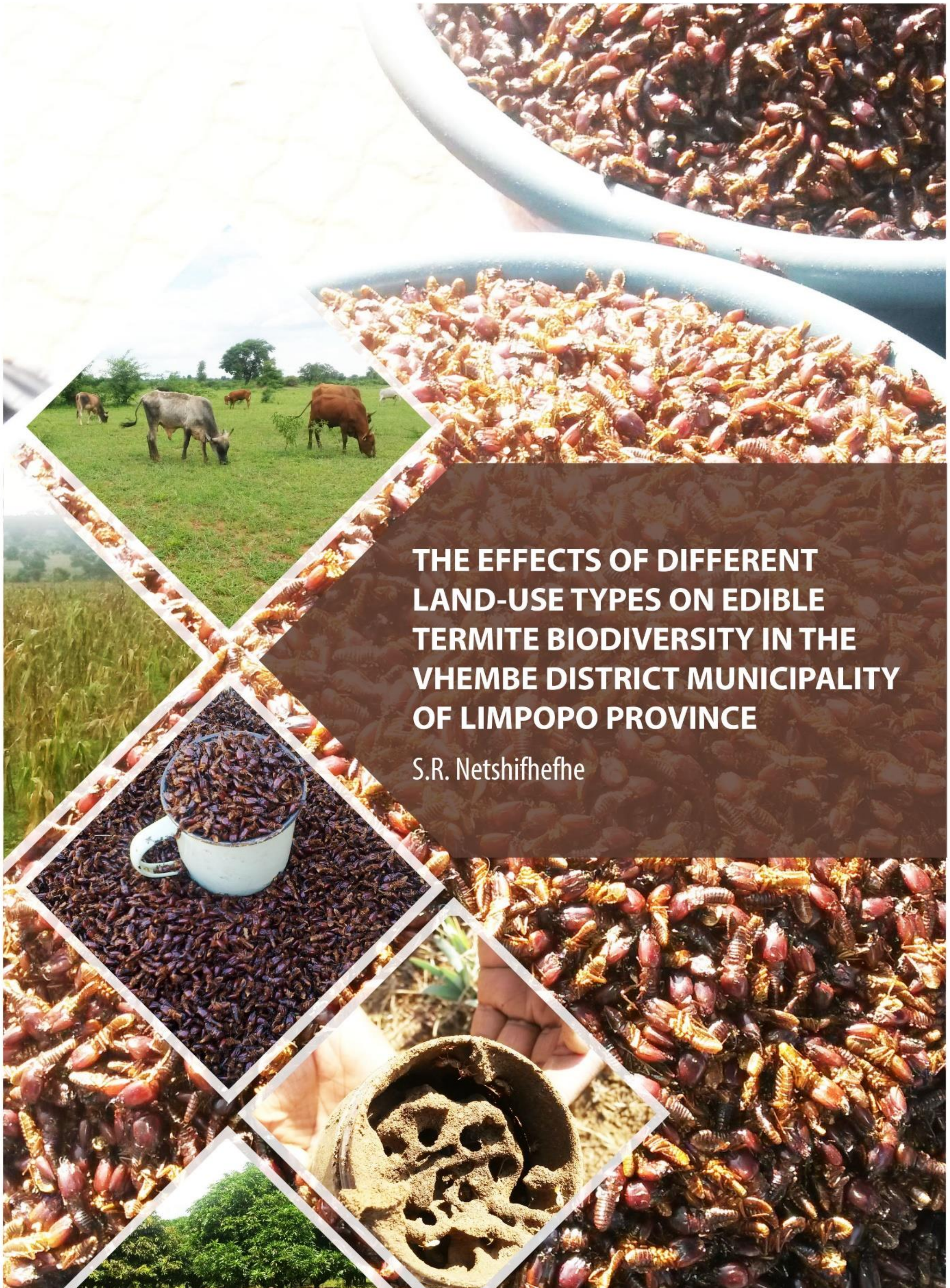

THE EFFECTS OF DIFFERENT LAND-USE TYPES ON EDIBLE TERMITE BIODIVERSITY IN THE VHEMBE DISTRICT MUNICIPALITY OF LIMPOPO PROVINCE

S.R. Netshifhefhe

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A thesis submitted to the Faculty of Science, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Doctor of Philosophy in Insect Ecology

School of Animal, Plant and Environmental Sciences

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DECLARATION

I declare that the thesis hereby submitted to the University of Witwatersrand, for the degree of Doctor of Philosophy in Insect Ecology is my own original work. It has not been previously submitted by me at this or any other university for any qualification. All the materials contained herein have been accordingly referred and contributions acknowledged.

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SR Netshifhefhe

05 December 2018, Johannesburg

DEDICATION

This thesis is dedicated to both my late parents; my father, NETSHIFHEFHE SIMON NEKHAVHAMBE, and my mother, AVHAPFANI TSHAVHUNGWE ANNAH. My Mom passed away on the 12th November 2015, while I was busy with my studies; I thought she would witness my success. It was God’s will and I’m sure you have told Daddy how we missed him. My parents raised and nurtured me during difficult times where both of them did not have formal employment. You continuously prayed for me and taught me how great the Lord is. I will forever cherish the love, motivation, support and encouragement you have shown me. How great it was to be told by my parents who never went to school on the importance and value of education.

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ABSTRACT

The changing land use patterns result in the risk of losing many of the valuable economic services (ecosystem services and human food) provided by termites. Termites are rich in proteins, fats, vitamins and many essential mineral nutrients and are valuable economic contributors to food security. This study investigated the entomophagy of termites in the Vhembe District Municipality of the Limpopo Province, South Africa and the effects of different land use types (communal grazing lands, maize fields and mango orchards) on the biodiversity of termites and the distribution of the edible termite mounds.

Interviews using a structured questionnaire were conducted with 104 individuals comprising termite harvesters, consumers and sellers. The consumption of termites was recorded in 48 villages over three local municipalities, normally eaten with maize meal porridge. Three termite species are consumed by people in the Vhembe District Municipality and these are *Macrotermes falciger*, *M. natalensis* and *M. michaelseni*. Although *M. natalensis* is eaten throughout Africa, this study showed that soldiers of *M. falciger* is the preferred termite species consumed (89.90%) of all termites. Most of the respondents rated health benefits or nutrition and poverty as the main reasons for consumption. *Macroternes falciger* soldiers were the most eaten and the monetary contribution.

Three termite sampling methods were evaluated using standard transects of 2 x 100 m. A combination of transect search method and cattle dung bait method gives good indication of termite diversity. Termites were collected from three land use types using a standardized transect sampling protocol and baiting methods. Communal grazing lands recorded higher functional and taxonomic diversity with 15 termite species from five subfamilies and 10 genera, and a higher Shannon (H') and Simpson (1 - D) indexes of 2.23 and 0.84 respectively. Non-edible species of the genus *Microtermes* were the most dominant in the maize fields. Mounds were generally random distributed across all the land-use types. The mean number of termite mounds per hectare was higher in communal grazing lands (52.5) as compared to the maize fields (14.75) and mango orchards (7). Communal grazing lands were dominated by small and medium sized non-edible mounds of *Trinervitermes* sp while the maize fields had a greater density of *M. natalensis* mounds. Although the heights were roughly the same, the mound diameter and circumference of *M. falciger* was statistically larger than that of *M. natalensis*.

Termite species diversity and abundance varies across land use types with human activities and agricultural intensification causing a significant decline in termite diversity which has considerable implications for the ecosystem function, and impact negatively on the availability of termites as free sources of protein.

Keywords: Termites, entomophagy, *Macrotermes*, *Macrotermes falciger*, termite mounds.

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CHAPTER 1 – GENERAL INTRODUCTION AND OUTLINE OF CHAPTERS

1.1. INTRODUCTION

1.1.1. What are termites?

Termites are a group of eusocial insects that were classified at the taxonomic rank of Isoptera but are now accepted as the Infraorder Isoptera, of the Order Blattodea (Inward *et al*., 2007). Although termites are morphologically highly variable they all evolved from a common winged ancestor (Abe *et al*., 2000). Engel & Krishna (2004) recorded over 2600 species of Infraorder Isoptera comprising approximately 280 genera, and seven recognized families. According to Eggleton (2000), the richest continent in termite diversity is Africa. They are widely distributed throughout the tropical and sub-tropical regions, with fewer species living at higher latitudes. Some termite species extend their range of occurrence to the relatively cool zones of temperate regions (Araujo, 1970; Wood & Johnson, 1986; Eggleton, 1999). Termites are detritivores and they have a wide range of foraging and nesting habits, with many species showing a high degree of resource specialization (Wood & Sands, 1978; Collins, 1989). Termites are reported to feed on almost any cellulose-containing material, including living and dead wood, wood in the soil at different stages of decomposition, dead parts of living trees, twigs, roots, plant debris, paper, cardboard, fiberboard, and various types of fabric made of cotton and other plant-based materials (Donovan *et al.*, 2001a; Thorne, 1998). Several species of Macrotermitinae consume grass litter as a significant part of their diet and the most common of these species belong to the genera *Macrotermes*, *Odontotermes* and *Pseudacanthotermes* (Wood, 1991).

1.1.2. Termite life cycle

Termites undergo incomplete metamorphosis and have three life stages: egg, nymph (larva) and adult (Korb & Hartfelder, 2008). The termite's life cycle starts with mating between winged reproductive males and females (Noirot, 1970). After fertilization, the reproductives shed their wings and become the king or queen termites of their newly established colonies. The queen lays thousands of eggs and they hatch to become pale white larva. The larvae grow to assume a role in one of the three different types of termite or caste types: workers, soldiers, and reproductive (see Figure 1.1). Each of the termite castes differs in morphology and have their own role within a colony.

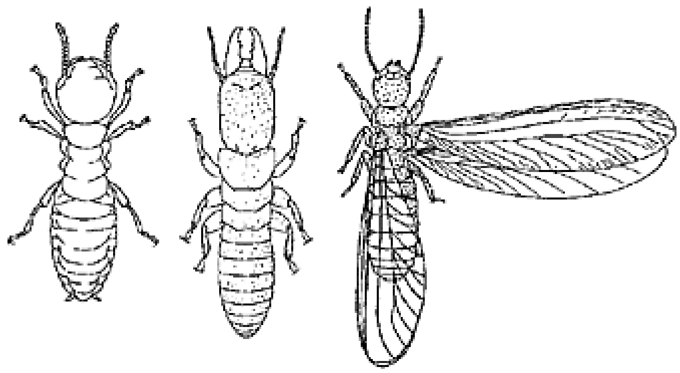

Figure 1.1 Castes of termite. From left: worker, soldier, and winged reproductive (alate) (from Boyer, 2002)

Workers caste is the smallest active termites (sometimes only 1 mm or 2 mm in length) and contain the greatest number of individuals within a colony (Watson *et al*., 1985). They carry out a range of duties such as nest building or building galleries and shelter tubes, regurgitating food for soldiers and reproductives, exploring food and water sources, caring for eggs and younger siblings (midwives), and chemically guarding against fungi and other micro-organisms (Watson *et al*., 1985).

The soldier caste of termites is unique due to their morphology, development and behaviour (Noirot, 1970). Soldier termites are immature males and females whose primary function is colony defense. Some species of the soldier caste can have large mandibles (size and shape differ with species) to repel enemies (Watson *et al*., 1985). In other species such as Nasutitermitinae, the soldier caste possess nasus, a pointed snout at the front of their heads used to squirt defensive / toxic or irritating chemicals / substances to entangle and repel their enemies such as ants (Krishna & Weesner, 1970).

The reproductive caste in an established colony includes the king (sperm production) and queen (egg-laying) (Wilson, 1971). The queen can be up to 6 cm long, produce up to 3,000 eggs per day (Creffield, 1991) and her abdomen becomes swollen as she becomes devoted to the mass production of eggs (Horwood & Eldridge, 2005). Alates are the young winged reproductive forms produced by mature colonies. Alates leave the nest after the first rainfall to mate and start a new colony (van Huis, 2003). Once they mate, the wings drop off as they land and the new king and queen find a new nest to start a new colony.

1.1.3. Families of termites

Wood and Johnson (1986) revised earlier works on classification of termites and classified known termite species into seven families: Mastotermitidae, Kolotermitidae, Termopsidae, Hodotermitidae, Rhinotermitidae, Serritermitidae, and Termitidae. These seven families may be divided into two main groups, the 'lower' and 'higher termites', depending on their mode of digestion. Six families belong to lower termites (mainly wood and/or grass feeders) and only the family of Termitidae belongs to higher termites which contains about 85% of known genera (Kambhampati & Eggleton, 2000). A much broader range of substrates are utilized by higher termites than by lower termites.

1.1.4. Termite feeding groups

Termites are classified into feeding groups on the basis of their food choice and feeding habits. These groups are; soil feeders, wood feeders, litter and wood feeders, soil and wood interference feeders, and grass feeders (Jones & Eggleton, 2000).

Soil-feeders are groups of termites that feed on humus and mineral soil (Jones & Eggleton, 2000; Swift & Bignell, 2001). They usually occur in the organic layer of soil and feed on the top soil that is rich in organic matter. This feeding group is found in many Termitinae, several Nasutitermitinae and most Apicotermitinae subfamilies (Eggleton *et al*., 1997).

Wood feeders feed on dead wood. They are known to excavate galleries in larger items of wood litter in which the entire colony may be housed (Jones & Eggleton, 2000; Swift & Bignell, 2001). This feeding group includes termites having arboreal nests such as species from the subfamily Macrotermitinae.

Litter and wood feeders forage for leaf litter and small woody items, usually cutting the material before consumption or transport to the nest (Eggleton & Bignell, 1995). Species from the genera *Macrotermes* and *Odontotermes* (subfamily Macrotermitinae) are predominantly litter feeders (Mitchell, 2002). This group includes most subterranean and mound-building species.

Soil and wood interface feeders feed in highly decayed wood predominantly within soil under logs or soil plastered on the surface of rotting logs or mixed with rotting leaves (DeSouza & Brown, 1994). An example is the species *Macrotermes natalensis,* where the workers continuously bring in partly degraded plant material (mainly decaying wood) to their colony (Um *et al.*, 2013).

Grass feeders forage on live or dry standing grass stems cutting and removing to the nest (Eggleton & Bignell, 1995). Species in the family Hodotermitinae and subfamilies Macrotermitinae, Termitinae and Nasutitermitinae are in this category.

1.1.5. Termite nesting groups

The termite nest is below ground and varies from simple galleries to complicated large nests built by fungus growing termites (Uys, 2002). Bignell *et al*. (2010) defined the termite mound as above ground soil structure. Termite mounds are the predominant features of the African savanna (Pullan, 1979). Termites can be classified according to their nesting behaviour. There are three major nest types, viz. hypogeal or subterranean nests, epigeal mounds and arboreal nests (Jones & Eggleton, 2000).

1.1.5.1. Hypogeal or subterranean nests

This group of termites house their colonies below the ground without any indication of their presence above ground (Materu *et al.*, 2013). These types of nests are very common in areas where moisture remains at low levels throughout the year thus the construction of a subterranean nest minimizes evaporation and desiccation. According to Snyder (1948), the underground tunnels and galleries of the subterranean nests can reach hundreds of feet to food sources and cover acres of land. The termites use their faeces and soil for nest construction.

1.1.5.2. Epigeal mounds

Epigeal mounds are visible as “dome-like” structures above ground (Uys, 2002) and originate from the subterranean beginnings or a colony established in wood and having some parts of their structure below the ground surface (Lavelle & Spain, 2001). Epigeal mound structure can differ widely within genera and also between regions within widely distributed species. Korb &

Linsenmair (1998) found a difference in the nest structure of the *Macrotermes bellicosus* depending on whether it was in a forest or in the open savannah. Chikuvire *et al.* (2007) and Holt & Lepage (2000) found the mounds to be different depending on location and species, often with very complex structures. Epigeal mounds are built by higher termite species including grass harvesters, litter feeders, wood-feeders and some soil-wood and soil feeders. Macrotermitinae (e.g. *Odontotermes* and *Macrotermes*) and Nasutitermitinae (*Trinervitermes*) species are known to build epigeal mounds (Wood & Johnson, 1986).

1.1.5.3. Arboreal nests

Arboreal nests are attached to a branch, angles between branches, to the stem of a tree or situated in a hollow (on a tree trunk) (Merritt & Starr, 2010). The arboreal nesting termites connect the nest to the soil surface by covered galleries through which workers and soldiers can move unexposed to and from foraging sites. They live entirely within their food source and their moisture requirements are drawn directly from wood (Horwood & Eldridge, 2005). Termites which build the arboreal nests include species such as *Microcerotermes*, *Psammotermes* and *Rhadinotermes*.

1.1.6. Economic significance of termites

Termites are cryptic social insects that play an important role in many ecosystems (Bignell & Eggleton, 2000). Their main roles are decomposition, soil fertility and food for many animals, including humans.

1.1.6.1. Decomposition

Termites are principal decomposers of wood and other cellulose-based materials, they physically redistribute soil materials thereby modifying soil profiles, and they recycle organic matter and nutrients (Holt & Lepage, 2000; Jouquet *et al*., 2002). The role of the termites is important for the long-term balance of nutrients in the soil. Mando *et al*. (1999) found that termites alone could account for up to 80% of litter disappearance in one year. Eggleton and Tayasu (2001) mentioned that termites are the main invertebrate decomposers in tropical forests. They also play essential roles in regulation of soil formation, structure, humification and conditioning, as well as breaking-up of organic detritus and nitrogen-fixation (Eggleton *et al*., 1996). Besides their importance in a number of ecosystem services, termites are also known to have an effect on fauna and floral biodiversity and ecosystem stability (Jouquet *et al*., 2011).

1.1.6.2. Soil fertility

The importance of termites in ecosystems and their role in the improvement of the fertility of soil has been described by Pearce (1997). Dangerfield *et al.* (1998) stated that termites are important ecosystem engineers with the ability of modifying the physical properties of soil such as texture, water infiltration rates and nutrient content, at various spatial scales. Studies conducted by Umeh (2003) found termites to be of economic importance in the tropics because of their ability to mix organic polymers with inorganic soil particles, thereby modifying the physical properties of soil and increasing soil fertility. Muvengwi *et al*. (2016) found that termite mounds were high in the proportion of sand and clay and minerals (Ca, Mg, K, NH_4, NO_3 and organic C), thus unique plant communities are found associated with termite mounds. These plant communities are rich in woody species but have less grasses due to induced shifts in soil parameters which are of the increased clay content, nutrient status and base cation concentration (Muvengwi *et al*., 2016).

1.1.6.3. Termites as human food

Although termites are food for many animals, they are also consumed by humans. The use of edible insects as human food, entomophagy, goes back to the early homonids (Meyer-Rochow *et al.,* 2007). Some examples of termites being consumed in Africa are; winged termite alates consumed in Cote d'Ivoire (Niaba *et al.,* 2012). In many parts of Nigeria, people eat the winged alates of *Macrotermes nigeriensis* as a delicacy (Igwe *et al*., 2011; Ajayi & Adedire, 2007). Queens collected from the inside of nests are also a great delicacy but are difficult to find. People living in southern Luanda in Zambia use termites as important part of their diets (Silow, 1983). San women in Botswana roast the winged alates of *Hodotermes mossambicus* (Nonaka, 1996). Kelemu *et al*. (2015) and Chavunduka (1976) recorded the consumption of soldiers and alates of *Macrotermes falciger* species in Zimbabwe.

About 21 species of termites have been reported to be consumed in Sub-Saharan Africa (van Huis, 2003; Figueirêdo *et al*., 2015) and are listed in Table 1.1. The most commonly eaten termite species by humans in southern Africa are the large *Macrotermes* species. Ecologically, *Macrotermes* prefer warm environments and are concentrated mainly in the tropics as well as sub-tropics between latitudes 45^0 North and South (Wood, 1988). Deshmukh (1989) found that

Macrotermes survive in environments with annual rainfalls as little as 250 mm, where several other termite species cannot survive. Dangerfield *et al*. (1998) and Turner (2006) reported *Macrotermes* as being able to survive in severe conditions because of their ability to create humid environments for themselves in their subterranean nests.

The queen, the soldiers and the alates (winged reproductive) are all edible. The alates emerge from holes after the first rains and often during the night. These are collected using light traps with water buckets and basins underneath to catch them as they drop (personal observations). In parts of the Democratic Republic of Congo, people place baskets upside down over the hole (van Huis *et al*., 2013). Instead of baskets, structures made of sticks or elephant grass covered with banana or maranta leaves or a blanket are also used to cover the holes (van Huis *et al*., 2013). To extract soldiers from the mounds, women or children lower saliva wetted grass blades (Uganda), often of *Imperata cylindrical* (Roulon-Doko, 1998) or parts of tree pods or barks (Takeda, 1990) into the shafts of termite mounds that have been opened by a machete.

Termites are eaten fresh or dried (Niaba *et al.*, 2012). They can be prepared in different ways; grilled, baked or fried, and seasoned. The termites are killed by boiling or roasting for a few minutes the morning after the swarming, and then they are sun-dried or smoke-dried, or both, depending on the weather (Silow, 1983). When ready for processing, they are seasoned with a little pinch of salt, fried and dehydrated (Oguwike *et al.*, 2013).

Table 1.1 List of termite species consumed in sub-Saharan Africa (van Huis, 2003; Figueirêdo *et al*., 2015)

Genus / Species	**Countries**
Acanthotermes millitaris Hagen	Angola
Acanthotermes spiniger Sjostedt	DRC and Zambia
Acanthotermes spp	Tanzania
Hodotermes mossambicus	Botswana and Zimbabwe
Macrotermes bellicosus Smeathman	Angola, Central African Republic, Congo, Democratic Republic of Congo, Guinea, Kenya, Nigeria, Senegal, Tanzania, Uganda and Zambia
Macrotermes falciger Gerstacker	Benin, Congo, South Africa, Zambia and Zimbabwe
Macrotermes gabonensis Sjoestedt	Congo
Macrotermes michaelseni Sjoestedt	Malawi
Macrotermes mossambicus Hagen	Botswana and Zimbabwe
Macrotermes natalensis (Haviland)	Central African Republic, South Africa and Zimbabwe
Macrotermes spp. (Unidentified)	Democratic Republic of Congo, Tanzania and Zimbabwe
Macrotermes subhyalinus Rambur	Angola, Kenya, Senegal, Tanzania, Uganda and Zambia
Macrotermes swaziae Fuller	South Africa
Macrotermes ukuzii (Fuller)	South Africa
Macrotermes vitrialatus Sjostedt	Zambia
Microhodotermes viator Latr	South Africa
Odontotermes badius Haviland	Kenya, South Africa, Zambia and Zimbabwe
Odontotermes capensis De Geer	South Africa
Odontotermes kibarensis Fuller	Uganda
Pseudacanthotermes militaris Hagen	Angola, Kenya, Tanzania and Uganda
Pseudacanthotermes spiniger Sjoestedt	Congo, Kenya, Tanzania, Uganda and Zambia

1.1.7. Diversity and density of termites in a range of land use types

Zeidler *et al*. (2002) found termite species assemblages differed between farms as well as across the land-use gradients. Studies conducted in other parts of the world have shown that the loss of forest biodiversity due to conversion of land for use in agriculture, construction, recreation and other purposes are always accompanied by selective loss of some termite functional groups, especially the soil feeders (De Souza & Brown, 1994; Eggleton *et al*., 1997, 1998). A reduction in termite genera and species composition were found in the disturbed farmland as compared to the forest (Olugbemi, 2013). However, Eggleton *et al*. (1997) found there was an increase in the relative abundance of fungus growing termites with increased level of disturbance land-use, while a significant reduction was observed for soil and other wood/litter feeders. Susilo & Aini (2005) found that the mean diversity and density of termites were different between land use types of increasing intensity and that the termites mean diversity dropped as land use changed from forest to unforested land use types. The study undertaken by Deblauwe *et al.,* (2007) confirmed the general finding that low to moderate disturbances do not significantly affect termite species richness.

1.1.8. Anthropogenic impacts on termite populations

Direct effects of human activities result in loss of biodiversity (Morris, 2010). The three major anthropogenic drivers of biodiversity loss are deforestation and fragmentation, over-exploitation and climate change.

Deforestation and fragmentation - Fragmented and disturbed forest areas result in reduced functional diversity (Davies *et al*., 2003) of the soil feeding termites that play a role in ecosystem in the soil (Donovan *et al*., 2001b). Clearance of forest land for agriculture destroys the habitat and result in decline of species diversity and abundance (Sala *et al*., 2000). Veld fires have negative impact on termites by destroying the habitat resources used by termites such as plant biomass and dead wood (Bond & Keeley, 2005).

Over-exploitation - Over-exploitation / over-harvesting of species result in extinction (Morris, 2010). For example: Mopane worm caterpillar, *Imbrasia belina* were being threatened in Botswana and South Africa due to over-harvesting for human consumption (van Huis & Oonincx, 2017).

Climate change - Changes in climate results in hotter and drier tropical environments (Wilson *et al*., 2007), this results in fewer free living fungal decomposers including termites by reducing the amount and availability of habitat (Pringle *et al*., 2010; Morris, 2010).

1.2. PROBLEM STATEMENT

The changing land use patterns result in the risk of losing many of the valuable ecosystem services provided by edible insects. Edible insects including termites are one of the many byproducts of low-intensity agriculture (Payne & van Itterbeeck, 2017), and are usually protein-rich food (Banjo *et al*., 2006) easily accessible by many in rural areas. Agricultural intensification, when it comprises mechanization, deforestation, chemical fertilizer and pesticide use, threatens the existence of many edible termites in Vhembe District Municipality.

Vhembe District exemplify rural former homeland areas that were previously under Venda and Gazankulu Bantustan's administration. The district is undergoing a rapid agricultural transformation with high land claims and uncertainty of land ownership especially regarding state owned land and tribal owned land. The Vhembe District Municipality is comprised of four local municipalities with each municipality having a dominant land use type viz., wide-ranging tropical and subtropical fruit crops such as guavas, mangoes, litchis, bananas and avocados; secondly maize and vegetable fields; thirdly communal grazing land and lastly the mining area. Large areas in the Makhado and Thulamela Municipalities have been converted to commercial tropical and subtropical crops farms, smallholder maize farms and agricultural irrigation schemes for vegetable production. Mutale Local Municipality is dominated by medium to high intensity livestock farming. The town, Messina, in the Musina Municipality was established in 1905 as a copper mining community around the copper reserves and mining activities. The mining sector in Musina Municipality is responsible for nearly a third of the output of the Vhembe economy. As a result of mining operations, the amount of degraded land has rapidly increased (personal observation).

Reyers *et al*. (2001) found that South Africa, like other regions, is subject to rapid and extensive biodiversity loss as a result of development-related habitat destruction. Lack of an integrated approach towards natural resource management was identified as a significant concern in many communities. The change in land use in the Vhembe district could cause loss of termite species which would have an effect on termite availability for consumption and make an impact on the soil organic properties. Studies conducted in Germany by Tscharntke *et al.* (2002) found that habitat conversion causes loss of termite food, shelter and protection. These disturbances affect termite species assemblages and diversity is often lost.

Edible termites are a natural renewable resource that provides food and economy to many rural people in Africa (Ayieko *et al*., 2010). There have been no studies on the effects that the changes of land-use have on termite biodiversity and the consumption of termites in the Vhembe District Municipality.

1.3. MOTIVATION FOR THE STUDY

Termites provide significant diet for many people around the world with a great potential for enhancing food security in many rural communities. De Foliart (1999) documented the nutritional, economic and ecological benefits of the use of insects as food in many developing countries. Termites are an important food supplementation for people living in Vhembe District (personal observation), yet comparatively little is also known about edible termites in South Africa and the factors that determine their occurrence, abundance and distribution. The impacts of land use on termites (edible and non-edible) have not been investigated in the district. If there is an impact on edible termites then this could impact on the communities in the Vhembe District Municipality. Research into the species of edible termites utilized in the Vhembe District Municipality and the attitudes and perceptions of the harvesters will provide policy makers, government organizations and NGO's with the information on termites as a means of enhancing food security. There is also a need for documentation of indigenous knowledge, cultivation and sustainable use of edible termites.

1.4. HYPOTHESIS

Termite species diversity and mound density varied across land use types, with agriculture adversely affecting termite diversity and mound distribution. According to the intermediate disturbance hypothesis, one would expect the moderately disturbed land-use type (communal grazing lands) to have the highest number of termite species compared to most intensively used land-use with more anthropogenic disturbances (mango orchards and maize fields) (Pickett & White, 1985; Huston, 1994).

1.5. RESEARCH AIM AND OBJECTIVES

The aims of the study were to evaluate the effects of different land uses on edible termite species and human uses of termites within the Vhembe District Municipality.

The specific objectives of each aim were:

- **Aim 1**: Human uses of termites within the Vhembe District Municipality

Objectives:

  - To identify the termite species consumed
  - To determine how termites are harvested
  - To determine the importance of termites in human diets in the community
  - To estimate the volume sold weekly and the variability of prices across seasons

- **Aim 2**: Effect of different land uses (communal grazing lands, maize fields and mango orchards) on termite (edible and non-edible) species within the Vhembe District Municipality.

