

**TERMITE SPECIES RICHNESS AND COMPOSITION WITHIN A SEMI-
ARID ENVIRONMENT: A COMPARISON OF LAND-USE PRACTICES AND
SAMPLING METHODS IN SELECTED AREAS OF SOUTHERN
SWAZILAND**

BY

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**UNIVERSITY OF NAMIBIA AND THE HUMBOLDT-UNIVERSITÄT ZU
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**A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE OF THE
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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
The Humboldt-Universität zu Berlin

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March 2007

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ABSTRACT

Termite species assemblages were investigated in four sites under different land-use practices in semi-arid southern Swaziland between April and June of 2006. The four sites included an acacia savannah, maize field, open grassland and woodland. The aim of the study was to determine differences in termite species richness and composition as well as plant species diversity in habitats under different land-use practices. The study further tested the suitability of three standard methods of sampling termites within a semi-arid environment. Methods tested were: - the baiting method, pit method and standardized transect method (i.e. search method).

A total of nine (9) termite species were found within the entire study namely: *Ancistrotermes latinotus* (Holgrem), *Hodotermes mossambicus* (Hagen), *Lepidotermes mtwalumi* (Fuller), *Macrotermes natalensis* (Haviland), *Macrotermes* sp., *Macrotermes ukuzii* (Fuller), *Odontotermes* sp., *Trinervitermes trinervoides* (Sjöstedt), and Macrotermitinae sp. The maize field transect was the most species rich with five species followed by the acacia savannah and open grassland with four species each and the woodland with three termite species. No sampling method recorded all taxa. There was a significant difference in the number of termite species recorded by each method and possible method combinations ($H=17.0782$, $df=6$, and tabular Chi-square values of 12.6 and 16.8 at 5% and 1% significance levels respectively).

Odontotermes sp., *Hodotermes mossambicus* (Hagen), *Macrotermes natalensis* (Haviland), and *Macrotermes ukuzii* (Fuller) were only detected by the search method while *Lepidotermes mtwalumi* (Fuller) was only detected by the bait method. The

Odontotermes genera was recorded for the first time in Swaziland. *Hodotermes mossambicus* (Hagen) and *Odontotermes* sp. were only present within the acacia savannah while *Lepidotermes mtwalumi* (Fuller) was only recorded in the maize field. *Macrotermes natalensis* (Haviland) was present only within the open grassland. Termite species composition differed between sampled plots of the same site and there was a tendency for similarities in termite species composition between plots of different sites.

Plant species richness also differed among the study sites, the acacia savannah was the most species rich with 31 plant species followed by the woodland with 24 species, maize field 13 species and lastly the open grassland with 11 plant species. There was also a significant difference in plant species richness among sites ($H=11.597$, $df=3$, $P=0.009$).

TABLE OF CONTENTS

Abstract	iii
List of Tables	viii
List of Figures	ix
Acknowledgements	x
Dedication	xii
Declaration	xiii
1.0 Introduction	1
1.1 Study background	1
1.2 Background on termites	2
1.3 Statement of the problem	5
1.4 Objectives and research questions	8
1.5 Expected results and research hypothesis	9
1.5.1 Termite species richness and composition	9
1.5.2 Comparison of sampling methods	10
1.5.3 Plant species richness and diversity	10
2.0. Literature review	11
2.1 Country background	11
2.2 The state of biodiversity in Swaziland	13
2.3 The ecological role of termites	14
2.4 Assessing termite species diversity	20
2.5 Comparing sampling methods	23
3.0. Materials and methods	25
3.1 Study sites	25
3.2 Approach and data collection	31

3.2.1 Determining land-use practice	31
3.2.2 Assessing termite species richness and composition	32
3.2.2.1 The standardized search protocol	32
3.2.2.2 The pit method	33
3.2.2.3 The baiting method	33
3.2.3 Assessing plant species richness and diversity	35
3.3 Analytic techniques	36
3.3.1 Termite species richness and composition	36
3.3.2 Effectiveness of sampling methods	38
3.3.3 Plant species richness and diversity	39
4.0 Results	40
4.1 The termite assemblage (species richness and composition)	40
4.2 The effectiveness of sampling methods	45
4.3 Plant species richness and diversity	49
5.0 Discussion	50
5.1 The termite assemblage (species richness and composition)	50
5.2 The effectiveness of sampling methods	60
5.2.1 The standardized search method	60
5.2.2 The pit method	62
5.2.3 The baiting method	63
5.2.4 Possible method combinations	63
5.3 Plant species richness and diversity	65
5.4 Management recommendations	66
5.5 Conclusion	67
List of references	71

Appendix 1	81
Appendix2	84

LIST OF TABLES

Table 2.1 Physiographic zones of Swaziland	13
Table 3.1 Study sites, their codes and geographic locations	25
Table 3.2 Soil chemical properties within sites	27
Table 4.1 Occurrence of termite species in each site	40
Table 4.2 Percentage of sampled plots that harboured termite species within sites ...	42
Table 4.3 Comparison of the number of termite species collected by each method per site	47
Table 4.4 Termite species detected by the three methods within sites	48
Table 4.5 Plant species richness and plant diversity indices for all sites.....	49

LIST OF FIGURE

Figure 2.1 A map of part of the Southern African Region	11
Figure 3.1 An agro-ecological map of Swaziland	26
Figure 3.2 An aerial photograph of a section of Maloma	29
Figure 3.3 An aerial photograph of a section of Ngudzeni	30
Figure 4.1 A dendrogram showing average linkage between sampled plots	44
Figure 4.2 A histogram showing the effectiveness of sampling methods	46

ACKNOWLEDGEMENTS

I am grateful to a number of people who rendered moral, spiritual, professional, technical, physical and material support during the course of my studies and while carrying out these investigations. My family's prayers were always supportive in all means while I was away from home pursuing my studies in Namibia. Mr Eugene Marais of the National History Museum of Namibia was very inspirational during the conception of the idea. Dr. Juliane Zeidler and Dr. John Mfuno my research supervisors, for their initial critiques, helpful counsel, and stimulating discussion throughout the study and reading several earlier drafts of the manuscript from the proposal stage to the end. Sibusiso Ndwandwe and Zwelithini Vilakati from the Bush Control Crew within the Range Management Section of the Ministry of Agriculture and Cooperatives in Swaziland, for their diligent assistance during the data collection process and their valuable knowledge of indigenous Swazi names of most plant species encountered during the study. I thank Dr. Musa Nsibande (Entomologist) from The Malkerns Research Station for having provided the vials and alcohol for the preservation of termite specimens as well as laboratory space in which most of the sorting was conducted. Many thanks also go to the head of the Soil Chemistry Laboratory, Malkerns Research Station as well as his personnel for their assistance with soil chemical analysis. Many thanks to Vivian Uys, Manager; Biosystematics Division of The Plant Protection Research Institute in Pretoria for her enormous work in identifying termite specimens. Many thanks go to The Government of The Kingdom of Swaziland particularly The Ministry of Agriculture and Cooperatives, having released me to pursue my studies in Namibia as well as The Ministry of Public Service and Information for sponsoring my studies. The Ministry of Agriculture and Cooperatives (Swaziland) fully supported this exercise, particularly the Animal

Production Division within the Department of Veterinary and Livestock Services. Many thanks go to the head of the Division Mr. Brenton B. Xaba. Bongumenzi Makhanya from SKIPE (Swaziland) provided the maps and assisted in the overlaying of waypoints. Many thanks go to Sikhumbuzo Vilane for having provided accommodation, transport, and a lot more in the countless trips I made between Swaziland, Johannesburg, Pretoria and Namibia (Windhoek) as well as the countless other people who have been helpful throughout my stay in Namibia, the list is endless. Last but not least, I would like to thank The Almighty God for having guided and protected me for this long, May He do so for many more years to come.

DEDICATION

To my loving family, wife Ncamsile S., kids D'nice and Mendel having endured life in my absence, in honour of my late mother Sannah T. Vilane (Ndlangamandla) and in memory of my father Dr. Peter M. Vilane for the love and value system they instilled in me.

DECLARATION

I Mavela Wilson Vilane, hereby 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 other institution of higher education.

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Chapter 1

1.0 Introduction

1.1 Study background

Invertebrates are an integral part of healthy soils and play a critical role in ecosystem services such as decomposition and nutrient cycling (Jones *et al.*, 2003). However, organisms that live for at least part of their lives in the soil, leaf litter and dead wood are ubiquitous; numerous and diverse, are also poorly known, particularly in their taxonomy but also in their ecologies and specific contributions to ecosystem processes (Jones *et al.*, 2003).

Their diversity extends to all taxonomic levels with up to 30 orders and many hundreds of species present within a single habitat. But as with all other groups of organisms, numbers are dominated by just a few taxa with the majority being locally rare. Soil organisms are critical to decomposition, nutrient cycling, soil formation and moderate many physical and chemical processes in the soil. They form soil food webs built on root herbivores and others on decomposers (Timberlake & Childes, 2004).

Soil fauna is extremely variable in composition; factors influencing its composition include climate, soil, habitat type and degree of disturbance (Curry & Good, 1992). Soil animals are rarely considered by conservation organizations, yet in many cases the functions performed by these organisms are critical to the overall performance of the system. For instance, some soil animal species i.e. termites and ants are capable of significant ecosystem engineering, modifying both the magnitude and direction of

resource flows in both natural and managed ecosystems. It is also likely that some landscapes are a consequence of ecosystem engineering by soil animals (Curry & Good, 1992).

1.2 Background on termites

Termites are small white to tan coloured social insects. Termites have different looking individuals (called castes) in the nest (FAO, 2000). The largest individual is the queen. Her job is to lay eggs, sometimes thousands in a single day. A king is always by her side. Other individuals have large heads with powerful jaws, or a bulb-like head. These individuals are called soldiers. But most termites are called workers, they toil long hours tending to the queen, building the nest, or gathering food. Unique to termites, workers can be male or female (FAO, 2000).

Termites are soft-bodied and depend on tiny hair-like appendages called sensilla (or setae) to guide them in feeding, defence and reproduction. Little is known of the exact mechanism for their complicated behaviour; it has been hypothesized that termites are born “hard-wired” with the ability to create and react to a complex intermingling of chemical signals and ritualized behaviour (Mommer, 2003). A rather interesting method of chemical protection of the colony appears when termites produce compounds such as naphthalene for communication and defence against ants, pathogenic microorganisms and nematodes. The topic of chemical defensive techniques of termites is a relatively new area currently being studied in the scientific community (Mommer, 2003).

Taxonomically, all termites can be placed into Kingdom Animalia, Phylum Arthropoda, Class Insecta, and Order Isoptera. Although termites come in many shapes and sizes, every termite species is common to the Order Isoptera. Mommer (2003), reported the current worldwide termite species count at 2,761 while Rahman and Tawato (2003), reported 2650 known species worldwide. These figure are contradictory hence there is need for reconciliation unless they are estimates, in which case the authors should duly clarify.

Mommer (2003), reported that out of the 2,761 species, 1,958 are higher termites. Lower termites can be described as a set of 6 families sharing the presence of symbiotic intestinal flagellates. Higher termites are further evolved than lower termites in that they have lost the flagellate protozoa and have replaced them with bacteria. Higher termites comprise three quarters of all described termite species; many species are yet un-described (Mommer, 2003).

Termites are characterized by their colonial behavior (Rahman and Tawatao, 2003). They are often referred to as 'white ants', however, morphologically and phylogenetically they are very different from the ants and the other social Hymenopterans (bees and wasps). The word Isoptera originated from the Greek, in which '*isos*' means equal and '*pteron*' means wing, and refers to the two pairs of identical wings in the adult (Rahman and Tawatao, 2003).

According to Rahman and Tawato (2003), out of the 2650 worldwide species count, 280 genera and seven families have so far been described. Five families, 54 genera

(19% of the world total) and 165 described species (about 6% of the world total) of termites occur in Southern Africa and about 5% of the world's species are endemic to the region (Uys, 2002).

Termites are widely dispersed throughout the tropics as well as some temperate regions and achieve their highest diversities and abundance in the rain forests of Africa, South America and Southeast Asia (Rahman and Tawatao, 2003). Of these,

There are more than 2,300 different types of termites now recognized. However, most of this diversity can be lumped into distinct groups; dampwood, drywood, subterranean, and mound builders (FAO, 2000). Dampwood termites are very restrictive in their distribution, most are found in North America. They derive their name from the fact that they live and feed in very moist wood especially stumps and fallen trees on the forest floor (FAO, 2000). Drywood termites are common in most continents and can survive in very dry conditions, even in dead wood in deserts (FAO, 2000). They do not require contact with moisture or soil. Subterranean termites are very numerous in many parts of the world and live and breed in soil, sometimes many meters deep (FAO, 2000). Lastly, the mound builders are capable of building earthen towers 8 meters or more in height. Mounds can be soil-based or aerial in trees. These towers are very noticeable and beautiful where they occur. Mounds are common in Africa, Australia, Southeast Asia, and parts of South America. Termite mounds are not found in North America and Europe (FAO, 2000).

Termites are classified in to functional groups based on their nesting and feeding behaviour. At present only four functional groups have been distinguished, namely: -

- 1) Rhinotermitidae (subterranean termites);
- 2) Macrotermes/Microtermes/Odontotermes (mostly mound builders);
- 3) Nasutitermes; snout termites (mostly mound and aerial nest builders); and
- 4) Kalotermitidae (drywood termites), (FAO, 2000).

Termites can either be beneficial or destructive to man, and this is determined very much by which species are present and their feeding and nesting behavior (Rahman and Tawatao, 2003).

1.3 Statement of the problem

For a number of years, there has been growing concern that Swaziland's natural resources are constantly being depleted. This can mostly be attributed to the lack of clear policies and/or laws governing the sustainable use of the country's biodiversity, a shortage of environmental expertise, lack of an integrated approach towards natural resource management, and largely to the fact that the country's environmental authority means of ensuring environmental sustainability have been clouded by many factors including the ever increasing population, industrialization, urbanization and the high unemployment rate (personal observation).

Over recent decades many of the remaining pristine natural environments in Swaziland have been replaced with agricultural and silvicultural systems. Vast amounts of landscapes have been converted to large-scale sugarcane plantations,

medium to high intensity cattle farming operations, mining operations and various other operations, which are disruptive to the natural set-up. Such conversions include damming, industrialization, and road constructions, just to mention a few. As a consequence, the amount of degraded land has increased rapidly (personal observation).

