturbance, but will not have enough time between disturbances to out-compete the harder and faster invading colonizer species which dominate soon after each disturbance, or to exclude the less fit and slow-invading species (Pickett and White, 1985). Thus, total species diversity will be highest at an intermediate frequency and intensity of disturbance. According to Ríos-Casanova *et al*. (2006), disturbances of habitats whether by physical or biological factors can affect richness and abundance of the ground-dwelling invertebrates.

There was clear separation of the three sites during the hot dry and cold dry seasons (Figures 12 and 14) suggesting that bush density and plant species composition had an impact on the Family distribution of invertebrates. The differences in Family composition suggest particular niche preferences for the different Families of invertebrates (Pickett and Bugg, 1998). During the hot dry and cold dry seasons, normal savanna site is more prone to harsh temperatures compared to intermediate bush encroached and high bush encroached sites where there is some cover moderating the harsh temperature and this determines which Families are to be found in the three different sites. At the same time, Families found in the intermediate bush encroached and the high bush encroached sites may indicate some adaptation to high canopy cover and litter layer which may not be the same in the normal savanna site because the sites had different vegetation composition and structure (Figures 4 and 5). The differences in Family composition of invertebrates support the fact that the invertebrates have different microclimate requirements depending on life stage, seeking optimal conditions for larval development, protection from desiccation and extreme temperatures, and overwinter survival (Pickett and Bugg, 1998; Tallamy, 2004; Burghardt *et al.*, 2008).

During the hot wet season, there was significant difference in Family richness of invertebrates among the three sites. Family richness and abundance of invertebrates were highest in the normal savanna and lowest in the high bush encroached site (Figure 11 and Table 2). This is due to the fact that some bush encroaching species such as *Dichrostachys ciner*ea usually displace other plant species (Joubert, 2003), resulting in a decline in plant diversity providing homogeneous habitats for invertebrates (Blaum *et al.*, 2009). With available moisture during the hot wet season, a diversity of plants grow (mostly forbs and grasses) in the normal savanna sites providing a heterogeneous habitat (Armbrecht *et al*., 2004) capable of supporting a wide range of invertebrate Families.

The Hierarchical Cluster Analysis dendrogram for the hot wet season did not separate the plots according to sites (Figure 14) suggesting invertebrates composition was not influenced by woody plant density in a major way during the hot wet season. This is probably because all the three sites are located in the same area and exposed to similar abiotic conditions. In a study on the effects of heavy grazing on assemblages of invertebrates in the Succulent Karoo, Seymour and Dean (1999) reported that invertebrate assemblages were most similar in composition where environmental factors such as topography, soil type and elevation were similar; while Blaum, *et al.*, (2009) in a study on changes in invertebrate diversity along land use driven gradient in shrub cover in savanna rangelands reported that changes in invertebrates species composition showed definite changes according to density of shrub cover.

5.4 Seasonal variation in invertebrate family abundance, richness, diversity, and composition

In the normal savanna site, the highest diversity of Families of invertebrates was recorded during the cold dry season followed by the hot dry season and was lowest in the hot wet season (Figure 8). This was explained by the fact that there was even distribution of Families of invertebrates in the cold dry season than during the hot wet and hot dry seasons when the Family Formicidae dominated the niches. In the normal savanna site, the lowest abundance of the Formicidae Family was recorded in the cold dry season (Tables 3a, 3b and 3c).

Abundance of invertebrates (Table 2) and Family richness (Figure 10) for the normal savanna site were highest during the hot wet season. This was because of availability of soil moisture (through rainfall) which greatly influences available plant nutrients promoting vegetation growth and having a direct positive impact on the population of invertebrates (Frampton *et al.,* 2000). This influences abundance and richness of invertebrates in a positive way. During the hot wet season, there is an increase in the availability of forbs and grasses increasing habitat heterogeneity and resource availability (Armbrecht *et al.*, 2004; Ribas and Schoereder, 2007). This provided diverse invertebrates with their required niches (Tallamy, 2004). While invertebrate richness and abundance were significantly higher during the hot wet season, diversity was significantly lower suggesting there is uneven distribution of invertebrate abundance among Families and this is attributed to inter-specific interactions between the Families present in the form of competitive exclusion (Brown *et.al*, 2007). Dejean and Corbara (2003), reported that some species of the Family Formicidae can influence the distribution of the less competitive ground dwelling invertebrates in a habitat. Invertebrates' Family abundance was high in the hot wet season followed by the hot dry season and lowest in the cold dry season (Table 2). This was because the availability of soil moisture (through rainfall) influenced the available plant nutrients promoting vegetation growth and having a direct positive impact on the population of invertebrates (Frampton *et al.,* 2000). This influenced abundance and richness of invertebrates in a positive way. During the hot wet season, there is an increase in the availability of forbs and grasses increasing habitat heterogeneity and availability of resources (Armbrecht *et al.,* 2004, Ribas & Schoereder, 2007).

In the high bush encroached site there was no significant difference in the diversity and richness of Families of invertebrates among the three seasons (Figures 8). This may be attributed to the fact that only Families of invertebrates that are adapted to the microclimate changes (increased humidity and soil moisture, decreased temperature) due to canopy cover by bush encroaching species may have survived in the high bush encroached sites (Samways *et al.*, 1996). Due to woody plant canopies, there were less forbs and grasses in the high bush encroached site (Figure 5) such that there was little structural change between the hot dry and the hot wet seasons. According to Samways *et al.* (1996), changes in vegetation structure lead to associated changes in ecosystem processes and diversity of fauna. In this study, Families of invertebrates such as the Salticidae and Gnaphosidae both of the Order Aranea were significantly dominant in the high bush encroached site compared to the other two sites in all the seasons suggesting that the bush encroachment provided these Families with favorable habitats hence their high abundance.