Objectives:

  - To identify termite species occurring in the area
  - To determine the most appropriate method for sampling termites in savanna areas
  - To investigate the effect of different land uses on the distribution, availability and biomass of edible termites
  - To investigate the effect of land use on the density and distribution patterns of Macrotermes mounds

1.6. STUDY AREA

The study area is located in the Vhembe District Municipality of the Limpopo Province (Figure 1.2). The district is in the northern part of Limpopo Province and shares borders with Zimbabwe in the north, Mozambique through Kruger National Park in the east and Botswana in the north-west. The district is comprised of four local municipalities, namely; Makhado, Musina, Thulamela and Mutale.

The district has an estimated population of over 1.1 million with the number of households estimated at 274 480 (PIMS, 2006). Xitsonga, Tshivenda, Sepedi, English and Afrikaans are the major spoken languages in the district. The district has diverse agricultural activities which include a small number of relatively large and highly productive commercial farmers or producers and multiple fragmented smallholder subsistence crop and livestock farming. Agriculture is the second biggest contributor to employment and economy in the district.

Agriculture in the Vhembe District Municipality is dominated by fresh produce mainly tropical and subtropical crops such as avocado, banana, citrus, coffee, guavas, litchi, macadamia nuts, mango, papaya, pecan nuts and indigenous fruits. Vhembe produced 8.4% of the country's sub-tropical fruit and 63% of its citrus according to the Kayamandi Development Services tasked with developing Vhembe District Municipality's Local Economic Development Strategy. Field crops are also produced in this district. Game and livestock farming (mainly cattle and goats) are practiced in the district.

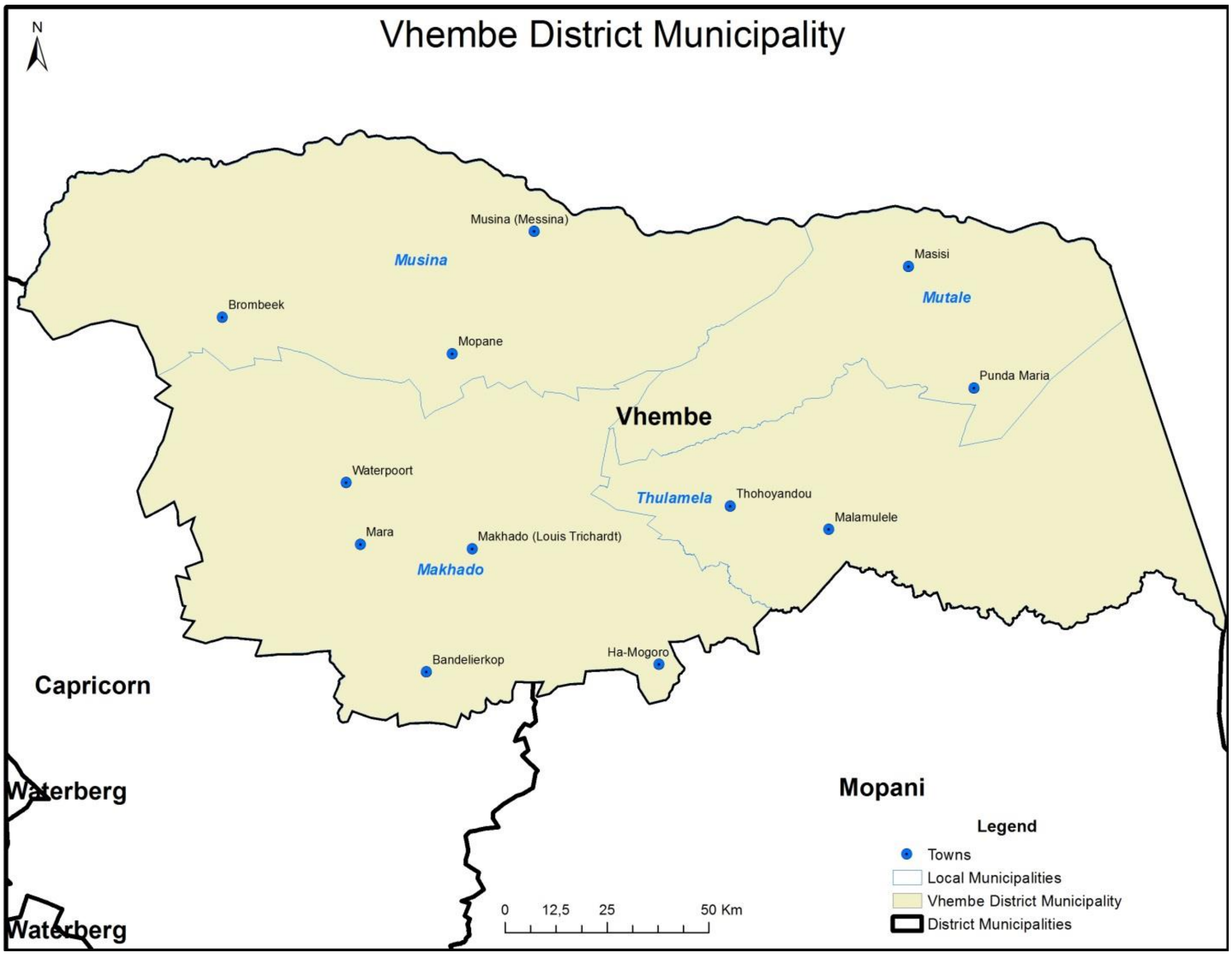

Figure 1.2 Map of Vhembe District Municipality with local municipal boundaries

Source: Municipal Demarcation Board (2011)

1.6.1. Locality

This study was conducted in 55 villages situated in Mutale, Makhado and Thulamela Local Municipalities within the Vhembe District. The villages were chosen for their accessibility, harvesting activities, presence of termite consumers and sellers, land use type and availability of termite mounds. Termite mound distribution patterns and termite species composition studies were conducted in 15 villages in all three local municipalities with each site having a different land use type. The three land use types are listed in the Table 1.2 below. There was no sampling in Musina, the mining region, because there were fewer people consuming termites and very few vendors selling termites in this area.

Table 1.2 The three land use types, areas and the local municipality

Land-use type	Areas	Local Municipality
Communal grazing lands	Dzwerani, Mangaya, Mhinga Zone 2, Mukula and Vuwani (Tshivhulana)	Mutale / Thulamela / Makhado
Maize fields	Lwamondo, Mudabula, Muledzhi, Nwiini and Tshandama	Thulamela / Mutale
Mango orchards	Dopeni, Lukalo, Makonde, Tshifudi and Vyeboom	Makhado / Thulamela

Mango orchards belonged to smallholder farmers in communal areas, situated away from homesteads averaging about 10 ha. The orchards were poorly resourced without irrigation and little or no inputs (inorganic fertilizers). Pesticides were applied by farmers to control various pests and diseases such as fruit flies, mango weevil, termites, anthracnose, etc. The age of orchards used in this study varied from 10 to 20 years. The planting population density for mangos was 200 plants per hectare (10 m inter-row and 5 m intra-row spacing).

Maize is the most important staple food crop and commonly grown under rainfed in the district and is produced mainly for consumption at the homestead with some of the farmers selling part of their produce for financial gains. There were several farmers on one large maize field. Few maize farmers applied fertilizers received from the Limpopo Department of Agriculture and Rural Development at various stages of crop development in their averaged 2 ha per household. Pesticides were used to control major pests such as fall armyworm, stalk borer and streak virus.

Livestock farmers use communal lands for grazing. These areas are a communal property without controlled grazing thus leading to high stocking rates. Communal grazing lands are also used for fuelwood harvesting. The distance from the nearest villages to the communal grazing land sites was estimated to be between 500 m to 1 km.

1.7. OUTLINE OF THE CHAPTERS

This thesis comprises four data chapters. Chapters 2 and 3 have been accepted and published in peer-reviewed journals, whilst Chapters 4 and 5 have been prepared and submitted to journals. There is no general methods chapter as the methods are different in each chapter and so are part of the relevant chapter.

Chapter 2 addresses aim 1 which is the investigation into edible termite species in the Vhembe district. This includes which species are consumed, how they are harvested, prepared, preserved, graded, packaged and marketed. This chapter also looks at the socio-economic factors of the harvesters, sellers and consumers (culture and religion, ethnic preferences and prohibitions, uses of termites, frequency and means of termite consumption, species preference, knowledge of termite taxonomy, knowledge of termite abundance and distribution and knowledge of the role of termites in human nutrition and health). Marketing, selling prices, marketer’s estimated income and quantity of termites transported per batch, the type and volume of the packaging unit, grading and quality standards, including size, aroma and colour, variability of prices between seasons and volumes sold are highlighted. This chapter gives an overall significance of edible termites and their contribution to the rural livelihoods and the indigenous knowledge of edible termites.

Chapter 3 evaluates three field termite sampling methods during the dry and wet seasons to determine termite species diversity. The sampling methods include the cattle dung method, toilet paper roll method and the visual searching (scouting) method. The number of termite species and occurrences recorded by each method and their classification by feeding and nesting groups and number of occurrences using three sampling methods over two seasons within a transect were analysed. Species diversity of each method was compared using Simpson's Diversity Index (1-D) and the Shannon Wiener (H) Index. Species richness was estimated and compared for all seasons combined per method using Jackknife and Chao2 estimators to make predictions of total species richness. This chapter shows that cattle dung bait and transect search method should be considered for monitoring termite diversity.

Chapter 4 addresses aim 2 which evaluates the effect of different land use types (agricultural land, cultivated/ploughed land and minimally disturbed land) on termite species distribution. The termite sampling methods recommended in Chapter 3 were used. A comparison of the abundance of edible and non-edible termites is given. The possible benefits and constraints of each land use type on termite diversity and the seasonal potential of edible termites in existing agricultural systems are discussed. This chapter reveals that edible termites are being lost from agricultural areas as a result of soil cultivation and application of pesticides.

Chapter 5 examines the density and distribution patterns of termite mounds and their activity across three land-use types: agricultural land, cultivated/ploughed land and minimal disturbed land. The spatial distribution of the mounds is compared accross the three land use types. The results are compared to the results from a study of the termite mounds in a close by almost natural site. Using the results from Chapter 2 which indicate that *Macrotermes falciger* and *M. natalensis* are the most edible species within the Vhembe District, part of the focus in this chapter is on the size of these mounds. Mound sizes (basal circumference, width, height) are compared between the two species and the impact of land use on these two species is assessed.

Chapter 6 serves as a general concluding chapter with key findings emanating from the thesis. The implications of edible termites for rural livelihoods and conservation debate are discussed with emphasis on legislation and indigenous knowledge. Recommendations and areas for further research are also identified.

1.8. REFERENCES

Abe, T., Bignell, D.E. & Higashi, M. (Eds). 2000. *Termites: Evolution, Sociality, Symbioses, Ecology.* Dordrecht, Netherlands: Kluwer Academic Publishers. Pp 1-23.

Abe, T. & Darlington, J.P.E.C. 1985. Distribution and abundance of a mound-building termite, *Macrotermes michaelseni*, with special reference to its subterranean colonies and ant predators. *Physiology and Ecology Japan* **22**: 59-74.

Ajayi, O.E. & Adedire, C.O. 2007. Nutrient characteristics of the subterranean termite, *Macrotermes subhyalinus* (Rambur) (Isoptera: Termitidae). *Nigeria Journal of Entomology* **24**: 42-47.

Araujo, R.L. 1970. Termites of the Neotropical Region. In: *Biology of Termites*, Krishna, K. & Weesner, F.M. (Eds.). Academic Press, New York. Pp 527-576.

Ayieko, M.A., Oriamo, V. & Nyambuga, I.A. 2010. Processed products of termites and lake flies: improving entomophagy for food security within the Lake Victoria region. *African Journal of Food, Agriculture, Nutrition and Development* **10**: 2085-98.

Banjo, A.D., Lawal, O.A., & Songonuga, E.A. 2006. The nutritional value of fourteen species of edible insects in Southwestern Nigeria. *African Journal of Biotechnology* **5**(3): 298-301.

Bignell, D.E. & Eggleton, P. 2000. Termites in ecosystems. In: *Termites: Evolution, sociality, symbioses, ecology*. Abe, T., Bignell, D.E., & Higashi, M. (Eds.) Dordrecht, the Netherlands: Kluwer Academic Publications. Pp. 363-387.

Bignell, D.E. Roisin, Y. & Lo, N. (Eds). 2010. *Biology of Termites: a Modern Synthesis* (1st edition). Dordrecht: Springer. Chapter 13, Pp. 349-374.

Bond, W.J. & Keeley, J.E. 2005. Fire as a global 'herbivore': the ecology and evolution of flammable ecosystems. *Trends in Ecology & Evolution* **20**: 387-394.

Boyer, M.M. 2002. Spatial analysis of environmental conditions conducive to termite infestation for a half hectare site. Unpublished MSc Thesis. University of Florida. Published Online: http://etd.fcla.edu/UF/UFE1000108/boyer_m.pdf (Accessed 25 June 2018)

Chavunduka, D.M. 1976. Insects as a source of protein to the African. *The Rhodesia Science News* 217-220.

Chikuvire, T.J., Mpepereki, S. & Foti, R. 2007. Soil fertility variability in sandy soils and implications for nutrient management by smallholder farmers in Zimbabwe. *Journal of Sustainable Agriculture* **30**: 69-87.

Creffield, J.W. 1991. *Wood-destroying insects, wood borers, and termites*. Collingwood VIC, Australia: CSIRO Publishing.

Collins, N.M. 1989. Termites. In: *Tropical Rain Forest Ecosystems: Biogeographical and Ecological* Studies. Lieth, H. & Werger, M.J.A. (Eds). Elsevier, Amsterdam. Pp. 455-471.

Dangerfield J.M., McCarthy T.S. & Ellery W.N. 1998. The mound-building termite *Macrotermes michaelseni* as an ecosystem engineer. *Journal of Tropical Ecology* **14**: 507-520.

Davies, R.G., Eggleton, P., Jones, D.T., Gathorne-Hardy, F.J. & Hernandez, L.M. 2003. Evolution of termite functional diversity: analysis and synthesis of local ecological and regional influences on local species richness. *Journal of Biogeography* **30**: 847-877.

Deblauwe, I. 2009. Temporal Variation in Insect-eating by Chimpanzees and Gorillas in Southeast Cameroon: Extension of Niche Differentiation. *International Journal of Primatology* **30**: 229-252.

Deblauwe, I., Dibog, L, Missoup, A.D., Dupain, J, Van Elsacker, L., Dekoninck, W., Bonte, D. & Hendrickx, F. 2007. Spatial scales affecting termite diversity in tropical lowland rainforest: a case study in southeast Cameroon. *African Journal of Ecology* **46**: 5-18.

De Foliart, G.R. 1999. Insects as food: Why the western attitude is important. *Annual Review of Entomology* **4**: 21-50.

Deshmukh, I. 1989. How important are termites in the production ecology of African savannas? *Sociobiology* **15**: 155-168.

De Souza, O.F.F. & Brown, V.K. 1994. Effects of habitat fragmentation on Amazonian termite communities. *Journal of Tropical Ecology* **10**: 197-206.

Donovan, S.E., Eggleton, P. & Bignell, D.E. 2001a. Gut content analysis and a new feeding group classification of termites. *Ecological Entomology* **26**: 356-366.

Donovan, S.E., Eggleton, P., Dubbin, W.E., Batchelder, M. & Dibog, L. 2001b. The effect of a soil-feeding termite, *Cubitermes fungifaber* (Isoptera: Termitidae) on soil properties: termites may be an important source of soil microhabitat heterogeneity in tropical forests. *Pedobiologia* **45**: 1-11.

Eggleton, P. 1999. Termite species description rates and the state of termite taxonomy. *Insectes Sociaux* **46**: 1-5.

Eggleton, P. & Bignell, D.E. 1995. Monitoring the response of tropical insects to changes in the environment: troubles with termites. In: *Insects in a Changing Environment*. Harrington, R. & Stork, N. E. (Eds.). Academic Press, London. Pp. 473-497.

Eggleton, P., Bignell, D.E., Sands, W.A., Mawdsley, N.A., Lawton, J.H., Wood, T.G. & Bignell, N.C. 1996. The diversity, abundance and biomass of termites under differing levels of disturbance in the Mbalmayo Forest Reserve, southern Cameroon. *Philosophical Transactions of the Royal Society of London Series B - Biological Sciences* **351**: 51-68.

Eggleton, P., Homathevi, R., Jeeva, D., Jones, D.T., Davies, R.G. & Maryati, M. 1997. The species richness and composition of termites (Isoptera) in primary and regenerating lowland dipterocarp forest in Sabah, East Malaysia. *Ecotropica* **3**: 119-128.

Eggleton, P., Davies, R.G. & Bignell, D.E. 1998. Body size and energy use in termites (Isoptera): the response of soil feeders and wood feeders differ in a tropical forest assemblage. *Oikos* **81**: 525-530.

Eggleton, P. 2000. Global patterns of termite diversity. In: *Termites, evolution, sociality, symbioses, ecology*. Abe, T., Bignell, D.E. & Higashi, M. (Eds). Kluwer Academic Publishers. Pp. 25-51.

Eggleton, P. & Tayasu, I. 2001. Feeding groups, life types and the global ecology of termites. *Ecological Research* **16**: 941-960.

Engel, M.S. & Krishna, K. 2004. Family-group names of termites (Isoptera). *American Museum, Novitates* **3432**: 1-9.

Figueirêdo, R.E.C.Rde, Alexandre, V. Iamara, S.P. & Alves, R.R.N. 2015. Edible and medicinal termites: a global overview. *Journal of Ethnobiology and Ethnomedicine* **11**:29. DOI: http://dx.doi.org/10.1186/s13002-015-0016-4

Holt, J.A. & Lepage, M. 2000. Termites and soil properties. In: *Termites: Evolution, Sociality, Symbioses, Ecology.* Abe, T, Bignell, D.E., Higashi, M. (Eds.). Netherlands Kluwer Academic Publishers, Dordrecht. Pp. 389-407.

Howse, P.E. 1970. *Termites: A Study in Social Behaviour*. London: Hutchinson.

Horwood, M.A. & Eldridge, R.H. 2005. *Termites in New South Wales*. Technical Publication. Forest Resources Research. Published online: https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0017/252008/Termites-Part-2---Termite-Infestations.pdf (Accessed 09 August 2018).

Huston, M.A. 1994. *Biological Diversity: The coexistence of species on changing landscapes*. University of Cambridge: Press syndicate.

Igwe, C.U, Ujonwundu C.O, Nwaogu L.A. & Okwu C.N. 2011. Chemical analysis of an edible termite, *Macrotermes nigeriensis*; A potential antidote to food security problem. *Biochemistry & Analytical Biochemistry* **1**:105. DOI:10.4172/2161-1009.1000105.

Inward, D., Beccaloni, G., & Eggleton, P. 2007. Death of an order: a comprehensive molecular phylogenetic study confirms that termites are eusocial cockroaches. *Biology Letters* **3**: 331-335.
Jones, D.T. & Eggleton, P. 2000. Sampling termite assemblages in tropical forests: testing a rapid biodiversity assessment protocol. *Journal of Applied Ecology* **37**: 191-203.

Jouquet, P., Mamou, L., Lepage, M. & Velde, B. 2002. Effect of termites on clay minerals in tropical soils: fungus-growing termites as weathering agents. *European Journal of Soil Science* **53**: 521-527.

Jouquet, P., Traoré, S., Choosai, C., Hartmann, C. & Bignell, D. 2011. Influence of termites on ecosystem functioning. Ecosystem services provided by termites. *European Journal of Soil Biology* **47**: 215-222.

Kambhampati, S. & Eggleton, P. 2000. Taxonomy and phylogeny of termites. In Abe T., Bignell D.E., Higashi M. (Eds.), *Termites: evolution, sociality, symbioses, ecology*. Kluwer Academic Publishers, Dordrecht, Netherlands. Pp 1-24.

Kelemu, S., Niassy, S., Torto, B., Fiaboe, K., Affognon, H., Tonnang, H., Maniania, N. K., & Ekesi, S. 2015. African edible insects for food and feed: inventory, diversity, commonalities and contribution to food security. *Journal of Insects as Food and Feed* **1**: 103-119.

Krishna, K. & Weesner, F.M. 1970. *Biology of Termites*. 643pp. Academic Press, New York.

Korb, J. & Hartfelder, K. 2008. Life history and development - a framework for understanding developmental plasticity in lower termites. *Biological Reviews* **83**: 295-313.

Korb, J. & Linsenmair, K.E. 1998. The effects of temperature on the architecture and distribution of *Macrotermes bellicosus* (Isoptera, Macrotermitinae) mounds in different habitats of a West African Guinea savanna. *Insectes Sociaux* **45**: 51-65.

Lavelle, P. & Spain, A.V. 2001. *Soil Ecology*. Kluwer Scientific, Amsterdam.

Mando, A., Brussaard, L. & Stroosnijder, L. 1999. Termite- and mulch-mediated rehabilitation of vegetation on crusted soil in West Africa. *Restoration Ecology* **7**: 33-41.

Materu, C., Yarro, J. & Nyundo, B. 2013. Seasonal changes on termite foraging behaviour under different habitats in Rufiji District Tanzania. *Journal of Biology, Agriculture and Healthcare* **3**: 11.

Merritt, N.R.C. & Starr, C.K. 2010. Comparative Nesting Habits and Colony Composition of Three Arboreal Termites (Isoptera: Termitidae) in Trinidad & Tobago, West Indies. *Sociobiology* **56**: 3.

Meyer-Rochow V.B, Kenichi N. & Somkhit, B. 2007. More feared than revered: Insects and their impact on human societies (with some specific data on the importance of entomophagy in a Lotian setting). *Entomologie Heute* 191-23.

Mitchell, J.D. 2002. Termites as pests of crops, forestry, rangeland and structures in Southern Africa and their control. *Sociobiology* **40**: 47-69.

Morris, R.J. 2010. Anthropogenic impacts on tropical forest biodiversity: a network structure and ecosystem functioning perspective. *Philosophical transactions of the Royal Society* **365**: 3709-3718.

Municipal Demarcation Board. 2011. Vhembe District Municipality: 2011 Municipal Boundaries. Pretoria, South Africa.

Muvengwi, J., Ndagurwa, H.G.T., Nyenda, T. & Mbiba, M. 2016. Nutrient dynamics and plant assemblages of Macrotermes falciger mounds in a savanna ecosystem. *Acta Oecologica* **76**: 13-21.

Niaba, K.P.V., Ocho-Anin, A.L., Gbassi, K.G., Beugre, A.G., Adou, M., Anon, A.B. & Gnakri, D. 2012. Consumption survey of edible winged termites in Cote d'Ivoire. *International Journal of Agriculture and Food Science* **2**(4): 149-152.

Noirot, C. 1970. The nests of termites. In: *Biology of termites*. Krishna K. & Weesner F.M. (Eds). Academic Press, New York. Volume 2. Pp 73-125.

Nonaka, K. 1996. Ethnoentomology of the central Kalahari San. *African Study Monographs Supplementary* **22**: 29-46.

Oguwike, F.N., Ebede, S.O., Offor, C.C. & Onubeze, D.P.M. 2013. Evaluation of the effect of consumption of termites (*Macrotermes nigeriensis*) on Biochemical and Haematological profile of male albino wister rats. *Greener Journal of Medical Sciences* **3**(9): 314-318.

Olugbemi, B.O. 2013. Termite assemblages and decomposition of tissue paper baits along a gradient of land use intensification in Owena. *Applied Ecology and Environmental Research* **11**(2): 223-235.

Payne, C.L.R & van Itterbeeck, J. Ecosystem Services from Edible Insects in Agricultural Systems: A Review. *Insects* **8**: 24. doi:10.3390/insects8010024

Pearce, M.J. 1997. *Termites. Biology and Pest Management*. Cambridge University Press, Cambridge.

Pickett, S.T.A & White, P.S. (Eds). 1985. *The Ecology of natural Disturbance and Patch Dynamics*. New York Academic Press, Orlando, FL. 472pp.

PIMS. 2006. Integrated Development Plan Review for 2005/6 Financial Year. Vhembe District Municipality.

Pringle, R.M., Doak, D.F., Brody, A.K., Jocque, R. & Palmer, T.M. 2010. Spatial Pattern enhances ecosystem functioning in an African savanna. *Plos Biology* 8.

Pullan, R.A. 1979. Termite hills in Africa: their characteristics and evolution. *Catena* **6**: 267-291.

Reyers, B., Fairbanks, D.H.K, van Jaarsveld, A.S. & Thompson, M. 2001. Priority areas for the conservation of South African vegetation: a coarse filter approach. *Diversity and Distribution* **7**: 77-96.

Roulon-Doko, P. 1998. Les activités de cueillète. In: Insects as food in sub-Saharan Africa.van Huis, A. (Ed). *Insect Science and its Application* **23**(3): 163-185.

Sala, O.E., Chapin, F.S., Armesto, J.J, Berlow, E., Bloomfield, J., Dirzo, R., Huber Sanwald, E., Huenneke, L.F., Jackson, R.B., Kinzig, A., Leemans, R., Lodge, D.M., Mooney, H.A., Oesterheld, M., Poff, N.L., Sykes, M.T., Walker, B.H., Walker, M. & Wall, D.H. 2000. Biodiversity: Global biodiversity scenarios for the year 2100. *Science* **287**: 1770-1774. doi:10.1126/science.287.5459.1770

Silow, C.A. (Ed). 1983. *Notes on Ngangela and Nkoya Ethnozoology*. Ants and termites. *Etnologiska Studier* 36. Goeteborg (Sweden): Etnografiska Museum. Pp 171-177.

Skinner, J.D. & Chimimba, C.T. 2005. *The Mammals of the Southern African Subregion*. 3rd edition. Cambridge University Press, Cambridge, England.

Snyder, T.E. (Ed). 1948. *Our Enemy the Termite*. 2nd edition. Ithaca, N.Y., Comstock Publishing Co., Inc.; London, Constable & Co., Ltd. 257pp.

Susilo, F.X. & Aini, F.K. 2005. Diversity and density of termites in a range of land use types in the Rigis hill area, Sumberjaya, Lampung. *Jurnal Sains dan Teknologi* **11**(3): 129-136.

Suzuki, S., Kuroda, S. & Nishihara, T. 1995. Tool-set for termite-fishing by chimpanzees in the Ndoki Forest, Congo. *Behaviour* **132**: 219-235.

Swift, M. & Bignell, D. 2001. Standard Methods for Assessment of Soil Biodiversity and Land Use Practice. ASB Lecture Note 6B. 40. International Centre for Research in Agroforestry. Published online: http://www.fao.org/fileadmin/templates/nr/images/resources/pdf_documents/manual-soil_20bioassessment.pdf (Accessed 25 June 2018).

Takeda, J. 1990. The dietary repertory of the Ngandu people of the tropical rain forest: An ecological and anthropological study of the subsistence activities and food procurement technology of a slash and burn agriculturist in the Zaire river basin. *African Study Monographs Supplementary* **11**: 1-75.

Taylor, W.A., Lindsey, P.A. & Skinner, J.D. 2002. The feeding ecology of the aardvark *Orycteropus afer*. *Journal of Arid Environments* **50**: 135-152.

Thorne, B.L. 1998. Part I. Biology of subterranean termites of the genus Reticulitermes. In: *NPCA Research Report on Subterranean Termites*. Viginia, National Pest Control Association. Pp. 1-30.

Tscharntke, T., Steffan-Dewenter, I., Kreuss, A. & Thies, C. 2002. Characteristics of insect populations on habitat fragments: A mini review. *Ecological Research* **17**: 229-239.

Turner, J.S. 2006. Termites as mediators of the water economy of arid savanna ecosystems. In: *Dryland Ecohydrology*. D'Odorico, P. & Porporato, A. (Eds). Berlin: Springer Science Business Media. Pp 303-313.

Um, S., Fraimout, A., Sapoontzis, P., Oh, D. & Poulsen, M. 2013. The fungus growing *Macrotermes natalensis* harbors bacillaene-producing *Bacillus sp*. that inhibits potentially antagonistic fungi. *Scientific Reports* **3**:3250. Published online https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3832938/pdf/srep03250.pdf (Accessed 25 June 2018).

Umeh, V.C. 2003. An appraisal of farmer’s termite control methods in some traditional cropping system of West Africa. *Nigerian Journal of Entomology* **20**: 25-39.

Uys, V. 2002. A guide to the Termite Genera of Southern Africa. ARC-Plant Protection Research Institute Unit, Pretoria, South Africa.

van Huis, A. & Oonincx, D.G.A.B. 2017. The environmental sustainability of insects as food and feed. A review. *Agronomy for Sustainable Development* 37: 43. doi: 10.1007/s13593-017-0452-8.

van Huis, A., van Itterbeeck, J., Klunder, H., Mertens, E., Halloran, A., Muir, G. & Vantomme, P. 2013. Edible insects: Future Prospects for Food and Feed Security. Food and Agriculture Organization of the United Nations Rome. Published Online: http://www.fao.org/docrep/018/i3253e/i3253e.pdf (Accessed 25 June 2018).

van Huis, A. 2003. Insects as food in sub-Saharan Africa. *Insect Science and its Application* **23**(3): 163-185.