The relentless disturbance, conversion and fragmentation of natural landscapes and biomes are a major cause of biodiversity loss. There has been much debate over the extent to which declining biodiversity and changes in trophic structure will impact on ecosystem functioning and stability (Jones *et al.*, 2003). Moreover, there is growing concern that land-use intensification and loss of biodiversity threatens soil fertility and the sustainability of agricultural production (Jones *et al.*, 2003).

In arid and semi-arid environments, termites constitute a dominant portion of the soil macro-fauna (Dangerfield, 1990). Termites are known to affect soil fertility and resilience through the translocation of organic matter and other processes. However, it is of paramount significance that the majority of termite studies refer to termite species living in temperate habitats (Dangerfield, 1990). Dangerfield goes on to mention the fact that despite the importance of soil fauna in tropical ecosystems, termites have been marginalized by researchers and are poorly understood. Given the central role of the decomposer food web in regulating plant growth, and the particular influence that termites have over soil processes, it is important to understand how land-use practice and intensification affects termite assemblages.

One reason for the lack of attention from conservation groups is that whilst individual species may be sensitive to disturbance, the overall soil animal assemblage may remain quite robust because there will always be tolerant taxa, such as termites, ants, mites and collembola present (Timberlake & Childes, 2004).

Much is known about the general roles of soil organisms in ecosystem processes in both temperate and tropical systems, for example the importance of termites in nutrient cycling (Swift and Bignell, 2001) or earthworms in soil structure modification, but little is known about the specifics of individual species or particular soil animal assemblages. This is an important gap in knowledge because management of soil biological resources is critical to the sustainability of managed systems (Swift and Bignell, 2001).

While a few studies have shown that termites are sensitive to habitat disturbance, very few studies in Southern Africa have correlated termite assemblage parameters (i.e. species richness and composition) along a disturbance gradient with quantitative measures of vegetation structure, habitat modification and/or under different land-use practices and no such studies have been carried out in Swaziland.

Recent studies however, suggest that environmental degradation and/or disturbance may cause severe and long lasting modifications on termite assemblages (Roisin and Leponce, 2004); such modifications may be positive or negative depending on the local, regional and/or global concerns i.e. socio-economic vs. ecological integrity. The current study was therefore aimed at serving, among others, as a baseline for the

establishment of case studies in the exploration of indicators of habitat and/or ecosystem integrity, including termite diversity measures, to determine land-use practice effects on the termite assemblage in a semi-arid environment like Swaziland.

1.4 Objectives and research questions

The main objective of the study was to determine the diversity of termite assemblages (i.e. species richness and composition) and plant species diversity under different land-use practices within a semi-arid environment.

Specific objectives included the following: -

Objective 1

To determine termite species richness and composition on four sites under different land-use practices.

Key question

How does land-use practice affect termite species assemblages (i.e. richness and composition)?

Objective 2

To compare the termite species that would be detected by three different termite sampling methods within a semi-arid environment.

Key questions

- 1) Do sampling methods detect similar termite species within a semi-arid environment?
- 2) Which is the most suitable method to apply in assessing termite species richness and composition within a semi-arid environment?

Objective 3

To conduct a rapid botanical assessment on four sites under different land-use practices in an effort to determine plant species richness and diversity in each site.

Key question

Are the four sites under study ecologically different in terms of plant species richness and diversity?

1.5 Expected results and research hypothesis.

1.5.1 Termite species richness and composition under differing land-use practices.

According to the intermediate disturbance hypothesis, one would expect the moderately disturbed land-use type to have the highest number of termite species than the other land-uses and/or sites (Johst and Huth (2005); Picket and White 1985; Huston, 1994). However, termites, being possible indicators of habitat conditions, one would further expect the less disturbed area to have the highest number of species and possibly even functional groups with the more disturbed area having fewer species consisting mainly of tolerant taxa.

Disturbance in this regard was based on the intensity of management by humans whereby less intensively managed sites were regarded as less disturbed. Overall it is expected that the whole study area will be less diverse & dominated by few species of termites. This is expected mainly as a result of the aggressive nature of termite colonies territorially (Van der Linde *et al.*, 1989) hence, one would expect the most aggressive species to dominate an area at one point in time.

1.5.2 Comparison of sampling methods in detecting different termite species.

Methods that were compared in this study were the standardized transect (search method); the bait; and the pit method (see detailed method description in the materials and methods, section 3.2.2). The three sampling methods will yield a significant difference in the number of species detected. This may be a result of the fact that different species and functional groups nest in different microhabitats and feed on different materials such that one would expect the search protocol to reveal more litter and wood feeders, while the pit method would be expected to reveal both soil and litter feeders, with the baiting method probably revealing wood or litter feeders.

1.5.3 Plant species richness and composition on sampled sites.

One would expect the four different land-use types to differ in terms of plant species richness and composition. It is further expected that the woodland and the acacia savannah will be the most species rich sites with the open grassland coming third while the maize field will be last. This is expected due to the degree and/or intensity of management by humans on the part of the maize field, which will basically favour for cultivated crops in the sense that other plants will be considered to be weeds and eliminated.

Chapter 2

2.0 Literature review

2.1 Country background

The Kingdom of Swaziland is a sub-tropical country, lying between latitudes 25 and 28 degrees south and 31 and 32 degrees east in the South-Eastern part of Africa. The country is landlocked and covers an area of 17, 364 km². It is bounded by the Republic of South Africa in the north, west and south, and by Mozambique in the east (Figure 2.1). Although Swaziland is small in size, it has great variation in landscape, geology and climate (Sweet and Khumalo, 1994).

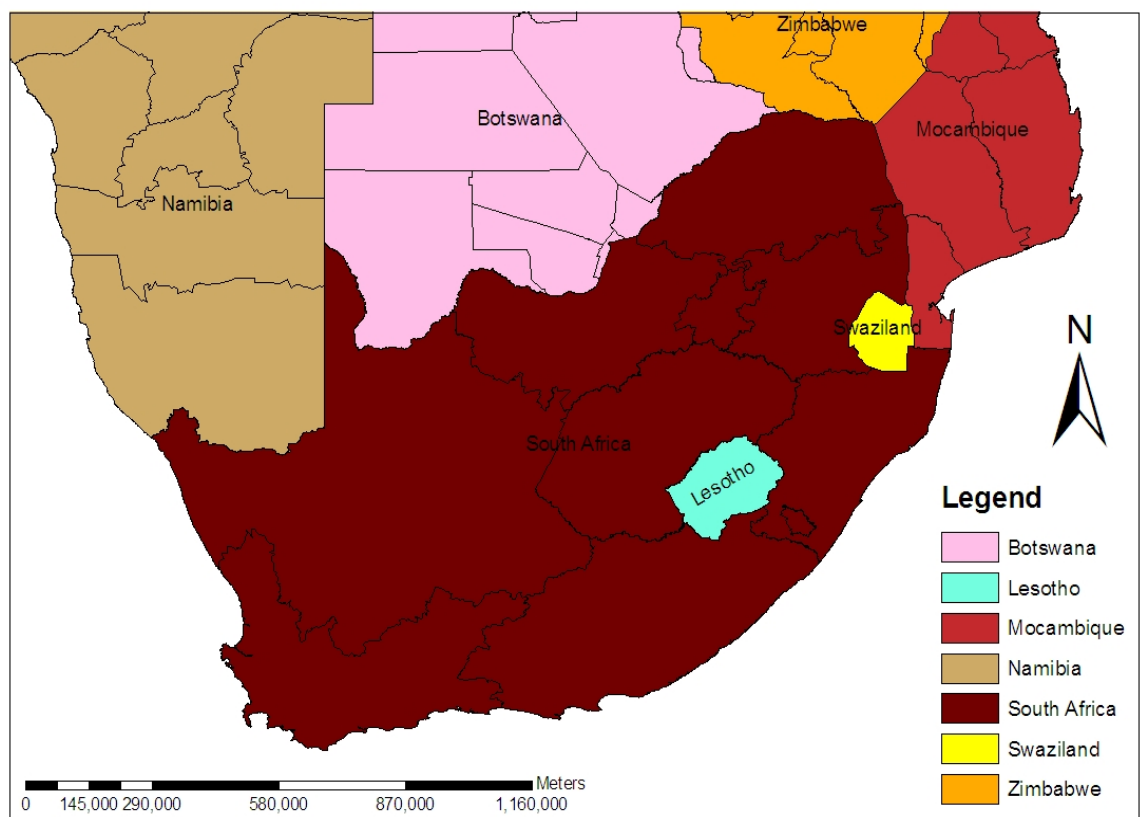


Figure 2.1. A map of a section of the Southern African Region showing the location of Swaziland within the region (source: SKIPE-Swaziland).

Swaziland is located between the South African plateau (reaching over 1500 metres) and the coastal plains of Mozambique. Thus the western part of the country lies in escarpment area, and the eastern part in the zone of the coastal plains. Separating the Swaziland coastal plains from the Mozambique coastal plains is the Lubombo Mountain Range (Sweet and Khumalo, 1994). The country experiences distinct wet (September – March) and dry seasons (April – August) each year, with their respective periods varying lately perhaps due to the El Niño and La Niña phenomena (Sweet and Khumalo, 1994). When considering the country's physiography, there are six agro-ecological zones namely; the Highveld, Upper Middleveld, Lower Middleveld, Eastern Lowveld, Western Lowveld and the Lubombo plateau (Sweet and Khumalo, 1994). The characteristics of the agro-ecological zones are shown in Table 2.1.

From the total area of 17, 364 Km², 64% has been classed as natural veld/rangeland (CSO, 1991). This is land, which has been used for wildlife conservation and communal grazing purposes in the past. However, due to population increase, most portions of this land now exists in arable/grazing/settlement mosaics and has been drastically modified by cultivation, wood extraction, heavy grazing such that it is arguable they are no longer true rangelands supporting predominantly natural plant and animal life (Sweet and Khumalo, 1994).

Table 2.1. Physiographic zones of Swaziland (van Waveren and Nhlengetfwa, 1992).

Physiographic zones	Area (km ²)	Altitude (m)	Rainfall (mm)	Geology	Vegetation Type
Highveld (HV)	5 680	900-1400	700-1200	Granite	Short grassland with forest patches
Upper Middleveld (UM)	2 420	600-800	700-850	Granodirite Granite	Tall grassland with scattered trees and shrubs
Lower Middleveld (LM)	2 420	400-600	550-700	Gneiss	Broad leaved savannah
Western Lowveld (WL)	3 410	250-400	450-550	Sandstone/ Clay stone	Mixed savannah
Eastern Lowveld	1 960	200-300	400-550	Basalt	Acacia savannah
Lubombo Ridge	1 480	250-600	550-850	Ignimbrite	Hillside bush and plateau savannah

2.2 The state of biodiversity in Swaziland

Despite her small size, Swaziland supports a rich and varied biodiversity with over 820 species of vertebrates having been recorded to date (Monadjem, 1998). Although the country's higher plants have been collected and studied since the 1950s, the distributions of most species is poorly known and new records are constantly being added (SEA, 2001).

To date, at least 2418 species of plants have been recorded within Swaziland, but this figure may well rise to over 3000 species with additional fieldwork. In addition to

harbouring high species richness, Swaziland also supports 18 endemic species of plants and one endemic vertebrate; at present, invertebrates of Swaziland are too poorly known (SEA, 2001). Considering the country's small size, these figures suggest that Swaziland's biodiversity is of global significance.

Swaziland recognizes the importance of taking an ecosystem approach for the successful conservation of its biodiversity. The following four ecosystems are recognized in Swaziland: -

- 1) Montane grasslands;
- 2) Savannah-woodland mosaics;
- 3) Forests; and
- 4) Aquatic systems (including rivers, streams, wetlands and marshes).

The value of Swaziland's biodiversity has long been recognized by Swazis who make use of it on a daily basis for various reasons including: food, traditional medicine, building material, traditional attire and many more. Traditional methods of conserving biodiversity also exist but have not been documented and are currently eroding (SEA, 2001).

2.3 The ecological role of termites

It seems natural to dislike termites. Most of them are very small, off-white, alien-looking insects, they live in the darkness, and they have a reputation for being "pests" by causing millions of dollars in damage to wooden structures and vegetation all around the world (Mommer, 2003). Norman E. Hickin exhibits this widespread

negative view of termites in the title of his 1971 book, Termites a World Problem. Nevertheless, recent studies and discoveries have begun to correct the downbeat view of the termite. Surely a creature that exists (or has existed) on every continent in a wide range of environments has a greater ecological niche than a “pest” (Mommer, 2003).

Literature on termites and small farmers in Africa generally concentrates on the damage done by termites. Certainly, termites can cause considerable damage to crops, trees and buildings; for instance, losses of 70% in maize and yams and 40% in groundnuts and cassava have been recorded. However, most termites are harmless, it has been studied that of the 120 species of termites present in Nigeria, no more than 20 damage crops and buildings and only eight of the forty one termite genera in Zimbabwe contain pest species (Logan, 1992).

Recent studies into the evolution of this order of insects, suggests a much more accurate relationship of their contribution to the environment now and in the millions of years they have existed. The termites’ ability to adapt to arid environments has led them filling the important role of decomposition where common decomposers such as bacteria and fungi cannot function (Mommer, 2003).

The dominance of termites in tropical ecosystems is mainly related to their ability of utilizing dead plant material rich in cellulose (the most abundant organic matter on the earth). With this they become important in processes such as decomposition of organic matter, supplying material for many food chains, soil engineering

(translocating and altering soils physically and chemically and maintaining soil fertility) (Wood, 1988), providing a possible input of nitrogen through symbiont fixation methane gas release, and carbon-flux.