CHAPTER 6

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The main purpose of this study was to determine and compare Family abundance, diversity, richness and composition of ground dwelling invertebrates among the normal savanna, intermediate bush encroached and high bush encroached sites. The other objective was to determine seasonal variation in abundance, diversity, richness and composition of ground dwelling invertebrates among the three sites that significantly differed in levels of bush encroachment.

There was no significant difference in invertebrate Family diversity among the normal savanna, intermediate bush encroached site and the high bush encroached site during the cold dry and the hot dry seasons because all the three sites are located in the same ecological area and are exposed to similar climatic variables (moisture, temperature and sunlight). During the hot wet season, invertebrate Family diversity was significantly higher in the high bush encroached site because closed woodlands such as the high bush encroached site offer more shade during the hot season thereby making the microclimatic conditions better than more open sites. The study provides evidence to support the hypothesis that invertebrate Family diversity will be significantly different in the three sites because of differences in vegetation structure and habitat heterogeneity.

The study further revealed that invertebrate Family richness was significantly different in the three sites during the cold dry season due to habitat heterogeneity. The hypothesis that invertebrate richness will be significantly higher in intermediate bush encroached site due to increased habitat heterogeneity is supported.

The Hierarchical Cluster Analysis separated plots from the normal savanna site from the bush encroached sites for the hot dry and the cold dry seasons because of increased habitat heterogeneity due to bush encroachment. The study provided supporting evidence to the hypothesis that Family composition of invertebrates will be significantly different in the bush encroached sites from the normal savanna site due to differences in bush density and plant species composition.

The results of the study provide supporting evidence that the invertebrate Family abundance, diversity, richness and composition significantly varied in the three sampling sites. This is because of changes in vegetation structure due to bush encroachment.

6.2 Recommendations

It is recommended that in future studies, attempts should be made to identify invertebrates to species level to determine how bush encroachment affects individual species. Family level analysis puts together species of invertebrates that are affected differently by both vegetation structure due to bush encroachment and season.

Future studies must also selectively study specific species or Families of invertebrates to determine effects of bush encroachment on different functional groups.

Long term seasonal studies should be conducted in the different habitats in which seasonal variation of herbaceous cover is also monitored to understand how it affects variation in invertebrate composition.

It is recommended to conduct studies in habitats with different bush encroaching species in order to test whether effect of bush encroachment on invertebrates is influenced by different plant species or just changes in woody vegetation structure.

REFERENCES

Archer, S., Schimel, D.S., & Holland, E.A. (1995). Mechanisms of shrub land expansion; land use, climate or CO_2. *Climatic Change* **29**, 91-99.

Armbrecht, I., Perfecto, I. & Vandermeer, J. (2004). Enigmatic biodiversity correlations: Ant diversity responds to diverse resources. *Science* **304**, 284-286

Attignon, S.E., Weibel, D., Lachat, T., Sinsin, B., Nagel, P.& Peveling, R., (2004). Leaf litter breakdown in natural and plantation forests of the Lama Forest reserve in Benin. *Applied Soil Ecology*.

Auerswald, K., (1995). Percolation stability of aggregates from arable top soil. *Soil Science* **159**, 142-148.

Barbaro, L., Pontcharraud, L., Vetillard, F., Guyon, D. & Herveacute, J., 2005. Comparative responses of bird, carabid, and spider assemblages to stand and landscape diversity in maritime pine plantation forests. *Ecoscience* **12**, 110–121.

Bass, A. (2003). *Long-term monitoring of impacts to vegetation associated with the South Thornwell 3-D seismic survey at Lacassine National Wildlife Refuge, Louisiana Geological Survey, Louisiana State University*. Baton Rauge: Los Angeles, USA.

Beeby, A. (1993). *Applying Ecology*. Chapman & Hall, New York, NY, USA.

Blaum, N. & Wichmann, M. (2007). Short term transformation of matrix into hospitable habitat facilitates gene flow and mitigates fragmentation. *Journal of Animal Ecology* **76,** 1116–1127.

Blaum, N., Rossamanith, E., & Jeltsch, F. (2007).Land use affects rodent communities in Kalahari savanna rangelands. *African Journal of Ecology* **45**, 189-195.

Blaum, N., Seymour, C., Rossamanith, E., Jeltsch, F.& Schwager, M. (2009).Changes in arthropod diversity along a land use driven gradient of shrub cover in savanna rangelands: identification of suitable indicators Biodiversity. *Conservation* **18**, 1187–1199 ·

Britz, M. L. & Ward, D. (2007). The effects of soil conditions and grazing strategy on plant species composition in a semi-arid savanna. *African Journal of Range & Forage Science*, **24**(2) 51-61.

Brown, R.L., Jacobs, L.A. & Peet, R.K., (2007). *Species Richness: Small Scale. Ecyclopedia of Life Sciences*, John Wiley & Sons, Ltd.

Burghardt, K. T., Tallamy, D.W. & Shriver, W.G. (2008). Impact of native plants on bird and butterfly biodiversity in suburban landscapes. *Conservation Biology* **23**, 219–224.

Burke, A. (2006). *Flowers of the Central Namib*.John Meinert Printing.

Chrisholm, A. & Dumsday, R. (1987). *Land Degradation*. Cambridge.

Christian, J. M., & Wilson, S. D. (1999). Long-term ecosystem impacts of an introduced grass in the northern Great Plains. *Ecology* **80**, 2397–2407.

de Klerk, J.N. (2004). *Bush Encroached in Namibia: Report on phase 1 of the bush encroached Research, Monitoring and Management Project*. Windhoek. John Meinert Printers.

DEA (2003). An Environmental Impact Assessment on Bush control methods proposed under the bush encroachment research monitoring and management project. International Development Consultancy, Windhoek.