Watson, J.A.L., Okot-Kotber, B.M., & Noirot, C.H. (Eds). 1985. *Caste Differentiation in Social Insects*. Oxford, New York, Toronto, Sydney, Paris, Frankfurt: Pergamon Press. 405pp.

Wilson, E.O. 1971. *The Insects Societies*. Cambridge, MA: Belknap Press of Harvard University.

Wilson, R. J., Davies, Z. G. & Thomas, C. D. 2007 Insects and climate change: processes, patterns and implications for conservation. In Proc. Royal Entomological Society's 23rd Symp. Insect Conservation Biology (eds A. J. A. Stewart, T. R. New & O. T. Lewis), ch. 11, pp. 245–279. Wallingford, UK: CABI Publishing.

Wood, T.G. 1988. Termites and the soil environment. *Biology and Fertility of Soils* **6**: 228-236. DOI:10.1007/BF00260819.

Wood, T.G. & Sands, W.A. 1978. The role of termites in ecosystems. In: *Production Ecology of Ants and Termites*. Brian, M.V. (Ed.). Cambridge University Press, Cambridge. Pp. 245-292.

Wood, T.G. & Johnson, R.A. 1986. The biology, physiology and ecology of termites. In: *The economic impact and control of social insects.* Vinson, S.B. (Ed.) Praeger publications. Pp. 1-68.

Wood, G.T. 1991. Termites in Ethiopia: The Environmental Impact of Their Damage and Resultant Control Measures. *Ambio* **20**: 3-4.

Zeidler, J., Hanrahan, S. & Scholes, M. 2002. Termite species richness, composition and diversity on five farms in southern Kunene region, Namibia. *African Zoology* **37**(1): 7-11.

CHAPTER 2: HUMAN USES AND INDIGENOUS KNOWLEDGE OF EDIBLE TERMITES IN VHEMBE DISTRICT, LIMPOPO PROVINCE, SOUTH AFRICA

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This chapter is presented in the format in which it was published. After publication, the article had an impact on the general public as can be seen in Table 2.1.

Table. 2.1 Media and magazines publications which referred to the publication

Name	Type	Website link
Saturday Star / Iol	Online / Print	https://www.iol.co.za/saturday-star/yebo-for-limpopos-goggas-13013774
City Press / Business Insider	Online / Print	https://www.businessinsider.co.za/fried-termites-found-by-60-year-old-vhembe-masters-are-a-marketable-business-in-limpopo-and-eaten-by-the-whole-family-at-r20-a-cup-2018-3-2
Cape Argus / Iol	Online / Print	https://www.iol.co.za/capeargus/news/could-edible-termites-be-next-on-the-menu-13278139 https://www.pressreader.com/south-africa/cape-argus/20180214/281702615179365
Food Stuff South Africa	Magazine (Online / Print)	https://www.foodstuffsa.co.za/eating-insects-nothing-new-sa-research-termites/
Wits University	Online	http://www.wits.ac.za/news/latest-news/research-news/2018/2018-01/yum-yum-tasty-termites.html
Wits Review April 2018, Volume 39	Magazine (Print)	Publisher chose not to allow downloads on the internet

2.1. ABSTRACT

Termites are good sources of edible food, being rich in proteins, fats, vitamins, and many essential mineral nutrients, and thus provide food security for poor households. I report on a survey conducted in the Vhembe District Municipality of Limpopo Province, South Africa. The objectives were to identify the edible termite species and find out how they are harvested, prepared, graded, packaged and marketed. I also looked at the socio-economic factors of the harvesters, sellers and consumers. Using a structured questionnaire, 104 individuals were interviewed from 48 villages. Most of the harvesters were over the age of 60 years but termites are consumed by the whole family. The results of the survey revealed that only three termite species are consumed: soldiers of *Macrotermes falciger* (89.90%), *M. natalensis* (8.08%) and *M. michaelseni* (2.02%). The preferred method of preparation was frying (77.55% of the respondents). At least 80.77% of the respondents indicated that some religions have restrictions on termite consumption but no ethnic restrictions were reported. The income derived from selling termites was estimated to range from ZAR 2 040 to ZAR 17 680 per annum between April 2015 and April 2016. The results of this study showed that edible termites contribute significantly to the livelihoods of many rural families and this indigenous knowledge should be passed on to younger generations. Research on the sustainability of termite harvesting is recommended.

Keywords: Termites**,** entomophagy, harvesters, sellers, *Macrotermes spp*

2.2. INTRODUCTION

The consumption of insects by humans is commonly known as entomophagy.[1] Early hominids have been reported to have eaten insects, with termite soldiers and alates of the genus *Macrotermes* being part of their diet.[2,3] Termites are rich in proteins, vitamins and mineral nutrients.[4] The crude protein content of termites ranges from 20.4% in *Macrotermes bellicosus* (Smeathman) to 35.88% in *Macrotermes nigeriensis* (Sjostedt).[4,5] *Macrotermes bellicosus* alates have been found to be rich in vitamins, with contents of 2.89 ug/100g for Vitamin A; 1.98 mg/100g for Vitamin B2 and 3.41 mg/100 g for Vitamin C.[4] Mbah and Elekima[5] found alates to be high in minerals, *i.e.* calcium, 21 mg/100g; phosphorus, 1.36 mg/100g; iron, 27 mg/100g; and magnesium, 0.15 mg/100g. In addition to these nutrients, a study conducted by Banjo et al.[4] found that *M. bellicosus* has a carbohydrate content of 43.3%, while Mbah and Elekima[5] found that the oil content of the same termite species is 28.37%. The studies conducted by Phelps et al.[6] in Zimbabwe found that *M. falciger* are very high in energy with 761 kcal/100g. Termites can therefore provide food security in many poor African countries as they contain essential nutrients, which are often lacking in the diets of people in those countries.[7]

Macrotermes nigeriensis alates have been reported by Igwe et al.[8] and Ajayi and Adedire[9] as being consumed as a delicacy in certain parts of Nigeria. People living in Nkoya in the north eastern part of the Western Province of Zambia use termites as an important part of their diets.[10] Chavunduka[11] reported the consumption of termite soldiers of *Macrotermes* species in Zimbabwe. About 14 species of the family Macrotermitidae have been reported to be consumed in the sub-Saharan Africa alone, including in some parts of South Africa.[12] The majority of these termite species belong to the genus *Macrotermes*. Of the 12 recognized species of *Macrotermes* that occur in the sub-Saharan Africa region, nine are commonly eaten and have been recorded from southern Africa.[13,14] These species are all naturally open-woodland or savanna dwellers and all termite castes: queen, soldiers, alates and workers are eaten.[15,16] In South Africa, Bodenheimer[17] documented the alates of *Macrotermes swaziae* (Full) and *Microhodotermes viator* (Latreille) as edible termite species, while Quin[18] also reported *Odontotermes badius* (Haviland) and *O. capensis* (DeGeer).

Harvesting of soldier termites in Uganda was reported to have been done by using wet grass blades or parts of tree pods or bark, by inserting them into the holes of termite mounds that have been opened with a knife.[19] Alates emerge from holes at the mound after the first rains, and are collected using light traps suspended over water buckets and basins to collect them as they drop. Bergier[20] indicated that baskets placed upside down over the holes were used in Democratic Republic of Congo to collect the emerging alates.

Termites are either killed by drowning, boiling or roasting for a few minutes and are then sun-dried.[10] A study conducted by Niaba et al.[21] in Cote d'Ivoire found that termites prepared for human consumption were either dried or fresh and prepared through grilling, baking, frying, seasoning or roasting. Botswana women of San origin prepared the alates of *Hodotermes mossambicus* (Hagen) by roasting.[22]

Comparatively little is known about the use of termites as food in South Africa. The current study was consequently undertaken to document the edible termite species found in the Vhembe District Municipality of South Africa. The study also looked at consumption, harvesting and biomass harvested, processing and marketing of edible termites as an income generating activity and lastly, assessed the contribution of termites to food security.

2.3. MATERIAL AND METHODS

2.3.1. Study area

The study was carried out in major termite consumption areas in 48 villages in the three local municipalities of the Vhembe District in the Limpopo Province, namely: Thulamela, Makhado and Mutale, over a period of 12 months from April 2015 to April 2016. The areas were selected because termites are an important food supplement for people living in the district (personal observation).

The Vhembe District Municipality is one of the five districts of the Limpopo Province in South Africa. The district is located at 22^{o}56'S and 30^{o}28'E in the far north and shares borders with Zimbabwe in the north, Mozambique in the east and Botswana in the north west.[23] According to Mpandeli[24], the average annual precipitation in the Vhembe District is 820 mm, with the rainfall season starting October and peaking in January and February. Winter starts in May and ends in August. The district has been reported to have extreme temperatures, with average temperature range from 6 °C to 41 °C and the temperature of more than 35 °C during summer months in most parts of the district.[25]

Agriculture is the largest contributor to the district's economy, with small numbers of commercial farmers and predominantly medium to smallholder farmers cultivating both field, tropical and subtropical crops and livestock.[26] Figure 2.1 depicts the location of the Vhembe District with termite harvesting mounds and markets where the studies were conducted. A significant portion of the land is arable. The district falls under communal tenure systems, where most of the land legally belongs to the state and is administered by traditional authorities.[27] Most of the villages within the district are rural with a high unemployment rate and the majority of residents, mainly women, are living in poverty and/or depend on government social grants.[28]

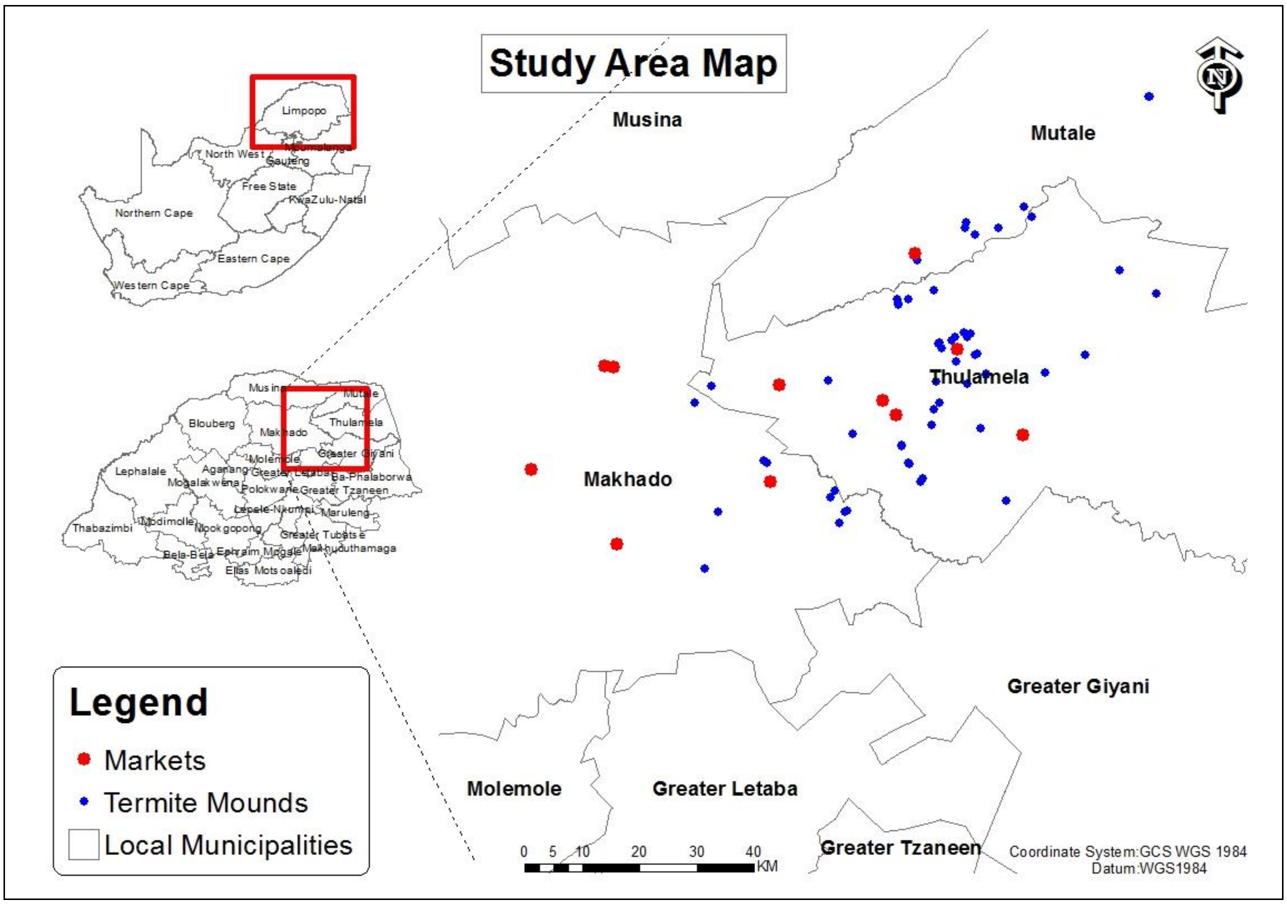

Figure 2.1 Location of the Vhembe District in the Limpopo Province, South Africa (inset) with specific study sites (termite harvesting sites/mounds and markets)
(enlarged area: 22°49'S to 23°41'S and 29°77'E to 31°02'E)

2.3.2. Data collection methods

2.3.2.1. Questionnaires/interviews

Three sets of structured questionnaires were developed to source the information from the selected harvesters, sellers and consumers (University of Witwatersrand Human Research Ethics Committee, Protocol Number: H15/0314). Sellers and consumers were randomly selected. The sellers were interviewed at the markets. The consumers who are the buyers of termites were interviewed at their homes and work places. The consumers were randomly selected by knocking on people's doors or households (households were randomly selected from the list of households in every village) and selecting from those seen purchasing at the markets (selected using random numbers list). Consumers are a separate group and are people who eat termites. Sellers and harvesters also consume termites but were not interviewed as part of the consumer group in Table 2.2.

A chain referral sampling technique as explained by Biernacki and Waldorf[29] was applied to locate the harvesters through the assistance of the termite sellers at the vendor markets around the study areas. The harvesters were randomly selected from the list provided by the sellers, community members and referrals from other harvesters. Harvesters were interviewed at harvest sites and at their homes. The questionnaire took between 1h and 1h 30min to complete, depending on how quickly the respondents answered the questions. All the interviews were conducted individually in local languages, *i.e.* Tshivenda and XiTsonga with assistance from a XiTsonga field worker who is competent in the language.

The consumers', sellers' and harvesters' questionnaires covered the socio-economic characteristics of the respondents, including culture and religion, importance of termites as food, ethnic preferences and prohibitions, uses of termites, frequency and means of termite consumption, species preference, knowledge of termite taxonomy, knowledge of termite abundance and distribution and knowledge of the role of termites in human nutrition and health. In addition to the above aspects, the marketer's questionnaire also covered marketing, selling prices, marketer's estimated income, what consumers look for before buying, quantity of termites transported per batch, the type and volume of the packaging unit, grading and quality standards, including size, aroma and colour, variability of prices between seasons and volumes sold. Harvester's questionnaires also covered seasonal availability, distance travelled to harvesting sites, how they know a particular species is edible, how termites are harvested or captured, preparation, preservation, which species is easy or difficult to harvest, how often harvesting occurs, and the quantity of termites harvested or captured in a single harvest.

2.3.2.2. Edible termite surveys

A total of 62 mounds were randomly selected and sampled from the list of mounds mentioned as being eaten locally in the household surveys compiled in each village with the assistance of harvesters. Harvesters were asked to identify all edible termite mounds in the area that they were harvesting from. The positions of the selected edible termite mounds were recorded using a Garmin GPS 60. At least 10 minor and 10 major soldier castes were collected from each mound and preserved in vials containing 80% ethyl alcohol. These samples were identified to species by the Biosystematics Division of the ARC-Plant Protection Research Institute in Pretoria, South Africa. Termites were identified to species level using morphological characters.

2.3.3. Statistical procedures and data analysis

Statistical Analysis System (SAS), version 9.3 of 2012 was used for the analysis of the descriptive statistics.[30] Data from the three local municipalities questionnaire surveys were analysed separately per municipality and also combined (Vhembe District) as the total for the study area. The termite soldiers and alates harvested or captured were determined by recording the number of litres harvested per week, adding this over a period of 12 months. The daily intake of termites was determined by recording the number of cups consumed per household per day and dividing this by the number of household members, and multiplying this by 64.8 grams (steel cup is equivalent to 64.8 g of termites). The volumes of termites sold annually were determined by recording the number of cups sold per week per month and adding this over a period of 12 months. The Rand value of termites was determined using a price of ZAR 20.00 per cup (one steel cup was equivalent to 0.3 l) of termites. Dry weight of termites was determined after sun dried (ready for market). Mapping of the villages and mounds was done using ArcGIS 6.3 software. Chi-square was used to test for associations between species and local municipalities and between termite types and local municipalities and the proportions of education between harvesters and sellers.[31] Analysis of Variance (ANOVA) was used to test whether there were significant differences between the harvesters, sellers and consumers for daily intake.[32] The data satisfy assumptions of ANOVA.

2.4. RESULTS AND DISCUSSION

2.4.1. Socio-economic characteristics

Overall, respondents to the three questionnaires were females (79.03%), over 50 years (Table 2.2). However, in Mutale the age of respondents ranged from 25 - 39 years (47.37%), unlike the other two municipalities. Most harvesters were over 60 years of age (67.6%) and most sellers were over 50 years of age (64.5%). The interviews were conducted during normal school hours and this might have affected the availability of the younger age group due to their attendance at educational institutes. In light of that, the results demonstrate that individuals within the district across all ages participate in edible termite activities, be it as a consumer, marketer or harvester. The school attending children only participated in a limited way mainly during harvesting. Thirty five percent of the respondents never attended school, while a large proportion of those that attended had secondary education. A 2x2 chi-square test on the proportions of no versus some education between harvesters and sellers (who eat termites) was significant (Chi-square value = 5.25; degrees of freedom = 1; p = 0.022) (Table 2.2). At least 65.5% of the sellers had some form of formal education compared with 26.4% of the harvesters. Tshivenda and Christianity were most dominant language and religion respectively in the district.

Table 2.2 Socio-economic characteristics of harvesters, sellers and termite consumers' respondents in the Vhembe District. Data is given as percentage of respondents with the number in brackets. Not all respondents consumed termites.

		Local Municipality							
		Makhado			**Mutale**		**Thulamela**		
		Harvesters	Sellers	Consumers	Harvesters	Consumers	Harvesters	Sellers	Consumers
Characteristics									
Number of respondents		12	10	10	9	10	16	21	16
Age (years)									
	18 – 24								6.25 (1)
	25 – 39			50.00 (5)	22.22 (2)	70.00 (7)		19.05 (4)	25.00 (4)
	40 – 49		30.00 (3)	20.00 (2)		10.00 (1)	6.25 (1)	19.05 (4)	37.50 (6)
	50 – 59	16.67 (2)	20.00 (2)	30.00 (3)	22.22 (2)	20.00 (2)	31.25 (5)	28.57 (6)	18.75 (3)
	>60	83.33 (10)	50.00 (5)		55.56 (5)		62.50 (10)	33.33 (7)	12.50 (2)
Gender									
	Male		10.00 (1)	30.00 (3)		20.00 (2)			43.75 (7)
	Female	100.00 (12)	90.00 (9)	70.00 (7)	100.00 (9)	80.00 (8)	100.00 (16)	100.00 (21)	56.25 (9)
Language									
	Shona							4.76 (1)	
	Tshivenda	91.67 (11)	50.00 (5)	90.00 (9)	100.00 (9)	100.00 (10)	93.75 (15)	85.71 (18)	93.75 (15)
	XiTsonga	8.33 (1)	50.00 (5)	10.00 (1)			6.25 (1)	9.52 (2)	6.25 (1)
Religion									
	African Tradition	50.00 (6)	20.00 (2)	20.00 (2)	66.67 (6)	10.00 (1)	25.00 (4)	19.05 (4)	18.75 (3)
	Christianity	50.00 (6)	80.00 (8)	70.00 (7)	33.33 (3)	90.00 (9)	75.00 (12)	80.95 (17)	81.25 (13)
	Rastafarian			10.00 (1)					
Educational status									
	No schooling	83.33 (10)	80.00 (8)		55.56 (5)		56.25 (9)	19.05 (4)	
	Primary schooling	8.33 (1)	10.00 (1)	10.00 (1)	22.22 (2)	20.00 (2)	25.00 (4)	19.05 (4)	25.00 (4)
	Secondary Schooling	8.33 (1)	10.00 (1)	70.00 (7)	22.22 (2)	80.00 (8)	18.75 (3)	57.14 (12)	31.25 (5)
	Tertiary education			20.00 (2)				4.76 (1)	43.75 (7)

A 2x2 chi-square test on the proportions of sellers' education (no versus some) between municipalities was highly significant (Chi-square value = 10.83; degrees of freedom = 2; $p = 0.001$) (Table 2.2). Thus, there was strong association between education status and municipality, as the sellers from Makhado were less educated than those from the Thulamela municipality.

2.4.2. Termite species diversity and preferences

In all municipalities, I found that most of the respondents were able to identify the major edible termite genera, species and the castes using vernacular names. A 3x2 chi-square test on the proportions of knowledge between the three groups was significant ($p < 0.05$) and the harvester group had 100% knowledge of the termite species, while the consumer group had only 83.3% consistency in the knowledge/identification of species by respondents and the sellers had 90.3% knowledge. Harvesters and sellers were mainly consistent in providing the vernacular names of termite species as compared to the consumers.

Table 2.3 Termites genera, list of castes, corresponding vernacular names and level of consumption of each type in Vhembe District, South Africa. Data is given as percentage of respondents in the district with the actual number in brackets.

Common name / Scientific name	**Vernacular names**		**Level of consumption of each type / species**			
			Local Municipalities			District
	Tshivenda	XiTsonga	Makhado	Mutale	Thulamela	Vhembe
Termite species						
Macrotermes falciger	Madzhulu a nthwa	Tintshwa	25.25 (25)	18.18 (18)	46.47 (46)	89.90 (89)
Macrotermes natalensis	Madzhulu a nemeneme	Timenemene	5.05 (5)	1.01 (1)	2.02 (2)	8.08 (8)
Macrotermes michaelseni	Madzhulu a nemeneme	Timenemene	1.01 (1)	0 (0)	1.01 (1)	2.02 (2)
Termite type						
Alates	Nthwa Nemeneme	Tintshwa Tintshwa	11.11 (11)	5.05 (5)	21.21 (21)	37.38 (37)
Major soldier	Magena	Majenje Jendze	20.20 (20)	14.14 (14)	28.28 (28)	62.62 (62)
Minor soldiers	Vhutshembelane Vhutshemela	Swijenjana Jendze				

The edible termite species collected from the district belonged to one family of the higher termite species of Termitidae: Macrotermitinae. All of the collected species belonged to the genus *Macrotermes* Holmgren. The fungus-growing termite genus *Macrotermes* has been reported by Roonwal[32] as the most important and widely distributed genera in Africa. The three consumed species collected in the study areas in order of preference were *M. falciger*, *M. natalensis* and *M. michaelseni*. The most preferred termite species were the soldiers of *M. falciger* (89.90%), *M. natalensis* (8.08%) and *M. michaelseni* (2.02%). *Macrotermes natalensis* and *M. michaelseni* were mainly preferred in Nzhelele (Makhado) and some parts of Mutale areas where *M. falciger* is either not available or is rarely available. The collection of soldier termites all year round seems to be widespread. The level of consumption of *M. natalensis* and *M. michaelseni* was not large enough for a reliable test and was combined for the chi-square test. A 2x3 chi-square test on the proportions of species consumed per local municipality was not significant (Chi-square value = 4.27; degrees of freedom = 2; p = 0.118). Species *M. falciger* was most common in Thulamela (51.7%) followed by Makhado (28.1%) then Mutale (20.2%) (Species under Table 2.3).

Macrotermes falciger has larger soldiers than *M. natalensis* and *M. michaelseni*, and was the only species sold at all six surveyed local markets Harvesters preferred collecting the major soldiers of *M. falciger* because of their higher demand and filling the buckets quicker. It was observed that soldier termites were available all year round even though they are scarce in winter months (May to July). The winged alates were collected during the beginning of the rainy season in October/November in the Vhembe District. Studies conducted by van Huis[12] found that alates are mainly collected during the night and emerge from the holes of the mounds after the first summer rainfall. Meyer[33] found that the alates release of the *M. natalensis* in the Kruger National Park occurs mainly during December and February.

Contrary to the findings by Nonaka[22] in studies conducted in Botswana, all the harvesters in the Vhembe District collected more soldiers than the winged reproductives (alates) because they are available all year round, easy to harvest and are in more demand than alates. This substantiates the findings by Chavunduka[11] who found that major soldiers and alates of *M. falciger* are eaten as food in many parts of Zimbabwe. During the surveys conducted in the Vhembe district, it was reported by consumers that alates can cause stomach disorders.

Macrotermes natalensis are smaller than *M. falciger* and the species was not found in any of the markets surveyed. The *M. natalensis* major soldiers are roughly the size of the ignored minor soldiers of *M. falciger*. The minor soldiers of *M. natalensis* in Vhembe are quite small, but both major and minor soldiers are harvested and consumed together. These termites are not thought to be as palatable as the *M. falciger* species. *Macrotermes michaelseni* was the least preferred species, was also not available in the market and only detected twice after directed to the species by harvesters. This might be due to very few mounds of this species in the study area. Although *Odontotermes sp* and *H. mossambicus* occur in Vhembe and are known to be eaten by human,[18,22,34] these species were not sold at any of the markets surveyed.

2.4.3. Termite consumption

The overwhelming majority of the respondents (94.23%) across all ages and gender from three local municipalities consumed termites. The findings by Nyeko and Olubayo[35] on the studies conducted in Uganda found that both men and women of all ages consumed soldiers, alates or workers. A majority (97.96%) of the respondents grew up eating termites. Soldiers of mainly *M. falciger* were the most preferred and regularly consumed in the district followed by alates. A 2x3 chi-square test on the proportions of termite type consumption per local municipality was not significant (Chi-square value = 1.67; degrees of freedom = 2; p = 0.434). In all three municipalities, more soldiers than alates were consumed (62.6%) (Table 2.3). No workers were consumed. Table 2.4 shows the state in which edible termites are consumed in the district. It was observed that most of the respondents in the district consumed termites as frequently as possible (31.63%).

Table 2.4 Results of consumption survey from three groups of harvesters, sellers and consumers combined. Data is given as percentage of respondents with the number in brackets.

	Local Municipalities			**District**
Characteristics	Makhado	Mutale	Thulamela	Vhembe
Number of respondents	31	18	49	98
Frequency of termite consumption				
Much as possible	32.26 (10)	22.22 (4)	34.69 (17)	31.63 (31)
Occasionally	25.81 (8)	11.11 (2)	12.24 (6)	16.33 (16)
Once a week	22.58 (7)	27.78 (5)	30.61 (15)	27.55 (27)
Twice a week	19.35 (6)	38.89 (7)	22.45 (11)	24.49 (24)
Why termites are eaten				
Curiosity	3.23 (1)	5.56 (1)	2.04 (1)	3.06 (3)
Custom	19.35 (6)	5.56 (1)	4.08 (2)	9.18 (12)
Desire			4.08 (2)	2.04 (2)
Enjoyment	9.68 (3)			3.06 (3)
Flavours	9.68 (3)	5.56 (1)	6.12 (3)	7.14 (7)
Nutrition	38.71 (12)	61.11 (11)	63.27 (31)	55.10 (54)
Poverty	19.35 (6)	22.22 (4)	20.41 (10)	20.41 (20)
Most preferred termite castes				
Alates	35.48 (11)	22.22 (4)	42.86 (21)	33.73 (36)
Soldiers	64.52 (20)	77.78 (14)	57.14 (28)	63.27 (62)

The results of this survey showed that the termites were either eaten fresh, dried or were refrigerated. Termites were prepared in a variety of ways; boiled, fresh (raw straight out of the mound), fried, grilled, roasted and sundried. They were normally eaten with maize meal porridge. At least 77.55% of consumers prefer fried termites mixed with tomato and onions followed by boiled (11.22%), sundried (5.01%), fresh (3.06) and least grilled (1.02%). The results of this study also affirmed the studies of Niaba et al.[21] who found that the majority of Ivorians preferred fried termites seasoned with spices. It was observed from this study that fresh termites were consumed by the harvesters while harvesting. The average daily intake of soldier termites per person was 22.27 g (dry weight), with a maximum of 38 g and a minimum of 7.70 g. Termite consumers in the study area indicated that one steel cup (0.30 l) of soldier termites (dry weight) can feed an average of three members of a household daily. No significant differences in daily intake were found ($p > 0.05$) at the 5% level between the three groups involved in termites. Consumers ate more (23.17 g) than harvesters (21.09 g), but the differences among the three groups were not significant (Table 2.5).