Almost all species of termites are detritivorous (Mommer, 2003; Eggleton *et al.*, 1995). They consume a wide range of freshly dead or decaying plant material including dry grass, leaf litter, decaying wood, dung and humus. Living plant tissues, including lichen and mosses are taken by a few species. Another feeding group that may be common and important in many tropical forests is the soil-feeding termite group (Eggleton *et al.*, 1995). Accurate information on the natural history and feeding habits of termites is still scarce for some groups, particularly the subterranean species. Nonetheless, termite species can be categorized into five broad trophic categories according to their food, foraging galleries or columns, colors of the abdomen and known biology (Eggleton *et al.*, 1996; Bignell *et al.*, 1997):

i. Wood feeders. These are primitive wood eating termites that feed on wood and woody litter, including dead branches still attached to trees. These termites have the tendency to live in their feeding galleries which in some cases become colony centres (Eggleton *et al.*, 1996). The condition of wood taken is very important. This may include living trees (*Coptotermes*, *Schedorhinotermes* and *Microcerotermes dubius*), sound dead wood (Kalotermitidae), and/or fungus-attacked wood (Nasutitermitinae, some Termitinae, and Macrotermitinae). Most of these termites are arboreal (attached to trees), subterranean or epigeal nesters (Eggleton *et al.*, 1996).

ii. Soil feeders. Within this group are termites feeding on the upper mineral soil, with some degree of selection of silt and clay fractions. The vast majority of species in this group ingest topsoil rich in organic matter. They are normally distributed in the soil profile, in the organic litter layer (leaves and twigs) and/or in epigeal mounds (Bignell *et al.*, 1997; Eggleton *et al.*, 1995; 1996; 1997). This form is found in many Termitinae (the *Capritermes*-group and *Labritermes*), several Nasutitermitinae (the *Subulitermes*-group), and most Apicotermitinae (the *Anoplotermes*-group) (Eggleton *et al.*, 1997).

iii. Soil-wood interface-feeders. Termites in this group feed on highly decayed (friable and soil-like) wood, the soil under logs or soil plastered to logs, or soil mixed with leaf litter in stilt-root complexes (Eggleton *et al.*, 1997). Soil/-wood interface-feeders are only found in the Termitinae, Apicotermitinae and Nasutitermitinae. Most of them nest within dead logs, build epigeal nest or form colony centres in the soil (Eggleton *et al.*, 1997).

iv. Litter-foragers. In this group, we find termites that forage for leaf litter and small woody items in various stages of decaying. Food sources are often taken back and stored temporarily in the nest. This group includes some subterranean and other mound-building Macrotermitinae (with fungal association), as well as certain Nasutitermitinae that forage on the surface of the ground or litter layers (Bignell *et al.*, 1997; Eggleton *et al.*, 1996; 1997). Genera such as *Laccessitermes* and *Longipeditermes* are also known as arboreal foragers.

v. Micro-epiphyte-feeders. Termites of this group forage for moss, algae, lichens and fungi on tree barks. In South-East Asia, *Hospitalitermes hospitalis* is known to feed on lichen (Eggleton *et al.*, 1997).

Grass-feeders are another important feeding group. Grass feeders will also take dung and may sometimes scavenge vertebrate corpses. Grass-feeders are mainly of the family Hodotermitidae, found only in savannah and deserts (Mommer, 2003; Eggleton *et al.*, 1997; Jones, 1990).

Termites can be both beneficial and destructive in many ecosystems. In some instances they are thought to be important in nutrient cycling and soil formation, whereas in others they are regarded as major factors in range deterioration and soil erosion. Soil macrofauna, such as termites, implement different forms and scales of activity that can influence nutrient cycles and alter the soil physico-chemical environment. The form of termite activity may be in the shape of mounds or foraging galleries and the scale of their activity varies temporally and spatially (Mommer, 2003).

All too often, the effects of termite activity on soil properties are considered in isolation from the scale of their activity yet, the significance of their activity to soil modification is dependant on the temporal and spatial dynamics of their activity in or above the soil. For instance, mound longevity has a profound influence on soil turnover calculations, but there are no reliable data, although researchers have

suggested mound turnover times between 50 and 250 years depending on climatic conditions (Lobry de Bruin and Conacher, 1995).

Hewitt *et al.* (1990) suggested that the role of termites in nitrogen cycling bears closer examination and, went on to suggest that “termites may play a hitherto unrecognized role in soil fertility by replenishing combined nitrogen compounds in the soil”. Termites obtain nitrogen from a number of sources. The intestinal bacterial florae of termites are able to fix atmospheric nitrogen (MacKay *et al.*, 1982).

According to Hewitt *et al.* (1990), studies have estimated that up to 66 g of nitrogen can be fixed per year ha^{-1} by the gut micro-flora of termites. However, MacKay *et al.* (1982), argue that most nitrogen in termites is obtained from the consumption of organic matter, with litter contributing the greatest amount followed by dead wood and lastly annuals and grasses. It is estimated that 879 g N ha^{-1} are incorporated into termite biomass per year with 510 g of this being recycled annually through carbon production and predation. Predation has been reported to account for 80% of the N flux through the termite subsystem (MacKay *et al.*, 1982).

2.4 Assessing termite species diversity

Eggleton *et al.* (1996), did not record much differences in termite species abundance between plots of differing disturbance levels within a forest ecosystem. In their study, Eggleton *et al.* (1996) only realised differences according to assemblage composition between forest like and plantation forest plots. In the same study, there were some differences in termite functional and taxonomic groups between similar plots.

Roisin and Leponce (2004) tested the standardized transect protocol in three forest sites where the local termite fauna was already comprehensively documented. Two transects were run at Danum Valley (Sabah, Borneo), one at Pasoh Forest Reserve (Peninsular; Malaysia) and one at Mbalmayo Forest Reserve (Cameroon). At the three sites the transect samples contained 31–36% of the known local termite species pool. The taxonomic and functional group composition of the transect samples did not differ significantly from that of the known local fauna (Roisin and Leponce, 2004). The two transects run at Danum Valley gave very similar patterns, suggesting that the protocol produces consistent within-site results. After sampling 20 sections, pseudo turnover between the two Danum transects had declined to a relatively low level. Roisin and Leponce (2004) then suggested that the transect method is effective because it utilizes collecting expertise within a protocol that standardizes sampling effort and area.

According to Roisin and Leponce (2004), the protocol provides a much more rapid and cost-effective method for studying termite assemblage structure than sampling

regimes designed to estimate population abundances. It was demonstrated that one supervised training transect was sufficient to ensure the protocol was conducted with the required level of sampling efficiency. The protocol offers a rapid tool for investigating spatial and temporal patterns of termite species distribution and representativeness of a standardized transect at the local community scale. Nineteen termite species in 129 occurrences were recorded from 100 quadrats within a 500 m transect. A close association emerged between the occurrence of termite species and the density of terrestrial bromeliads. The number of bromeliad rosettes per transect quadrat of 10 m x 2 m was a significant predictor of termite occurrence whereas canopy openness was not a significant predictor of termite occurrence. Increased occurrence in bromeliad patches mostly involved soil- or interface-feeding termites, whereas wood-feeding species were more evenly distributed along the transect.

The primary forest transect was the richest with 34 species, while the two non-forested sites were the most depauperate. Two species were found in the *Imperata* grassland transect (6% of the total number of species found in the primary forest transect) while only one species was found in the cassava garden transect (3% of the primary forest transect).

The Termitinae was the most species-rich taxonomic group in every transect except the *Paraserianthes* plantation and the cassava garden. There was a very strong positive correlation between termite species richness and relative abundance in the transects. Relative abundance was highest in the primary forest transect and lowest in the two non-forested transects.

Ferrar (1982), exposed cellulose toilet roll baits in three different sub habitats at Nylsvley Reserve, northern Transvaal. Respective attacks by up to eight species of termites are described and illustrated by Ferrar (1982). In broad-leaved savannah attack was principally by *Microcerotermes*, a slow feeder that attacked rolls throughout the year, finding about half the rolls exposed each season. In *Acacia* savannah the attack was largely by *Microtermes*, a fast feeder active only during wetter times of year. In open, grassy areas there was relatively little attack, except sporadically by *Macrotermes*, which consumed whole rolls within a day or two. Bush-fires delayed initial attack on rolls, perhaps because reduced surface litter gave less protection to soil. The amount of each roll eaten during the trials was consistently greater in *Acacia* than in broad-leaved savannah. The soil-feeding termites *Aganotermes* and *Promirotermes* were attracted during the wet season to the undersides of rolls, perhaps as a source of organic-rich soil (or possibly of water).

In a study to determine inventories and whether land-use history had an influence on termite diversity on five farms in southern Kunene region in Namibia, Zeidler *et al.* (2002) discovered that overall termite diversity in western Namibia was low relative to other parts of the country. In their study, the authors reported that diversity was generally highest at sites under relatively low land-use intensity and the reverse was true for sites with more arid climatic conditions. Termite species diversity differed between the various farms, as well as across land-use intensity gradients. However, no conclusion was reached as to whether the differences were as a result of different environmental parameters or land-use histories.

2.5 Comparing sampling methods

Zeidler *et al.* (2004) conducted a study to compare three methods of sampling termite diversity in arid Namibian rangelands during the wet (March) and dry (October) seasons of 1998. Six sites were chosen: one pair on each of three farms representing a gradient of land-use intensity. The methods used in the study were a modified standard transect system with superficial groundbreaking, a visual searching and the baiting method. All sites under study were similar in climate, soil conditions and topography. A total of 11 termite genera were found, including at least 19 species (Zeidler *et al.*, 2004).

The three authors reported that not a single sampling method recorded all taxa. The baiting method detected 69% of the taxa, and the soil excavation transect as well as the visual search method each found 63% of all taxa. Some taxa were detected with one method only, and were absent seasonally. The authors concluded that all methods, therefore, if used concurrently, would help maximize a species inventory. More termite taxa were found on the commercially managed than on the two communally managed farms. More taxa were found at the perceived high-intensity land-use site than at the low-intensity land-use site on the commercially managed farm, the reverse being true on the two communally managed farms (Zeidler *et al.*, 2004).

In a study comparing five timber species, their dust and two types of toilet paper rolls as termite baits in a Western Australian wheat-belt, Abensperg-Traun (1993), reported that no termites were sampled on sawdust baits. Termites were present at all

other baits. A total of 21 termite species were detected in the Australian study. The study further revealed that termites preferred pine (being associated with 80% of pine baits compared to 10-40% at other baits). Abensperg-Traun (1993) concluded that termites could rapidly locate a new source of food.

Chapter 3

3.0 Materials and methods

3.1 Study sites

Four sites were studied in Swaziland between April and June of 2006, each site representing a distinct land-use practice. The four land-use types are listed in Table 3.1 below.

Table 3.1 The four sampled sites, their codes, location and geographic co-ordinates

Land-use type	Site code	Location	Geographic location
Acacia savannah	AS	Maloma	26. 99956° S 31. 67220° E
Maize field	MF	Ngudzeni	27. 04570° S 31. 56991° E
Open grassland	OG	Ngudzeni	27. 04294° S 31. 56888° E
Woodland	WL	Ngudzeni	27. 04260° S 31. 57076° E

The acacia savannah (AS) was located in Maloma, in the Lubombo Region falling within the Western Lowveld of Swaziland and the three other sites (MF, OG, and WL) were situated at Ngudzeni, in the Shiselweni Region and fell within the Upper Middleveld (Figure 3.1).

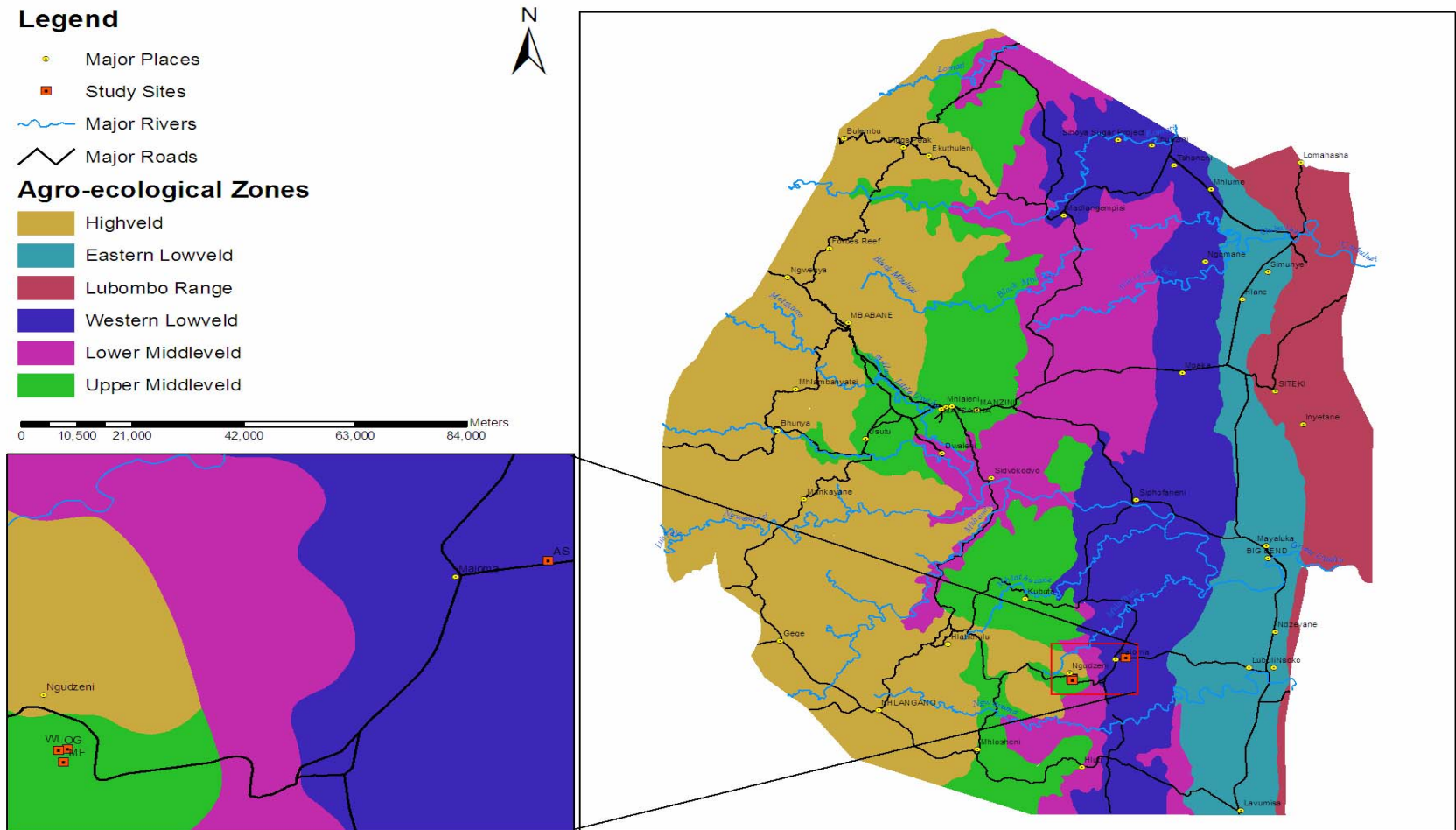


Figure 3.1. An agro-ecological map of Swaziland showing the location of study sites within the country (source: SKIPE-Swaziland)

A botanical survey to determine plant species diversity was conducted at each site and used as the distinguishing factor for differences in land-use practice between sites. One termite transect (100m x 2 m) was run along relatively flat terrain at each site and soil samples were collected from each site for chemical property analysis.