DEES (2003). Baseline Survey on the impact of Agricultural Extension services in Omaheke Region: Ministry of Agriculture, Water, and Rural Development, Gobabis, Namibia.

Dejean, A. & Corbara, B. (2003). A review of mosaics of dominant ants in rainforests and diversity response to diverse resources. *Science* **304**, 284-286.

Dougill, A. & Cox, J. (2007). Land degradation in the Kalahari: new analysis and alternative Perspectives. *Pastoral Development Network* 38.

Duelli, P., Obrist, M. K. & Schmatz, D. R. (1999). Biodiversity in agricultural landscapes: above-ground insects. *Agriculture, Ecosystems and Environment*, **74**, 33-64.

Dye, P.J. & Spear, P.T. (1982). The effects of bush clearing and rainfall variability on grass yield and composition in south-west Zimbabwe. *Zimbabwe journal of agricultural research,* **20**,103–118.

Eldridge, D.J., Bowker, M. A., Maestre, F.T., Roger, E., Reynolds, J.F. &. Whitford, W. G. (2011).Impacts of shrub encroached on ecosystem structure and functioning. *Towards a global synthesis. Ecology Letters,* **14**,709–722.

Els, J.F. (1995). *Production Analysis of Boer Goat. Flock in Bush Savanna-Veld*. Masters of Science in Agriculture - Animal Science thesis, University of Pretoria, Pretoria, South Africa.

Frampton, G.K., Van Den Brink, P.J. & Gould, P.J. (2000). Effects of spring drought and irrigation on farmland arthropods in Southern Britain. *Journal of Applied Ecology,* **37,** 865–883.

Fry, R. & Lonsdale, D. (ed.) (1991). *Habitat Conservation for Insects – A Neglected Green Issue. Middlesex*, Amateur Entomologists" Society.

Gauch, H.G. (1982). *Multivariate Analysis in community ecology*. Cambridge, Cambridge University Press.

GRoN (2006). Regional Poverty Profile: Based on Village-Level Participatory Poverty Assessments in the Omaheke Region, National Planning Commission, Windhoek, Namibia.

Hatley, C.L. & MacMahon, J.A. (1980). Spider community organization: seasonal variation and the role of vegetation architecture. *Environmental Entomology* **9**, 632–639.

Higgins, S. I., Bond, W. J. & Trollope, W. S. W. (2000). Fire, resprouting and variability: a recipe for grass-tree coexistence in savanna. *Journal of Ecolology*, **88,** 213-229.

Hill, M. O., Mountford, J. O., Roy, D. B. & Bunce, R. G. H. (1999). *ECOFACT Volume 2a: Technical Annex - Ellenberg's indicator values for British Plants*. Huntingdon, Centre for Ecology and Hydrology.

Hoffmann, A. & Zeller, U. (2005). Influence of variations in land use intensity on species diversity and abundance of small mammals in the Nama Karoo, Namibia. *Belgian Journal of Zoology,* **135**, 91-96.

Holland, J.M., & Reynolds, C.J.M. (2003). The impact of soil cultivation on arthropod (Coleoptera and Araneae) emergence on arable land. *Pedobiologia*, **47**, 181-191.

Isaacs, R., J. Tuell, A., Fiedler, M., Gardiner, & Landis, D. (2009). Maximizing arthropod-mediated ecosystem services in agricultural landscapes: the role of native plants. *Frontiers in Ecology and the Environment* **7,**196–203.

Joubert, D.F. (2003). *The impact of bush control measures on the ecological environment (biodiversity, habitat diversity and landscape considerations)*. Unpublished specialist report prepared for the Ministry of Environment and Tourism, Windhoek.

Kappes, H., Lay, R. & Topp, W. (2007). Changes in different trophic levels of litter-dwelling macrofauna associated with giant knotweed invasions. *Ecosystems* **10**, 734–744.

Kraaij, T. & Ward, D. (2006). Effects of rain, nitrogen, fire and grazing on recruitment and early survival in bush encroached savanna, South Africa. *Plants Ecology* **186**, 235-246.

Krebs, J.C. (1994). *Ecology, 4th Edition*. London; Harper Collins College Publisher.

Lamprey, H.F. (1983). Pastoralism yesterday and today: the overgrazing problem, in Bouliere, F. (ed.). *Tropical Savannas*: *Ecosystems of the World*. Elsevier, Amsterdam, The Netherlands. pp. 643-666.

Langevelde, F., van de Vijver, C.,Kumar, L., van deKoppel, J., de Ridder, N., van Andel, J., Skidmore, A.K., Hearne, J.W., Stroosnijder, L., Bond, W.J., Prins, H.H.T. & Rietkerk, M. (2003). Effects of fire and herbivory on the stability of savanna ecosystems. *Ecology*, **84,** 337–350.

Luff, M. L. (2007). *The Carabidae (ground beetles) of Britain and Ireland. RES Handbooks for the Identification of British Insects Volume 4 Part 2. 2nd edition*. Shrewsbury, Field Studies Council.

Maestre, F.T., Bowker, M.A., Puche, M.D., Hinojosa, M.B., Martinez, I. & Garcia-Palacios, P. (2009). Shrub encroached can reverse desertification in semiarid Mediterranean grasslands. *Ecology Letters*, **12**, 930–941.

Maggs, G.L., Craven, P. & Kolberg, H.H. (1998). "Plant species richness, endemism, and genetic resources in Namibia". *Biodiversity and conservation*, **7** (4),435–446.

Maggs, G.L., Kolberg, H.H. & Hines, C.J.H. (1994). "Botanical diversity in Namibia: An overview". *Strelitzia*, **1**, 93–104

Mannheimer, C. A. & Curtis, B. A.(eds)(2009). *Le Roux and Muller's Field Guide to the Trees and Shrubs of Namibia. Wi*ndhoek: Macmillan Education Namibia.