Table 2.5 Termite daily intake per respondent between three groups of people associated with termites in the Vhembe District

Group	Sample size	Mean (g)	Standard error of the mean (SEM)
Harvesters	37	21.09	1.325
Sellers	31	22.55	1.435
Consumers	36	23.17	1.288

F probability is $p = 0.519 > 0.05$

Most of the respondents rated health benefits or nutrition as the main reason for consumption, as termites were reported to enhance good health and ease digestion (Table 2.4). Of interest, one of the sellers, a qualified retired nurse, stated that termites are high in proteins compared to beef, fish and poultry and that termites are good for breastfeeding mothers as they contain iron. She also stated that termites were used by many households to combat malnutrition in the district. Banjo et al.[4] found *M. bellicosus* and *Macrotermes natalensis* (Holmgren) to have the higher iron content.at 29 mg/100g and 27 mg/100 g respectively. A study conducted in Owerri, Nigeria by Igwe et al.[8] revealed that *Macrotermes nigeriensis* is a good source of proteins, minerals and nutrients and played a significant role in fighting protein energy malnutrition. Termites have been reported by Igwe et al.[8] to be rich in fat (44.82-47.31 g/100 g) and protein contents (33.51-39.74 g/100g).

In addition to the health benefits derived from consuming termites, it was also observed that some pregnant and lactating women consumed soil from termitaria of the three identified *Macrotermes* species for nutrients and good health. This phenomenon of eating soil is termed as geophagy and has health benefits of enhanced maternal calcium status and improved foetal skeletal formation.[36] This corroborates the findings by Saatoff et al.[37] who stated that women in South Africa consumed soil from termitaria. It was also found that some babies within the study area were fed soft porridge mixed with ground powder of termite soldiers and alates by their parents who were either termite consumers or sellers. Other reports were in the study area were that traditional healers used powdered termites in their traditional medicines to cure diseases and injuries. Figueirêdo et al.[38] documented the use of *M. nigeriensis* in Nigeria in the treatment of wounds and sickness of pregnant women.

2.4.4. Termite type preferences and prohibitions

With reference to religion, of the 37 harvesters, most were Christians (63.6%) and four of them did not consume termites, the rest are of the African tradition. Similarly, most of the 29 sellers were Christians (86.2%) and one of them did not consume termites, the rest are of the African tradition. One of the consumers was a Rastafarian, most are Christians (80.6%) and the rest were of the African tradition. The majority (80.77%) of respondents indicated that some religions have restrictions on termite consumption, they stated that some of the old traditional churches prohibit the eating of termites while the charismatic churches do not. The results of this study support the findings made by Silow[10] that some missionaries condemned the eating of winged termites as a heathen custom and Christians were advised not to eat as the practice was non-Christian. A study conducted by Egan[39] in the Blouberg Municipality in the Limpopo Province found that members of the Zion Christian Church were prohibited from eating any other insects than locusts. No VhaVenda or VaTsonga clans were reported to have restrictions on termite consumption in the district.

2.4.5. Harvesting of edible termites

Harvesting of termites was mostly done by women and in some cases assisted by their children. Harvesting of soldier termites was done all year round, which seems to be much widespread. During harvesting, both the major and minor soldiers were collected. The majority (29.73%) of the harvesters captured termite soldiers three days a week, followed by two days (21.62%) then 4 days and 6 days (13.51%), 7 days (10.81%) and least 1 and 5 (5.41%) days a week. This study showed that harvesters were actively involved in feeding the population and also contributing to the economy of the district. The winged termites were collected after the first rains of the rainy season mainly in October/November periods. In some of the villages, mainly in the Thulamela Municipality, the alates were also collected until January. The harvesting of the alates was done 2 days (66.67%) and 3 days (33.33%) a week. Reasons given for harvesting termites during this study included: poverty, to get money, high demand of termites in the study area, part of tradition, following parent’s tradition, interest and to be kept busy.

The harvesters indicated that the knowledge about which termite species to harvest was indigenous passed on them by their parents or grandparents at a very young age or from other harvesters. The harvesters used size, taste and colour of termites as well as the mound type and size to identify the species. According to the harvesters, *M. falciger* is identified by dark brown/red colour, dark abdomen, big head, large size and good taste, whereas *M. natalensis* are differentiated by a light brown/red colour, thin, small head, shiny colour and sour taste. *Macrotermes michaelseni* was reported to be similar to *M. natelensis* except that the head of *M. michaelseni* is slightly darker than *M. natalensis*. Low and wide mounds characterize *M. falciger* whereas higher and narrower are those of *M. natalensis* and *M. michaelseni*.

Distance travelled by harvesters to the harvest sites varied between 100 m and 8 km. Most harvesters travelled up to 4 km to harvest sites (81.1%) and 37.8% had to only travel up to 2 km. Harvesting took place in the yard, next to roads, open fields, orchards and mountains. Harvesters raised the issue of safety as a major concern and they resorted to harvest in groups.

Harvesting of soldier termites was carried out any time during the day but more termites were collected in the morning and late afternoon. Soldier termites were collected by inserting grasses or fibres made from trees into the “eyes” small openings of the of the termite’s nests and after a short period withdrawing the grass. Both the soldier termites and workers who had bitten the grass or fibre were then stripped into the harvesting container. The grass or fibres were either moistened with water or saliva when becoming dry to facilitate grasping. Harvesters usually wrapped grasses or fibres with plastics, put them in empty mealie meal bags and stored them under shade during harvesting to prevent desiccation. Stems of Cyperaceae family and fibres of various plant species were mostly used for harvesting soldier termites (Table 6). Studies conducted in Uganda by Roulon-Doko[40] also described that the women lower saliva moistened grass blades of *Imperata cylindrica* to collect soldier termites. Harvesters used plant leaves in attracting termite soldiers to the mouth of the mound by closing the mouth with leaves (Table 2.6). All of these plants have putrid and strongly scented leaves which is believed to attract termite soldiers. The most used plant species to harvest termites were the stems of *Cyperus spp* and ground or pulverized *Nicotiana tabacum* leaves and *Clerodendrum glabrum* leaves were the most widely used plants to attract termites during harvesting (Table 2.6).

Table 2.6 Plants used for harvesting and attracting termites and their extent of use. The values in the table are percentages with actual counts in brackets

Botanical name	Common name	Vernacular name (Tshivenda)	Family	Part of the plant used	Extent of use (Actual counts)			
					Thulamela	Makhado	Mutale	Total (Vhembe)
Plants for harvesting								
Cyperus latifolius Poir	Smooth flat sedge	Dzhesi	Cyperaceae	Stems	7.14 (4)	8.92 (5)	5.36 (3)	21.42 (12)
Cyperus sexangularis Nees	Bushveld sedge	Mutate	Cyperaceae	Stems	1.79 (1)	1.79 (1)	8.92 (5)	12.50 (7)
Cyperus rotundus Linnaeus	Nut sedge grass, purple sedge grass	Mutate	Cyperaceae	Stems	19.64 (11)	12.50 (7)	3.57 (2)	35.71 (20)
Plectranthus laxiflorus Benth	Citronella spur-flower, White spur flower	Bunganyunyu Sindambudzi	Lamiaceae	Stems	0 (0)	3.57 (2)	0 (0)	3.57 (2)
Annona senegalensis Pers.	African/ Wild custard apple	Muembe	Annonaceae	Fibers	7.14 (4)	1.79 (1)	1.79 (1)	10.72 (6)
Musa spp Linnaeus	Banana	Muomva	Musaceae	Leaves Fibers	3.57 (2)	0 (0)	0 (0)	3.57 (2)
Agave sisalana Perrine	Sisal plant	Tshikwenga Savha	Asparagaceae	Leaves Fibers	3.57 (2)	0 (0)	0 (0)	3.57 (2)
Balanites maughamii Sprague	Torchwood	Mudulu	Zygophyllaceae	Fibers	0 (0)	1.79 (1)	0 (0)	1.79 (1)
Grewia flava DC	Velvet raisin / Wild currant	Muhwana Murabva	Malvaceae	Fibers	0 (0)	1.79 (1)	0 (0)	1.79 (1)
Cocculus hirsutus (L.) Diels	Broom creeper	Muzwingwe	Menispermaceae	Stems	1.79 (1)	0 (0)	3.57 (2)	5.36 (3)
Total					44.64 (25)	32.14 (18)	23.21 (13)	100 (56)

Attractants								
Clerodendrum glabrum E. Mey	Tinder wood	Munukhatshilongwe	Lamiaceae	Leaves	11.11 (2)	22.22 (4)	0 (0)	33.33 (6)
Lippia javanica (Burm. f.) Spreng	Lemon bush	Musudzungwane Mukundamboho	Verbenaceae	Leaves	0 (0)	16.66 (3)	0 (0)	16.66 (3)
Nicotiana tabacum Linnaeus	Tobacco plant	Fola	Solanaceae	Ground or pulverised tobacco leaves	16.66 (3)	11.11 (2)	5.56 (1)	33.33 (6)
Cannabis sativa Linnaeus	Marijuana plant	Mbanzhe	Cannabaceae	Leaves	5.56 (1)	0 (0)	0 (0)	5.56 (1)
Plectranthus laxiflorus Benth	Citronella spur-flower, White spur flower	Bunganyunyu Sindambudzi	Lamiaceae	Leaves	0 (0)	11.11 (2)	0 (0)	11.11 (2)
Total					33.33 (6)	61.11 (11)	5.56 (1)	100 (18)

Most of the harvesters indicated that soldiers were easy to harvest because they were available any time, quick to harvest and many could be harvested from one hole. Alates were reported to be the most difficult to harvest due to high labour intensity, not available on windy days, sensitive to noise, emerge in the evening (concern to safety of harvesters), only available after rains and because it took at least 3 days to harvest after placing the trap. Mounds of *M. natalensis* were also reported to be harder than those of *M. falciger*.

Alates were collected after rains using a bucket or pot by digging a hole in the soil at the bottom end of the mound on a steep slope and then placing an empty bucket (without the lid) in the cavity. The hole was covered with sticks and leaves of either banana (*Musa paradisiaca* Linnaeus and *M. sapientum* Linnaeus) or *Peltophorum africanum* (Sond). It was claimed that the leaves of these two plants provide good shade. As alates leave the nest, they roll/fly to the bottom of the hole where they were trapped and collected. A similar harvesting method was reported in Zimbabwe by Chavunduka[11]. The only difference was that in Zimbabwe, the roof was covered with grass and a pot containing water was used. To limit the number of alates flying in an evening, harvesters used pestles to close the openings at the onset of a rainy season. This is traditionally known as “u tsivha” in Tshivenda. Households did collect termites for home consumption but the alates were also sold at the market.

Table 2.7 shows summary statistics of edible termites harvested, marketed and consumed in the Vhembe District. The results show that a minimum of 1 l of soldier termites and 20 l of alates were harvested in a single harvest compared to the highest harvest of 10 l and 40 l respectively. The soldier termite biomass of *M. falciger* varied from 641.3 - 642.8 g (fresh weight/litre). These soldiers weigh on average 0.15 g each and these values corresponded to approximately 4280 individuals/litre. Harvesting season of the alates lasted a maximum of 4 months depending on rainfall.

Table 2.7 Summary statistics of edible termites harvested, marketed and consumed in the Vhembe District (as estimated by the respondents)

	Municipalities			
Characteristics	Makhado	Mutale	Thulamela	Vhembe
Termite soldiers captured in a single harvest (litres)				
AVERAGE	3.25	4.44	4.25	3.97
MIN	1.00	2.00	2.00	1.00
MAX	5.00	6.00	10.00	10.00
Alates captured in a single harvest (litres)				
AVERAGE	40.00	20.00	35.00	33.33
MIN	40.00	20.00	20.00	20.00
MAX	40.00	20.00	40.00	40.00
Termite soldiers harvested during peak times per week (litres)				
AVERAGE	13.33	15.00	23.81	18.27
MIN	3.00	5.00	2.00	2.00
MAX	35.00	24.00	60.00	60.00
Alates captured during peak times per week (litres)				
AVERAGE	120.00	80.00	65.00	76.66
MIN	120.00	80.00	40.00	40.00
MAX	120.00	80.00	80.00	120.00
Volumes delivered to the market per consignment (litres)				
AVERAGE	14.00	*	22.00	19.70
MIN	10.00	*	5.00	5.00
MAX	20.00	*	80.00	80.00
Volumes of soldiers and alates sold daily by sellers (litres)				
AVERAGE	2.40	*	4.95	4.13
MIN	1.00	*	1.00	1.00
MAX	4.00	*	20.00	20.00
Volumes of soldiers and alates sold annually by sellers (litres)				
AVERAGE	101.00	*	111.43	108.06
MIN	80.00	*	30.00	30.00
MAX	120.00	*	260.00	260.00
Daily intake per person (dry weight in grams)				
AVERAGE	25.23	22.00	20.54	22.27
MIN	9.00	11.00	8.00	8.00
MAX	32.00	38.00	32.00	38.00

* No termites were found to be sold in Mutale informal markets.

With the growing population and the mass collection of termites, questions are being raised on the sustainability of harvesting. Indications from the harvesters, based on the yields received per mound, were that there have not noticed any decline in termite availability over the years, even though harvesting has been increasing. Termite harvesters promoted responsible harvesting through mounds rotations and protected mounds from destruction. They were concerned about the destruction of mounds in new areas zoned for housing developments.

Farmers and local community also played their part in protecting the termite mounds. Most of the termite mounds located within the crop fields were not destroyed during ploughing and farmers planted around the mounds. Mounds are considered the property of the family if found near their homes or fields. The permission of that family has to be requested before harvesting can take place. However, research into the sustainability of termite harvesting is recommended.

2.4.6. Preparation and preservation of edible termites

Harvested termite soldiers were killed using boiled or cold water or by roasting and either sun dried or refrigerated to reduce spoilage. *Macrotermes natalensis* and *M. michaelseni* soldiers were prepared differently because these two species were not as palatable as *M. falciger*. Their preparation for cooking included vigorously whisking them with a natural whisk (forked fresh tree branch) in water and then rinsing. The whisking process created foam in the water, which suggests some chemical/toxin was being released and removed. The harvesters believed that whisking was to eliminate the bitter taste mainly produced by the soldiers of these two species.

2.4.7. Marketing and economic benefits of edible termites

Thirteen informal street markets were surveyed in the district: Makhado (8), Thulamela (4) and Mutale (1) (Figure 2.1). About 46% of the informal markets sold termites, where 66.67% were in Thulamela and 33.33% in Makhado. No termites were found to be sold in Mutale informal markets. The vendors in both Thulamela and Makhado municipalities rented space from the municipalities on the side of the road or pavement and no one was registered as a business entity. Sellers also rented space for storage of the termites, other edible insects and dried vegetables. The majority (96.77%) of vendors selling termite were women between the ages of 50 and 60 years. The sellers were not actively involved in any harvesting but only bought termites from harvesters. There were large numbers of sellers in Thohoyandou (Thulamela Municipality) sitting close to one another, resulting in competition for buyers and this led to sellers giving extras to attract more customers. It was observed that customers checked for freshness, presence of legs, cleanliness, species type and oil on alates before they bought. Sellers allowed buyers to taste before buying. Some buyers preferred termites fresh from the mounds.

Termites were graded using a traditional way of sieving according to morpho-species, size and type by harvesters before selling to sellers or consumers. Major soldiers were separated from minor soldiers and workers. Minor soldiers were fed to chickens. The average marketer in the district, sold 14, 120 and 367 steel beakers (0.30 l) of termites daily, monthly and annually respectively. Table 2.8 shows the number of sellers, volumes sold plus unit weights and prices in South Africa Rand (ZAR) with the standard deviation. The price of termites per steel beaker (0.30 l) was ZAR 20. The dry weight of termites per the packaging unit (steel beaker) was 64.8 g. The lowest volume of termites sold daily was 1 litre (3.5 steel beakers) and this was equivalent to ZAR 70 while the highest volume sold daily during peak times was 20 litres (70 steel beakers) which equals to ZAR 1 400. Peak is the season when termites are most visible and available (normally between October and February). The majority of sellers reported no price fluctuations during the year or between seasons. The quality of the termites did not affect the price. Buyers can either purchase soldiers or alates separately in a beaker or in a mix. All of the termite sellers sold throughout the year and six days a week, with Saturday being a half day. The average daily income derived from termites was estimated at ZAR 292, monthly ZAR 2 395 and annually ZAR 7 348. The lowest annual income from the sales of termites was estimated at ZAR 2 040 compared to highest annual income of ZAR 17 680.

Table 2.8 The number of sellers, volumes sold plus unit weights and prices in ZAR recorded in Vhembe District

Characteristics	Number of sellers, litres sold, weight & price per mug	Standard Deviation
Number of sellers selling termites	31	
Average litres sold per day (estimate by seller)	4.13	4.61
Average litres sold per month (estimate by seller)	35.23	20.52
Average litres sold per year (estimate by seller)	108.06	44.90
Average dry weight of termites in 1 beaker (kg)	0.0648	
Price per steel mug (ZAR)	20	

The retail prices of various fresh meat from Statistics South Africa[41] as at end of January 2017 showed the following prices: beef chuck (ZAR 73.67/kg), beef rump steak (ZAR 117.18/kg), pork chops (ZAR 78.59/kg), whole chicken (ZAR 43.69/kg) and lamb leg (ZAR 123.84/kg). The price per kilogram of termites was estimated at ZAR 100.00/kg. The retail prices obtained from two local butcheries of dried beef meat, sausages and pork were ZAR 329/kg, ZAR 320/kg and ZAR 430/kg respectively. Dried lamb and dried chicken are not sold. This indicated that the price per kg for termites was more than most of the fresh chicken, beef and pork meat but less than lamb chops and dried meats. The advantage is that one kilogram of termites can feed at least 15 people without having to add the appropriate additional ingredients like potato, turnip, carrots, corn, barley, etc., unlike the kilogram of the fresh chicken, beef or pork and dried meats. The total protein is also higher per unit mass compared to conventional protein. This makes termite to be more affordable in prices to consumers irrespective of age groups and income levels of both rural and urban dwellers that could serve as sources of animal protein. In addition, the costs of harvesting termites in the district was relatively low such that everyone could harvest their own at no cost.

Termites represented an interesting additional source of income, mostly for women in the Vhembe District, as most of the households face a daily poverty due to the high unemployment rate (Review of Thulamela Municipality Integrated Development Plan 2010/11–2012/13). The other alternative sources of income for termite sellers were from other edible insects (mopane worms and edible stinkbugs) and vegetables (dried/fresh pumpkin leaves and flowers, *Amaranthus hybridus*, *Cleome gynandra*, dried/fresh *Corchorus tridens*, *Solanum nigrum* and dried *Biden pilosa*). The results of this study indicate that termites are contributing to socio-economic wellbeing and food security of the people living in the district and most of the termite trading took place in Thulamela, with the Thohoyandou Complex as the largest provider of termite markets, followed by the Sibasa Complex.

2.5. CONCLUSION

Macrotermes termites could potentially play a significant role in food security in many communities in the Vhembe District, thus the indigenous knowledge of harvesting and preparation should be retained. As termites are a protein source and can generate income, promotion of sustainable termite harvesting for food security should be adopted. Further research into the sustainability is required as well as the nutritional value of various termite species. In conclusion, the approach of entomophagy can play a big role in combating the global food and feed crisis. Promoting indigenous knowledge of diets and sustainable harvesting of insects should be taught at schools at an early stage.

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2.7. AUTHOR'S CONTRIBUTION

S.R.N. and F.D.D. worked on the original concept of the manuscript. E.C.K. gave valuable scientific inputs during conceptualization and also provided significant contribution during the editing of the manuscript**.**

2.8. REFERENCES

1. DeFoliart GR. Insects as food: why the Western attitude is important. Annu Rev Entomol. 1999;44:21-50. http://dx.doi.org/10.1146/annurev.ento.44.1.21

2. Meyer-Rochow VB, Kenichi N, Somkhit B. More feared than revered: insects and their impact on human societies (with some specific data on the importance of entomophagy in a Lotian setting). *Entomol Heute.* 2007;7:19-23.

3. Lesnik JJ. Termites in the hominin diet: A meta-analysis of termite genera, species and castes as a dietary supplement for South African robust australopithecines. J Hum Evol. 2014;71:94-104. http://dx.doi.org/10.1016/j.jhevol.2013.07.015

4. Banjo AD, Lawal OA, Songonuga EA. The nutritional value of fourteen species of edible insects in Southwestern Nigeria. Afr J Biotechnol. 2006;5(3):298-301.

5. Mbah CE, Elekima GOV. Nutrient composition of some terrestrial insects in Ahmadu Bello University, Samaru, Zaria Nigeria. Sci World J. 2007;2(2):17-20. http://dx.doi.org/10.4314/swj.v2i2.51728

6. Phelps RJ, Struthers JK, Moyo SJL. Investigations into the nutritive value of *Macrotermes falciger* (Isoptera: Termitidae). Afr Zool*.* 1975;10:123-132. DOI: http://dx.doi.org/10.1080/00445096.1975.11447501

7. Ayieko MA. Nutritional value of selected species of reproductive Isoptera and Ephemeroptera within the ASAL of Lake Victoria basin. Discov Innov. 2007;19(2):126-130.

8. Igwe CU, Ujonwundu CO, Nwaogu LA, Okwu CN. Chemical analysis of an edible termite, *Macrotermes nigeriensis*; A potential antidote to food security problem. Biochem Anal Biochem. 2011;1:105. http://dx.doi.org/10.4172/2161-1009.1000105

9. Ajayi OE, Adedire CO. Nutrient characteristics of the subterranean termite, *Macrotermes subhyalinus* (Rambur) (Isoptera: Termitidae). Nig J Entomol. 2007;24:42-47.

10. Silow CA. Notes on Ngangela and Nkoya ethnozoology. Ants and termites. Etnol Stud. 1983;36:177.

11. Chavunduka DM. Insects as a source of protein to the African. The Rhodesia Science News. 1975;9:217-220.

12. van Huis A. Insects as food in sub-Saharan Africa. Insect Sci Appl. 2003;23(3):163-185. http://dx.doi.org/10.1017/S1742758400023572

13. Ruelle JE. A revision of the termites of the genus *Macrotermes* from the Ethiopian region (Isoptera: Termitidae). Bull Brit Mus (Nat Hist) Entomol. 1970;24(9):365-450.

14. Ruelle JE, Coaton WGH, Sheasby JL. National survey of the Isoptera of Southern Africa. The genus *Macrotermes* (Holmgren) (Termitidae: Macrotermitinae). Cimbebasia (Series A). 1975;3(8):73-94.

15. Ruelle JE. Isoptera. In: Werger MJA, van Bruggen AC, editors. Biogeography and Ecology of Southern Africa. W. Junk, The Hague; 1978. p. 747-762.

16. Ajayi OE. Biochemical analysis and nutritional content of four castes of subterranean termites, Macrotermes sybhyalinus (Rambur) (Isoptera: Termitidae) Differences in digestibility and anti-nutrient contents among castes. Int J Biology. 2012;4(4):54-59. http://dx.doi.org/10.5539/ijb.v4n4p54

17. Bodenheimer FS. Insects as Human Food: A Chapter of the Ecology of Man. Dr. W. Junk, Publishers, The Hague; 1951.

18. Quin PJ. Food and feeding habits of the Pedi with special reference to identification, classification, preparation and nutritive value of the respective foods. Witwatersrand University Press, Johannesburg; 1959.

19. Takeda J. The dietary repertory of the Ngandu people of the tropical rain forest: An ecological and anthropological study of the subsistence activities and food procurement technology of a slash and burn agriculturist in the Zaire River basin. Afr Study Monogr Suppl. 1990;11:1-75. http://dx.doi.org/10.14989/68351

20. Bergier E. Peuples entomophages et insectes comestibles: étude sur les moeurs de l'homme et de l'insecte. Avignon, Imprimerie Rulliere Freres; 1941.

21. Niaba KPV, Ocho-Anin AL, Gbassi KG, Beugre AG, Adou M, Anon AB, Gnakri D. Consumption survey of edible winged termites in Cote d'Ivoire. Int J Agr Food Sci. 2012;2(4):149-152.

22. Nonaka K. Ethnoentomology of the central Kalahari San. Afr Study Monogr Suppl.. 1996;22,29–46.

23. van Averbeke W. Improving Plot Holder Livelihood and Scheme Productivity on Smallholder Canal Irrigation Schemes in the Vhembe District of Limpopo Province. 2013.

24. Mpandeli NS. Managing Climate Risks Using Seasonal Climate Forecast Information in Vhembe District in Limpopo Province, South Africa. J Sustain Dev. 2014;7(5):68-81. http://dx.doi.org/10.5539/jsd.v7n5p68

25. Mpandeli NS. Coping with climate variability in Limpopo Province. Unpublished PhD thesis, University of Witwatersrand; 2006.

26. Gaffney. Local Government in South Africa 2009 – 2011. Official Yearbook, 2009;948-950.

27. Isaacs M, Mohamed N. Co-managing the commons in the new South Africa: Room for Manoeuvre? In: 8th Biennial Conference of the International Association for the Study of Common Property, University of Western Cape; South Africa; 2000.

28. Statistics South Africa. Community Survey, Revised version: Statistical release. Pretoria: Statistics South Africa. 2007

29. Biernacki P, Waldorf D. Snowball sampling: problem and techniques of chain referral sampling. Sociological Methods and Research. 1981;10:141–163.

30. SAS. SAS® Statistics User's Guide, Statistical Analysis System, 9.3 version, SAS Institute Inc, Cary, NC, USA; 2012.

31. Snedecor GW, Cochran WG. Statistical methods, 7th edition. Ames, Iowa State University Press; 1980. p 234.

32. Roonwal ML. Termites of the Oriental region. In: Krishna K, Weesner FM, editor. Biology of termites. Academic, New York; 1969;2:315-391.

33. Meyer VW. Intracolonial demography, biomass and food consumption of *Macrotermes natalensis* (Haviland) (Isoptera: Termitidae) colonies in the Northern Kruger National Park, South Africa (dissertation). University of Pretoria; 2001.

34. Uys V. A guide to the Termite Genera of Southern Africa. Plant Protection Research Institute Handbook No. 15. Agricultural Research Council; Pretoria; 2002.

35. Nyeko P, Olubayo FM. Participatory assesssment of farmers'experiences of termites problems in agroforestry in Toronto, Uganda. Agricultural Research and Extension Network. 2005.

36. Wiley SS, Katz SH. Geophagy in pregnancy: a test of a hypothesis. Curr Anthropol. 1998;39:532-545.

37. Saathoff E, Olsen A, Kvalsvig JD, Geissler PW. Geophagy and its association with geohelminth infection in rural schoolchildren from KwaZulu-Natal, South Africa. Trans R Soc Trop Med Hyg. 2002;96:485-490.

38. Figueirêdo RECRde, Alexandre V, Iamara SP, Alves RRN. Edible and medicinal termites: a global overview. J Ethnobiol Ethnomed. 2015;11:29. http://dx.doi.org/10.1186/s13002-015-0016-4

39. Egan BA. Culturally and Economically Significant Insects in the Blouberg Region, Limpopo Province, South Africa. Unpublished PhD thesis, University of Limpopo; 2013.

40. Roulon-Doko P. Les activités de cueillète. In: van Huis, editor. Insects as food in sub-Saharan Africa. Insect Sci Appl. 1998;23(3):163–185.

41. Statistics South Africa. Livestock Prices. Pretoria: Statistics South Africa. 2017

CHAPTER 3: AN EVALUATION OF THREE FIELD SAMPLING METHODS TO DETERMINE TERMITE DIVERSITY IN CATTLE GRAZING LANDS

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Netshifhefhe major contributer, helped design the experiment, collected the data, analysed the data and wrote the manuscript, Kunjeku and Duncan are supervisors of Netshifhefhe, Visser provided advice and access to the area where the study was conducted, Madzivhe assisted with the data collection.

3.1. ABSTRACT

The aim of this survey was to evaluate three field termite sampling methods to investigate whether there is a method for the evaluation of termite diversity which does not require experienced personnel. The sampling methods included the cattle dung method, toilet paper roll method and the visual searching (scouting) method. The methods were evaluated in a transect of 2 x 100 m in cattle grazing lands during the dry and wet seasons. Thirteen species from eight genera and three sub-families were recorded with all three methods. The results for the number of species detected revealed differences between the three methods with 57% of the termite species found using the transect search method, 29% of the species were attracted to the cattle dung bait and 14% attracted to the toilet roll bait. The most abundant species, based on the number of encounters, was for individuals in the *Odontotermes* genus 15 (33%), followed by *Microtermes* 12 (27%). A higher Shannon diversity index (1.80) was recorded with the transect search method, followed by the cattle dung bait method (1.54), while the toilet roll bait method recorded the lowest diversity index (0.95). Results of the Chao2 and Jackknife estimators showed that all the methods underestimated the taxa present. A combination of the transect search method and the cattle dung bait method is recommended for monitoring termite diversity.

Keywords: termite diversity index, cattle dung bait, transect search method, feeding groups.