The researcher walked in a zigzag along the diagonal of each site collecting soil samples at every fifteenth (15th) pace with the aid of an auger. The first 3-5cm of topsoil was scraped off from sampling sites to remove organic debris and to ensure sampling of the soil mineral layer. Samples were loaded in plastic bags which were properly labelled and sent to the Malkerns Research Station for Chemical composition analysis. The results of the soil analysis are presented in Table 3.2 below.

Table 3.2 Soil chemical properties within each study site. N: nitrogen, P: phosphorus, K: potassium, EA: exchangeable acidity, OM: organic matter, ppm: parts per million, me: mille-equivalent.

SITE	PH	N (%)	P (ppm.)	K (me %)	EA (%)	OM (%)
Acacia Savannah	5.37	0.12	2.10	2.69	3.03	2.31
Maize Field	5.26	0.12	0.56	1.15	1.48	1.93
Open Grassland	4.86	0.16	1.33	0.51	2.02	1.91
Woodland	4.43	0.22	0.56	0.32	4.75	2.97

It is observed from Table 3.2 above that the acacia savannah had the highest PH followed by the maize field, open grassland and lastly the woodland while the opposite was true for nitrogen percentage where the woodland was highest followed by the open grassland with the maize field and acacia savannah coming last. Phosphorus was highest in the woodland and lowest in the maize field while potassium was highest in the acacia savannah and lowest in the woodland. On the one hand, exchangeable acidity was highest in the woodland followed by the acacia savannah, open grassland and lastly the maize field. On the other hand, soil organic matter was highest within the woodland followed by the acacia savannah, maize field and lastly the open grassland.

The Maloma site hereinafter referred to as AS, fell within an area with an altitude ranging between 200-300 m asl, average annual rainfall between 400-550 mm while the other sites hereinafter referred to as MF (maize field), OG (open grassland), and WL (woodland) fell within an area whose average altitude ranged between 400-600 m having an average rainfall ranging between 550 and 700 mm (Sweet & Khumalo, 1994). All sites fell within areas that have a distinct wet and dry season with a wetter season of six months (wettest months December to February) and a drier season of six months (driest months July and August).

The Ngudzeni sites were all within a 5-km radius while the Maloma site was approximately 15 km to the south-east of the other sites. Local people described all sites as not being in their original states but were not in a position to firmly articulate as to how the sites looked like in their original states.

Site 1 (AS; acacia savannah) was a patch of moderately disturbed savannah situated in Maloma in the southern part of Swaziland (Figures 3.1 and 3.2), on title deed land (TDL) under intensive cattle ranching centred around 26. 99956° S, 31. 67220° E consisting of about 100 ha. The state of bush encroachment made accessibility very difficult but the willingness of the farmers to have the research conducted on their farms and lack of time to scout for other possible study sites left the researcher without other options. Grass cover was moderately thick with a larger proportion being standing dead grass. This was as a result of the elimination of fire during the previous dry season.



Figure 3.2 An aerial photography of Maloma showing the location of the acacia savannah within a semi arid environment in Swaziland (source: SKIPE-Swaziland).

Site 2 (OG; open grassland) was a patch of highly disturbed grassland situated in Ngudzeni in the southern part of Swaziland (Figures 3.1 and 3.3), which was previously under maize production but has been uncultivated for the past 30-40 years giving room to colonisation by grasses at an advanced successional stage. Overgrazing has however led to degradation of the area, which is evidenced, by the extent of termite mounds and bare patches within the site. Centred around 27. 04294° S, 31. 56888° E and measuring approximately 20 ha. Sites 2-4 all fell on Swazi Nation Land (SNL).



Figure 3.3. An aerial photography of Ngudzeni area showing the location of the maize field, open grassland and woodland within a 5km radius in a semi arid environment in southern Swaziland (source: SKIPE-Swaziland).

Site 3 (WL; woodlot) was a patch of moderately undisturbed woodland situated in Ngudzeni in the southern part of Swaziland and centred around 27. 04260° S, 31. 57076° E (Figures 3.1 and 3.3), measuring approximately 20 ha along the boundaries of a shallow stream, which separated this site from the maize field (site 4). Sites 2 and 3 are adjacent to each other with site 2 being to the north-west of site 3. At the time of sampling, the site consisted of a medium density of indigenous and/or natural woody species used by the community for various household purposes with tree height estimated at an average of 5-10 m.

Site 4 (MF; maize field) comprised of rows of harvested maize stalks with the only living plant material being various weeds and remnants of other crops which were intercropped with the maize such as soybeans. The site was also situated in Ngudzeni in the southern part of Swaziland and centred around 27. 04570° S, 31. 56991° E (Figures 3.1 and 3.3). At the time of sampling cattle and other livestock had not been let out to feed on the crop residues since not all community members had finished harvesting their fields.

3.2 Approach and data collection

3.2.1 Determining land-use practices

For determining land use practice, the researcher simply employed the current use of each site to denote land-use practice. Vegetation structure i.e. woodland, acacia savannah, etc. were also used to denote land-use practice combined with consultation from local indigenous people in as far as what individual sites selected for the study were being used and for how long.

3.2.2 Assessing termite species richness and composition

To determine termite species richness and composition for all study sites, a combined sampling protocol was employed. Three sampling methods were used for this exercise, namely the standardized search protocol; the pit method; and the baiting method in an effort to uncover different functional groups existing within the study sites as well as increase sampling effort. All three methods were employed in each site so as to enable the researcher to compare the suitability and/or applicability of each method within a semi-arid environment.

3.2.2.1 The standardized search protocol (modified after Roisin and Leponce, 2004).

One transect (100m x 2 m) was run in each site following the sampling protocol described by Roisin and Leponce (2004). In order to standardize sampling effort, each transect was divided into 20 contiguous sections of 5m x 2m. In an effort not to compromise sampling interval within and between sites, the sampling protocol was modified, such that only 10 of the 20 (5m x 2m quadrats) were sampled. The first and every second section were sampled until the 20th section. Each of the sampled sections were considered as replicates within each site and each of the ten (10) 5m x 2m plots were searched for termites by the researcher and his two assistants for 20 minutes (i.e. 1man hour of sampling). In each section the collectors searched the following common microhabitats of termites: litter accumulation and humus at the base of trees and between buttress roots; the inside of tree stumps; dead logs; branches and twigs; the soil between and beneath very rotten logs; subterranean nests; mounds; runways on vegetation; and visible arboreal nests (Jones *et al.*, 2003).

Mounds were sampled destructively to allow for sampling of inquiline species (Jones *et al.*, 2003). Termite representatives from different microhabitats and encountered populations were collected and preserved in 70% ethanol for later identification.

3.2.2.2 The pit method (modified after Eggleton *et al.* 1996)

At the centre of each of the ten (5m x 2m) section/plots sampled in 3.2.2.1 above, a 20 x 20 x 30 cm pit was dug using a peak and shovel instead of the 20 x 20 x 50 cm pit used by Eggleton *et al.* (1996). The reduction in the depth of the pits was as a result of the hard nature of the soils within most of the study sites, the bulky nature of the soil and the need not to compromise sampling interval within and between sites. All soil from the pit was first sorted in the field with the aim of removing unbreakable material like stones. The soil was then sieved with a mason's sieve and loaded into properly labelled waste poultry feed bags. Bags were then taken to the Entomology laboratory at Malkerns Research Station where soil was hand sorted in search for termites. Later on the soil was hand sorted in search for termites. A representative number of termite specimens collected from the soil were preserved in 70 % ethanol for later identification.

3.2.2.3 The baiting method (modified after Zeidler *et al.* 2004).

Toilet paper baits were used in this study, within each of the ten (5m x 2m) plots sampled in 3.2.2.1 above, a grid overlay of 1m x 1m was marked on the ground using a tape measure; this yielded 18 baiting points per 5m x 2m plot (180 baiting points/site). At each baiting point, toilet paper baits (a handful of low grade single ply toilet paper), held together with the aid of a clear tape strip to avoid unfolding

were half buried on the ground. A stone or in some cases tin can lead was placed on top of each bait to protect baits from trampling by passing livestock and from rainfall. The baits were left in the field for two weeks after which they were examined once a week for a month. Termite specimens present in each bait at inspection were collected and placed in vials containing 70 % ethanol for later identification. Most termite specimens were identified to the species level at the Plant Protection Research Institute in Pretoria (RSA).

The standardised transect protocol (i.e. search method) was carried out first in all sites followed by the pit method and lastly the baiting method. All three methods were also conducted on the same ten (10) plots within each site. It is presumed that the sampling protocol and/or regime did not have much influence on the number and type of termite species detected by the various methods. This is so in the sense that during the searching exercise, not all encountered individuals were taken and at the same time not all available termites were encountered. This therefore implies that the other methods conducted after the search method would have still detected some of the termite species left behind during the search method. Another reason for this presumption is the fact that, termites may have been encountered during the search method while they were foraging hence this would not have had any effect on encounter by the other methods since individuals of other termite species would have still foraged the same areas after the searching exercise.

The pit method only took out a relatively small section of the soil from sampling plots; as a result this would have not affected sampling by the baiting method.

Nesting and feeding behaviour of termites would possibly be the underlying factor contributing to differences in numbers and types of termites detected by these methods as outlined earlier in the research hypothesis.

The fact that the baiting method was extended over a period of over a month, implies that even if the other methods had taken a majority of earlier colonisers of the plots, there was enough time for re-colonization by other termites to enable this method to at least detect certain taxa.

3.2.3 Assessing plant species richness

This was achieved through the use of the quadrat system whereby a 1m x 1m wire quadrat was used. The researcher walked on relatively flat terrain along the diagonal of each site. For every 20 paces, the 1m x 1m wire quadrat was thrown randomly either to the left or right. At each fall of the quadrat, vascular plants within the quadrat were identified and presence counted (i.e. number of occurrences for a total of 40 throws). Trees and shrubs within a five (5m) radius from centre of quadrat were also identified and occurrence per 40 throws also ascertained at each site.

To make the sampling process much easier, indigenous Swazi names were assigned as species names in the field with pressed specimens taken for those plants in which the researcher nor his assistants had knowledge of either indigenous, common English or scientific names. Such specimens were wrapped in newspapers with labels showing numbers according to when and in which site the specimen was encountered. The specimens were later identified to the species level with the aid of

personnel from the national herbarium at the Malkerns Research Station. Those specimens that were previously assigned indigenous Swazi names were given correct scientific names with the help of the booklet by Dlamini (1981).

3.3 Analytic techniques

3.3.1 Termite species richness and composition across land-use types

Descriptive statistics were calculated for most collected data in comparing sites; these included the quadrat sampling statistical technique (to present the frequency of occurrence of each termite species within the study sites). Data on the presence/absence of termite species in each of the ten (10) sampled plots for each site were subjected to a hierarchical cluster analysis to investigate differences and/or similarities between sites in terms of termite species composition.

With termites being social insects, the unit of interest for this study was defined beyond just the individual level. Focusing on numbers of individuals and colonies was found not to be satisfactory, because the size of individual colonies may differ considerably between or even within species and more particularly because numbers of individual encounters were based on the sampling effort and method used. This is why diversity indices were not computed for termites but only species richness and composition were considered.

A scientifically accepted compromise that of focussing on occurrences (i.e. analysing presence/absence data) for each species within sampling units was therefore applied in this study. Although non quantitative in terms of numbers of individuals or

biomass, occurrence records at least provide an estimate of the probability of encounter with various species, or of the fraction of the total area in which each species occur (Roisin and Leponce, 2004).

The Hierarchical Cluster Analysis: -

Cluster analysis is a statistical technique that groups data objects based on information found in the data that describes the objects and their relationships. The goal is that the objects in a group be similar (or related) to one another and different from (or unrelated to) the objects in other groups (Dacheng, 1999). The greater the similarity (or homogeneity) within a group, and the greater the difference between groups, the 'better' or more distinct the clustering. What constitutes a cluster is not well defined, and, in many applications clusters are not well separated from one another. Nonetheless, most cluster analysis seeks, as a result, a crisp classification of the data into non-overlapping groups (Dacheng, 1999).

Cluster analysis is a method used in "classification" cluster in mathematical statistics. It can also be viewed as a divided branch in multivariate statistical analysis (Dacheng, 1999). The basic method of it is: to define the distance in multi-dimension space, and to classify the objects that are close to each other into one cluster and those far from each other are classified to different clusters. The definitions of the distance are different according to the different types of variables (Dechang, 1999).

In Cluster analysis, Hierarchical Clustering Methods are well used at present. Its main idea is: - take the n observations as each cluster respectively, and define the distance between observations and clusters. Initially, because each observation is a cluster, the distance of observations is the same as that of clusters; choose a couple of observations that have the shortest distance to unite into a new cluster; calculate the distance between the new cluster and the other, and then combine the two nearest clusters. So every time, the amount of clusters will be reduced by one until all the clusters are nested, i.e., can have sub-clusters, but are otherwise non-overlapping (Dacheng, 1999).

3.3.2 Effectiveness of sampling methods

Descriptive statistics including the mean number of termite species detected by each method as well as the standard error of the mean for each method and method combinations were calculated for this purpose. The Kolmogorov-Smirnov test for normality revealed that data on the number of species detected by each method were not normally distributed. The Kruskal-Wallis test statistic within the MSTAT-C statistical package was then used to compare methods in terms of numbers of termite species detected by each method.

3.3.3 Plant species richness and diversity

Descriptive statistics including the mean and standard error of the mean were also calculated for plant occurrence data within sites together with plant species richness per site. The Shannon Wiener diversity index (H') was also calculated for all sites

together with Pielous' species evenness (J') as means of comparing termite diversity on sites.

The Shannon Wiener index: -

$$H' = - \sum (p_i \log p_i)$$

Where p_i is the proportion of the total sample (i.e., of the total number of individuals or total biomass) composed of species i (Davidson, 1977). Pielous' species evenness was obtained through dividing the Shannon Wiener diversity index with the highest possible diversity within each site as suggested by Stiling (1999). Stiling suggested that to obtain the highest possible diversity of any given area, one ought to compute and/or obtain the natural logarithm of species richness.

The Kolmogorov-Smirnov normality test revealed that plant species data were not normally distributed for all sites. Plant species richness data between sites was therefore subjected to the Kruskal-Wallis test statistic within the MSTAT-C statistical package to detect differences between sites in terms of species richness.