Mannheimer, C. A., Maggs, K.,Kolberg, H., and Rugheimer, S (2008).*Flowers of the southern Namib.* Macmillan Namibia.

Meik, J.M., Jeo, R.M. & Jenks, K.E. (2002). Effects of bush encroachment on an assemblage of diurnal lizard species in central Namibia. *Biological Conservation.* **106**:29-36.

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

MoET, (2011). Omaheke and Otjozonjupa Environmental adaptation Toolkit.

MoET, (2011). Africa Adaptation Programme-Namibia Project (AAP-NAM). Integrated Environmental Consultants Namibia (IECN).

NEPAD/FAO/GoRN.(2005). *Bankable Project Implementation Profile, Infrastructure Upgrade of Rural Water Supply.* Volume II of IV.

Netshilaphala, N.M., Milton, S.J. & Robertson H.G. (2005). Response of an ant assemblage to mining on the arid Namaqualand coast, South Africa. *African Entomology*, **13**, 162-167.

Nghikembua, M.T., Muroua, D., Jeo, R.M., Ekondo, F.E. & LL Marker. (2002). *"Assessing the ecological impact of bush encroached on Namibian farmlands"*. Unpublished proceedings of the 16th Annual Meeting of the Society for Conservation Biology, 14–19 July 2002, Canterbury.

Nichols, K.A., S.F. Wright, M.A. Liebig, & J.L. Pikul Jr. (2004). *Functional significance of glomalin to soil fertility*. *Proceedings from the Great Plains Soil Fertility Conference*. Denver, CO, March 2-4, 2004.

Oberprieler, R. (1995). *The Emperor Moths of Namibia.* Hartebeestpoort: *Ecological guild*.

Ottesen, P. S. (1990). Diel activity patterns of Carabidae, Staphylinidae and Perimylopidae (Coleoptera) at South Georgia, Sub-Antarctic. Polar Biology, **10,** 515-519.

Pearce, J.L. & Venier, L.A. (2006). The use of ground beetles (Coleoptera: Carabidae) and spiders (Araneae) as bioindicators of sustainable forest management: a review. *Ecological Indicators* **6,** 780–793.

Picker, M., Griffiths, C. & Weaving, A. (2004). *Field Guide to Insects of South Africa.* Cape Town: Struik Publishers.

Pickett, C.H., & Bugg, R.L. (1998). *Enhancing biological control: habitat management to promote natural enemies of agriculture pests*. Los Angeles, California: University of California Press

Pickett, S.T.A. & White, P.S (1985). *The Ecology of Natural Disturbance and Patch Dynamics*. New York, USA: Academic Press.

Pimentel, D., Lach, L., Zuniga, R. & Morrison, D. (1999). Environmental and economic costs of nonindigenous species in the United States. *Biological Science* **53**, 53–65.

Pimentel, D., Stachow, U., Takacs, A.D., Brubaker, H.W., Dumas, A.R., Meaney, J.J., O'Neil, J.A.S., Onsi, D.E. & Corzilius D.B. (1992). Conserving biological diversity in Agricultural/Forestry systems. *Biological Science*, **42**, 354-362.

Quan, J., Barton, D & Conroy, C. (1994). “A preliminary assessment of the economic impact of desertification in Namibia”. *DEA research discussion paper, No. 3. Windhoek: Directorate of Environmental Affairs (DEA), Ministry of Environment and Tourism*.

Ribas, C.R. & Schoereder, J.H. (2007). Ant communities, environmental characteristics and their implications for conservation in the Brazilian Pantanal. *Biodiversity Conservation*, **16,** 1511–1520.

Ríos-Casanova, L., Valiente-Banuet, A. & Rico-Gray, V. (2006) Ant diversity and its relationship with vegetation and soil factors in an alluvial fan of the Tehaucán Valley, Mexico. *Acta Oecologica*, **29**, 316-323.

Rivers-Moore, N.A. & Samways, M.J. (1996). Game and cattle trampling and impacts of human dwellings on arthropods at a game park boundary. *Biodiversity and Conservation,* **5,** 1545-1556.

Roques, K.G., O’Connor, T.G. & Watkinson, A.R. (2001). Dynamics of Shrub Encroached in an African Savanna: Relative Influences of Fire, Herbivory, Rainfall and Density Dependence. *Journal of Applied Ecology,* **38**(2), 268–280.

Samways, M. J., Caldwell, P. M., & Osborn, R. (1996). Ground-living invertebrate assemblages in native, planted, and invasive vegetation in South Africa. *Agriculture, Ecosystems, and Environment* **59**, 19–32.

Samways, M.J. (1994). *Insect Conservation Biology*. London: Chapman and Hall.

Sands, J.P., Brennan, L.A., Hernandez, F., Kuvlesky, W.P., Gallagher, J.R., Ruthven, D.C. & Pittman, J.E. III. (2009). Impacts of buffelgrass (*Pennisetum ciliare*) on a forb community in south Texas. *Invasive Plant Science and Management* **2**,130–140.

Schneider, H.P. (1994). *Animal health and veterinary medicine in Namibia*. Windhoek: Agrivet.

Scholes, R. J. & Archer, S. R. (1997). Tree-grass interactions in savannas. *Annual Review of Ecology and Systematics,* **28**, 517-544.

Scholes, R.J. & Walker, B.H. (1993). An African savanna: Synthesis of the Nylsvley study. Cambridge studies in applied ecology and resource management. Cambridge University Press, Cambridge.

Seymour, C., L. & Dean, W.R.J. (1999). Effects of heavy grazing on invertebrate assemblages in the Succulent Karoo,South Africa. *Journal for Arid Environ* **43**,267–286.