3.2. INTRODUCTION

Termites play a significant role in the functioning of ecosystems. Jouquet *et al*. (2011) found that termites have a positive effect on faunal and floral biodiversity and ecosystem stability. Habitat loss due to agriculture and other activities threatens biodiversity. For termites, habitat loss is always accompanied by selective loss of certain functional groups, especially the soil feeders (Eggleton *et al*. 2002). In order to predict how ecosystems will be affected along a habitat disturbance gradient, assessment of changes in termite species biodiversity is essential (March 2013).

Termite species diversity and richness can be determined through sampling and monitoring programs. The number of termite species captured and/or occurrences provide a relative measure of their composition and activity (Debelo *et al*., 2014). Chao2 and Jackknife are some of the estimators used for measuring true species richness and are used to find what the 'true' number of species may have been in a bio-community (Colwell & Coddington, 1994; Chazdon *et al.*, 1998; Hortal *et al*., 2006). Chao2 can detect the number of unsampled species of an area based on the observed number of species (S_{obs}) (Chao, 1984). The Jackknife estimator is based on the presence or absence of a species in a given area (Turkey, 1958; Heltshe & Forrester, 1983). Cumulative number of observed species are used to develop species accumulation curves (Colwell *et al*., 2004). Species accumulation curves helps to determine sufficient collecting to stop sampling and shows the rate of which new species are found. The curves assume that initially new species will be collected with each subsequent sample, thereafter collecting the same species already collected in the previous samples called an asymptotic maximum number of species (Gotelli & Chao, 2013). Sampling should be thorough to reveal the total species richness, otherwise incomplete sampling results in upward trend curves, showing the extent to which more species would have been found should the sampling efforts increased.

Research on the importance of termite diversity to soil function is hampered by sampling difficulties and lack of standardized sampling protocols (Dawes-Gromadzki 2003; Jones & Eggleton 2000). Sampling techniques, costs and habitat conditions should be considered when selecting a suitable sampling method of the targeted species (Gullan & Cranston 2005).

Several methods have been used to estimate termite species populations and diversity (e.g. Taylor *et al*. 1998; Zeidler *et al*. 2004; Sheppe 1970). These methods include baits, using artificial and natural products, soil cores and visual transect search or scouting. Artificial baits are usually made of uncoated corrugated cardboard blocks (Taylor *et al*. 1998) and unscented rolls of toilet paper. Lafage *et al*. (1973) and Taylor *et al*. (1998) demonstrated that the toilet rolls were more attractive for termites, with 83% of the samples containing termites, although theft of toilet rolls and disturbances by pack rats (*Neotoma* sp.) were a concern. Cattle dung filled tins buried in soil have also been successful in attracting termites (Taylor *et al*. 1998). Other natural baits used in the past include *Dasyochloa pulchella* and *Bismarckia nobilis* stems (Taylor *et al*. 1998) and pine wood medical tongue depressors (Zeidler *et al*. 2004). In both these studies the cattle dung was found to be the more effective natural bait. Davies *et al*. (2012) found baiting to be a quantitative assessment of termite activity. Other methods have involved searching the area for termites (Coaton & Sheasby 1972; Zeidler *et al*. 2004) and using litter sweeps (Taylor *et al.* 1998). To standardize the termite searching methods, Davies (1997) and Eggleton *et al*. (1997) developed a standard belt transect method which has been successful in determining termite diversity in tropical regions.

All the various methods demonstrated significant variation in termite diversity and abundance (Zeidler *et al*. 2004), with accompanying differences in cost implications. Thus, the objectives of this study were to evaluate three methods for determining termite activity, species diversity and relative occurrence, as well as dominance of species. Results from this study should assist in the implementation of a quick evaluation strategy for the detection of termite biodiversity without needing experienced personnel.

3.3. MATERIALS AND METHODS

3.3.1. Study area

The study was carried out over two seasons (wet and dry) on a cattle grazing farm of the Agricultural Research Council-Animal Production Institute (ARC-API), Roodeplaat, Gauteng (northeast of Pretoria) (25°33’7”S, 28°23’14”E), South Africa. The study was conducted between September 2015 and March 2017. The area falls within the austral summer rainfall region and receives an average precipitation of 650 mm per annum (Nyathi *et al*. 2016). The rainfall season is from October to March. The highest average monthly temperature at Roodeplaat is in January (30 °C), and the lowest average monthly temperature in July (1.5 °C). The vegetation is dominated by two grass species, *Heteropogon contortus* and *Aristida congesta*. Sweet thorn trees (*Vachellia karroo*) were scattered amongst the grasses on the southern side of the transect. A few *Odontotermes* mounds were scattered on the edge of the field.

3.3.2. Termite sampling

The three sampling methods that were evaluated were: standardized transect search protocol as prescribed by Eggleton *et al.* (1997) and Davies (1997), cattle dung bait, and the toilet paper roll (cardboard tubes) bait as described by Taylor *et al.* (1998). The three methods have not been tested in disturbed semi-arid savannas.

The transect dimension was 2 × 100 m, which was divided into 18 sampling sections of 2 × 5 m (Fig. 3.1). The experiment consisted of three treatments with six replications. The cattle dung baits and the toilet paper roll baits were placed using a triangle fractal sampling design (Ewers & Marsh, 2013). The baits were buried 15 m apart, with groups of three baits per sampling section.

Fresh cattle dung was collected from a cattle kraal in the early morning and used to fill 340 ml clear plastic bottles without lids. They were buried upside down, 12 cm deep, and covered with soil. In preliminary experiments it was found that when bottles were buried with the open side up and uncovered, the dung dried out too quickly to attract termites.

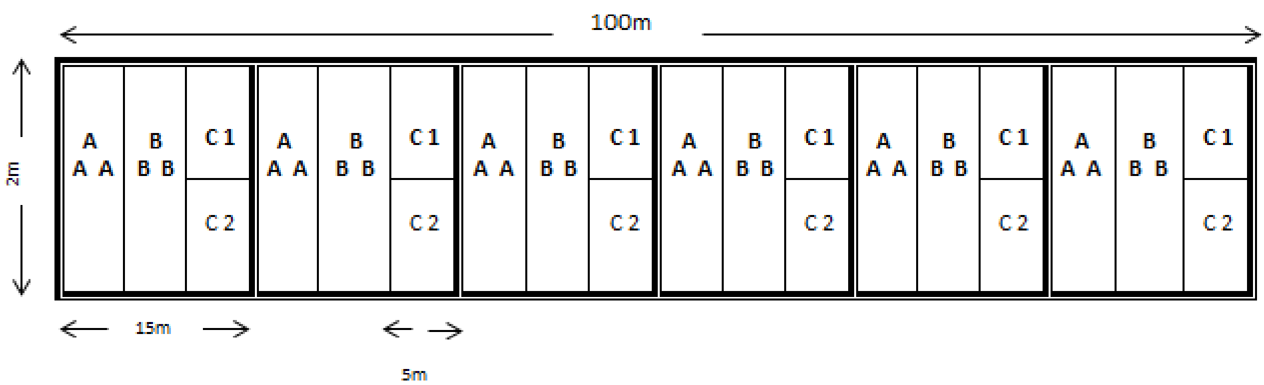

Fig. 3.1 A diagrammatical representation of the experimental layout/design. Transect of 100 m x 2 m with three termite sampling methods. Two bait types and one search method. A, Cattle dung bait, B, Cardboard roll bait, C1 and C2, Standard transect search method. The 100m transect is divided into the six repetitions.

The toilet paper roll baits were buried similarly to the cattle dung baits. The top of the toilet paper roll was covered with aluminium foil to prevent foreign objects from falling into the opening; the inside of the roll was therefore kept open. The cattle dung baits and toilet paper roll baits were buried to prevent desiccation or removal by animals.

The baits were examined after 7, 14, and 28 days. At each of these time intervals, 12 baits (six dung and six toilet paper rolls) were removed and any termites present were collected. The numbers of baits attacked were recorded during each examination interval; any bait station damaged or removed by cattle or wild animals was also noted. In addition to the cattle dung baits that were placed within the transect, 12 more dung baits were buried next to four *Odontotermes* termite mounds adjacent to the transect. A further nine cattle dung baits were buried under *V. karroo* trees, and another nine cattle dung baits were buried between grasses, all adjacent to the transect. The reason for placing out these extra cattle dung baits was to investigate if termite species other than the ones intercepted within the transect, would be attracted.

The standard transect search method was performed in the third subdivision of each repeating block, which was further subdivided into two sections. Because the search area was dominated by grasses, a modified search method was used (Jones & Eggleton 2000). Two trained people sampled each subdivided section for 15 min (a total of 30 min per block). The micro-habitats that were sampled included: soil surface, a layer of soil 10 cm deep, grass roots, mud runways, and mud runways on plants and on the soil surface. The sampling was undertaken during the early morning.

There was a total of 18 experimental units or traps for each sampling method per season. The effectiveness of the methods used was based on the total number of species recorded, and species diversity occurrences encountered. Occurrence is when a species is found or encountered. All termites collected were placed in vials containing 80% ethanol, for identification by the Agricultural Research Council-Plant Protection Research Institute (ARC-PPRI) in Pretoria, South Africa. Termites were identified to species level using morphological characters

3.3.3. Data analysis

Generalized Linear Model (GLM) analysis was used with the Poisson distribution and logarithmic link to test for differences between the three methods, three day intervals, and wet and dry season effects, as well as interactions and baits attacked (Payne 2014). Bait attack is the presence of termites on the bait or presence of termite fragments on the bait in case of no termite found during the sampling period. The GLM was used because termite occurrences did not correspond with the assumptions for normality and homogeneous variances. Predicted means were separated using Fisher's protected least significant difference test at the 5% level of significance (Snedecor & Cochran 1980). Termite species occurrence was calculated by dividing the number of occurrences where termite species were detected by the total number of occurrences multiplied by 100. The collected data were summarized using descriptive statistics and cross tabulation. Simpson's Diversity Index (1-D) and the Shannon Wiener (H) Index were used to measure termite species diversity with all three methods. All data were analysed using the statistical program GenStat® (Payne 2014). Species accumulation curves were constructed to calculate the average species richness for each sampling method using Estimates 9.0.1 software (Colwell 2013). Species richness was estimated and compared for all seasons combined per method using Jackknife and Chao2 estimators to make predictions of total species richness.

3.4. RESULTS AND DISCUSSION

3.4.1. Termite species composition and diversity

A total of 13 termite species were trapped or observed by all three methods over a period of 56 days during the dry and wet seasons (Table 3.1). Six species were collected in the dry season and 11 during the wet season. Four of the species detected in the dry season were again detected during the wet season. The 13 termite species trapped or observed belonged to two families (Termitidae and Hodotermitidae), five sub-families (Macrotermitinae, Nasutitermitinae, Cubitermitinae, Amitermitinae and Hodotermitinae) and eight genera (*Odontotermes*, *Trinervitermes*, *Microtermes, Allodontermes, Fulleritermes, Microcerotermes, Hodotermes* and *Lepidotermes*).

The termite species recorded belonged to three feeding groups: wood and leaf consumers, incorporating fungus growers (WL); grass feeders (G); and soil/humus consumers (SH). The WL group were the most abundant, comprising 69% of the total species. Apart from *Hodotermes mossambicus* and *Trinervitermes trinervoides* that mainly feed on grass and *Lepidotermes lounsburyi* that feed on soil or humus, all the other species were wood and litter feeders that often take leaves and woody items for temporary storage back in the nest. Two nesting groups were represented, i.e. subterranean (S) and epigeal (E). The subterranean group comprised 46% of all species, while the epigeal and unidentified groups made 38% and 15% respectively.

The studies conducted by Mugerwa *et al*. (2011) in the grazing land of the semi-arid region of Nakasongola District in Uganda found that Macrotermitinae and Termitinae were the most dominant termite species. In this study, the most represented subfamily was Macrotermitinae with seven species (54%), and Nasutitermitinae and Cubitermitinae with 15% each. The most abundant species based on the number of encounters were in the *Odontotermes* genus 15 (33%) which were represented by four species, and *Microtermes* 12 (27%). *Microcerotermes* sp., *H. mossambicus* and *L. lounsburyi* were rarely encountered. The Simpson's Diversity Index (D-1) and Shannon Wiener Index (H) values are indicated in Table 3.2. I observed a higher Shannon diversity index (1.80) and Simpson diversity index (0.89) in the transect search method, followed by the cattle dung bait method 1.54 and 0.73, while the toilet roll bait method recorded the lowest diversity indexes of 0.95 and 0.56 respectively.

Table 3.1 Number of termites samples and classified by feeding and nesting groups and number of occurrences using three sampling methods over two seasons within the transect. [Nesting group: S – subterranean, E – epigeal. Feeding group: WL - Wood and leaves consumers / Fungus growers, W – Wood, SH - Soil or humus consumers, G – grass].

Family/Subfamily/Species	Sampling method/Season						Total	Nesting group	Feeding group
	Cattle dung		Search		Toilet roll				
	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season			
Termitidae: Macrotermitinae									
Allodontermes rhodesiensis	-	1	-	3	-	-	**4**	S	WL
Microtermes sp.	-	6	-	3	1	2	**12**	S	WL
Odontotermes badius	2	-	-	1	-	-	**3**	E	WL
Odontotermes latericius	2	1	-	5	-	-	**8**	E	WL
Odontotermes sp.	1	-	2	-	-	-	**3**	E	WL
Odontotermes transvaalensis	-	-	-	-	-	1	**1**	E	WL
Indet*	-	-	2	-	-	-	**2**	-	WL
Termitidae: Nasutitermitinae									
Fulleritermes coatoni	-	-	-	1	-	-	**1**	S	WL
Trinervitermes trinervoides	-	1	1	3	-	-	**5**	E	G
Termitidae: Cubitermitinae									
Lepidotermes lounsburyi	-	-	-	1	-	-	**1**	S	SH
Indet*	-	-	-	1	-	1	**2**	-	SH
Termitidae: Amitermitinae									
Microcerotermes sp.	-	-	-	2	-	-	**2**	S	WL
Hodotermitidae:									
Hodotermes mossambicus	-	-	-	1	-	-	**1**	S	G
Total number of encounters	**5**	**9**	**5**	**21**	**1**	**4**	**45**		
Unique species	**0**		**5**		**1**				
Total number of species	**6**		**12**		**3**				

*These species were only identified to Family level

Table 3.2 Number of termites sampled in the dry and wet season. [The diversity indexes were calculated by combining the seasonal data. The values in the table for the method and baits attacked are percentages with actual counts in brackets].

	N (Dry season)			**N (Wet season)**			**Total**	**Simpson's Diversity Index (1-D)**	**Shannon Wiener Index (ΣH^1)**
	Day 7	Day 14	Day 28	Day 7	Day 14	Day 28			
Sampling Method									
Cattle dung bait	2.22 (1)	8.89 (4)	0.00 (0)	8.89 (4)	6.67 (3)	4.44 (2)	**31.11 (14)**	0.7347	1.5367
Toilet paper roll bait	0.00 (0)	0.00 (0)	2.22 (1)	2.22 (1)	6.67 (3)	0.00 (0)	**11.11 (5)**	0.5600	0.9503
Transect search	4.44 (2)	4.44 (2)	2.22 (1)	17.78 (8)	11.11 (5)	17.78 (8)	**57.78 (26)**	0.8920	1.8019
Total number of occurrences	**6.67 (3)**	**13.33 (6)**	**4.44 (2)**	**28.89 (13)**	**24.44 (11)**	**22.22 (10)**	**100.00 (45)**		
Baits attacked									
Cattle dung bait	4.17 (1)	8.33 (2)	8.33 (2)	16.67 (4)	12.50 (3)	8.33 (2)	**58.33 (14)**		
Toilet paper roll bait	0.00 (0)	0.00 (0)	8.33 (2)	4.17 (1)	12.50 (3)	16.67 (4)	**41.67 (10)**		
Total number of baits attacked	**4.17 (1)**	**8.33 (2)**	**16.67 (4)**	**20.83 (5)**	**25.00 (6)**	**25.00 (6)**	**100.00 (24)**		

3.4.2. Frequency of bait attacks

Eighty six percent (31/36) of the toilet paper rolls were recovered within the transect. The rest were damaged or removed by cattle and wild animals (5/36). Only 10 (32%) showed signs of termite attack and/or activity. Four toilet paper roll baits were completely consumed, while the others had termite feeding marks in and on the outside. No termites were found where the rolls were completely consumed, only fragments of the toilet roll.

Most (35/36) of the cattle dung baits were recovered. Termite activity was observed as follows: within the transect, 14/35 (40%); next to mounds, 16/24 (67%); under trees, 7/12 (58%); and on grasses, 6/12 (50%). Termites typically made tunnels and runways inside the cow dung within the plastic containers. All baits that were attacked showed tunnelling; two of the baits were incorporated into the mound with mud structures. Eleven percent of the baits within the transect were completely tunnelled. Five baits placed next to mounds were also tunnelled. Tunnelling was only observed during the dry season. A reason might be a shortage of leaf litter and other food substances during the dry season.

All the dung baits attacked next to the mounds were situated on the south-eastern side of the mounds, while none on the northern side of the mounds was attacked. The reason for this observation must still be investigated. The frequency of attack and number of species encountered within the transect was higher with the cattle dung bait compared to the toilet paper roll baits.

3.4.3. Performance of sampling methods

Most (8) genera were sampled using the transect search method, with 4 genera sampled using the cattle dung bait method and only 2 genera sampled using the toilet roll bait method. The transect search method recorded seven species of wood and leaf consumers / fungus growers, followed by the cattle dung bait with five, and toilet paper roll bait with two species (Table 3.1). The cattle dung bait and transect search methods recorded the same number (4) of epigeal nesting species with only one species recorded by the toilet roll bait method. Six of the subterranean nesting species were collected by the transect search method with only two species by the cattle dung bait method and one species from the toilet roll bait method.

Six termite species were recorded with the cattle dung bait method within the transect (Table 3.1). Three species belong to the genus *Odontotermes*, with eight encounters amounting to 18% of all the total occurrences. Termite taxa detected by cattle dung baits placed next to *Odontotermes* mounds, between grasses, under *V. karoo* trees were the same species detected by this method within the transect. The cattle dung bait method only attracted workers and alates, and because soldiers are needed for species identification, some of these could only be identified to subfamily level.

The toilet paper roll bait method recorded fewer species compared to the other two methods (Table 3.1). Only five observations were made over two seasons, comprising 23% of the total number of species. Only three species were recorded using this method, the least of all three methods. Two of the species detected by this method were also detected by the other two methods. Compared to the other bait method, toilet paper roll bait recorded less genera, as we observed only three species with this method compared to six species using cattle dung as bait.

The standard transect search method captured more termite species 12 (92.31%) than the other two methods (Table 3.1). This is the only method that detected both termite families (five sub-families). The most dominant species collected by the transect search method was *Odontotermes latericius* (five encounters during the wet season) followed by *T. trinervoides* (three encounters during the wet season and one during the dry season). *Fulleritermes coatoni*, *L. lounsburyi* and *H. mossambicus* were all detected on one occasion, all during the wet season. Six of the 12 species detected by the transect search method were not detected by the other two methods. This method should therefore be preferred in biodiversity studies.

There were significant differences in the efficacy of the methods used in two seasons. A GLM analysis with Poisson distribution and logarithmic link revealed significant ($P < 0.05$) differences among the counts for the three methods and also between seasons (wet & dry) (Table 3.3) but not among the day intervals (day interval 7, 2.67 ± 0.67; day 14, 2.83 ± 0.69; day 28, 2.0 ± 0.58). There was no evidence of differences over the day intervals ($P > 0.05$). My results also show that the most useful methods were transect search and cattle dung bait. In combination, these methods recorded the highest occurrences and most species. The methods (over the day/time intervals) were significantly different ($P < 0.001$), with the transect search method (26 occurrences, 57.8%), not different from that of the cattle dung method (14 occurrences, 31.1%), but both these methods significantly different from the toilet roll method (5 occurrences, 11.1%). The tests for significance of the effects between the termite species occurrences (mean number of encounters per species ± SE) for the three sampling methods differed significantly using Fisher's LSD test at 5% level, with transect 4.33 and cattle dung 2.33 significantly different from that of toilet roll bait 0.83. The season effect differed significantly with more occurrences in the wet season (3.78) than in the dry season (1.22) (Table 3.3). There was no significant differences on baits attacked between the two baiting methods, day intervals or any interactions ($P > 0.05$) (day 7, 1.5 ± 0.61; day 14, 2.0 ± 0.71; day 28, 2.5 ± 0.79). The two season means (over the methods and day intervals) were significantly different ($P = 0.038$), with the dry season (7 attacks, 29.2%), significantly lower from that of the wet season (17 attacks, 70.8%) (Table 3.3).

Table 3.3 Tests for significance of the effects between the termite species occurrences (mean number of encounters per species ± SE) for the three sampling methods and baits attacked. GLM with Poisson distribution and log-link function was used. The number in brackets is the total occurrences.

Characteristics	Sampling method			Season	
	Cattle dung bait	Toilet roll bait	Transect search	Dry	Wet
Termite species occurrences					
Mean ± SE	2.33 ± 0.62a (14)	0.83 ± 0.37b (5)	4.33 ± 0.85a (26)	1.22 ± 0.37b (11)	3.78 ± 0.65a (34)
Baits attacked					
Mean ± SE	2.33 ± 0.62a (14)	1.67 ± 0.53a (10)	-	1.17 ± 0.44b (7)	2.83 ± 0.69a (17)

Means within the season or sampling method occurrences followed by the same letters did not differ significantly (*P* > 0.05) using Fisher's LSD test

3.4.4. Analysis of species detected by methods

The transect search method detected 57.1% of all the different species, followed by the cattle dung bait method that detected 28.6% and lastly the toilet roll method that only detected 14.3% of all the different species. I compared the three methods using species accumulation curves based on the number of species richness (Fig. 3.2). All the three methods failed to reach a clear asymptote on sample-based rarefaction curve of computed species observations. The observed species richness (S_{obs}) for the toilet paper roll bait method (3) is likely to increase to 6 using Chao2 and Jackknife estimators while the cattle dung bait method S_{obs} 6 which is likely to increase to 7 on Chao2 and 9 for Jackknife where transect search method S_{obs} 12 likely to increase to 16 using Chao2 estimator and 16 for Jackknife estimator. In my study, based on this range of estimators, if only one method was used, 1 to 4 species may not have been sampled. The addition of cattle dung bait method to the toilet roll bait method increased the estimated species richness detected by the two baits and incorporating the transect search method further more than doubled the species richness. The overall species richness was influenced by the land use type. My results suggest that all the methods underestimated the taxa present with the highest underestimation from using the toilet roll bait method. The species accumulation curves for all the methods suggest that the number of species would have been more were the sampling efforts increased.

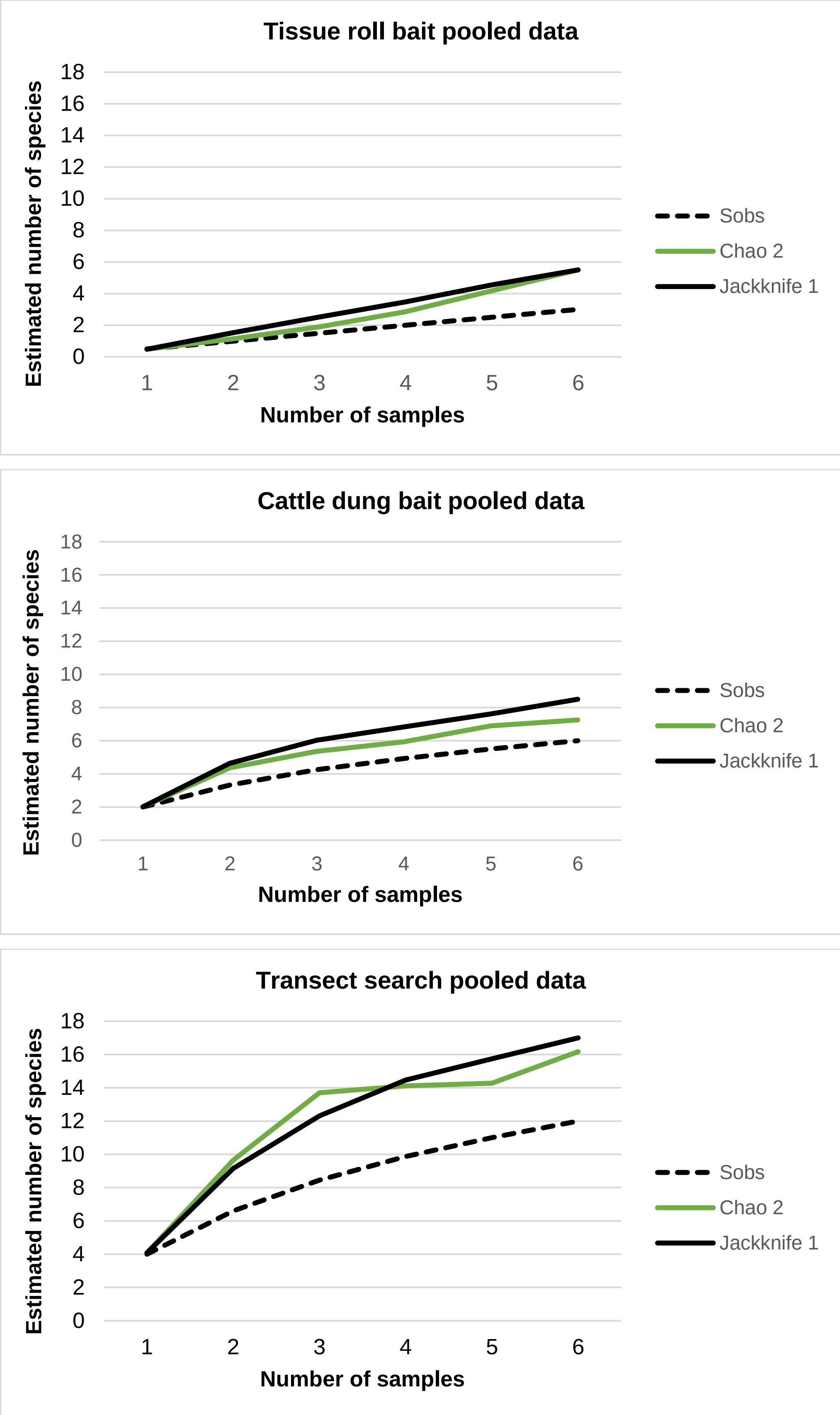

Fig. 3.2 Species accumulations. Observed and estimated species richness for cattle dung bait, toilet roll bait and transect search methods.

3.4.5. Comparative analysis of sampling methods

None of the three sampling methods detected all the termite species. Unique species were captured by transect search and toilet toll baits methods (Table 3.1). Cattle dung and toilet roll baits methods captured many of the same species captured by transect search method. Only one termite species, *Microtermes* sp. was captured by all methods. It was also the most abundant species (occurrences) captured on 12 occasions, followed by *O. latericius,* captured on eight occasions (Table 3.1). The toilet paper roll bait method mostly recorded the non-dominant species. The relative abundance of termites based on the number of occurrences by each method is given in Table 3.2. Transect search method recorded the highest occurrences followed by cattle dung bait method while toilet paper roll bait method was the least effective.

The Simpson's Diversity Index (D-1) and Shannon Wiener Index (H) values are indicated in Table 3.2. Both these indexes revealed a higher diversity with the transect search method than with the other two methods. The difference between two diversity indices is that Simpson measures dominance while Shannon Weiner assumes equal and random samples. Collections with the toilet roll bait method resulted in the lowest diversity. Studies conducted by Adekunle (2006) found that the physical environment such as soil characteristics and temperature could affect soil arthropod abundance and diversity, a possible reason for the higher abundance and diversity in the wet season. That only two toilet paper rolls were attacked by termites during the dry season suggest that soil moisture is an important variable affecting foraging activities of termites. *Microtermes* sp. are polyphagous herbivores and detritivores (Uys 2002). The rare occurrence of *T. trinervoides* in the dry season could have been attributed to the slow regeneration of grasses, due to high temperatures and no rainfall. The high temperatures combined with no rain during the dry season may also have forced the subterranean termite species to move deeper down into the soil and thus did not come into contact with the shallowly buried baits. Mitchel *et al*. (1993) also found that termites stayed in nesting sites or shelters for longer periods to protect themselves from high temperatures.

3.5. CONCLUSION

I conclude that the most effective methods for determining termite diversity in cattle grazing lands are the transect search and cattle dung bait methods. A combination of these two methods should give a good indication of termite diversity required for biodiversity studies. In addition, the cattle dung bait method does not require high cost, maintenance, or trained personnel, and has low risk of theft. Other advantages of the cattle dung method during this study include: easy to set up (readily available dung in cattle areas), environmentally friendly and low risk of damage by animals or weather conditions. Although, my results showed that the use of cattle dung was effective, this should be augmented with other methods.

3.6. ACKNOWLEDGEMENTS

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3.7. REFERENCES

ADEKUNLE, V.A.J. 2006. Conservation of tree species diversity in tropical rainforest ecosystem of south west Nigeria. *Journal of Tropical Forest Science* **18**: 91-101.