Chapter 4

4.0 Results

4.1 The termite assemblage

The occurrence (presence/absence) of different termite species in sampled areas and percentage infestation of sampled plots per site are presented in Tables 4.1 and 4.2 respectively.

Table 4.1 Occurrence (presence/absence) of termite species within the four sampled sites regardless of collection method used and combining all sampled plots per site. One (1) signifies a species as having been recorded in that site regardless of the number of individuals for that particular species and a zero (0) implies the absence of that particular species within a specified site. AS: acacia savannah, MF: maize field, OG: open grassland and WL: woodland.

Termite species	Occurrence of termite species in different sampled sites			
	AS	MF	OG	WL
<i>Ancistrotermes latinotus</i> (Holmgren)	0	1	1	0
Gen. et. spec. indent.*	0	1	0	1
<i>Hodotermes mossambicus</i> (Hagen)	1	0	0	0
<i>Lepidotermes mtwalumi</i> (Fuller)	0	1	0	0
<i>Macrotermes natalensis</i> (Haviland)	0	0	1	0
<i>Macrotermes</i> sp.	1	1	1	1
<i>Macrotermes ukuzii</i> (Fuller)	0	1	0	1
<i>Odontotermes</i> sp.	1	0	0	0
<i>Trinervitermes trinervoides</i> (Sjöstedt)	1	0	1	0
Species richness	4	5	4	3

* This species was only identified to family level (Macrotermitinae)

Overall a total of nine (9) termite species were collected from the four sites (Table 4.1). Most termite specimens were identified to the species level except Gen. et. spec. indent. which was only identified to the family level, *Macrotermes* sp. and *Odontotermes* sp. were only identified to the genus level (Table 4.1). Worth noting is the case of the *Macrotermes* sp. which occurs in all sites, since it was only possible to identify specimens of this species only to the genus level. This may therefore lead to ambiguity in the sense that these individuals could belong to either a separate *Macrotermes* species or fall in either the *Macrotermes natalensis* (Haviland) or *Macrotermes ukuzii* (Fuller) species. The same goes also for Gen. et. spec. indent. which was only identified to the family level (Macrotermitinae), which happens to include all the *Macrotermes* spp. This study was the first one to record the *Odontotermes* genus in Swaziland.

Termite species richness was highest in the maize field (five species) followed by the Acacia savannah and open grassland with four species each. Three species were recorded from the woodland transect (60% of the total number of species found in the maize field transect). The Termitidae and Macrotermitinae were the most species-rich taxonomic groups in all land-use practice sites. Within the entire study, the litter forager trophic group was the most abundant group (i.e. members of the Macrotermitinae family).

From Table 4.1, it is observed that *Hodotermes mossambicus* (Hagen) and *Odontotermes* sp. were only detected in the acacia savannah while *Macrotermes*

natalensis (Haviland) was recorded only in the open grassland. On the other hand The *Macrotermes* sp. was recorded on all sites.

Table 4.2 reveals that the *Macrotermes* species was harbored by the highest number of plots in all sites (60%, 50%, 30% and 20% for the acacia savannah, maize field, open grassland and the woodland respectively). It was followed by the *Trinervitermes trinervoides* (Sjöstedt) occurring in 20% of the open grassland plots with the rest of the species occurring in 10% of all plots that harboured these species respectively.

Table 4.2 Percentage of the ten (10) sampled plots in each site that harboured each termite species, (numbers represent the percentage of all ten (10) sampled plots per site that had a particular species with all sampling methods combined). AS: acacia savannah, MF: maize field, OG: open grassland, WL: woodland.

Taxon	Sampled sites			
	AS	MF	OG	WL
<i>Ancistrotermes latinotus</i> (Holmgren)	0	10	10	0
Gen. et. spec. indent.*	0	10	0	10
<i>Hodotermes mossambicus</i> (Hagen)	10	0	0	0
<i>Lepidotermes mtwalumi</i> (Fuller)	0	10	0	0
<i>Macrotermes natalensis</i> (Haviland)	0	0	10	0
<i>Macrotermes</i> sp.	60	50	30	20
<i>Macrotermes ukuzii</i> (Fuller)	0	10	0	10
<i>Odontotermes</i> sp.	10	0	0	0
<i>Trinervitermes trinervoides</i> (Sjöstedt)	10	0	20	0

* This species was only identified to family level (Macrotermitinae)

The hierarchical cluster analysis results showing the relatedness of sampled plots/site with regards to termite species occurrence (composition) are shown in Figure 4.1.

The analysis identifies two groups from the broader horizon narrowing these down to five similar groups of plots with their respective outliers (Fig. 4.1). A detailed description of the relatedness of plots and sites was as follows: - The cluster analysis has classified plots from the four study sites into two main groups with a third minor group according to similarities with regards to termite species composition within plots. It is observed that the first group extends from plot WL3 down to plot AS2.

Members of this group are closely related in the sense that all plots belonging to this group regardless of which land-use practice they belonged to, contained the *Macrotermes* species within them. Plots WL3 down to AS4 all had only the *Macrotermes* species while the other members of the group had an extra species i.e. MF10 had *Macrotermes ukuzii* (Fuller), MF6 with *Lepidotermes mtwalumi* (Fuller), whereas AS2 contained *Hodotermes mossambicus* (Hagen) in addition to the unifying *Macrotermes* species within this group (Figure 4.1).

From this analysis we can also observe the existence of a second larger group, which extends from plot WL8 down to MF3. Within this group, the majority of member plots are those from which no termite species were detected during the sampling exercise. Minor groupings can also be distinguished such as the group consisting of MF2 and OG5, which contained only one species (*Ancistrotermes latinotus*

(Holgrem)). Last but not least, a group whose member plots contained one species each (i.e. WL6, OG3 and AS3), containing *Macrotermes ukuzii* (fuller), *Macrotermes natalensis* (Haviland) and *Odontotermes* sp. respectively.

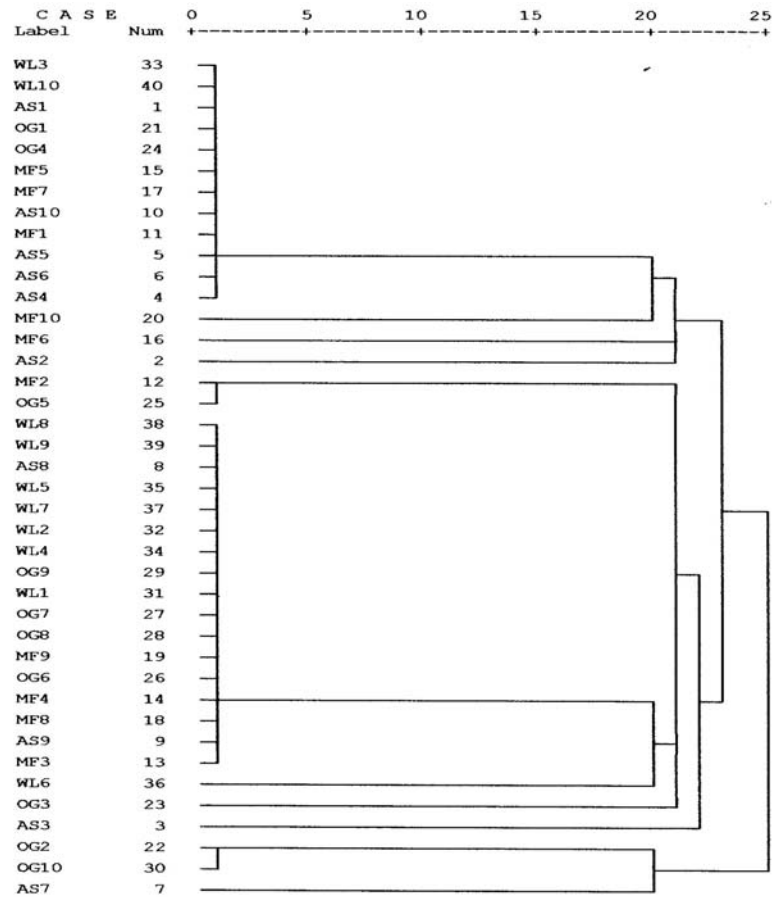


Figure 4.1 A dendrogram with average linkage (between plots, using the rescaled distance cluster combine). AS: acacia savannah, MF: maize field, OG: open grassland, WL: woodland. Numbers attached to site codes denote plot identities for each site (i.e. plots arranged numerically according to sampling sequence in each site) and, numbers attached to the dendrogram itself represent the position of that particular plot in the initial spreadsheet which contained data that was subjected to the analysis and should not be considered of importance in the analysis and subsequent interpretation of results.

The last group is that of plots containing *Trinervitermes trinervoides* (Sjöstedt) plots OG2 to AS7 with plot AS7 being an outlier due to the fact that it had *Macrotermes* species in addition.

4.2 Effectiveness of sampling methods

Not a single sampling method detected all termite species present in all the study sites. The search method detected 66.7% of all species, followed by the baiting method with 33.3% of all species and lastly the pit method, which detected only 20% of all species in this study. Combining the pit and the search method yielded 80% of all species while the combined protocol of baiting and search methods revealed 69.3% of all taxa. The baiting and pit combination was lowest at 32.4% (Fig. 4.2).

When comparing the number of termite species collected using the different methods in different land-use types, it was observed that the search method recorded the highest number of termite species within the acacia savannah with four (4) termite species. The search method was again the best within the maize field recording three (3) termite species while the pit method was the best within the open grassland with two (2) termite species. The search method was again the best in the woodland recording two (2) termite species (Table 4.3).

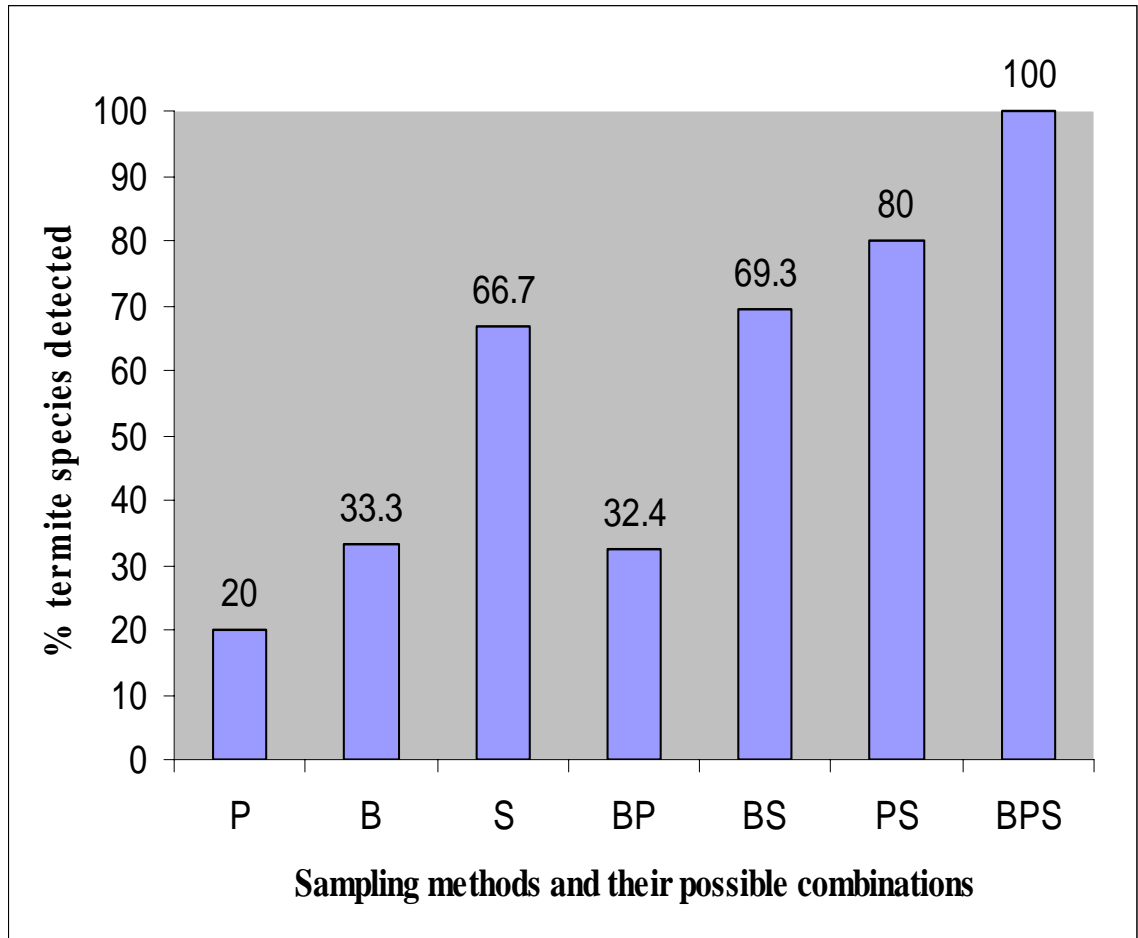


Figure 4.2 Percentage of termite species detected by different methods and their possible combinations, B: baiting method, P: pit method, S: search method, BP: bait and pit combination, BS: bait and search combination, PS: pit and search combination, BPS: bait, pit and search combinations. Effectiveness for each method is given as the percentage of the mean number of species sampled using the combination of all three methods (BPS).

Table 4.3 Comparison of the number of species collected using the three different methods and their combinations. B: bait method, P: pit method, S: search method, BP: bait and pit methods combined, BS: bait and search methods combined, PS: pit and search method combined, BPS: all three methods combined. AS: acacia savannah, MF: maize field, OG: open grassland, WL: woodland. On average, the combined B.P.S. protocol sampled most of the species. Effectiveness of each method within sites is given as the percentage of the mean number of species uncovered by the combination of all three methods. Results exclude the unidentified species.

Site	B	P	S	BP	BS	PS	BPS
AS	1	1	4	1	4	4	4
MF	2	0	3	2	4	3	4
OG	1	2	1	3	3	3	4
WL	1	0	2	1	2	2	3
Mean	1.25±0.50	.75±0.96	2.50±1.29	1.75±0.96	3.25±0.96	3.00±0.82	3.75±0.50

The *Macrotermes* species was detected using all the applied methods and also recorded in all sampled sites while other species were found through the use of a specific method, i.e. *Odontotermes* sp., *Hodotermes mossambicus* and *Macrotermes natalensis* (Haviland) and *Macrotermes ukuzii* (Fuller) were only detected by the search method while *Lepidotermes mtwalumi* was only detected by the bait method (Table 4.4).