Seymour, C., L. (2006). *The influence of size and density on Acacia erioloba's role as a keystone species in the southern Kalahari*. Dissertation, University of Cape Town

Shannon, C.E. & Weaver, W. (1949). *The mathematical theory of communication.* Chicago: University of Illinois Press.

Sheuyange, A., Oba, G., & Weladji, R.B., (2005). Effects of Anthropogenic Fire History on Savanna Vegetation in Northeastern Namibia. *Journal of Environmental Management* ***75**, 189-198.*

Skowno, A.L., Midgley, J.J., Bond, W.J. & Balfour, D. (1999). Secondary succession in *Acacia nilotica* (L.) savanna in Hluhluwe Game Reserve. *South Africa.Plant Ecology*, **145**, 1-9.

Smit, G. N. (2004). An approach to tree thinning to structure southern African savannas for long-term restoration from bush encroached. *Journal of Environmental Management*, **71**, 179-191.

Statistical Package for Social Scientists (SPSS) for Windows Version Release Version 16.0 Software.

Stewart, A.J.A. (2001). The impact of deer on lowland woodland invertebrates: a review of the evidence and priorities for future research. *Forestry*, **74,** 259-270.

Strohbach, B. J., M. Strohbach, T., Katuahupira & Mouton, H. D. (2004). *A reconnaissance survey of the landscapes, soils and vegetation of eastern communal areas (Otjozondjupa and Omaheke Regions, Namibia*). Windhoek: National Botanical Research Institute.

Tallamy, D.W. (2004). Do alien plants reduce insect biomass? *Conservation Biology,* **18,** 1689–1692.

Teague, W.R., & Smith, G. N., (1992). Relations between woody and herbaceous components and the effects of bush-clearing in southern African savannas. *Journal of the Grassland Society of Southern Africa*, **9 (**2), 60-71.

Van Auken, O.W. (2009).Causes and consequences of woody plant encroached into western North American grasslands. *Journal on Environmntal Management*, **90,** 2931–2942.

Van Oudtshoorn, F. (2009). *Guide to Grasses of Southern Africa*. Briza Publication, Pretoria South Africa.

Walker, B.H. (1985). “Structure and function of savannas: An overview”. In Tothill, J.C. & J.J. Mott (Eds.), *Ecology and management of the world’s savannas* (pp. 83–92*)*. Canberra: Australian Academy of Science.

Walter, H. (1971). *The ecology of tropical & subtropical vegetation*. Oliver and Boyd, Edinburgh.

Walter, H. (1976). An approach to monitoring of changes in the composition and utilization of woodland and savanna vegetation. *Southern Africa Journal of Wildlife Research,* **6** (1), 1-32.

Ward, D. (2005). Do We Understand the Causes of Bush Encroached in Africa Savannas? *Africa Journal Range and Forage Science*, **22,**101-105.

Wiegand, K.; Saltz, D. & Ward, D. (2006). *A patch –dynamics approach to savanna dynamics and woody plant encroachment-insights from an arid savanna* Perspectives in plant Ecology, Evolution and Systematics, **7** (4) 229-242.

Wu, Y., Wang, C., Zhang, X., Zhao, B., Jiang, L., Chen, J. & Li, B. (2009). Effects of Saltmarsh invasion by *Spartina alterniflora* on arthropod community structure and diets. *Biological Invasions,* **11**, 635–649.

Zeleke, A.A. (2009). *Bush Encroachment and its Impacts on Plant Biodiversity in the Borana Rangelands*. A Thesis Submitted to the School of Graduate Studies Addis Ababa University in partial fulfillment of the Requirements for the Degree of Master of Science Environmental Science.

Zimmermann, I. & Joubert, D.F. (2002). “A crude quantification of wood that is and can be harvested from bushthickening species in Namibia”. Unpublished paper presented to the Forestry Research Workshop.

APPENDICES

Appendix 1a. Abundance of invertebrates captured during the hot wet season in three sites (NSV=normal savanna, IBE= intermediate bush encroached, HBE= high bush encroached).

Hot wet season (March)					
NSV					
Order	**Family**	**Rank**	**abundance**	**proportion**	**Log abundance**
Hymenoptera	Formicidae	1	962	79.2	3.0
Coleoptera	Tenebrionidae	2	53	4.4	1.7
Orthoptera	Gryllidae	3	37	3	1.6
Blattodea (Blattaria)	Blattellidae	4	27	2.2	1.4
Hemiptera	Suborder Heteroptera	5	27	2.2	1.4
Orthoptera	Acrididae	6	17	1.4	1.2
Coleoptera	Meloidae	7	9	0.7	1.0
Aranea	Gnaphosidae	8	9	0.7	1.0
Diptera	Athericidae	9	7	0.6	0.8
Coleoptera	Carabidae	10	7	0.6	0.8
Diplura	Japygidae	11	6	0.5	0.8
Hymenoptera	Pteromalidae	12	6	0.5	0.8
Diptera	Tabanidae	13	6	0.5	0.8
Orthoptera	Tettigonidae	14	6	0.5	0.8
Hymenoptera	Mutilidae	15	5	0.4	0.7
Hymenoptera	Colletidae	16	4	0.3	0.6
Coleoptera	Scarabaedae	17	4	0.3	0.6
Hymenoptera	Sphecidae	18	4	0.3	0.6
Aranea	Solifugae	19	4	0.3	0.6
Aranea	Salticidae	20	4	0.3	0.6
Hemiptera	Suborder Homoptera	21	3	0.2	0.5
Hemiptera	Correidae	22	2	0.2	0.3
Diptera	Ceratopogonidae	23	1	0.1	0.0