CHAO, A. 1984. Non-parametric estimation of the number of classes in a population. *Scandinavian Journal of Statistics* **11**: 265-270.

CHAZDON, R., COLWELL, R., DENSLOW, J. & GUARIGUATA, M. 1998. Statistical methods for estimating species richness of woody regeneration in primary and secondary rain forests of NE Costa Rica, p. 285-309. In Dallmeier, F. & Comiskey, J. (eds.), *Forest Biodiversity Research, Monitoring and Modeling: Conceptual Background and Old World Case Studies*. Parthenon Publishing, Paris.

COATON, W.G.H. & SHEASBY, J.L. 1972. Preliminary report on a survey of the termites (Isoptera) of South West Africa. *Cimbebasia Memoir* **2**: 1-129.

COLWELL, R.K. 2013. EstimateS: Statistical estimation of species richness and shared species from samples. Version 9. User's Guide and application. Available online at http://purl.oclc.org/estimates.

COLWELL, R.K. & CODDINGTON, J.A. 1994. Estimating terrestrial biodiversity through extrapolation. *Philosophical Transactions of the Royal Society B: Biological Sciences* **345**: 101-118.

COLWELL, R.K., MAO, C.X. & CHANG, J. 2004. Interpolating, extrapolating, and comparing incidence-based species accumulation curves. *Ecology* 85: 2717-2727.

DAVIES, R.G. 1997. Termite species richness in fire-prone and fire-protected dry deciduous dipterocarp forest in Doi Suthep-Pui National Park, northern Thailand. *Journal of Tropical Ecology* **13**: 153-160.

DAVIES, A.B., EGGLETON P., VAN RENSBURG, B.J. & PARR, C.L. 2012. The pyro diversity biodiversity hypothesis: A test with savanna termite assemblages. *Journal of Tropical Ecology* **49**: 422-430.

DAWES-GROMADZKI, T.Z. 2003. Sampling subterranean termite species diversity and activity in tropical savannas: an assessment of different bait choices. *Ecological Entomology* **28**: 397-404.

DEBELO, D.G. & DEGAGA, E.G. 2014. Termite species composition in the central rift valley of Ethiopia. *Agriculture and Biology Journal of North America* **5**(3): 123-134.

EGGLETON, P., HOMATHEVI, R., JEEVA, D., JONES, D.T., DAVIES, R.G. & MARYATI, M. 1997. The species richness and composition of termites (Isoptera) in primary and regenerating lowland dipterocarp forest in Sabah, East Malaysia. *Ecotropica* **3**: 119-28.

EGGLETON, P., BIGNELL, D.E., HAUSER, S., DIBOG, L., NORGROVE, L. & MADONG, B. 2002. Termite diversity across an anthropogenic gradient in the humid forest zone of West Africa. *Agriculture, Ecosystems and Environment* **90**: 189-202.

EWERS, M.R. & MARSH, C.J. 2013. A fractal-based sampling design for ecological surveys quantifying β-diversity. *Methods in Ecology and Evolution* **4**: 63-72.

GOTELLI, N.J. & CHAO, A. 2013. Measuring and Estimating Species Richness, Species Diversity, and Biotic Similarity from Sampling Data. In: Levin S.A. (ed.) *Encyclopedia of Biodiversity*, second edition, Volume 5, pp. 195-211. Waltham, MA: Academic Press.

GULLAN, P.J. & CRANSTON, P.S. 2005. *The Insects: an Outline of Entomology. Chapter 17. Methods in Entomology: Collecting, Preservation, Curation, and Iidentification*. Wiley-Blackwell, Hoboken, NJ, U.S.A.

HELTSHE, J. & FORRESTER, N.E. 1983. Estimating species richness using the jackknife procedure. *Biometrics* **39**: 1-11.

HORTAL, J., BORGES, P. & GASPAR, C. 2006. Evaluating the performance of species richness estimators: sensitivity to sample grain size. *Journal of Animal Ecology* **75**: 274-287.

JONES, D.T. & EGGLETON, P. 2000. Sampling termite assemblages in tropical forests: testing a rapid biodiversity assessment protocol. *Journal of Applied Ecology* **37**: 191-203.

JOUQUET, P., TRAORÉ, S., CHOOSAI, C., HARTMANN, C. & BIGNELL, D. 2011. Influence of termites on ecosystem functioning. Ecosystem services provided by termites. *European Journal of Soil Biology* **47**: 215-222.

LAFAGE, J.P., NUTTING, W.L. & HAVERTY, M.L. 1973. Desert subterranean termites: a method for studying foraging behavior. *Environmental Entomology* **2**: 954-956.

MARCH, J.J. 2013. Termite (Blattodea: Termitoidae) functional diversity across a forest disturbance gradient in Sabah, Malaysia. Thesis, Imperial College, London, U.K.

MITCHELL, J.D., HEWITT, P.H. & VAN DER LINDE, T.C. 1993. Critical thermal limits and temperature tolerance in the harvester termite *Hodotermes mossambicus* (Hagen). *Journal of Insect Physiology* **39**(6): 523-528.

MUGERWA, S., NYANGITO, M., MPAIRWE, D., BAKUNEETA, C., NDERITU, J. & ZZIWA, E. 2011. Termite assemblage structure on grazing lands in semi-arid Nakasongola. *Agriculture and Biology Journal of North America* **2**(5): 848-859.

NYATHI, M.K., BELETSE, Y.G., BEUKES, D.J., VAN HALSEMA, G.E., ANNANDALE, J.G. & DU PLOOY, C.P. 2016. Water productivity of traditional vegetables. In: *Nutritional Water Productivity of Traditional Vegetable Crops*. Water Research Commission of South Africa, WRC Report No K5/2171/4.

PAYNE, R.W. (Ed.). 2014. *Introduction to GenStat® for Windows™* (17^{th} Edition), VSN International, Hemel Hempstead, Hertfordshire, U.K. © 2014 VSN International.

SHEPPE, W. 1970. Daily and seasonal patterns of construction activity by *Odontotermes latericius* (Isoptera: Termitidae). *Insectes Sociaux* **17**: 225-232.

SNEDECOR, G.W. & COCHRAN, W.G. 1980. Statistical Methods. 7th edition. Iowa State University Press, Ames, IA, U.S.A.

TAYLOR, H.S., MACKAY, W.P., HERRICK, J.E., GUERRERO, R.A. & WHITFORD, W.G. 1998. Comparison of field methods to detect termite activity in northern Chihuahuan Desert (Isoptera). *Sociobiology* **32**: 1-16.

TUKEY, J. 1958. Bias and confidence in not quite large samples. Annals of Mathematical Statistics **29**: 614.

UYS, V. 2002. *A guide to the Termite Genera of Southern Africa*. ARC-Plant Protection Research Institute Unit, Pretoria, South Africa.

ZEIDLER, J., HANRAHAN, S. & SCHOLES, M. 2004. Determining termite diversity in arid Namibian rangelands – a comparison of sampling methods. *African Zoology* **39**(2): 285-292.

CHAPTER 4: EFFECTS OF DIFFERENT LAND USE PATTERNS ON SEASONAL TERMITE SPECIES DIVERSITY WITHIN THE VHEMBE DISTRICT OF THE LIMPOPO PROVINCE, SOUTH AFRICA

This chapter has been submitted for publication and is currently under review as Netshifhefhe, S.R., Kunjeku, E.C. & Duncan, F.D. Effects of different land use patterns on seasonal termite species diversity within the Vhembe District of the Limpopo Province, South Africa.

4.1. ABSTRACT

This study evaluated the effects of three different land use types: mango orchards, maize fields and communal grazing lands on termite species distribution in the Vhembe District, Limpopo Province, South Africa. The main objective was to identify the termite species found in the area and investigate the effect of land use on termite species diversity as this could compromise food security in the area. Termites were collected from six study sites using a standardized transect sampling protocol and baiting methods in a transect of 2 x 100 m during the dry and wet seasons. A total of 18 termite species from 2 families (Termitidae and Rhinotermitidae), 5 subfamilies (Macrotermitinae, Amitermitinae, Apicotermitinae, Nasutitermitinae and Cubitermitinae) and 11 genera (*Allodontotermes*, *Ancistrotermes*, *Macrotermes*, *Microtermes*, *Odontotermes*, *Microcerotermes*, *Rhadinotermes*, *Trinervitermes*, *Psammotermes*, *Schedorhinotermes* and *Cubitermes*) were recorded. Communal grazing resulted in a higher Shannon diversity index (H') of 2.23 and Simpson diversity index (1-D) of 0.84 followed by mango orchard (H' = 1.41, 1-D = 0.68), while maize field recorded the lowest (H' = 1.07, 1-D = 0.48). Macrotermitinae constituted 77% of the total number of species recorded across all the land use types. Wood and litter feeders belonging to Macrotermitinae, Nasutitermitinae and Rhinotermitinae were dominant species in all land use types, comprising 72% of the total species, with subterranean nesting group the most dominant. Communal grazing areas had the most species (15) followed by mango orchards (9) while maize fields had the least (8) species. *Ancistrotermes latinotus* and *Odontotermes* sp. were the most abundant in communal grazing lands while, *Microtermes* sp. was the most dominant species in maize fields. Termite species diversity varied across land use types with agriculture (mango orchards and maize fields) adversely affecting the diversity. Termites are important in rural communities to supplement human protein requirements and they provide ecosystem services thus, there is a need for studies that quantify the trade-off between costs (crop damage) and benefits of maintaining termites in agricultural landscapes.

Key words: Termite diversity, species richness, land use, relative abundance, diversity index.

4.2. INTRODUCTION

Termites (Isoptera) are eusocial insects of economic importance (ecosystem services and human food) in many tropical and subtropical ecosystems (Eggleton, 2000; Sileshi et al, 2009; Netshifhefhe *et al*., 2018a). Engel and Krishna (2004) recorded over 2600 species of termites worldwide comprising approximately 280 genera, and seven recognized families. The seven families are: Mastotermitidae, Kolotermitidae, Termopsidae, Hodotermitidae, Rhinotermitidae, Serritermitidae, and Termitidae. These families may be divided into two main groups, the 'lower' and 'higher termites', depending on their mode of digestion (Wood and Johnson, 1986). The African continent has more than 1000 species and has the highest termite diversity (van Huis, 2017).

Termites are major decomposers of wood and other cellulose-based materials (Macrotermitinae, Termitinae and Nasutitermitinae subfamilies), redistribute soil materials thereby modifying the physical soil properties such as texture [e.g. *Macrotermes* sp. Holmgren (Termitidae: Macrotermitinae)], water infiltration rates, and recycle organic matter and nutrients [e.g. *Odontotermes* sp. Holmgren (Termitidae: Macrotermitinae)] (Holt and Lepage, 2000; Jouquet *et al.*, 2002; Dangerfield *et al.*, 1998). Studies conducted by Jouquet *et al*. (2011) and Dangerfield *et al*. (1998) found termites [e.g. *Macrotermes michaelseni* Sjöstedt (Termitidae: Macrotermitinae)] to have a positive effect on the biodiversity of fauna and flora and the stability of ecosystems.

Termite species of Macrotermitinae, Termitinae and Nasutitermitinae families are reported to be destructive pests of many agricultural crops and rangelands (Mitchell, 2002 and Abdurahman, 1990). The most economically important termite genera in agricultural and rangeland areas are *Macrotermes*, *Odontotermes*, *Microtermes*, *Hodotermes*, *Trinervitermes* and *Cubitermes* (Uys, 2002; Mitchell, 2002; Kumar and Pardeshi, 2011). *Macrotermes* sp. and *Odontotermes* sp. were reported by Debelo and Degaga (2014) in studies conducted in the central Rift Valley of Ethiopia to be destructive pests of fruit trees and maize crops. In Southern Africa, the harvester termite *Hodotermes mossambicus* Hagen (Termitidae: Hodotermitidae), considered a serious threat to pasture and rangeland (Uys, 2002), can reduce the carrying capacity of the grasslands in certain areas by up to 25% (Coaton, 1960).

The termite species richness and abundance are influenced by a combination of both the abiotic environmental factors and biotic interactions such as competition and predation (Begon *et al*., 2006; Lavelle and Spain, 2001). Mugerwa *et al.* (2011) reported that quantities of plant litter and biomass influenced the variability in the composition of subterranean termites such as the generalist termite feeders (members of sub-family Macrotermitinae) and the specialized grass feeders, *Trinervitermes* sp. Sjöstedt (Termitidae: Nasutitermitinae). Abiotic factors such as soil type, pH and nutrient availability also play a major role in the abundance of termites (Davies *et al*., 2003; Roisin *et al.*, 2004). Low soil pH had low soil organic matter which limits availability of nutrients for plant establishment and adequate food resources for survival and activity of various termite species (Mugerwa *et al*., 2011). Seasonal weather patterns are reported to have an influence on termite species composition (Dibog *et al.*, 1998; Materu *et al*., 2013). For example, surveys conducted in Malaysia found that termites were more abundant in the grassland sites during the wet season than during the dry season (Lee and Wood, 1971). Johnson *et al.* (1981), in Nigeria observed a higher abundance and level of foraging activity of *Microtermes* spp. Holmgren (Termitidae: Macrotermitinae) in the wet season.

Land use is a major contributor to termite species richness and the biggest driver of biodiversity loss worldwide (Eggleton *et al*., 2002). Clearing and soil cultivation decreases species richness and abundance of soil feeding termites, *Cubitermes* sp. Wasmann (Termitidae: Cubitermitinae) as compared to other types of termites such as wood feeders, *Schedorhinotermes lamanianus* Sjöstedt (Blattodea: Rhinotermitidae) (De Souza & Brown 1994; Eggleton *et al.* 2002). Reduction in termite species richness is also due to the changes of food availability as well as suitable nesting sites. (Edwards and Mill, 1986). According to Lawton *et al.* (1998), the decline in termite species richness in tropical rainforest ecosystems was due to human activities such as deforestation. Habitat disturbances (Eggleton and Bignell, 1995; Eggleton *et al.*, 2002) and habitat fragmentation resulted in termite species decline (Davies, 2002). Conversion of land for use in agriculture and settlement purposes resulted in the loss of soil feeder termites in Brazil, East Malaysia and West Africa (De Souza and Brown, 1994; Eggleton *et al*., 1998, 2002). In a study conducted in Namibia, Zeidler *et al*. (2002) reported that termite diversity and composition vary within and between ecosystems as well as across the land-use gradients. Relative abundance of fungus growing termites increases with land-use intensity (Eggleton *et al*., 2002). There was a decrease in termite diversity in deforested ecosystems (Susilo and Aini, 2005). Low to moderate disturbances do not significantly affect termite species richness (Deblauwe *et al.*, 2007).

Termites are beneficial to humans and play an important socio-economic role in rural communities. Edible termites provide food and economic value to many rural people in the Vhembe District in the Limpopo Province, South Africa (Netshifhefhe *et al*., 2018a). Three termite species that belong to the *Macrotermes* genus, mound building termites which dominate the African savanna are consumed by people in the district (Netshifhefhe *et al*., 2018a), and it has been shown that termites have high nutritional content (Banjo *et al*., 2006). The most preferred edible termite species in the Vhembe District was *Macrotermes falciger* Gerstäecker (Termitidae: Macrotermitinae). People in this community also generate income from the collection and sale of edible termites. Land use patterns have a potential to affect these activities in the district. The effect of land use on seasonal termite species diversity, distribution and availability in Vhembe District is poorly studied. Very few comprehensive studies on termite diversity and the impact of different land use patterns are available for the Vhembe District. The only studies were done by Meyer *et al.* (1999) in the Kruger National Park (KNP) (an almost pristine environment) on the distribution and density of mounds of *Macrotermes*. This study was aimed at determining the effect of three land use types, viz. communial grazing lands, maize fields and mango orchards, on termite species diversity, abundance and distribution in the Vhembe District.

In this study, we evaluate the effect of three land uses (communal grazing lands, maize fields and mango orchards) on termite (edible and non-edible) species diversity, abundance, and distribution within the Vhembe District Municipality. We expect that termite species diversity and density will decrease with increased land disturbances.

4.3. MATERIAL AND METHODS

4.3.1. Study area

The study was conducted in the Vhembe District of Limpopo Province, South Africa (Fig. 4.1). The district is located 70 km north of Polokwane and covers an area of about 25 597 square km of land, with a population of over 1 294 722 (Statssa, 2015), and is bordered by Zimbabwe, Mozambique and Botswana (van Averbeke, 2013). It is mostly rural as 95% of the population lives in tribal lands and farms, and the remaining 5% living in urban areas (SDF, 2007). The average annual rainfall is 820 mm received from October to March, reaching a peak in January and February (Mpandeli, 2006), with the annual precipitation during the summer season normally influenced by the Inter-Tropical Convergence Zone (Kabanda, 2004). The dry season lasts from April to September. The district is located in micro- climatic areas, with temperature ranges from 16 to 41 ^{o}C, and can reach 35 ^{o}C most of the time especially during summer (wet season) (Mpandeli, 2006). Gusty winds of between 75 to 100 km/h are recorded in winter (Semenya *et al*., 2013).

Vhembe District is comprised of various land use types dominated by a wide range of tropical and subtropical fruit farms, smallholder maize fields and the medium to high intensity livestock farming on communal lands. Termites were collected from three land uses types: communal grazing (CG), maize fields (MF) and mango orchards (MO), at six study sites (two replicates per land use) during wet and dry seasons between April 2016 and March 2017, covering a total of 4800 m^2. The sampling of termites was permitted by the village Chief and/or land-use owner. Descriptions of each study area per land use type in the district are presented in Table 4.1. Environmental data (temperature and rainfall) for the duration of this study were sourced.

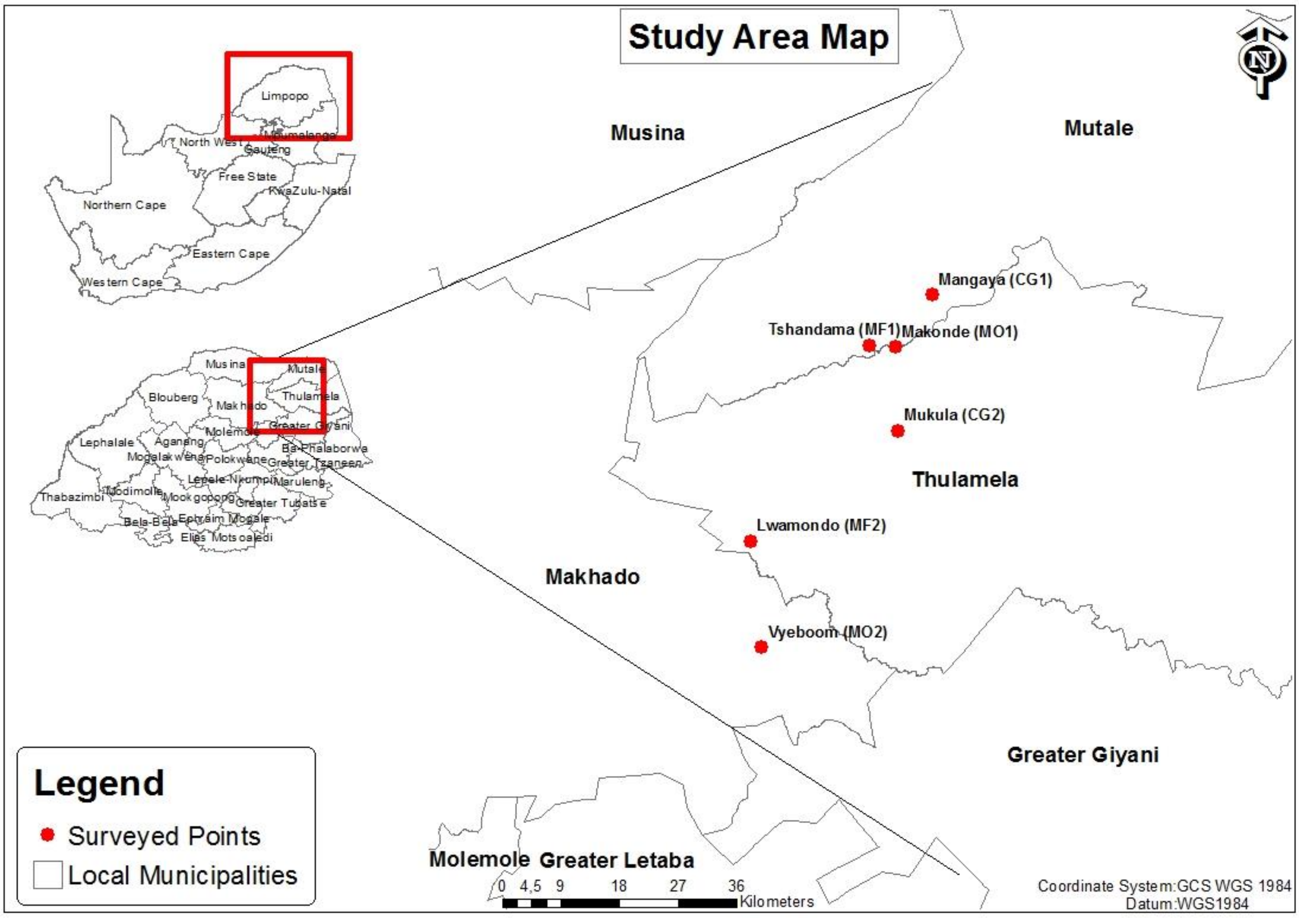

Figure 4.1 Location of the Vhembe District in the Limpopo Province, South Africa (inset) showing the locations of the six study sites (circles)

Table 4.1 Description of the study sites

Area and abbreviation (as in Fig. 4.1)	Land use type	Co-ordinates	Average slope (Degrees) (Calculated for an area of 100 m around the coordinate)	Slope description	Vegetation dominance	Frequency of use	Soil appearance
Mangaya (CG1)	Communal grazing lands	22°41’57”S, 30°36’43”E	0.47	Level	Dominated by a layer of grass species with scattered trees.	Very often, livestock grazing	Soil compacted (livestock trampling)
Mukula (CG2)	Communal grazing lands	22°52’23”S, 30°33’53”E	3.66	Gently sloping	Dominated by a layer of grass species with scattered trees.	Very often, livestock grazing	Soil compacted (livestock trampling)
Tshandama (MF1)	Maize fields	22°45’50”S, 30°31’31”E	1.36	Very gently sloping	Dominated by maize plants planted in straight rows. Spacing: Inter-row (0.9 m) & Intra-row (0.35 m).	Annual seasonal cropping	Loose soil (ploughing)
Lwamondo (MF2)	Maize fields	23°0’48”S, 30°21’43”E	2.90	Gently sloping	Dominated by maize plants planted in straight rows. Spacing: Inter-row (0.9 m) & Intra-row (0.35 m).	Annual seasonal cropping	Loose soil (ploughing)

Makonde (MO1)	Mango orchards	22°46’0”S, 30°33’42”E	1.88	Gently sloping	Dominated by mango trees planted in straight rows. Rows spacing of 10 m and tree spacing of 5m.	Perennial crop with limited soil disturbance in the inter-row	Soil compacted
Vyeboom (MO2)	Mango orchards	23°8’53”S, 30°22’37”E	1.76	Gently sloping	Dominated by mango trees planted in straight rows. Rows spacing of 10 m and tree spacing of 5m.	Perennial crop with limited soil disturbance in the inter-row	Soil compacted

4.3.2. Soil characteristics analyses

Soil samples were taken from six study sites at a depth of 30 cm. According to Bandeira and Vasconcellos (2002), the soil termite fauna is more abundant at depths up to 20 cm of soil, thus this is the recommended depth for quantitative and qualitative surveys of the termite fauna. At least eight soil samples were collected from each site and mixed to get one representative sample that was taken for analysis of texture, pH and organic matter content. The soil pH (H_2O) was determined using a combined glass-calomel electrode system (The non-affiliated Soil Analysis Work Committee, 1990). The total organic matter was determined using the method described by Walkley and Black (1934) and particle size distribution, through the hydrometer method (Day, 1956).

4.3.3. Sampling methods

Termites were sampled using the standardized transect search protocol (Jones and Eggleton, 2000; Eggleton *et al.*, 1997) and cattle dung bait method as described by Netshifhefhe *et al*. (2018b). Two standardized transects of 2 x 100 m were laid out adjacent to one another in each site, one for the placement of cattle dung baits and the other for transect searches. In the mango orchards, the transects were in the middle of the orchards between the trees. The transects in the maize fields were also laid in the middle of the fields which were large enough such that the transects did not span across multiple fields. The distance from villages to the transects in communal grazing lands was between 500 m to 1 km. For transect searches, the 100 m transect was divided into 10 sampling sections 2 x 10 m. Each sampling section was further subdivided into 2 subsections of 2 x 5 m, totalling 20 sampling subsections. Sampling of termites using transect search method was done on the soil surface after 7, 14 and 21 days interval on 6, 6 and 8 sampling subsections respectively, with two people searching each subsection for 15 minutes, which equalled 30 minutes per section. Total sampling time was 2 hours 30 minutes. In addition, sampling using cattle dung baited traps was also used. These traps were 340 ml clear plastic bottles without lids filled with fresh cattle dung buried in the ground at 12 cm depth and covered with soil, in a set of three traps per sampling section alongside a transect every 10 m in a triangle fractal sampling design (Ewers *et al*., 2013, Netshifhefhe *et al.* 2018b). There was a total of 60 cattle dung bait traps per season in each study site. The baits were left in the ground and examined after 7, 14, and 28 days. At each of these time intervals, ten baits (experimental units) were removed per site and any termites present were collected, preserved in vials containing 80% alcohol. Termite specimens were identified to species level using morphological characters.

4.3.4. Data analysis

Descriptive statistics and cross tabulation were used for termite occurrence data within the land use types with species richness per land use per season. The diversity data classification by feeding groups against each land use was estimated using the classification method developed by Donovan *et al*. (2001). Termites were also grouped according to trophic, taxonomic and nesting parameters according to the techniques of Eggleton and Bignell (1995). Relative abundance was measured in this study instead of absolute values. Termite species richness was calculated based on the number of occurrence a species was found per transect and cattle dung bait in each land use type per season. Occurrence is when a species is found or encountered. We calculated termite abundance based on the number of times each species was found from the two sampling methods combined. As the data did not agree with the assumptions for normality and homogeneous variances, Generalized Linear Model (GLM) analysis was used with the Poisson distribution and logarithmic link to test for differences between three land use types, three-day intervals and wet and dry season effects, as well as all the interactions (Payne, 2015). Predicted means were compared using Fisher's protected least significant difference test at the 5% level of significance (Snedecor and Cochran, 1980). All data were analyzed using the GenStat® program (Payne, 2015). Accumulation curves were constructed to calculate the average species richness for each land use type per season using EstimatesS 9.0.1 Software (Colwell, 2013). Accumulation curves were used to compare the species richness in various land use types. Termite species richness was estimated by estimators Bootstrap, Chao2 and Jackknife1 (Estimates: Version 9. 2013) to make predictions of total species richness using morphological characters.

Termite species richness was calculated using Shannon-Wiener index (H′) while termite species diversity was calculated using the Simpson Diversity index (1-D) (Hemachandra *et al.*, 2010; Kemabonta and Balogun, 2014; Zar, 1999; Shannon and Wiener, 1949). The two indexes can be calculated as follows:

$$H' = -\Sigma (Pi \ln Pi)$$

Where **P** is the proportion of individuals found in the **i** th species, **ln** is the natural log, **Σ** is the sum of the calculations.

The Simpson Diversity Index (1-D) was calculated as follows:

$$D = \frac{\sum_{i=1}^{s} n_i (n_i - 1)}{N(N-1)}$$

N = Total number of all species found, **n** = number of individuals in **i** th species, **Σ** is the sum of the calculations.

The two indexes take into account the number of species found in the area per land use type and the number of individuals per species. Species diversity and richness was analysed using Microsoft Excel 2013.

4.4. RESULTS

4.4.1. Soil characteristics and weather data

The soil at most study sites had high sand content and low clay (range 65 – 85% sand; 5 – 18% clay) with an exception of one maize field at Lwamondo which had high clay (43%) and organic matter (4%) content. The soil pH was moderately to slightly acidic and ranged between 5.41 and 6.71 (Table 4.2). The minimum and maximum temperatures reported during this study ranged from 6 to 38 ^{o}C in 2016 and 14 to 43 ^{o}C in 2017, with the monthly rainfall of 6.86 and 99 mm in the dry and wet seasons respectively. As expected, the average minimum and maximum relative humidity was higher 58 and 93% in the wet season with 36 and 90% in the dry season.