The Kruskal-Wallis comparison of the number of termite species detected by the sampling methods and their possible combinations revealed a significant difference ($H = 17.0782$, $df = 6$, and tabular Chi-square values of 12.6 and 16.8 at 5% and 1% significance levels respectively).

Table 4.4 Termite species detected by the three sampling methods. Numbers in cells signifies a detection of a particular species by a particular method regardless of the number of individuals of that species each method detected per site (one (1) merely stands for a record of a species by a method and should not be taken to imply anything otherwise and (-) denotes unrecorded species). AS: acacia savannah, MF: maize field, OG: open grassland, WL: woodland. B: baiting method, P: pit method, S: search method.

Species	Sampled sites and methods											
	AS			MF			OG			WL		
	B	P	S	B	P	S	B	P	S	B	P	S
<i>Ancistrotermes latinotus</i> (Holmgren)	-	-	-	-	-	1	-	1	-	-	-	1
Gen. et. spec. indent.*	-	-	-	-	1	1	-	-	-	1	-	-
<i>Hodotermes mossambicus</i> (Hagen)	-	-	1	-	-	-	-	-	-	-	-	-
<i>Lepidotermes mtwalumi</i> (Fuller)	-	-	-	1	-	-	-	-	-	-	-	-
<i>Macrotermes natalensis</i> (Haviland)	-	-	-	-	-	-	-	-	1	-	-	-
<i>Macrotermes sp.</i>	1	1	1	1	-	1	1	-	-	1	-	-
<i>Macrotermes ukuzii</i> (Fuller)	-	-	-	-	-	1	-	-	-	-	-	1
<i>Odontotermes sp.</i>	-	-	1	-	-	-	-	-	-	-	-	-
<i>Trinervitermes trinervoides</i> (Sjöstedt)	-	-	1	-	-	-	-	1	-	-	-	-
Total no. of species	1	1	4	2	1	4	1	2	1	2	0	1

* This species was only identified to family level (Macrotermitinae)

4.3 Plant species richness and diversity

A total of 44 plant species were detected within the four sites combined (Appendix 1). A descriptive comparison of sites (i.e. species richness and diversity indices) is presented in Table 4.5. Overall, the acacia savannah was more species rich with 31 species followed by the woodland with 24 plant species. Surprisingly, the maize field was richer than the open grassland in terms of plant species composition with 13 and 11 species respectively. The acacia savannah had the highest diversity index (H') of 3.05 and the lowest evenness index (J') of 0.89 (Table 4.5).

Table 4.5 Comparison of mean plant species richness (\pm standard error of the mean) within the four sites as well as indices of diversity and evenness. Species richness values represent the average number of plant species recorded per site. AS: acacia savannah, MF: maize field, OG: open grassland, WL: woodland.

Site	AS	MF	OG	WL
Species richness	31 \pm 5.8	13 \pm 14.6	11 \pm 12.6	24 \pm 11.2
Shannon's H'	3.05	2.33	2.18	2.93
Pielous' J'	0.89	0.91	0.92	0.92

Even though the woodland followed with the second highest diversity index, its evenness index was relatively similar to those of the maize field and open grassland suggesting that plants were not that evenly distributed within these sites (Table 4.5). There was a significant difference in plant species richness between sites ($H = 11.579$, $P = 0.009$).

Chapter 5

5.0 Discussion

5.1 The termite assemblage

There was evidently a variation in termite species richness and composition at the four sites (Table 4.1, Table 4.2 and Figure 4.1). The woodland (WL), being the less human managed habitat and with relatively high plant species richness, had the lowest number of termite species (three species) while the other sites (acacia savannah (AS), maize field (MF) and open grassland (OG) had four species each. Arranging the sites along a land-use practice and/or intensity of use gradient, the maize field was the most highly intensively used site with more anthropogenic stress, followed by the open grassland, the acacia savannah and lastly the woodland. This arrangement of sites merely takes into account the degree of management and/or disturbance by human practices.

Although our knowledge of the biodiversity of organisms in all soils is still very poor, the conversion from natural to managed ecosystems generally induces a substantial decrease in soil C-stock and leads to modified soil biodiversity (Hairiah, *et al.*, 2001).

It is generally expected that soil biota are very responsive to human-induced disturbance e.g. intensive agricultural practices, but there is remarkably little data to support this expectation (Hairiah, *et al.*, 2001).

As intensification proceeds, above-ground biodiversity is reduced and the biological regulation of soil processes is altered and often substituted by the use of mechanical tillage, chemical fertilizers and pesticides (Hairiah, *et al.*, 2001).

In the present study, the woodland had more trees as well as higher plant species diversity with relatively few visible termite mounds. The open grassland which consisted mainly of grasses had the lowest plant species diversity with a relatively higher mound density. The acacia savannah on the one hand had the second highest plant species diversity with a moderate mound density. On the other hand the maize field came third with regards to plant species diversity and had the lowest number of termite mounds, which were basically only found, in the areas surrounding the fields and in the land separating different fields.

When looking at the termite assemblages of these different sites, *Ancistrotermes latinotus* (Holgrem) occurred only within the maize field and the open grassland both areas having more anthropogenic stress with an accompanying high degree of disturbance. The absence of this species on the other sites (i.e. woodland and acacia savannah) which had relatively low human induced stress and were less disturbed may imply that the species favours more disturbed areas hence a potential indicator of land degradation. This may also explain the presence of the *Lepidotermes mtwalumi* (Fuller) species in all the other sites except in the maize field which may imply that the species does not favour disturbance. The absence of dry wood within the two sites harbouring this species and the fact that *Ancistrotermes* sp. has been

reported to possibly rely only on dry wood as a source of food in tropical climates is contrary (Okwakol, 2001).

Hodotermes mossambicus occurred only within the acacia savannah (Table 4.1). The acacia savannah happened to fall within a warmer and drier area as opposed to the other three sites. *H. mossambicus* has previously been recorded in the Lowveld of Swaziland an area within which the acacia savannah falls. This species is a specialist grass feeder, which has been reported to favour drier areas and also reported to compete directly with game and livestock for feed (Duncan & Hewit, 1989; TPPRI, 2005; Van DER Linde *et al.*, 1989). As a dryland species, it is therefore understandable why this species only occurs in the low rainfall area and not in the Ngudzeni sites, which on average receives good rains opposed to the Maloma site. If not for climatic differences between the sites (i.e. Ngudzeni and Maloma), one would have expected *H. mossambicus* to also occur in the open grassland as a result of the fact that it has not been reported to favour certain grass species (Coaton, 1958) hence differences in grass species diversity alone may not have eliminated the species from the other sites.

Members of the Macrotermitinae family seemed to be the least affected by land-use practice. This is due to the fact that members from within this family were represented in almost all sites. It is difficult to treat the family members separately considering the fact that the unidentified species was at least identified to the family level and it belonged to the Macrotermitinae family. Apart from this fact, another member of this family was only identified to the genus level and it occurred in all

four sites. Within this species (i.e. *Macrotermes*) species might fall the *M. ukuzii* (Fuller), which occurred within the maize field and woodland as well as *M. natalensis* (Havilandi), which occurred in the open grassland only.

Members within the Macrotermitinae family are not specialist feeders and are known to occur throughout the country. This therefore entails that the fact that this family occurred in all four sites may entail that they are not sensitive to land-use practice and will easily adapt to changes in land-use practice. According to FAO (2000), members of this family belong to the functional group of mound builders most of which are fungus growers. Within the present study, mounds were evident on all sampled sites and/or land-use types, which explain why Macrotermitinae were detected in all sites. Furthermore, the Macrotermitinae belong to group I in the feeding group classification. Members of this group are wood feeders most of which are arboreal (attached to trees), subterranean or epigeal nesters (Eggleton *et al.*, 1996).

Okwakol (2001) reported a similar trend with members of the Macrotermitinae family which were not affected by deforestation and cultivation within a tropical rain forest in Uganda. Okwakol (2001) concluded that this might have been as a result of their ability to utilize a variety of food sources and their nest building behavior whereby most species build nests below ground level. This entails that they are sheltered from the effects of environmental change experienced by the surface nesting and arboreal termites. In addition, those that construct mounds have nest systems within which microclimate is controlled with narrow limits of accuracy

(Okwakol, 2001). Cultivation results in the destruction of mounds of *Macrotermes*, *Odontotermes* and *Trinervitermes* (Okwakol, 2001). This may explain the absence of *Odontotermes* sp. and *T. trinervoides* in the maize field.

A similar trend was observed in other studies in Africa. In Nigeria, for example, the abundance of *Microtermes* rose substantially as they fed on cultivated maize (Wood *et al.*, 1982). Wood *et al.* (1982) reported that such outbreaks usually occur only if the pest species had been present in the original species pool or had been introduced by humans.

Only two specialist feeders *H. mossambicus* and *T. trinervoides* have been recorded in this study while the majority of the termites feed on dead dry wood, fungus, grass, litter, detritus or even soil (polyphagous).

The analysis of similarities between sites as well as plots within sites in as far as termite species composition was concerned by way of a cluster analysis (Figure 4.1), revealed that there were two main similar groups with a third minor group. The analysis also showed that no matter how closely related plots from different and/or similar sites may have been, there were always outliers within members of a whole. This analysis showed that even within each site, different plots differed in as far as termite species composition was concerned which may be an indication of the degree of heterogeneity within sites (Figure 4.1).

This similarity between different sites and differences in termite species composition between plots of the same site may best be explained by the theory of patch dynamics (White and Pickett, 1985). As a result of different levels of disturbance within and between sites, a distribution of patch mosaics has occurred. According to White and Pickett (1985), many patches are remnants of the original habitat. A patch suggests an area that is relatively discrete in space (White and Pickett, 1985), not constrained by size, area, persistence, composition, or geographic location. Patches are areas that are different than the landscape matrix, depending on the process or pattern of interest (Turner *et al.*, 2001).

Patch dynamics is a process across a landscape, in which a changing patchwork is created from disturbances differing in frequency (e.g. seasonality), size, type (e.g. abiotic, biotic, human induced), shape and intensity (Turner *et al.*, 2001). The effects of patch dynamics are evident in changing landscapes, as various patterns (e.g. natural plant communities) at different scales (e.g. annual herbs, biome) are altered. As patches change, associated processes (e.g. succession and persistence) are also predicted to change. The configuration of landscape patches will directly impact the ability of plant and animal populations to colonize and persist (Turner *et al.*, 2001).

This therefore suggests that even though the sites differed in land-use and patch dynamics, it is possible that within the sites, there existed patches that were similar (i.e. in size, type and causal effects) as well as different patches existing within the same site thereby resulting in the observed trend in Figure 4.1.

An insight into the biology of individual termite species encountered by this study as well as the patches that existed among the different sites and plots within sites would provide more basis for making conclusive biological meaning from the results of the cluster analysis.

The information base on termite diversity in Swaziland is inadequate and this study did not aim to produce a full species inventory for an entire ecosystem, but only for the comparative study sites and land-use practices. The checklist of the termites of South Africa (Appendix 2) indicates that most genera that were previously recorded in Swaziland have been detected by this limited and restricted sampling design. In addition, restricted as it may have been, the present study managed to detect an extra genera namely *Odontotermes* sp. which was previously not recorded within the whole of Swaziland. Whether this genus was found due to an intensified sampling effort in this study or because of a change in their distribution pattern cannot readily be ascertained.

Zeidler *et al.* (2004), detected eleven (11) taxa within an arid environment in Namibia using a combined search protocol. In the Namibian study, the protocol did not detect certain taxa that have previously been recorded in the study area and went on to detect among others, taxa that were previously not recorded within the study area. Zeidler *et al.* (2004), also realized that the low-use intensity sites had the highest species diversity, something which is the direct opposite in this study where it has been discovered that the low intensity site had the lowest number of termite species. The differences between the findings of these two studies may be attributed

to the fact that the degree of disturbance as well as the type of disturbance and patch dynamics operating in the present study may have differed from those of the former study.

The decline in termite assemblages with intensity of use has been found to hold for most tropical ecosystems (Jones *et al.*, 2003; Roisin and Leponce, 2004) and in such ecosystems termite species richness has been found to decline in isolated forest fragments compared with continuous forests. However, some termite populations were reported to increase with agricultural intensification. In Nigeria, for example, the abundance of *Microtermes* rose substantially as they fed on cultivated maize (Wood *et al.*, 1982).

The distribution of epigeal mounds of the humus feeding termite *Cubitermes sankurensis* (Wassmann) was studied in relation to small-scale variation in vegetation pattern on three permanent transects within a 5 ha stand of Miombo woodland in Zimbabwe (Dangerfield, 1990). In this study, Dangerfield discovered that vegetation structure had a significant effect on the abundance of *C. sankurensis* (Wassmann). There was increased mound aggregation in open canopy plots (Dangerfield, 1990).

In Australia, a pilot survey was conducted on the effects of sheep on vegetation and soil variables, and the abundance, diversity and species frequency of occurrence of subterranean termite communities (Abensperg-Traun, 1992). In his study Abensperg-Traun, used ten 1/4 ha study plots for paired grazed/ungrazed comparisons. Ungrazed

plots had more litter mass (dry weight), leaf and woody litter, canopy cover (%) and soil moisture (moisture content <1.2% across study plots); grazed plots had a higher percentage of bare ground. Termites were as abundant and as diverse, in grazed as in ungrazed plots, and were equally often sampled in the soil and surface wood. Termite species eating sound wood, decayed wood/debris and grass were sampled equally, often, and were of comparable diversity in sheep-grazed as in ungrazed plots. The mounds of *Drepanotermes tamminensis* were more abundant in grazed plots. Abensperg-Traun therefore concluded that, his findings indicated that prolonged sheep grazing in remnants of Wandoo woodland of the Western Australian wheat belt has had no detrimental or beneficial effect on its subterranean termites.

Within the present study, sampling was only conducted in one season (i.e. the rainy season). As a result the termite assemblages recorded within each site should not be taken to represent all year round termite species richness and composition within the different land-use types. The issue of certain termite species (i.e. *Hodotermes mossambicus* and *Odontotermes* sp.) being found to be site specific should therefore not be conclusive since some termite species occurrences have been shown to be seasonal (Zeidler *et al.*, 2004).

The feeding habits of some of the termite species encountered by this study are not clearly understood and require further study by rearing them in the laboratory and observing their feeding behaviour as well as food preferences. The study showed that qualitative differences in termite communities occur when land is subjected to

different land-use practices. These differences appear to be associated with destruction of nesting sites and the removal of feeding material for the termites.