Hymenoptera	Eumenidae	24	1	0.1	0.0
Ephemeroptera	Leptophlebidae	25	1	0.1	0.0
	Myriapoda	26	1	0.1	0.0
Orthoptera	Pyrogomorphidae	27	1	0.1	0.0
Mantodea	Mantidae	28	1	0.1	0.0
	Total		**1215**		
INTERMEDIATE BUSH ENCROACHMENT					
Order	**Family**	**Rank**	**abundance**	**proportion**	**logabundance**
Hymenoptera	Formicidae	1	879	81.9	2.9
Coleoptera	Tenebrionidae	2	44	4.1	1.6
Orthoptera	Acrididae	3	20	1.9	1.3
Blattodea (Blattaria)	Blattellidae	4	20	1.9	1.3
Coleoptera	Scarabaedae	5	16	1.5	1.2
Aranea	Gnaphosidae	6	11	1	1.0
Orthoptera	Gryllidae	7	10	0.9	1.0
Coleoptera	Meloidae	8	10	0.9	1.0
Orthoptera	Tettigonidae	9	8	0.7	0.9
Diptera	Athericidae	10	6	0.6	0.8
Hymenoptera	Colletidae	11	6	0.6	0.8
	Myriapoda	12	6	0.6	0.8
Aranea	Solifugae	13	6	0.6	0.8
Hymenoptera	Pteromalidae	14	5	0.5	0.7
Hemiptera	Suborder Heteroptera	15	5	0.5	0.7
Coleoptera	Carabidae	16	4	0.4	0.6
Hymenoptera	Sphecidae	17	4	0.4	0.6
Hymenoptera	Agoanidae	18	2	0.2	0.3
Phasmatodea	Bacilidae	19	2	0.2	0.3
Hymenoptera	Vespidae	20	2	0.2	0.3
Hymenoptera	Anthophoridae	21	1	0.1	0.0
Coleoptera	Drilidae	22	1	0.1	0.0
Mantodea	Hymenopodidae	23	1	0.1	0.0
Coleoptera	Pyrogomorphidae	24	1	0.1	0.0
Aranea	Theraphosidae	25	1	0.1	0.0
Hemiptera	Tingidae	26	1	0.1	0.0
Coleoptera	Trogossitidae	27	1	0.1	0.0
	Total		**1073**		

HBE					
Order	**Family**	**Rank**	**abundance**	**proportion**	**logabundance**
Hymenoptera	Formicidae	1	278	54.2	2.4
Diptera	Athericidae	2	88	17.2	1.9
Coleoptera	Tenebrionidae	3	24	4.7	1.4
Blattodea (Blattaria)	Blattellidae	4	22	4.3	1.3
Coleoptera	Meloidae	5	15	2.9	1.2
Orthoptera	Tettigonidae	6	10	1.9	1.0
Hymenoptera	Colletidae	7	8	1.6	0.9
Orthoptera	Gryllidae	8	8	1.6	0.9
Orthoptera	Acrididae	9	7	1.4	0.8
	Myriapoda	10	7	1.4	0.8
Aranea	Gnaphosidae	11	7	1.4	0.8
Aranea	Salticidae	12	6	1.2	0.8
Diptera	Calliphoridae	13	4	0.8	0.6
Coleoptera	Carabidae	14	4	0.8	0.6
Hymenoptera	Pteromalidae	15	4	0.8	0.6
Hemiptera	Suborder Heteroptera	16	4	0.8	0.6
Coleoptera	Scarabaedae	17	3	0.6	0.5
Aranea	Solifugae	18	3	0.6	0.5
Phasmatodea	Bacilidae	19	2	0.4	0.3
Hymenoptera	Eumenidae	20	2	0.4	0.3
Orthoptera	Anastotomatidae	21	1	0.2	0.0
Coleoptera	Curculionidae	22	1	0.2	0.0
Diplura	Japygidae	23	1	0.2	0.0
Hymenoptera	Sphecidae	24	1	0.2	0.0
Coleoptera	Chrysomelidae	25	1	0.2	0.0
Ephemeroptera	Caenidae	26	1	0.2	0.0
Isoptera	Termittidae	27	1	0.2	0.0
	Total		**513**		

Appendix 1b.Abundance of invertebrates captured during the hot dry season in three sites (NSV=normal savanna, IBE= intermediate bush encroached, HBE= high bush encroached.

Hot dry Season (September)					
NSV					
Order	**Family**	**Rank**	**abundance**	**proportion**	**logabundance**
Hymenoptera	Formicidae	1	218	55.6	2.3
Hemiptera	Suborder homoptera	2	67	17.4	1.8
Coleoptera	Meloidae	3	23	6.0	1.4
Araneae	Salticidae	4	19	4.9	1.3
Orthoptera	Grylidae	5	11	2.8	1.0
Diptera	Athericidae	6	9	2.3	1.0
Coleoptera	Tenebrionidae	7	8	2.1	0.9
Hymenoptera	Sphecidae	8	6	1.6	0.8
Blattodea (Blattaria)	Blattellidae	9	5	1.3	0.7
Coleoptera	Carabidae	10	4	1.0	0.6
Orthoptera	Acrididae	11	3	0.8	0.5
Araneae	Gnaphosidae	12	3	0.8	0.5
Araneae	Solifugae	13	3	0.8	0.5
Hymenoptera	Colletidae	14	2	0.5	0.3
Hymenoptera	Mutilidae	15	1	0.3	0.0
Mantodea	Hymenopodidae	16	1	0.3	0.0
Hymenoptera	Pteromalidae	17	1	0.3	0.0
Blattodea (Blattaria)	Polyphargidae	18	1	0.3	0.0
Hemiptera	Suborder heteroptera	19	1	0.3	0.0
			386		
INTERMEDIATE BUSH ENCROACHMENT					
Hymenoptera	Formicidae	1	435	78.5	2.6
Coleoptera	Tenebrionidae	2	23	4.2	1.4
Araneae	Salticidae	3	18	3.2	1.3
Araneae	Gnaphosidae	4	16	2.9	1.2
Coleoptera	Meloidae	5	14	2.5	1.1
Hymenoptera	Sphecidae	6	13	2.3	1.1