Table 4.2 Soil characteristics and texture of the study sites as determined in the laboratory by hydrometer method and the standard test methods for moisture, ash and organic matter

Study site	Land use type	pH	Sand (%)	Silt (%)	Clay (%)	Soil type (Top soil)	Organic matter content (%)
Mangaya (CG1)	Communal grazing lands	5.83	65.00	12.67	18.46	Sandy Loam	0.95
Mukula (CG2)	Communal grazing lands	5.92	85.71	5.89	5.11	Sand	0.21
Tshandama (MF1)	Maize fields	5.41	85.02	6.44	6.20	Loamy Sand	0.48
Lwamondo (MF2)	Maize fields	5.71	23.11	30.45	42.56	Clay	4.18
Makonde (MO1)	Mango orchards	6.07	85.26	4.00	7.26	Loamy Sand	0.56
Vyeboom (MO2)	Mango orchards	6.71	78.50	12.46	5.48	Loamy Sand	2.93

4.4.2. Termite species composition

A total of 18 termite species representing two Families, comprising five Subfamilies and 11 genera were collected (Table 4.3). The majority of species (89%) belonged to the Termitidae, the so-called higher termites, while 11% were lower termites (Rhinotermitinae) (Table 3). Species in the subfamily/tribe Macrotermitinae constituted 77% of the total number of species collected while Apicotermitinae and Nasutitermitinae constituted 11% each. Macrotermitinae was found in all the land use types while Apicotermitinae and Nasutitermitinae were only found in communal grazing lands and maize fields (Table 4.3).

Nine species were collected in both cattle dung bait and transect search methods. *Macrotermes* was the most common subfamily in all three land use types. Five genera (*Microtermes*, *Macrotermes*, *Odontotermes*, *Ancistrotermes, Allodontotermes*) were common to both communal grazing lands, mango orchards and maize fields, whereas *Trinervitermes*, *Rhadinotermes*, *Psammotermes* and *Cubitermes* were only found in communal grazing lands.

Table 4.3 Termite species recorded from both seasons within three land use types from combined standardized search method and the cattle dung bait method.

Family / Subfamily	Communal Grazing	Mango Orchard	Maize Field
Termitidae: Macrotermitinae	*Allodontotermes rhodesiensis* *Allodontotermes* sp. *Ancistrotermes latinotus* *Macrotermes natalensis* *Macrotermes* sp. *Macrotermes vitrialatus* Macrotermitinae: Indet* *Microtermes* sp. *Odontotermes* sp.	*Allodontotermes rhodesiensis* *Ancistrotermes latinotus* *Macrotermes natalensis* *Macrotermes ukuzii* *Macrotermes vitrialatus* Macrotermitinae: Indet* *Microtermes* sp. *Odontotermes* sp.	*Allodontotermes rhodesiensis* *Ancistrotermes latinotus* *Macrotermes natalensis* *Macrotermes* sp. *Microtermes* sp. *Odontotermes* sp.
Termitidae: Amitermitinae	*Microcerotermes* sp.	*Microcerotermes* sp.	
Termitidae: Apicotermitinae			Apicotermitinae: Indet*
Termitidae: Cubitermitinae	*Cubitermes* sp.		
Termitidae: Nasutitermitinae	*Rhadinotermes coarctatus* *Trinervitermes* sp. *Trinervitermes trinervoides*		
Rhinotermitidae	*Psammotermes allocerus*		*Schedorhinotermes lamanianus*
Total number of species	**15**	**9**	**8**

Indet* - Species only identified to subfamily level

4.4.3. Species richness and diversity

The species richness differed significantly among the land use types. The highest number of species were found in communal grazing lands (15) mainly during the wet season, followed by the mango orchards (9) while maize fields had the lowest (8) (Table 4.3). The species richness was lowest in highly disturbed maize fields possibly due to human activities and highest on less disturbed land use (communal grazing lands). *Macrotermes ukuzii* Fuller (Termitidae: Macrotermitinae) and *S. lamanianus* were restricted to the mango orchards and maize fields respectively.

Shannon-Wiener index (H') and Simpson diversity index (1-D) in three land use types during wet and dry seasons are summarized in Table 4.4. A higher species diversity index was observed for the wet season. The communal grazing lands showed the highest species diversity index of H' = 2.23 and followed by mango orchard H' = 1.41 and 1 - D = 0.68 while the maize field had the lowest index value H' = 1.07. The Simpson Diversity Index and Shannon diversity index show us that as dominance of termite species and abundance increases, the diversity and evenness get proportionally lower respectively.

Table 4.4 Termite species diversity index as measured by individual occurrences from different land use in Vhembe District

	Land use type			**Season**	
	Communal grazing lands	Maize fields	Mango orchards	Dry	Wet
Shannon-Wiener index (H')	2.23	1.07	1.41	1.59	1.92
Simpson diversity index (1-D)	0.84	0.48	0.68	0.72	0.77

The estimation of expected number of species in three land use types using Chao2, Bootstrap and Jackknife1 are represented in Figure 4.2. The number of observed species were closer to Chao2 and Bootstrap estimates in all land use types over all seasons with an underestimation of between 1 and 9 species. Bootstrap estimations in communal grazing during wet season were close to the observed values. None of the accumulation curves from all the three land use types in both dry and wet season showed a stabilization tendency, which means that the number of species is likely to be higher.

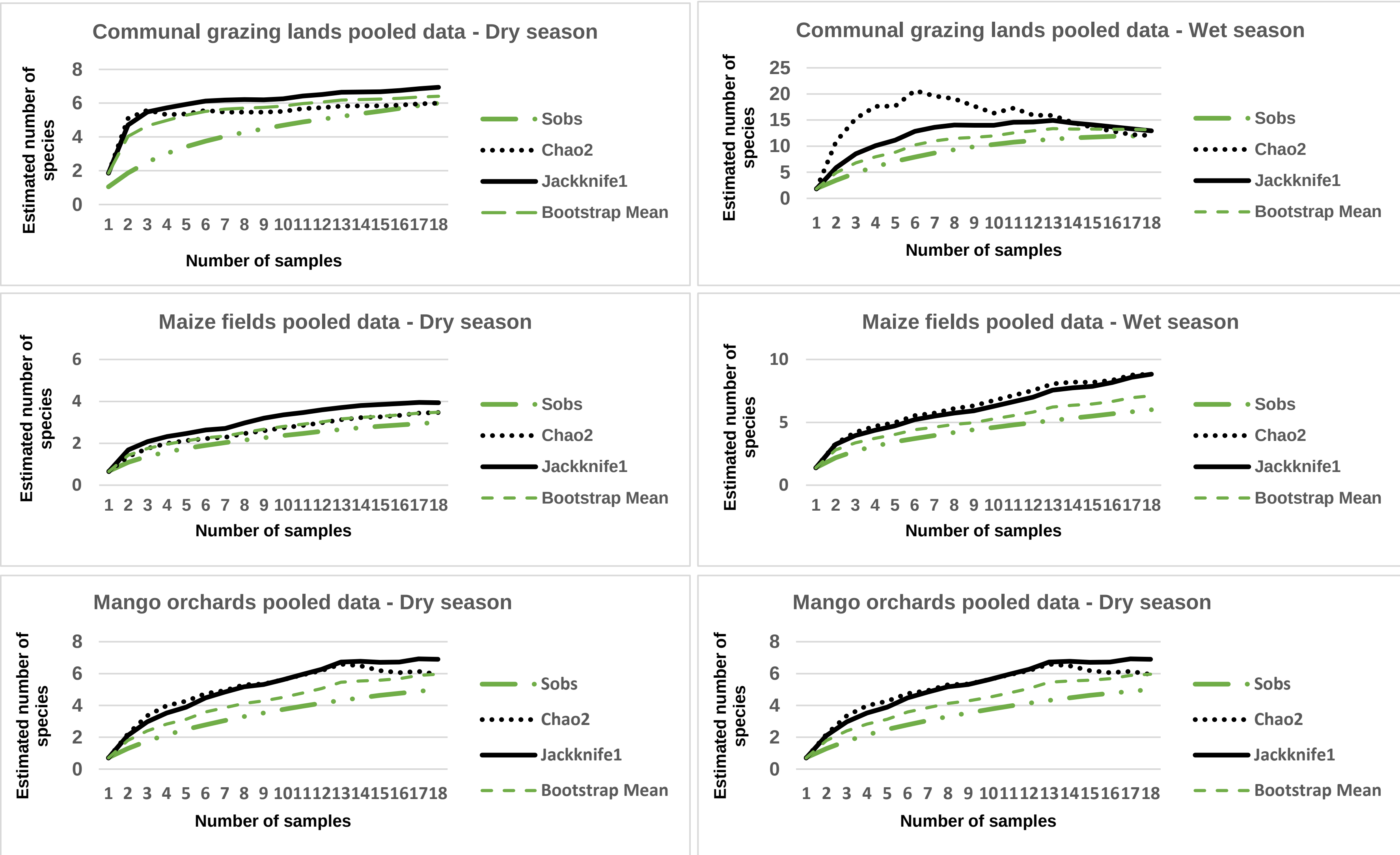

Figure 4.2 Accumulation curves with the observed termite species richness and estimates from Bootstrap, Chao2 and Jackknife1 for communal grazing lands, maize fields and mango orchards over two seasons

4.4.4. Termite feeding and nesting groups

All four feeding groups classified by Donovan *et al*. (2001) were represented in the Vhembe District. Out of eighteen species identified from the study, nine species are wood and litter feeder (fungus growers) and two species are wood and litter feeders (non-fungus growers). Wood and litter feeders are higher termites and belonged to Group II and were dominant, comprising 72% of the total species and was recorded on 283 occurrences. 31% of these species belonged to *Macrotermes* and 15% to *Allodontotermes*. *Microcerotermes* genus was mainly recorded in mango orchards and communal grazing lands. Feeding Group I (*S. lamanianus*) are the lower termites that feed on wood. This group was present only in the maize fields and during the wet season. This was the smallest group with rare species contributing 6% of the total species. *Cubitermes* sp. are true soil and humus feeders belongs to Group III and were only recorded in communal grazing lands, and comprised 11% of species. *Trinervitermes trinervoides* Sjöstedt (Termitidae: Nasutitermitinae) and *Trinervitermes* sp. Holmgren (Termitidae: Nasutitermitinae) are grass feeders, all belongs to Group IV. Termite assemblage and feeding group structure differed significantly ($p < 0.05$), higher in communal grazing than other land use types.

Three nesting habitats (categorized according to the classification system of Donovan *et al*., 2001) were represented in the study area. Seven of the species belong to subterranean nesting type. Two of the species identified to subfamily level (Apicotermitinae and Macrotermitinae) also belonged to this nesting group. Eight species belong to epigeal nesting type. Subterranean termites are defined by Materu *et al*. (2013) as those termites that have colonies housed below the ground without any indication of their presence above ground. Epigeal nesting species which are also mound building termites, on the other hand, are group of termites whose colony centres are associated with living (free standing or tree buttresses) or dead vegetation above ground (Jones, 1990).

Species nesting in epigeal nests were most abundant (44% each) followed by subterranean nests while the wood nesting species were the least abundant. 11% of the species recorded were not allocated to any nesting group as their genera were unknown. *Rhadinotermes coarctatus* Sjöstedt (Termitidae: Nasutitermitinae) and *Psammotermes allocerus* Silvestri (Blattodea: Rhinotermitidae) were the only subterranean nesting species found on communal grazing lands, while the other species were represented in all land use types. *Odontotermes* sp. and *M.*

natalensis were the most dominant epigeal nesting species. The only arboreal species recovered was *S. lamanianus*.

4.4.5. Relative abundance of termite species

The study recorded a combined total of 305 termite encounters from communal grazing lands, maize fields and mango orchards (Table 4.5). *Microtermes* sp. were the most widely distributed and abundant taxon across all the land use types, followed by *Ancistrotermes latinotus* Holmgren (Termitidae: Macrotermitinae), while the least distributed and abundant species were *M. ukuzii* and *R. coarctatus*. Maize fields had significantly higher 47.28% (61) number of encounters of *Microtermes* sp. compared to the other land use types. Higher abundance of *A. latinotus* taxa was detected in communal grazing lands and mango orchards.

Table 4.5 Abundance (number of encounters per species for the combined standardized search protocol and the cattle dung bait method per season) of termite species collected from three land use types. N – Number of times in which a species was encountered.

Family / Subfamily / Species	Communal Grazing lands		Mango Orchards		Maize Fields		Total	%
	N (Dry)	N (Wet)	N (Dry)	N (Wet)	N (Dry)	N (Wet)		
Termitidae: Macrotermitinae								
Allodontotermes rhodesiensis	-	2	-	7	-	13	22	7.21
Allodontotermes sp.	9	-	-	-	-	-	9	2.95
Ancistrotermes latinotus	21	10	4	24	-	3	62	20.33
Macrotermes natalensis	-	5	3	3	-	1	12	3.93
Macrotermes sp.	1	2	-	-	1	1	5	1.64
Macrotermes ukuzii	-		1	-	-	-	1	0.33
Macrotermes vitrialatus	-	2	-	1	-	-	3	0.98
Microtermes sp.	18	16	14	20	28	33	129	42.30
Odontotermes sp.	20	4	1	-	-	1	26	8.52
Macrotermitinae: Indet*	-	2	-	1	-	-	3	0.98
Termitidae: Amitermitinae								
Microcerotermes sp.	-	5	-	1	-	-	6	1.97
Termitidae: Apicotermitinae								
Apicotermitinae: Indet*	-	-	-	-	3	-	3	0.98
Termitidae: Nasutitermitinae								
Rhadinotermes coarctatus	-	1	-	-	-	-	1	0.33
Trinervitermes sp.	-	1	-	-	-	-	1	0.33
Trinervitermes trinervoides	8	3	-	-	-	-	11	3.61
Rhinotermitidae								
Psammotermes allocerus	-	5	-	-	-	-	5	1.64
Schedorhinotermes lamanianus	-	-	-	-	-	3	3	0.98
Termitidae: Cubitermitinae								
Cubitermes sp.	-	3	-	-	-	-	3	0.98
Subtotal	**77**	**61**	**23**	**57**	**32**	**55**		
Total number of encounters	**138**		**80**		**87**		**305**	**100**

Indet* - Species only identified to subfamily level

GLM analysis on total abundance of all species to test for differences between land use types, seasons and day intervals indicated that there was no significant difference between day interval effects ($p > 0.05$). Therefore, these abundances were taken as "internal" replicates, resulting in mean abundances from 2 replicates by 3-day intervals (sample size = 6 per season). The three land use types differed significantly ($p < 0.001$), with communal grazing having the highest abundance (23.00±1.95) of species (Table 4.6). There was also evidence that the abundance differed between seasons ($p = 0.019$) with more species found in the wet season (19.22±1.46). Furthermore, there was strong evidence of a season by land use type interaction ($p < 0.001$), as communal grazing during both seasons produced the highest abundance of species and mango orchards and maize field with least abundance in the dry season.

Table 4.6 Termite mean abundance ± SE (total number of encounters per species) per land use type per season

Season	Land use type			Season mean abundance
	Communal grazing lands	**Mango orchards**	**Maize fields**	
Dry	25.67±2.92a (77)	7.67±1.59b (23)	10.67±1.88b (32)	14.67±1.27b (132)
Wet	20.33±2.60a (61)	19.00±2.51a (57)	18.33±2.47a (55)	19.22±1.46a (173)
Land use type mean abundance	23.00±1.95a (138)	13.33±1.49b (80)	14.50±1.55b (87)	

Land use type mean abundance and seasonal mean abundance, as well as the means within the land use type by season interaction followed by the same letters did not differ significantly (P>0.05) using Fisher's LSD test

The relative abundance of the five most dominant species are presented in Table 4.7. All the five most dominant species were represented in all land types and are comprised both edible and non-edible species. However, there was no significance difference in termite abundance of the five most dominant species between the land use types (Table 4.8). *Odontotermes* sp. was the most encountered edible species and attained the level of strong evidence in the communal grazing lands followed by *Macrotermes natalensis* Haviland (Termitidae: Macrotermitinae) in mango orchards. The relative abundance of edible and non-edible species per land use are shown on Table 4.9. The non-edible species were the most abundant species in each land use. The communal grazing lands had a significant number of edible termites.

Table 4.7 Percentages of the relative abundances of dominant species for three land use types. The total number of encounters are in brackets.

Dominant species / Species mean abundance	**Communal grazing lands**		**Mango orchards**		**Maize fields**		**Total**
	Edible	Non-edible	Edible	Non-edible	Edible	Non-edible	
Dominant Species							
Microtermes sp.	-	13.54 (34)	-	13.54 (34)	-	24.30 (61)	51.39 (129)
Odontotermes sp.	9.56 (24)	-	0.39 (1)	-	0.39 (1)	-	10.36 (26)
Macrotermes natalensis	1.99 (5)	-	2.39 (6)	-	0.39 (1)	-	4.78 (12)
Ancistrotermes latinotus	-	12.35 (31)	-	11.15 (28)	-	1.19 (3)	24.70 (62)
Allodontotermes rhodesiensis	-	0.79 (2)	-	2.78 (7)	-	5.17 (13)	8.76 (22)
Total	**11.55 (29)**	**26.69 (67)**	**2.78 (7)**	**27.49 (69)**	**0.79 (2)**	**30.67 (77)**	**100.00 (251)**

Table 4.8 The relative abundances of the five dominant species and most dominant species (*Microtermes* sp.) mean abundance ± SE (total number of encounters per species) per land use type per season. The number in brackets is the total occurrences.

Characteristics	**Season**		**Land use type means**
	Dry	Wet	
Dominant species			
Maize fields	9.33±1.76b (28)	17.00±2.80ab (51)	13.17±1.48a (79)
Mango orchards	7.33±1.56b (22)	18.00±2.44ab (54)	12.67±1.45a (76)
Communal grazing lands	19.67±2.56a (59)	12.33±2.02b (37)	16.00±1.63a (96)
Season means	**12.11±1.16b (109)**	**15.78±1.32a (142)**	**(251)**
***Microtermes* sp.**			
Maize fields	9.33±1.76a (28)	11.00±1.91a (33)	10.16±1.30a (61)
Mango orchards	4.66±1.24a (14)	6.66±1.49a (20)	5.66±0.971b (34)
Communal grazing lands	6.00±1.41a (18)	5.33±1.33a (16)	5.66±0.97b (34)
Season means	**6.66±0.86a (60)**	**7.66±0.92a (69)**	**(129)**

Dominant means abundance and seasonal mean abundance, as well as the means within the land use type by season interaction section followed by the same letters did not differ significantly (P>0.05) using Fisher's LSD test

Table 4.9 The relative abundances of edible and non-edible species mean abundance ± SE (total number of encounters per species) per land use type and per season.

Edible status	Season		Land use type means
	Dry	Wet	
Edible			
Maize fields	0.33±0.33a (1)	1.00±0.58a (3)	0.67±0.33b (4)
Mango orchards	1.67±0.75a (5)	1.33±0.67a (4)	1.50±0.50b (9)
Communal grazing lands	7.00±1.53a (21)	4.33±1.20a (13)	5.67±0.97a (34)
Season means	**3.00±0.58a (27)**	**2.22±0.49a (20)**	**(47)**
Non-edible			
Maize fields	10.33±1.86b (31)	17.33±2.40a (52)	13.83±1.52a (83)
Mango orchards	6.00±1.41b (18)	17.67±2.43a (53)	11.83±1.40b (71)
Communal grazing lands	18.67±2.49a (56)	16.00±2.31a (48)	17.33a±1.70a (104)
Season means	**11.67±1.14b (105)**	**17.00±1.37a (153)**	**(258)**

Edible and non-edible abundances means abundance and seasonal mean abundance, as well as the means within the land use type by season interaction section followed by the same letters did not differ significantly (P>0.05) using Fisher's LSD test

4.5. DISCUSSION

4.5.1. Termite species composition

Macrotermitinae and Nasutitermitinae were the most species rich taxonomic groups, whereas Apicotermitinae was very rare and only present in maize fields. Macrotermitinae are widely distributed throughout southern Africa (Uys, 2002) and have the ability to utilize a variety of food resources (Okwakol, 2001). Meyer *et al.* (1999) also found that most species collected from Kruger National Park (pristine area) were from the subfamily Macrotermitinae. They were also the dominant in the grazing lands in the Nakasongola District of Uganda (Sekamatte, 2001). Species from the family Rhinotermitidae comprised about 11% of the total species recorded in the present study. Their low number is explained by the absence of dead woods and trees in maize fields and communal grazing lands and the removal of dead woods in mango orchards. Rhinotermitidae usually build their nests in dead wood decaying at different stages or old trees (Cowie and Wood, 1989). The findings in the current study are consistent with Materu *et al.* (2013) who also found low numbers in crop land and grassland habitats in the Rufiji District of Tanzania.

The overall feeding and nesting groups did show differences from different land use types in Vhembe District. Higher numbers of subterranean nesting group in the mango orchards and maize field could be attributed to the more humid microclimate and protected microhabitat provided by the mango trees and maize plant cover (De Souza and Brown, 1994). The litter layer of the mango trees fallen to the ground provide abundant functional group resources for termites. Tractor slashing of weeds were common practices in mango orchards, which could have resulted in destruction of the termite nests, as suggested by Debelo and Degaga (2014) in their study in the central rift valley of Ethiopia. This may also explain the lower abundance levels of epigeal nesters in maize fields and mango orchards. Wood *et al.* (1982) found that clearing destroyed termite nesting habitats.

The wood and litter feeders were the most abundant group across all land use types, significantly higher in communal grazing areas. These results corroborated the findings of Mugerwa (2011) who recorded wood and litter feeders as the most dominant group on grazing lands in the semi-arid district of Nakasongola, Uganda and the findings of Dosso *et al.* (2012) in their studies conducted in two areas under different levels of disturbance in Central Cote D'Ivoire. These termite species prefer to occupy microhabitats such as rotting tree stumps, dead logs and humus around the base of trees (Eggleton and Bignell, 1997). The presence of the cattle dung patches in the communal grazing lands may have attracted more termite species that resulted in higher abundance. These are richer in nutrients than wood and are food sources for termites. The cattle dung has been found to be an effective bait that gives good indication of termite diversity (Netshifhefhe *et al*., 2018b). The cow dung also provides termites with temporary nesting sites, without being exposed to solar radiation and drying which then increases the intensity of foraging activities. According to Eggleton *et al.* (1996), the soil feeders are the most sensitive to habitat degradation, we found that this group was present in the maize fields and communal grazing lands but absent in the mango orchards. The absence of soil feeders in the mango orchards could be explained to continued agricultural practices such as weed clearing between trees, pesticides application, etc. *Cubitermes* species were rare and only detected on communal grazing lands. The presence of this soil and humus feeder species is associated with improved soil physical and; chemical properties as well as aeration and drainage (Donovan *et al*., 2001; Muvengwi *et al*., 2016).

The absence of *Trinervitermes* species in maize fields (most intensively used with more anthropogenic stress) may imply that the species is less resilient against disturbance. In Swaziland, *Trinervitermes* species were absent in the cultivated maize fields (Vilane, 2007). Mugerwa (2011) reported that the composition and activity of *Trinervitermes* species as a specialist grass feeder was affected by the loss of adequate grass vegetation which explains the absence of *Trinervitermes* species in maize fields and mango orchards. *Ancistrotermes* were mainly found in communal grazing lands and mango orchards in this study, this species is active in the breakdown of dung and feeds on leaf litter (Uys, 2002). The high livestock and leaf litters in communal grazing lands and mango orchards respectively may explain the presence of this species in these land use types. Gonçalves *et al.* (2005) demonstrated that tree species, size, growth form and variety of above ground parts affect the presence and abundance of termites. Information obtained from the orchard owners was that, mango trees were approximately 15 years of age. Coulibaly *et al*. (2016) found termite species richness to be lowest in the young orchards of less than 5 years (9 species) and increased with age of the trees until its maximum of over 30 years and over (28 species). The age of the mango trees in this study might have influence the species composition.

4.5.2. Termite species richness and diversity

My results show a total of 18 termite species recorded in the study areas, comprised of eight mound building species, less than the total mound building species reported by Meyer *et al.* (1999) in the northern Kruger National Park, where 11 species were recorded. Both areas have similar mean rainfall. Kruger National Park is a pristine conservation area close to my study sites. The current study yielded one more mound building termite genera in cattle grazing lands which was not recorded from the Kruger National Park study. Despite the higher number of termite mound species in the nearby Kruger National Park study, the fact that *Macrotermes vitrialatus* Sjostedt (Termitidae: Macrotermitinae) was only encountered in this study, suggest that rainfall and season might have contributed in the distribution of the species. The average annual rainfall in the Kruger National Park study area was 494 mm (Meyer, 1999) as compared to this study area of 820 mm Mpandeli (2006). Mitchell (1980) reported that in Zimbabwe, *M. vitrialatus* were not detected in areas receiving less than 400 mm of rainfall per year. In this study, *M. vitrialatus* was only detected during the wet season.

This study showed a variation of termite species richness and diversity across land use types with higher species richness and diversity in communal grazing lands than in maize fields and mango orchards (Tables 4.3 & 4.4). Increased agricultural production leads to reduced biodiversity and alterations in the biological regulation of soil processes (Hairiah *et al*., 2001). Agricultural operations such as chemical fertilization and application of pesticides may have contributed to the low number of species recorded in maize fields in this study. Ploughing and weeding lead to the direct solarisation of the soil and this potentially could result in decreased humidity and an increase in temperature, these could have negatively affected the activities of termites (Reddy *et al*., 2007). Debelo and Degaga (2014) found that ploughing eliminated some termite species in farm lands and Wood (1975) reported that termite species richness decline in croplands due to different human activities such as weeding. Contrary to findings by Debelo and Degaga (2014), who detected less termite species in rangelands, the present study observed more termite species from the communal grazing lands. The fact that one subfamily and one species were only encountered in maize fields suggest that although agriculture may result in localized decrease in diversity, at a landscape level, having patches of maize fields might add heterogeneity to habitat and food sources of termites, which might actually be beneficial for termite diversity at that scale.

Drought is one of the factors influencing the foraging activities of termites (Materu *et al*., 2013). During the dry season sampling period, South Africa was facing one of the worst droughts in the region for 30 years (BFAP, 2016). According to the South African Weather Service, 2016 recorded the lowest national annual rainfall in South Africa in 113 years. A pronounced seasonal effect on termite species richness in various land use types was evident with fewer termite species recorded during the dry season. Studies carried out in Tanzania showed that there were no significant differences between the seasons in terms of species richness (Materu *et al*., 2013). In line with these findings, Barbosa *et al.* (2003) recorded a decrease in number of termite species encounters in dry period as a result of high temperatures and low relative humidity in the Caatinga region of Brazil.

The higher Shannon value of 2.23 in the communal grazing lands represents a relatively higher diverse community of termites than in maize fields and mango orchards. Zeidler *et al.* (2002) in Southern Kuene region, Namibia, recorded 10 species with Shannon indices ranging from 0 to 1.46, with termite species varying across land use intensity gradients. Materu *et al.* (2013) conducted studies in Dar es Salaam in the Rufiji River in three different areas (cropland, forest and grassland) over two seasons (wet and dry). Shannon Wiener's indices were calculated: in cropland: wet - 2.0485 and dry - 1.7432; forest: wet - 2.2836; dry - 1.8724 and grassland: wet - 1.4854; dry - 1.2669. These values compare favourably with those found in the current study (Table 4.4).

Based on Chao2 estimate, maize (12 species) and communal grazing (16 species) seems to be underrepresented in terms of biodiversity especially when compared to mango orchards (18 species). The rising species accumulation curves observed for maize fields and mango orchards in both seasons and communal grazing during wet season by both Jackknife1 and Chao2 suggests that more species could have been collected with more sampling efforts or possibly, by adding another baiting method.

4.5.3. Termite relative abundance across land use types

The results show that abundance of termite species differed between land use types. Holloway *et al*. (1992) reported that agricultural activities had influence on termite availability and nesting habits. In this study, agricultural activities taking place destroyed and affected the establishment of new termite colonies and reduced the chances of termites finding unoccupied nesting sites. Cultivation results in loss of grass vegetation and the destruction of mounds of *Macrotermes*, *Odontotermes* and *Trinervitermes* (Okwakol, 2001). This explains the low abundance of these three species in this study on the maize fields. Similarly, Debelo and Degaga (2014) noted *Macrotermes* as the least abundant species in the farmlands of the central Rift Valley of Ethiopia. Some species seem to favour certain land use types and a higher degree of disturbance. *Microtermes* sp. is regarded as very destructive pest of maize (Umeh and Ivbijaro, 1997), its abundance in this study on maize fields is not surprising. Its high abundance may be attributed to increased intensity of cultivation and provision of food. My findings are in agreement with Debelo and Degaga (2014), who recorded higher abundance of *Microtermes* species in farmlands. The studies conducted in Nigeria found the abundance of *Microtermes* species to rise sharply in cultivated maize. It was reported by Black and Wood (1989) that the numbers of *Microtermes* increased as the species moved down into the soil to avoid the surface disturbances.

Macrotermes and *Ancistrotermes* are regarded as maize pests (Sileshi *et al*., 2009). In this study, maize fields harboured the lowest numbers *Macrotermes* and *Ancistrotermes* during wet season and this could be explained to the early stages of maize development during which the trial was conducted. Materu *et al*. (2015) reported termite abundance to differ with habitat in accordance with species type and human activities. In this study, we found *Cubitermes* sp in communal grazing lands and this is in agreement with Materu *et al.* (2013), who reported wide distribution of *Cubitermes* sp in grassland. *Cubitermes* sp was the only soil feeding termite species found in this study.