There is also a need to carry out laboratory food preference experiments using known termite species in order to assess the impact of alteration in material for their consumption. Termites play a keystone species role in ecosystems. Their importance in carbon and nitrogen fluxes in humid environments has been confirmed by researchers in West Africa, Malaysia and South America (Okwakol, 2001; Eggleton *et al.*, 1996). Similarly, the importance of termites in the decomposition of plant matter in natural ecosystems is well documented. In addition, the influence of termites on soil processes is dynamic, involving bioturbation and biochemical action. This suggests that a reduction in termite diversity and abundance would have a negative impact on overall ecosystem function through changes in termite-influenced or mediated ecological processes such as carbon and nitrogen mineralization. Productivity is also likely to be reduced with time. However, further research is required to assess these interactions fully in terms of ecosystem function and contributions of different land-use practices. A major problem faced would be hypothesising the original landscape as well as its inhabitants.

The loss of termites that accompanies severe forest modification may have negative impacts on soil processes (Donovan *et al.*, 2001). While research is needed to quantify the relationship between termites and soil quality, the immediate challenge is to achieve sustainable agricultural and silvicultural production with management

practices that protect soil biodiversity and maintain ecosystem functions (Donovan *et al.*, 2001).

5.2 The effectiveness of methods

None of the three methods used to assess termite diversity detected all taxa found during the present study and among different sites.

5.2.1 The search method

Within the acacia savannah, the search method revealed a total of four species namely *H. mossambicus*, *T. trinervoides*, *Odontotermes* sp. and *Macrotermes* sp. Within the maize field, this method detected *A. latinotus*, the unidentified species which belongs to the Macrotermitinae family, *Macrotermes* sp. and *Macrotermes ukuzii* (Fuller). Within the open grassland, the search method detected only one species, the *Macrotermes natalensis* (Haviland) and within the woodland, this method detected two species namely *A. latinotus* and *T. trinervoides* (Table 4.4).

The search method detected 66.7% of termite species recorded by the present study (Figure 4.2). The high number of species detected by this method in different sites may have been as a result of various spatial and temporal factors. One will recall that even within the same sites, there were differences in species composition between sampled plots (Figure 4.1). This may be a possible spatial factor answering to differences in species recorded by this very method in the different sites. A temporal possibility is the fact that during the sampling exercise, it was observed that plots which were sampled in the morning hours, when temperatures were cooler had more

termites. Termites became scarce, as temperature got warmer with time. This may be explained by the fact that termite foraging activity has been observed to be an early morning and late afternoon exercise (Oihagu, 1979). This is as a result of the possibility that there is a temperature range within which termites can escape desiccation. It can therefore be hypothesized that as temperature rises beyond this limit, termites will resort to nesting sites and/or seek refuge from available microhabitats to protect themselves from heat (Mitchel *et al.*, 1993; Dawes-gromadzki, 2003).

The reason why more termite species were recorded within the acacia savannah and maize field may have been the fact that, within these two sites, there were more shade effects to protect termites from desiccation in as far as microhabitats were concerned. This may have resulted in termites not disappearing into deeper nesting areas as temperature rose, but merely seeking refuge within available materials like maize straw, in the case of the maize field and, fallen dead logs together with high canopy and ground cover in the form of bush and thick grass within the acacia savannah (Wood *et al.*, 1982).

With the open grassland, even though a relatively high number of species were recorded overall, the search method only detected one species due to lack of microhabitats to protect termites from desiccation. This may have therefore resulted in termites resorting to their hypogean nests as soon as temperatures were not conducive for foraging. At this point in time it is difficult to suggest why this method detected fewer termite species within the woodland.

5.2.2 The pit method

The pit method was the lowest in terms of performance among all three single methods used in this study with a success rate of only 20% (Figure 4.2). The reason why this method detected such a few number of termite species may be explained by the fact that most termite species recorded in the present study belonged to the Macrotermitinae family. Species falling within this family are fungus growers. Most fungus-growing termites are arboreal nesters implying that few such species may be detected using the pit method. Within the acacia savannah, this method only detected the *Macrotermes* sp., which may have representatives from any of the *Macrotermes* species recorded by this study. In the maize field, this method also detected only one species (Gen. et. spec. indent.*). The pit method only detected more than one species within the open grassland namely *A. latinotus* and *T. trinervoides*, which are both specialist grass feeders. Nothing was recorded by the search method within the woodland.

Reasons for such differences may be explained similarly to 5.2.1 above. Additionally these differences may be as a result of differences in nesting as well as feeding behavior within the different termite species. Members of the Macrotermitinae (i.e. all *Macrotermes* species), being known for their varied nesting behavior (Okwakol, 2001), may well explain why almost all methods managed to detect members from within this family. Members within the Macrotermitinae family are hypogeal nesters as well as epigeal and arboreal nesters, implying that they build above ground nests which may be ground based extending a few centimeters below ground or attached to

trees (Primanda *et al.*, 2005). This nesting behavior (below ground) therefore subjected these termites to being detected by the pit method in this study.

5.2.3 The baiting method

The baiting method was second highest in terms of sampling success with a rate of 33.3% (Figure 4.1). Within the acacia savannah, this method detected only *Macrotermes* sp. a member of the Macrotermitinae family which feed across a range of food material including dead wood, grass, leaf litter, micro-epiphytes and fungi (Primanda *et al.*, 2005), has possibly enabled their detection this method in the sense that it is possible that these species were quick to identify baits as opposed to the other taxa. The same species was detected by this method within all four sites implying that this species was not only quick in detecting baits but also found them a suitable food material. The only unique feature of this method is that it detected a species within the maize field, *Lepidotermes mtwalumi* (Fuller), that was only detected by this method and also occurring only in the maize field. Investigations into the feeding and nesting behavior of this species may need to be conducted in order to be in a position to explain this observation.

5.2.4 Possible method combinations

The search sampling protocol applied in all sites detected more termite species than the other two methods. The combined search protocol (i.e. combining the bait, search and pit methods) was superior to any other method combinations (Table 4.3, 4.4, Figure 4.2). The fact that not a single method managed to detect all species uncovered by these investigations, implies the need for combining methods in

termite diversity assessments in semi-arid ecosystems like most ecosystems in Swaziland so that representatives from different nesting and feeding groups can be uncovered.

However, the sampling effort that is required for such a combined protocol is enormous. Although developed as a rapid assessment method in tropical forests, in arid ecosystems the transect method seems to be extremely labor-intensive, demanding 10 man-hours on a 10-section plot, and generating only slightly more complete termite species inventory data (Zeidler *et al.*, 2004). The baiting method is only intensive at the set-up stage. It has been observed, however, that baits do not attract soldiers, thus quick field identification of specimens is not possible (Zeidler *et al.*, 2004).

The search was confined to one man-hour in a 5m x 2m plot. It should therefore be tested whether an intensification and potential improvement on the current design would further enhance the sampling success. The extension of search time could lead to a higher detection rate of termite taxa, as would possibly the intensification of the transect method by doubling the sampling effort to the standard number of 20 sections sampled, or to any other appropriate sampling effort (Zeidler *et al.*, 2004). This would also allow a direct comparison with similar surveys undertaken in different ecosystems worldwide.

Termites show different ecological responses according to their feeding habit, for example with respect to habitat disturbance, and in natural and human-induced

successions (Donovan *et al.*, 2001). In addition, at least in African forests, more energy appears to flow through soil-feeders than through wood-feeders (Donovan *et al.*, 2001). It is therefore important to be able to recognize termite-feeding groups in order to understand the ecological processes that they mediate. This is especially true for the relatively poorly known soil-feeders.

5.3 Plant species diversity

Physically, the four sites differed in many aspects. The acacia savannah, apart from being the more species rich site of all the four sites, was at an advanced stage of bush encroachment and was not easy to sample for termite due to difficulty in penetrating certain parts of the site. This site was also in a warmer and arid location as compared to the other sites (i.e. the Ngudzeni sites). There was complete ground cover in the form of grass and tree canopy.

The maize field on the other hand had no standing live vegetation except for weeds, which survived the weeding season. Within this site, there were a lot of remnants of maize stover left over from harvesting. These were lying dead on the ground and may have served as a good source of food for termites since by the time of sampling livestock had not been let loose to make use of the crop by-products. There were virtually no trees within the maize field.

The open grassland was dominated by one grass species namely the *Eragrostis plana* (Appendix 1). This site was previously under maize production with the former maize field boundaries still showing. At the time of sampling this site was subjected

to heavy grazing by cattle and goats and it had evidence of degradation in the form of bare patches and had a high mound density than all other sites. The woodland on the one hand was second highest in terms of plant species richness; however, tree density was not as thick due to over harvesting by local communities. There was also the presence of alien invasive species within the woodland like bug weed. This may be an indication of the fact that the woodland is over utilized for various household uses.

5.4 Management recommendations

Sound ecosystem management requires adequate knowledge of temporal and spatial patterns of the abundance and diversity of the biota, as well as their role in ecosystem processes (Abensperg-Traun, 1998).

This study was useful in the sense that it was able to come out with useful information on the responses of termites to land-use practice change. It is recommended that where land is subjected to agricultural practices like maize production, actions be taken to ensure that portions of land are left in their original set-up in between the fields so as to minimize the outbreak of termites as pests to the maize. Even in that case, intercropping should be practiced in such a way as to mix crops of interest with other crops of minor importance that are not susceptible to termite attack. This will in a way minimize the pest status of most species within cultivated area. Crop rotation is yet another option that must be tried to see if indeed termite diversity will increase as land is being cultivated in Southern African Savannah regions.

In rangelands, it would be ideal to enforce policies that will ensure proper range management practices (i.e. proper stocking rates, resting of the range, etc) so as to ensure that vegetative cover is maintained at optimum levels, not allowing for bare patches of ground and ensuring that termites do not compete directly with stock and game for feed. It is also important to leave some lying dead logs and tree stumps within woodlands as a source of food for termites as well as other decomposers and not to harvest all for household uses. This may help in ensuring that termite diversity is maintained at high levels as well as minimizing the pest status of most termites found within the region and in Swaziland as a whole. Enforcing Policies that increase forest or silvicultural patch size and reduce the length of forest edges are likely to have a positive effect on the survival of forest dependent species.

5.5 Conclusion

As human land-use changes, there is a need to investigate the impacts of such changes on landscapes as well as upon inhabitants of these landscapes (biological resources). Certain animal species like termites have been described as indicator species, the availability of which enables us to study the effects of landscape modification and/or scale and degree of disturbance to their assemblages (richness, composition as well as diversity).

The present study revealed that the termite species assemblage (i.e. species richness and composition) differs with differing land-use types. This is evidenced by the differences in termite species richness and composition within the four study sites (i.e. acacia savannah, maize field, open grassland and woodland). The maize field

transect was the most species rich with five (5) termite species followed by the acacia savannah and the open grassland with four (4) termite species each and lastly the woodland with three (3) termite species (Table 4.1). It appears that the more disturbed (i.e. more intensively managed) an area/site is, the more termite species it is bound to have within a semi-arid environments like the ones in which this study was conducted.

The majority of termite species found within the present study sites belonged to the Macrotermitinae family which have been shown to occur in almost all habitats within their range and seemingly not sensitive to land-use change and/or disturbance. Members from this family were detected on all study sites within this study (Table 4.1). Not all termite collected in this study were identified to the species level; one of the species (i.e. Gen. et. spec. indent.*) was only identified to the family level while two others (i.e. *Macrotermes* sp. and *Odontotermes* sp.) were only identified to the genus level (Table 4.1). Some termite taxa were seen to be site specific (i.e. *Hodotermes mossambicus* (Hagen), *Lepidotermes mtwalumi* (Fuller), and *Macrotermes natalensis* (Haviland) and *Odontotermes* sp.), (Table 4.1). Restricted as it was, the study managed to add one genera in the termite taxa known to occur in Swaziland i.e. *Odontotermes* sp. (Appendix 2).

It has also been observed that none of the three termite sampling methods applied was able to detect all taxa that were uncovered by the present study. The baiting method detected 33.3% of the taxa, with the pit method revealing 20% and search method detecting 66.7% of the taxa (Figure 4.2). It is worth noting that the sampling

effort for the different sampling methods was not uniform, something which would have led to the differences in the percentage of termites detected by each method. A method combination revealed the highest number of species (Figure 4.2). This therefore implies that not one single method is ideal for use within a semi-arid environment like Swaziland for termite inventory purposes. A combined search protocol was required to increase sampling effort and is therefore recommended for future studies of this nature in similar environments.

The information base on termite diversity in Swaziland is inadequate and this study did not aim at producing a full species inventory for the entire country, but only for the comparative study sites and land-use practices. If a full inventory were to be achieved, study plots covering different ecosystems, all available land-use practices and different agro-ecological zones within Swaziland would be ideal.

Basic recommendations for future studies, as long as inter-site comparison of termite assemblage parameters are intended, are to run more transect per site thus increasing replication and to extend sampling as necessary to obtain a sufficient number of individual occurrences. The availability of data treatment methods that compensate for differences in sampling effort would still permit cautious comparison of sampling methods as well as comparison of results with those obtained by other standardized sampling protocols. The availability of methods for estimating termite biomass and/or total population based on percentage infestation may lead to the computation of diversity indices for termites and other social insects.

The results obtained in this study hold true for the studied sites and sampling methods applied. In order to obtain results that would be representative of the entire Swaziland as well as representative of a semi-arid environment, there is need to conduct further research in the field of termite diversity with regard to land-use practice. Studies including more than just four land-use practice types, carried in more than just two agro-ecological zones would be among priority investigations for a semi-arid environment like Swaziland. Having more different baiting material would give a better indication of the most ideal bait to use within a semi-arid environment. It would also be ideal to carryout investigation on the seasonal variation in termite assemblages within a semi-arid environment like Swaziland. Furthermore, it is essential that the biology of individual termite species encountered in this study be further investigated and clearly understood if more meaningful conclusions were to be drawn from such a study.

From the present study, it was also evident that plant species richness and diversity differed with differing land-use practice (Table 4.5). The acacia savannah was the most species rich with 31 plant species and the open grassland came last with species richness having only eleven (11) plant species. Even though the acacia savannah had the highest diversity index (H') of 3.05, species evenness (J') values had the tendency of approaching 1 across all study sites imply that certain species were dominant in all sites (Table 4.5; Appendix 1).

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Appendices

Appendix 1. Plant species occurrence within each study site (figures in the cells indicate the number of samples in which each species was recorded. AS: Acacia savannah, MF: Maize field, OG: Open grassland, WL: Woodland. N = 40.