Coleoptera	Carabidae	7	6	1.1	0.8
Araneae	Solifugae	8	6	1.1	0.8
Orthoptera	Gryllidae	9	5	0.9	0.7
Hymenoptera	Pteromalidae	10	4	0.7	0.6
Hemiptera	Sub order homoptera	11	4	0.7	0.6
Diptera	Athericidae	12	3	0.5	0.5
Diptera	Ceratopogonidae	13	3	0.5	0.5
Orthoptera	Acrididae	14	1	0.2	0.0
Blattodea (Blattaria)	Blattellidae	15	1	0.2	0.0
Hymenoptera	Mutilidae	16	1	0.2	0.0
Hemiptera	Sub order heteroptera	17	1	0.2	0.0
			554		
HBE					
Hymenoptera	Formicidae	1	177	56.0	2.2
Diptera	Athericidae	2	32	10.1	1.5
Aranea	Saltcidae	3	24	7.6	1.4
Hymenoptera	Pteromalidae	4	13	4.1	1.1
Coleoptera	Tenebrionidae	5	11	3.5	1.0
Aranea	Gnaphosidae	6	11	3.5	1.0
Hemiptera	Suborder heteroptera	7	9	2.8	1.0
Hemiptera	Suborder homoptera	8	9	2.8	1.0
Orthoptera	Gryllidae	9	8	2.5	0.9
Aranea	Solifugae	10	7	2.2	0.8
Coleoptera	Meloidae	11	6	1.9	0.8
Diptera	Ceratopogonidae	12	2	0.6	0.3
Hymenoptera	Colletidae	13	2	0.6	0.3
Blattodea (Blattaria)	Blattellidae	14	1	0.3	0.0
Coleoptera	Gyrinidae	15	1	0.3	0.0
Hymenoptera	Ichneumonidae	16	1	0.3	0.0
	Myriaoda	17	1	0.3	0.0
Hymenoptera	Mutilidae	18	1	0.3	0.0
			316		

Appendix 1c. Abundance of invertebrates captured during the cold dry season in three sites (NSV=normal savanna, IBE= intermediate bush encroached, HBE= high bush encroached.

Cold dry season (June)					
NSV					
Order	**Family**	**Rank**	**abundance**	**proportion**	**Log abundance**
Coleoptera	Tenebrionidae	1	44	25.1	1.6
Blattodea (Blattaria)	Blattellidae	3	22	12.6	1.3
Hymenoptera	Formicidae	2	22	12.6	1.3
Hymenoptera	Agoanidae	4	9	5.1	1.0
Diptera	Bombylidae	5	9	5.1	1.0
Araneae	Solifugae	6	9	5.1	1.0
Hemiptera	Suborder homoptera	7	9	5.1	1.0
Orthoptera	Acrididae	8	8	4.6	0.9
Hymenoptera	Megachillidae	9	8	4.6	0.9
Diptera	Athericidae	10	6	3.4	0.8
Araneae	Salticidae	11	5	2.9	0.7
Hemiptera	Correidae	12	4	2.3	0.6
Diptera	Calliphoridae	13	3	1.7	0.5
Diptera	Cullicidae	14	2	1.1	0.3
Hymenoptera	Ichneumonidae	15	2	1.1	0.3
Hymenoptera	Mutilidae	16	2	1.1	0.3
Hymenoptera	Pompilidae	17	2	1.1	0.3
Hymenoptera	Vespidae	18	2	1.1	0.3
Hemiptera	Alydidae	19	1	0.6	0.0
Coleoptera	Drilidae	20	1	0.6	0.0
Araneae	Gnaphosidae	21	1	0.6	0.0
Diptera	Sciaridae	22	1	0.6	0.0
Hemiptera	Tingidae	23	1	0.6	0.0
Diptera	Suborder heterptera	24	1	0.6	0.0
Orthoptera	Gryllidae	25	1	0.6	0.0
	Total		**175**		

INTERMEDIATE BUSH ENCROACHMENT					
Order	**Family**	**Rank**	**abundance**	**proportion**	**Log abundance**
Hemiptera	Suborder Heteroptera	1	96	30.0	2.0
Hymenoptera	Formicidae	2	55	17.2	1.7
Blattodea (Blattaria)	Blattellidae	3	43	13.4	1.6
Coleoptera	Tenebrionidae	4	36	11.2	1.6
Hemiptera	Correidae	5	14	4.4	1.1
Diptera	Athericidae	6	13	4.1	1.1
Hymenoptera	Agoanidae	7	10	3.1	1.0
Hymenoptera	Bombylidae	8	10	3.1	1.0
Hymenoptera	Megachillidae	9	8	2.5	0.9
Orthoptera	Acrididae	10	6	1.9	0.8
Aranea	Solifugae	11	5	1.6	0.7
Hymenoptera	Ichneumonidae	12	3	0.9	0.5
Aranea	Salticidae	13	3	0.9	0.5
Diptera	Muscidae	14	3	0.9	0.5
Diptera	Calliphoridae	15	2	0.6	0.3
Hemiptera	Tingidae	16	2	0.6	0.3
Coleoptera	Drilidae	17	1	0.3	0.0
Orthoptera	Grynidae	18	1	0.3	0.0
Hymenoptera	Mutilidae	19	1	0.3	0.0
Hymenoptera	Pompilidae	20	1	0.3	0.0
Mantodea	Hymenopodidae	21	1	0.3	0.0
Hymenoptera	Pteromalidae	22	1	0.3	0.0
Diptera	Sciaridae	23	1	0.3	0.0
Hymenoptera	Sphecidae	24	1	0.3	0.0
Hymenoptera	Braconidae	25	1	0.3	0.0
Coleoptera	Chrysomelidae	26	1	0.3	0.0
Hemiptera	Sub order homoptera	27	1	0.3	0.0
	Total		**320**		
HBE					
Order	**Family**	**Rank**	**abundance**	**proportion**	**Log abundance**
Hemiptera	Suborder heteroptera	1	123	37.0	2.1
Hymenoptera	Formicidae	2	59	17.8	1.8

Diptera	Athericidae	3	22	6.6	1.3
Hymenoptera	Agoanidae	4	21	6.3	1.3
Isoptera	Termittidae	5	20	6	1.3
Diptera	Culicidae	6	11	3.3	1.0
Diptera	Sciaridae	7	11	3.3	1.0
Blattodea (Blattaria)	Blattellidae	8	10	3.0	1.0
Coleoptera	Tenebrionidae	9	9	2.7	1.0
Hemiptera	Suborder homoptera	10	8	2.4	0.9
Araneae	Salticidae	11	8	2.4	0.9
Coleoptera	Drilidae	12	6	1.8	0.8
Hymenoptera	Bombylidae	13	4	1.2	0.6
Diptera	Muscidae	14	4	1.2	0.6
Hemiptera	Tingidae	15	3	0.9	0.5
Orthoptera	Acrididae	16	2	0.6	0.3
Hymenoptera	Megachilidae	17	2	0.6	0.3
Hymenoptera	Sphecidae	18	2	0.6	0.3
Orthoptera	Gryllidae	19	1	0.3	0.0
Araneae	Solifugae	20	1	0.3	0.0
Coleoptera	Elateridae	21	1	0.3	0.0
Hymenoptera	Braconidae	22	1	0.3	0.0
Coleoptera	Chrysomelidae	23	1	0.3	0.0
Neuroptera	Myrmeleantide	24	1	0.3	0.0
Araneae	Gnaphosidae	25	1	0.3	0.0
	Total		**332**		

Appendix 2. Mean site invertebrate diversity

June (Cold dry)	**Site mean**	**std error**	**Upper**	**Lower**
NSV	1.17	0.018	1.188	1.152
BE	1.36	0.013	1.373	1.347
HBE	1.14	0.015	1.155	1.125
March(Hot wet)				
NSV	0.87	0.011	0.881	0.859
BE	0.76	0.015	0.775	0.745
HBE	1.05	0.018	1.068	1.032
Sept(Hot dry)				
NSV	0.99	0.016	1.006	0.974
BE	0.79	0.014	0.804	0.776
HBE	0.98	0.015	0.995	0.965
NSV				
Cold dry	1.17	0.018	1.188	1.152
Hot wet	0.87	0.011	0.881	0.859
Hot dry	0.99	0.016	1.006	0.974
BE				
Cold dry	1.36	0.013	1.373	1.347
Hot wet	0.76	0.015	0.775	0.745
Hot dry	0.79	0.014	0.804	0.776
HBE				
Cold dry	1.14	0.015	1.155	1.125
Hot wet	1.05	0.018	1.068	1.032
Hot dry	0.98	0.015	0.995	0.965

Appendix 3: Mean site invertebrate richness

Richness					
	June (Cold dry)	**Site mean**	**std error**	**Upper**	**Lower**
	NSV	3.96	0.06	4.02	3.9
	BE	5.06	0.04	5.1	5.02
	HBE	4.4	0.06	4.46	4.34
	March(Hot wet)				
	NSV	6.07	0.063	6.133	6.007
	BE	4.96	0.077	5.037	4.883
	HBE	4.73	0.11	4.84	4.62
	Sept(Hot dry)				
	NSV	4	0.056	4.056	3.944
	BE	4	0.047	4.047	3.953
	HBE	3.8	0.057	3.857	3.743
	NSV				
	Cold dry	3.96	0.06	4.02	3.9
	Hot wet	6.07	0.063	6.133	6.007
	Hot dry	4	0.056	4.056	3.944
	BE				
	Cold dry	5.06	0.04	5.1	5.02
	Hot wet	4.96	0.077	5.037	4.883
	Hot dry	4	0.047	4.047	3.953
	HBE				
	Cold dry	4.4	0.06	4.46	4.34
	Hot wet	4.73	0.11	4.84	4.62
	Hot dry	3.8	0.057	3.857	3.743

Appendix4. Site coordinates for each of the 6 quadrats in the three sites in degrees decimals

Normal Savanna Site					
	S	E		S	E
1	22.85990	19.21067		22.86002	19.21029
2	22.85984	19.21065		22.85991	19.21027
3	22.85975	19.21065		22.85981	19.21024
4	22.85966	19.21064		22.85972	19.21021
5	22.85957	19.21063		22.85963	19.21020
6	22.85947	19.21061		22.85955	19.21018
Bush Encroached Site					
1	22.85634	19.20885		22.85614	19.20919
2	22.85641	19.2089		22.85623	19.20925
3	22.85648	19.20898		22.85627	19.20932
4	22.85654	19.20904		22.85634	1920941
5	22.85662	19.20909		22.85638	19.20945
6	22.85668	19.20917		22.85644	19.20951
Highly Bush Encroached Site					
1	22.84204	19.16925		22.84210	19.16962
2	22.84198	19.16928		22.84204	19.1696
3	22.84189	19.16929		22.84192	19.16964
4	22.84181	19.16933		22.8419	19.16966
5	22.84172	19.16936		22.84185	19.16967
6	22.84163	19.16942		22.84179	19.16972