Plant species	Occurrence			
	AS	MF	OG	WL
<i>Acacia caffra</i>	31	0	0	19
<i>Acacia davyi</i>	24	0	0	1
<i>Acacia grandicornuta</i>	12	0	0	5
<i>Acacia polyacantha</i>	28	0	0	9
<i>Acanthospermum hispidum</i>	0	40	12	2
<i>Allophylus africanus</i>	0	0	0	4
<i>Aristida adscensionis</i>	19	0	0	0
<i>Balanites maughamii</i>	12	0	0	1
<i>Berchemia zeyheri</i>	0	0	0	6
<i>Canthium ciliatum</i>	0	0	0	7
<i>Combretum kraussii</i>	0	0	0	9
<i>Combretum molle</i>	0	0	0	15
<i>Cussonia natalensis</i>	0	0	0	8
<i>Cymbopogon validus</i>	17	2	0	0
<i>Cynodon dactylon</i>	12	0	7	0
<i>Dactiloctenium aegyptium</i>	7	0	0	0
<i>Dichrostachys cinerea</i>	40	0	0	2

Plant species	Occurrence			
	AS	MF	OG	WL
<i>Diospyros dichrophylla</i>	12	0	0	1
<i>Englerophytum natalense</i>	4	0	0	2
<i>Eragrostis plana</i>	4	1	40	0
<i>Euphobia cooperi</i>	26	0	0	1
<i>Grewia caffra</i>	19	0	0	0
<i>Grewia hexamita</i>	12	0	0	0
<i>Gymnosporia buxifolia</i>	3	0	0	5
<i>Ilex mitis</i>	5	0	0	0
<i>Ipomea purpurea</i>	0	37	17	2
<i>Krausia floribunda</i>	2	0	0	2
<i>Lippia javanica</i>	0	2	13	2
<i>Mytenus undata</i>	7	0	0	5
<i>Panicum maximum</i>	40	0	24	13
<i>Richardia brasiliensis (Gomes)</i>	0	32	0	0
<i>Richardici brasidierri</i>	0	23	0	0
<i>Sclerocarya birrea</i>	0	0	0	3
<i>Sesbania bispinosa</i>	0	29	8	2
<i>Sesbania bispinatum</i>	0	18	8	0
<i>Sida acuta</i>	5	19	23	0
<i>Solanum mauritianum</i>	0	0	0	10
<i>Sporobolus africanus</i>	12	0	40	21

Plant species	Occurrence			
	AS	MF	OG	WL
<i>Syzigium cordatum</i>	0	0	0	8
<i>Tegetes minuta</i>	0	37	4	2
<i>Triumfetta sp.</i>	0	31	0	0
<i>Vangueria infausta</i>	0	0	0	18
<i>Xanthium strumarium</i>	0	40	0	1
<i>Ximenia caffra</i>	9	0	0	2

Appendix 2. A checklist of termites of South Africa (The Termitid termites (Isoptera: Termitidae) of South Africa.

Source: <http://www.ru.ac.za/academic/departments/zooento/Martin/isoptera.html>
[Accessed 2006 August 18].

Subfamily: MACROTERMITINAE (Fungus Growing Termites)

1. Genus: *ANCISTROTERMES* Silvestri 1912

1. *A. latinotus* (Holmgren 1912)

Termes crucifer Sjöstedt 1900: 127

Ancistrotermes latinotus Holmgren 1912: 42

Microtermes lebomboensis Fuller 1922: 103

Kwazulu-Natal, Swaziland, Mpumalanga, and Northern Province, to

Mozambique, Zimbabwe, Zambia, Angola, Zaire, Malawi and Tanzania.

2. Genus: *ALLODONTOTERMES* Silvestri 1914

1. *A. rhodesiensis* (Sjöstedt)

2. *A. schultzei* (Silvestri)

3. *A. tenax* (Silvestri)

South Africa, Zimbabwe, Malawi to Tanzania;

3. Genus: *MICROTERMES* Wasmann 1902

1. *M. albopartitus* (Sjöstedt)

2. *M. dubius* Fuller

3. *M. etiolatus* Fuller

4. *M. havilandi* Holmgren

5. *M. incertus* (Hagen)

6. *M. lounsburyi* Fuller

7. *M. uteus* Harris

8. *M. mokeetsei* Fuller

9. *M. occidentalis* Fuller

4. Genus: *MACROTERMES* Holmgren 1909

1. *M. falciger* (Gerstäcker 1891)

Termes falciger Gerstäcker 1891: 186

Termes goliath Sjöstedt 1899: 156

Termes michaelli von Rosen 1912: 223

Termes swaziae Fuller 1915: 462

Macrotermes usutu Fuller 1922: 79

Swaziland, Mpumalanga and Northern Province, to Mozambique, Zimbabwe, Zambia and east Africa.

2. *M. michaelsoni* (Sjöstedt 1914)

Termes bellicosus var *mossambicus* Hagen 1858: 59-83

Termes michaelsoni Sjöstedt 1914: 77

Macrotermes bellicosus form *kunenensis* Fuller 1922: 73

Macrotermes bellicosus form *limpopoensis* Fuller 1922: 73

Macrotermes bellicosus form *tonga* Fuller 1922: 73

KwaZulu-Natal, Swaziland, Mpumalanga, Northern Province and Northwest Province, to Mozambique, Zimbabwe, Zambia, Botswana, Namibia, Angola and Malawi.

3. *M. natalensis* (Haviland 1898)

Termes natalensis Haviland 1898: 383

Termes natalensis form *intermedius* Fuller 1922: 76

Termes natalensis form *natalensis* Fuller 1922: 76

Termes natalensis form *transvaalensis* Fuller 1922: 76

Termes natalensis form *durbanensis* Fuller 1927: 135

Eastern Cape, Free State, KwaZulu-Natal, Swaziland, Mpumalanga, Gauteng, Northern Province and Northwest Province, to Mozambique, Zimbabwe, Botswana, Namibia, Angola, and Zambia.

4. [*M. subhyalinus* (Rambur 1842)

Termes subhyalinus Rambur 1842: 307

Malawi, Zimbabwe, Zambia, Angola and Namibia, to Somalia and Sierra Leone.

5. *M. ukuzii* Fuller 1922

Termes parvus Holmgren 1913: 325

Macrotermes ukuzii Fuller 1922: 80

Macrotermes bellicosus var *ukuzii* Fuller 1927: 139

KwaZulu-Natal, Swaziland, Mpumalanga and Northern Province, to Zimbabwe

6. *M. vitrialatus* (Sjöstedt 1899)

Termes vitrialatus Sjöstedt 1899: 34

Termes imperator Sjöstedt 1913: 359

Termes waterbergi Fuller 1915: 466

Macrotermes schoutedeni Sjöstedt 1924: 39

Amplitermes mozambicus Sjöstedt 1926: 89

Macrotermes angolensis Noirot 1955: 142

Northern Province and Northwest Province, to Zimbabwe, Namibia, Zambia and east Africa.

5. Genus: *ODONTOTERMES* Holmgren 1912

1. *O. angustatus* (Rambur)
2. *O. badius* (Havliand)
3. *O. caffrariae* (Sjöstedt)
4. *O. capensis* (de Geer)
5. *O. clturarum* (Sjöstedt)
6. *O. flamifrons* (Sjöstedt)
7. *O. fockianus* (Sjöstedt)
8. *O. interveniens* Sjöstedt
9. *O. lacustrs* Harris
10. *O. latericus* (Haviland)
11. *O. lautus* (Sjöstedt)
12. *O. monodon* (Gerstäcker)
13. *O. okahandjae* Fuller
14. *O. partruus* (Sjöstedt)
15. *O. pretoriensis* Sjöstedt
16. *O. rehobothensis* (Sjöstedt)
17. *O. smeathmani* (Fuller)
18. *O. tragardhi* Holmgren
19. *O. transvaalensis* (Sjöstedt)
20. *O. vulgaris* (Haviland)
21. *O. zambesiensis* (Sjöstedt)
22. *O. zukunatalensis* Sjöstedt

6. Genus: *PSEUDACANTHOTERMES* Sjöstedt 1924

1. *P. militaris* (Hagen)

Zimbabwe;

2. *P. spiniger* (Sjöstedt)

Zimbabwe;

7. Subfamily: APICOTERMITINAE8. Genus: *SKATITERMES* Coaton 19711. *S.* sp.

KwaZulu-Natal and Northern Province;

9. Genus: *ACHOLOTERMES* Sands, 197210. Genus: *ADAIPHROTERMES* Sands, 197211. Genus: *ADYNATOTERMES* Sands, 197212. Genus: *AGANOTERMES* Sands, 197213. Genus: *ALYSCOTERMES* Sands, 197214. Genus: *APICOTERMES* Holmgren1. *A. tragardhi* Holmgren 1912*Apicotermes tragardhi* Holmgren 1912: 98*Apicotermes holmgreni* Emerson 1956: 12

KwaZulu-Natal, Mpumalanga and Northern Province, to Mozambique,

Zimbabwe, Malawi and Tanzania.

15. Genus: *ASTALOTERMES* Sands, 197216. Genus: *ATEUCHOTERMES* Sands, 1972**17. Subfamily: TERMITINAE**

18. Under construction: about 34 genera

19. Genus: *AMITERMES* Silvestri 19011. *A. hastatus* (Haviland)

20. Genus: *CUBITERMES* - 6 spp

KwaZulu-Natal and Northern Province;

21. Genus: *TERMES*

1. *T. winifredae* Snyder & Emerson

Mirotermes capensis Silvestri 1914: 128 (*nec Termes capensis* Linnaeus)

Termes winifredae Snyder & Emerson 1949: 187

Western Cape;

22. Genus: *ANGULITERMES* Sjoustedt 1924

KwaZulu-Natal and Northern Province;

23. Genus: *LEPIDOTERMES*

KwaZulu-Natal and Northern Province;

24. Genus: *PROMIROTERMES*

KwaZulu-Natal and Northern Province;

25. Genus: *MICROCEROTERMES*

KwaZulu-Natal and Northern Province;

26. Genus: *UNICORNITERMES* Coaton 1971: 23

1. *U. gaerdesi* Coaton 1971

Unicornitermes gaerdesi Coaton 1971: 23

Northern Province, to Namibia.

27. Subfamily: NASUTITERMITINAE (Snouted Termites)

28. Genus: *NASUTITERMES* Dudley 1890

1. *N. kempae* Harris

Nasutitermes kempae Harris 1954: 135

KwaZulu-Natal, to Mozambique;

29. Genus: *FULLERITERMES* Coaton 1962

1. *F. coatoni* Sands

Fuller itermes coatoni Sands 1965: 58

KwaZulu-Natal, Free State, Gauteng, Northern Province, Northwest Province
and Northern Cape, to Zimbabwe;

2. *F. mallyi* (Fuller)

Tenuirostris mallyi Fuller 1922: 115.

Western Cape and Northern Cape (endemic) ;

30. Genus: *RHADINOTERMES* Sands 1965

1. *R. coarcatus* (Sjöstedt)

Eutermes coarcatus Sjöstedt 1920: 304

KwaZulu-Natal, Swaziland, Mpumalanga, and Northern Province, to East
Africa;

31. Genus: *SPATULITERMES*

1. *S. coolingi*

32. Genus: *TRINERVITERMES* Holmgren 19121. *T. dispar* (Sjöstedt)*Eutermes dispar* Sjöstedt 1920: 303*Eutermes gemellus* Sjöstedt 1920: 303*Eutermes kulloensis* Sjöstedt 1912: 13*Eutermes katangensis* Sjöstedt 1913: 382*Eutermes erythrae* Holmgren 1913: 345*Eutermes grootfonteinsis* Sjöstedt 1914: 86*Trinervitermes umzinduzii* Fuller 1922: 114*Trinervitermes eldirensis* Ghidini 1941: 33

KwaZulu-Natal, Swaziland, Mpumalanga, Northern Province and Northwest Province, to East Africa;

2. *T. rapulum* (Sjöstedt)*Eutermes rapulum* Sjöstedt 1904: 99*Eutermes dispar* form *zuluensis* Holmgren 1913: 340*Eutermes dispar* form *disparoides* Holmgren 1913: 342*Trinervitermes pretoriensis* Fuller 1922: 114

Swaziland, Mpumalanga, and Northern Province, to Zimbabwe and East Africa;

3. *T. rhodesiensis* (Sjöstedt)*Eutermes rhodesiensis* Sjöstedt 1911: 186*Eutermes brutus* Sjöstedt 1911: 13

Eutermes roseni Holmgren 1913: 344

Eutermes kalaharicus Holmgren 1913: 346

Trinervitermes abassas Fuller 1922: 114

Trinervitermes thermarum Fuller 1922: 114

Eutermes diplacodes Sjöstedt 1924: 41

Eutermes muneris Sjöstedt 1924: 42

Eutermes loubetsiensis Sjöstedt 1924: 496

Northern Cape, Free State, Northwest Province, and Northern Province, to
Namibia, Botswana, Zimbabwe, Congo and East Africa;

4. *T. trinervoides* (Sjöstedt)

Eutermes trinervoides Sjöstedt 1911: 186

Eutermes trinerviformis Holmgren 1913: 336

Eutermes auriceps Holmgren 1913: 338

Eutermes bulbiceps Holmgren 1913: 339 (*nec Eutermes (Eutermes) bulbiceps*
Holmgren)

Eutermes dubius Holmgren 1913: 339

Eutermes hentschelianus Sjöstedt 1914: 88

Trinervitermes gemellus ssp. *thompseni* Fuller 1922: 111

Trinervitermes havilandi Fuller 1922: 113

Trinervitermes fuscus Fuller 1922: 113

Trinervitermes kurumanensis Fuller 1922: 113

Eutermes messor Sjöstedt 1924: 257

Trinervitermes hilli Snyder & Emerson in Snyder 1949: 327 (*nom. nov. pro*

Eutermes (Trinervitermids) bulbiceps Holmgren 1913

Western Cape, Eastern Cape, Free State, Lesotho, KwaZulu-Natal,

Swaziland, Mpumalanga, Gauteng, Northern Province, Northwest Province

and Northern Cape, to Namibia, Zimbabwe and Mozambique;

33. Genus: *BAUCALIOTERMES* Sands 1965

1. *B. hainesi* (Fuller 1922)

Subulitermes hainesi Fuller 1922: 115

Northern Province, to Namibia.

1. This is part of a catalogue of South African Insects revised: under construction.