The occurrence of more *Ancistrotermes* and *Odontotermes* species in communal grazing lands implied that availability of food resources was one of the key factors influencing the diversity and abundance of the species. The high abundance of *Microtermes* species may be due to the deep subterranean nests, as well as their ability to survive on both living crops and crop residues (Wood, 1986). The studies conducted in southwestern Nigeria by Umeh and Ivbijaro (1997) found that *Microtermes* populations increased significantly with increases in crop residues, particularly in maize farms. In the maize fields, termite food sources were mainly plant debris around the plants and cattle manure spread over the fields as organic fertilizers Davies *et al*. (2003) found organic matter which accumulated at the base of palm trees led to higher abundance of termites. The presence of pieces of dry wood in the communal grazing lands and mango orchards harboured *Ancistrotermes* species, which may rely on dry wood as food in the tropical climates, as reported by Okwakol (2001). Each of the study site has a distinct vegetation pattern influenced by the physical terrain. Topography of the area has implications for the soil characteristics and termite composition (Davies *et al*., 2014). The differences in vegetation results from catena processes with a distinct seepline, where water moves downslope through the soil accumulates against the clay-enriched zone of valley bottoms (Levick *et al*., 2010). Soil depth determine vegetation and grass density to a large degree. The cover provided by trees and shrubs promotes the growth of palatable species as moisture in the soil is retained for extended periods and protection provided against direct sunlight. The slope influences the soil fertility (Levick *et al*., 2010), thereby affecting the establishment of grasses and vegetation, food resources for termites. Gosling *et al*. (2012) reported that slope impacted on nutrient redistribution caused by erosion. Pomeroy (2005) at Ruaraka, Kenya observed less abundance of *Odontotermes stercorivorus* (Sjöstedt) (Termitidae: Macrotermitinae) in the upper slopes compared to bottom slopes. Slope is also likely to influence termite composition. This is evident in the gently sloping areas of Mukula and Lwamondo that recorded the least abundance of termites as compared to Mangaya area which is level and recorded the highest abundance.

This study suggest that edible termites were being lost from agricultural areas and this has significant impact on rural communities (personal observation). Edible termites were found to contribute significantly to the food security and livelihoods of rural communities in the Vhembe District as a reliable source of protein, oils, minerals, carbohydrate and vitamins (Netshifhefhe *et al*., 2018a). Greater awareness should be made to farmers on the ways in which edible termites are affected by agricultural activities, such as soil cultivation and inorganic fertilizer use.

4.6. CONCLUSION

Termite species diversity and abundance varies across land use types with human activities and agriculture causing a significant decline in termite diversity which has considerable implications for the ecosystem function important to agriculture such as decomposition and soil fertility. In rural areas, where termites are not only a source of food but are also a source of livelihoods as income generating activities, this decline in termite diversity may have significant impact. Thus I recommend further studies that determine how edible termite species interact with environment in other agro-ecological zones.

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4.8. REFERENCES

Abdurahman A. (1990) Foraging Activity and Control of Termites in Western Ethiopia, Ph.D. Thesis, University of London.

Bandeira A. G. and Vasconcellos A. (2002) A quantitative survey of termites in a gradient of disturbed highland forest in Northeastern Brazil (Isoptera). *Sociobiology* 39, 429-439.

Banjo A. D., Lawal O. A. and Songonuga E. A. (2006) The nutritional value of fourteen species of edible insects in Southwestern Nigeria. *African Journal of Biotechnology* 5, 298-301.

Barbosa D. C. A., Barbosa M. C. A. and Lima L. M. C. (2003) Fenologia de espécies lenhosas da Caatinga, p. xiii-xvii. In: Leal, I.R., Tabarelli, M., & Silva, J.M.C. (Eds.). *Ecologia e conservação da Caatinga.* Recife, Ed. Universitária UFPE.

Begon M., Harper J. L. and Townsend C. R. (2006) Ecology: from individuals to ecosystems, 4th Edition. Blackwell Publishing, Oxford, UK

Black H. I. and Wood T. C. (1989) Effect of cultivation on vertical distribution of *Microtermes sp.* (Isoptera Termitidae; Macro-termitinae) in soil at Mokwa, Nigeria. *Sociobiology* 15, 133-138.

Bureau for Food and Agricultural Policy (BFAP). (2016) Policy brief on the 2015/2016 drought. BFAP.

Coaton W. G. H. (1960) Destruction of grazing by harvester termites. *Farming in South Africa* 35, 6-9.

Colwell R. K. (2013) Estimates: Statistical Estimation of Species Richness and Shared Species from Samples, Version 9. 2013.

Coulibaly T, Akpesse A. A. M, Boga J. P., Yapi A., Kouassi K. P. and Roisin Y. (2016) Change in termite communities along a chronosequence of mango tree orchards in the north of Côte d'Ivoire. *Journal of Insect Conservation* 20, 1011–1019. doi: 10.1007/s10841-016-9935-1

Cowie R. H. and Wood T. G. (1989) Damage to crops, forestry and rangeland by fungus growing termites (Termitidae: Macrotermitinae) in Ethiopia. *Sociobiology* 15, 139-153.

Dangerfield J. M., McCarthy T. S. and Ellery W. N. (1998) The mound-building termite *Macrotermes michaelseni* as an ecosystem engineer. *Journal of Tropical Ecology* 14, 507-520.

Day P. R. (1956) Particle fractionation and particle size analysis. In C. A. Black et al. (ed.), Methods of soil analysis. Part 1. Agronomy 9, 545- 547.

Davies A. B., Levick S. R., Asner G. P., Robertson M. P., van Rensburg B. J. and Parr C. L. (2014) Spatial variability and abiotic determinants of termite mounds throughout a savanna catchment. *Ecography* 37, 001-011. doi: 10.1111/ecog.00532

Davies R. G. (2002) Feeding group responses of a Neotropical termite assemblage to rain forest fragmentation. *Oecologia* 133, 233-242.

Davies R. G., Hernández L. M., Eggleton P., Didham R. K., Fagan L. L. and Winchester N. N. (2003) Environmental and spatial influences upon species composition of a termite assemblage across Neotropical forest islands. *Journal of Tropical Ecology* 19, 509-524.

Deblauwe I., Dibog L., Missoup A. D., Dupain J., Van Elsacker L., Dekoninck W., Bonte D. and Hendrickx F. (2007) Spatial scales affecting termite diversity in tropical lowland rainforest: a case study in southeast Cameroon. *African Journal of* Ecology 46, 5-18.

Debelo D. G. and Degaga E. G. (2014) Termite species composition in the central rift valley of Ethiopia. *Agriculture and Biology Journal of North America* 5, 123-134.

De Souza O. F. F. and Brown V. K. (1994) Effects of habitat fragmentation on Amazonian termite communities. *Journal of Tropical Ecology* 10, 197-206.

Dibog L., Eggleton P. and Forzi F. (1998) Seasonality of soil termites in a humid tropical forest, Mbalmayo, southern Cameroon. *Journal of Tropical Ecology* 14, 841-850.

Donovan S. E., Eggleton P. and Martin A. (2002) Species composition of termites of the Nyika plateau forests, northern Malawi, over an altitudinal gradient. *African Journal of Ecology* 40, 379-385.

Donovan S. E., Eggleton P. and Bignell D. E. (2001) Gut content analysis and a new feeding group classification of termites. *Ecological Entomology* 26, 356-366.

Dosso K., Yeo K., Konate S. and Linsenmair K. E. (2012) Importance of protected areas for biodiversity conservation in Central Cote D'ivoire: Comparison of termite assemblages between two areas under differing levels of disturbance. *Journal of Insect Science* 12:131. Available from URL: http://www.insectscience.org/12.131

Edwards R. and Mill A. E. (1986) Termites in Buildings. Their Biology and control. Rentokil Ltd., West Sussex, U.K. 54-67.

Eggleton P. (2000) Global patterns of termite diversity. In: *Termites, evolution, sociality, symbioses, ecology* (eds T. Abe, D. E Bignell and M. Higashi) pp. 25–51. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Eggleton P. and Bignell D. E. (1995) Monitoring the response of tropical Insects to changes in the environment: troubles with termites. In: *Insects in changing environments* (eds R. Harrington and N. E. Strok), Academic Press, London. 535 pp.

Eggleton P. and Bignell D. E. (1997) Secondary occupation of epigeal termite (Isoptera) mounds by other termites in the Mbalmayo Forest Reserve, southern Cameroon, and its biological significance. *Journal of African Zoology* 111, 489-498.

Eggleton P., Bignell D. E., Hauser S., Dibog L., Norgrove L. and Madong B. (2002) Termite diversity across an anthropogenic gradient in the humid forest zone of West Africa. *Agriculture, Ecosystems and Environment* 90, 189-202.

Eggleton P., Davies R. G. and Bignell D. E. (1998) Body size and energy use in termites (Isoptera): the response of soil feeders and wood feeders differ in a tropical forest assemblage. *Oikos* 81, 525-530.

Eggleton P., Homathevi R., Jeeva D., Jones D. T., Davies R. G. and Maryati M. (1997) The species richness and composition of termites (Isoptera) in primary and regenerating lowland dipterocarp forest in Sabah, East Malaysia. *Ecotropica* 3, 119-28.

Eggleton P., Bignell D. E., Sands W., Mawdsley N. A., Lawton J. H., Wood T. G. and Bignell N. C. (1996) The diversity, abundance and biomass of termites under differing levels of disturbance in the Mbalmayo Forest Reserve southern Cameroon. *Philosophical Transactions of the Royal Society of London Series B* 35, 561-68.

Eggleton P., Bignell D. E., Sands W. A., Mawdsley N. A., Lawton J. H., Wood T. G. and Bignell N. C. (1996) The diversity, abundance and biomass of termites under differing levels of disturbance in the Mbalmayo Forest Reserve, Southern Cameroon. *Philosophical transactions of the Royal Society of London B* 351, 1-68.

Eggleton P., Bignel D. E., Sands W. A., Waite B., Wood T. G. and Lawton J. H. (1995) The species richness of termites (Isoptera) under differing levels of disturbance in the Mbalmayo Forest Reserve, southern Cameroon. *Journal of Tropical Ecology* 11, 85-98.

Engel M. S. and Krishna K. (2004) Family-group names of termites (Isoptera). *American Museum, Novitates* 3432, 1-9.

Ewers M. R. and Marsh C. J. (2013) A fractal-based sampling design for ecological surveys quantifying β-diversity. *Methods in Ecology and Evolution* 4, 63-72.

Gonçalves T. T., DeSouza O., Reis Jr R. and Ribeiro S. P. (2005) Effect of Tree Size and Growth Form on the Presence and Activity of Arboreal Termites (Insecta: Isoptera) in the Atlantic Rain Forest. *Sociobiology* 46, 2.

Gosling C. M., Cromsigt J. P. G. M., Mpanza N. and Olff H. (2012) Effects of Erosion from Mounds of Different Termite Genera on Distinct Functional Grassland Types in an African Savannah. *Ecosystems* 15, 128-139. doi:10.1007/s10021-011-9497-8

Hairiah K., Williams S. E., Bignell D., Swift M. & van Noordwijk M. (2001) Effects of land use change on below ground diversity. ASB lecture note 6A. International Centre for Research in Agroforestry (ICRAF).

Holloway J. D. A., Kirk Sprigs A. H. and Chey V. K. (1992) The response of rainforest insect groups to logging and conversion to plantation. *Philosophical Transactions of the Royal Society* 335, 425-436.

Hemachandra I. I., Edirisinghe J. P., Karunaratne W. A. I. P. and Gunatilleke C. V. S. (2010) Distinctiveness of termite assemblages in two Fragmented Forest types in Hantane hills in the Kandy district of Sri Lanka. *Ceylon Journal of Science* (*Biological Sciences*) 39,11-19.

Holt J. A. and Lepage M. (2000) Termites and soil properties. In *Termites: Evolution, Sociality, Symbioses, Ecology* (eds T. Abe, D. E. Bignell and M. Higashi), Kluwer Academic Publishers, Dordrecht, The Netherlands. pp. 389-407.

Jones D. T. (2000) Termite assemblages in two distinct montane forest types at 1000m elevation in the Maliau Basin, Sabah. *Journal of Tropical Ecology* 16, 271-286.

Jones J. A. (1990) Termites, soil fertility and carbon cycling in dry tropical Africa: a hypothesis. *Journal of Tropical Ecology* 6,291-305.

Jones D. T. and Eggleton P. (2000) Sampling termite assemblages in tropical forests: testing a rapid biodiversity assessment protocol. *Journal of Applied Ecology* 37,191-203.

Jouquet P., Mamou L., Lepage M. and Velde B. (2002) Effect of termites on clay minerals in tropical soils: fungus-growing termites as weathering agents. *European Journal of Soil Science* 53, 521-527.

Jouquet P., Traoré S., Choosai C., Hartmann C. and Bignell D. (2011) Influence of termites on ecosystem functioning. Ecosystem services provided by termites. *European Journal of Soil Biology* 47, 215-222.

Kabanda T. A. (2004) Climatology of long term drought in the Northern region of the Limpopo Province of South Africa. Unpublished PhD thesis. University of Venda.

Kemabonta K. A. and Balogun S. A. (2014) Species richness, diversity and relative abundance of termites (Insecta: Isoptera) in the University of Lagos, Lagos, Nigeria. *FUTA Journal of Research Sciences* 10, 188-197.

Kumar D. and Pardeshi M. (2011) Biodiversity of termites in agro-ecosystem and relation between their niche breadth and pest status. *Journal of Entomology* 8, 250-258.

Lavelle P. and Spain A. V. (2001) Soil ecology. 654 p. Kluwer Scientific Publications, Amsterdam.

Lawton J. H., Bignell D. E., Bolton B., Bloemers G. F., Eggleton P., Hammond P. M., Hodda M., Holt R. D., Larsen T. B., Mawdsley N. A., Stork N. E., Srivastava D. S. and Watt A. D. (1998) Biodiversity inventories, indicator taxa and effects of habitat modification in tropical forest. *Nature* 391, 72-76.

Levick S. R., Asner G. P., Chadwick O. A., Khomo L. M., Rogers K. H., Hartshorn A. S., Kennedy-Bowdoin T. and Knapp D. E. (2010) Regional insight into savanna hydrogeomorphology from termite mounds. *Nature Communications* 1, 1-7.

Materu C., Yarro J. and Nyundo B. (2013) Seasonal changes on termite foraging behaviour under different habitats in Rufiji District Tanzania. *Journal of Biology, Agriculture and Healthcare* 3, 11.

Materu C. L., Yarro J. G. and Nyundo B. A. (2015) Termite species richness, diversity under different land use in Rufiji District. *Research Journal of Agricultural and Environmental Sciences* 2, 7-13.

Meyer V. W., Braack L. E. O., Biggs H. C. and Ebersohn C. (1999) Distribution and density of termite mounds in the northern Kruger National Park, with specific reference to those constructed by *Macrotermes* Holmgren (Isoptera: Termitidae). *African Entomology* 7, 123-130.

Mitchell J. D. (2002). Termites as pests of crops, forestry, rangeland and structures in southern Africa and their control. *Sociobiology* 40, 47-69.

Mitchell B. L. (1980) Report on a survey of the termites of Zimbabwe. *Occasional Papers of the National Museums and Monuments of Rhodesia, series B, Natural Science* 6, 187-323.

Mpandeli N. S. (2006) Coping with climate variability in Limpopo Province. Unpublished PhD thesis, University of Witwatersrand.

Mugerwa S. (2011) Indigenous Knowledge and Ecology of Subterranean Termites on Grazing Lands in Semi-arid Ecosystems of Central Uganda. Unpublished PhD thesis. University of Nairobi.

Mugerwa S., Nyangito M., Mpairwe D. and Nderitu J. (2011) Effect of biotic and abiotic factors on composition and foraging intensity of subterranean termites. *African Journal of Environmental Science and Technology* 5, 579-588.

Muvengwi J., Mbiba M., Ndagurwa H. G. T. and Kabvuratsiye N. (2016) Pulsing hydrology and topography determine the structure and spatial distribution of *Cubitermes* mounds in a savanna ecosystem. *Catena* 145, 99-106.

Netshifhefhe S. R., Kunjeku E. C. and Duncan F. D. (2018a) Human uses and indigenous knowledge of edible termites in Vhembe District, Limpopo, South Africa. *South African Journal of Science* 114(1/2), 10p.

Netshifhefhe S. R., Kunjeku E. C., Visser D., Madzivhe F. M. and Duncan F. D. (2018b) An evaluation of three field sampling methods to determine termite diversity in cattle grazing lands. African Entomology 26, 224-233.

Okwakol M. J. N. (2001) Changes in termite (Isoptera) communities due to the clearance and cultivation of tropical forest in Uganda. East African Wild Life Society. *African Journal of Ecology* 38, 1-7.

Payne R. W. (ed.). (2015) Introduction to GenStat® for Windows™ 18th Edition Introduction. © 2015. VSN International, UK.

Pearce M. J. (1997) Termites. Biology and Pest Management. CAB International, Wallingford. 172 pp.

Pomeroy D. (2005) Dispersion and Activity Patterns of Three Populations of Large Termite Mounds in Kenya. *Journal of East African Natural History* 94, 319-341. doi:10.2982/0012-8317(2005)94[319:DAAPOT]2.0.CO;2

Reddy T. B. M., Govindappa M. R., Padmaja A. S., Shankarappa K. S., Siddaramaiah A. L. and Nanjappa H. V. (2007) Effect of soil solarization on microbial population under sole and sequential cropping systems. *Environment and Ecology* 25, 813-816.

Roisin Y. and Leponce M. (2004) Characterizing termite assemblages in fragmented forests: A test case in the Argentinian Chaco. *Austral Ecology* 29, 637-646.

SDF. (2007) Vhembe Final Spatial Development Framework.

Sekamatte M. B. (2001) Termite situation on crops and rangelands in Nakasongola District. A report submitted to the Environmental Protection and Economic Development (EPED) project, Kampala. Uganda.

Semenya S. S., Tshisikhawe P. and Potgieter M. T. (2013) Invasive alien plant species: A case study of their use in the Thulamela Local Municipality, Limpopo Province, South Africa. *Scientific Research and Essays* 7, 2363-2369.

Shannon C. E. and Wiener W. (1949) The mathematical theory of communication. Urbana, University of Illinois Press. 177 pp.

Sileshi G. W., Nyeko P., Nkunika P. O. Y., Sekematte B. M., Akinnifesi F. K. and Ajayi O. C. (2009) Integrating ethno-ecological and scientific knowledge of termites for sustainable termite management and human welfare in Africa. *Ecology and Society* 14, 48.

Snedecor G. W. and Cochran W. G. (1980) Statistical methods (7th Edition). Ames: Iowa State University Press.

Statistics South Africa. (2015) Statistics by place. *Retrieved 27 September 2015*.

Susilo F. X. and Aini F. K. (2005) Diversity and density of termites in a range of land use types in the Rigis hill area, Sumberjaya, Lampung. *Jurnal Sains dan Teknologi* 3, 129-136.

The Non-Affiliated Soil Analysis Work Committee. (1990) Handbook of standard soil testing methods for advisory purposes. Soil Science Society of South Africa, P.O. Box 30030, 0132 Sunnyside, South Africa.

Tscharntke T., Klein A. M., Kruess A., Steffan-Dewenter I. and Thies C. (2005) Landscape perspectives on agricultural intensification and biodiversity–ecosystem service management. *Ecology letters* 8, 857-874.

Umeh V. C. and Ivbijaro M. F. (1997) Termite Abundance and Damage in Traditional Maize Cassava Intercrops in Southwestern Nigeria. *International Journal of Tropical Insect Science* 17, 315-321.

Uys V. (2002) A guide to the termite genera of Southern Africa. ARC-Plant Protection Research Institute Handbook No. 15, Pretoria.

van Averbeke W. (2013) Improving Plot Holder Livelihood and Scheme Productivity on Smallholder Canal Irrigation Schemes in the Vhembe District of Limpopo Province.

van Huis, A. (2017) Cultural significance of termites in sub-Saharan Africa. *Journal of Ethnobiology and Ethnomedicine* 13, 8.

Vilane M. W. (2007) Termite species richness and composition within a semi-ari environment: A comparison of land-use practices and sampling methods in selected areas of southern Swaziland. MSc Thesis. University of Namibia and Humboldt-Universitat Zu, Berlin. 107 pp.

Walkley A. and Black I. A. (1934) An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* 37, 29-37.

Wood T. G. (1975) The effects of clearing and grazing on the termite fauna (Isoptera) of tropical savannas and woodlands. *In: Progress in soil zoology, procs5th Int.Coll.on*, soil Zoology. (Ed. G. Vanek). Academic, Prague. pp. 409-413.

Wood T. G. (1986) Assessment of Termite Damage in Ethiopia and Recommendations for Short term Control and Development of Long-term Pest Management Practices. Report prepared for the World Bank. 58 pp.

Wood T. G., Johnson R. A., Bacchus S., Shittu M. O. and Anderson J. M. (1982) Abundance and distribution of termites (Isoptera) in a riparian forest in the Southern Guinea savanna zone of Nigeria. *Biotropica* 14, 25-39.

Zar J. H. (1999) *Biostatistical analysis* 4th Ed. Prentice-Hall, Inc. Englewood cliffs, New Jersey, USA.

Zeidler J., Hanrahan S. and Scholes M. (2002) Termite species richness, composition and diversity on five farms in southern Kunene region, Namibia. *African Zoology* 37, 7-11.

CHAPTER 5: TERMITE MOUND DENSITY AND DISTRIBUTION PATTERNS ACROSS THREE LAND-USE TYPES IN THE VHEMBE DISTRICT OF THE LIMPOPO PROVINCE, SOUTH AFRICA

This chapter has been submitted for publication and is currently under review as Netshifhefhe, S.R., Kunjeku, E.C. & Duncan, F.D. Termite mound density and distribution patterns across three land-use types in the Vhembe District of the Limpopo Province, South Africa

5.1. ABSTRACT

This study examined the density and distribution pattern of termite mounds across three land-use types: communal grazing lands, maize fields and mango orchards. The main objective was to investigate the effect of land use on the density of edible termite mounds as this could compromise food security in the area. Mounds were counted manually in 1 ha plots from each land use area, total area of 12 ha, and the distances between mounds were measured. A total of 297 mounds from four termite species were recorded. All land-use types had large numbers of small mounds (134) and most of the mounds counted were active (239). Mound density was significantly higher in communal grazing lands, dominated by small and medium sized mounds of non-edible *Trinervitermes* sp. The maize fields had more mounds from the edible termite, *Macrotermes natalensis,* with a density of 6.75 mounds/ha. The average distance in the mango orchards between the nearest mounds (49.63 m) was higher than in the other areas. *Macrotermes falciger* mounds, the preferred edible termite species, were found in all land use types, with the highest density being in the maize fields. Although the mound height of *M. falciger* (1.23 m) was similar to that of *M. natalensis* (1.45 m), the mound circumference for *M. falciger* mounds was significantly larger at 22.79 m compared to 9.4 m, and this limits land available for agricultural use*.* Therefore removal of *Macrotermes* mounds would impact negatively on the availability of termites as a free sources of protein.

Keywords: Termite mounds, spatial distribution, land-use types, *Macrotermes*, *Trinervitermes*.

5.2. INTRODUCTION

Termite mounds or termitaria are defined by Bignell et al. (2010) as “nests that are covered by soil and protrude above the soil surface”. Uys (2002) reported that most of the termite species have nests which are below ground but some termite species have epigeal nests in which part of the nest is above ground level and extending into the mound. Termite mounds are a prominent feature of African savannas with different shapes and heights depending on the species (Turner, 2000; Uys, 2002). Termite mounds provide shelter for many vertebrates, provide cooler and wetter sites for refuge and breeding sites for various animals such as mammals and birds (Fleming & Loveridge, 2003). They are also sites where unique plant species are found (Muvengwi et al., 2017). Termite mounds of *Macrotermes* species influence the herbaceous and woody plant species diversity and distribution (Moe et al., 2009; Davies et al., 2016), and provide quality forage resources utilized by both grazer and browsers (Levick et al., 2010a).

Termites are known for their vital roles as ecosystem engineers (Jones et al., 1994) and for nutrient cycling (Jones, 1990). Jouquet et al. (2005) reported that termites may create patches rich in nutrients and may also increase landscape heterogeneity in nutrient deficient grass landscapes. Termites are also known for the redistribution of organic matter thereby improving physical and chemical properties of soil, improving soil water absorption and storing capacity (Lee & Wood, 1971; Holt & Lepage, 2000; Jude & Ayo, 2008). Mound soils are reported to have a high pH, moisture, organic matter and minerals level (Lee & Wood, 1971; Pomeroy & Service, 1986). Termites themselves are rich in proteins, vitamins and mineral nutrients (Banjo et al., 2006). Netshifhefhe et al. (2018) found three termite species of *Macrotermes* genus to be widely consumed (both alates and soldiers) in the Vhembe District, Limpopo Province. The alates of various species of the *Odontotermes* have been reported to be consumed in some African countries such as Cameroon, Democratic Republic of Congo, Kenya, South Africa, Uganda, Zambia and Zimbabwe (Jongema, 2015; Mitsuhashi, 2016).

Although termites are ecosystem engineers themselves, the environment in which they occur, type of ecosystem, landscape, termite species, mound activity status, size and ages of colonies contribute to the density and distribution patterns of mounds in an area (Grohmann et al., 2010; Korb & Linsenmair, 2001a; Davies et al., 2014; Levick et al., 2010b; Meyer et al., 1999; Muvengwi et al., 2018). Meyer et al. (1999) in a study on the mound distribution in a pristine natural area in the Vhembe District, northern Kruger National Park, found that soil type, geography and termite species influenced mound densities.

Slope has implications on termite mounds distribution, Levick et al. (2010b) observed more abundant termite mounds in the valley bottoms, hillslopes and lower slopes where clay is present. Similar patterns have been observed by Davies et al. (2014). Too high clay content prevents mound establishment because of slow permeability, and too sandy results in highly weathered mounds. Meyer et al., (1999) reported fewer mounds on high clay soils in the Mopane Shrubveld and many inactive mounds on granite soils. Termites avoid areas with greater risk of inundation thus mound density decreases as drainage line increases (Davies et al., 2014). The distribution of termite mounds also varies with landscapes and land uses (Meyer et al., 1999; Boga et al., 2015; Bandiya et al., 2012; Arifin et al., 2014). Hagan et al. (2017) found a higher density of *Trinervitermes trinervoides* mounds in the livestock grazing plots. Lee & Wood (1971) found that the abundance of termite mounds increased as secondary plant succession advanced from two-year fallow to undisturbed veld, while Ekundayo & Orhue (2002) reported an increase of termite mounds from cropping through to the riparian forest and palm plantation. Compared to a pristine environment, agriculture could affect the distribution of mounds. Orhue et al. (2007) reported that termite mound establishment at higher densities prevents farmers from utilizing agricultural land for cultivation. Mounds physically reduce arable land areas which result in less crop production.

The purpose of this study was to examine the differences in densities and distributions of termite mounds for edible and non-edible termites across three land-use types: communal grazing, maize fields and mango orchards in the Vhembe District. Due to the importance of edible termites to food security in the Vhembe community (Netshifhefhe et al., 2018), the influence of land use types on termite mound densities needs to be evaluated.

5.3. MATERIAL AND METHODS

5.3.1. Study area

The study was conducted in the Vhembe District, Limpopo Province of South Africa, in three land-use types: communal grazing lands, maize fields and mango orchards from July 2016 to August 2017 (Figure 5.1). Communal grazing lands were used primarily for cattle, goats and donkeys. Winter and spring are usually dry, whereas summer and autumn are normally wet. The average temperature and rainfall range from 6 ^{o}C to 41 ^{o}C and 820 mm per annum, respectively (Mpandeli, 2006). The study sites were all on the savanna biome. According to Low & Rebelo (1996), the savanna biome is the largest biome in southern Africa and covers about one-third of the area. From each land-use type, a total of 4 plots (100 m X 100 m) were randomly selected and surveyed, giving a total of 12 ha surveyed. All the study sites were located on flat terrain (1 - 2% gradient).

5.3.2. Sampling procedures

The mounds were counted manually by three trained people and the mound location (geographical coordinates), size, inhabiting species and activity (active or non-active) were recorded in each hectare. A Garmin GPS 60 was used to record the positions of each termite mound. The size of each mound was noted and ranked according to height: small mounds (≤ 30 cm), medium-sized mounds (30 cm - 1 m) and large-sized mounds (>1 m). In some cases, mounds were opened to collect individual termites for confirmation of species. The collected termite specimens from active mounds were preserved in vials containing 80% ethyl alcohol, and samples were taken to Biosystematics Division of the ARC-Plant Protection Research Institute in Pretoria, South Africa, for identification. Mounds were recorded as active if termites were seen in the ventilation pipes or wetness was visible at the tip of the mound showing fresh structures; and non-active if there was no termite activity upon breaking off a part of the mound or if it showed signs of weathering with galleries exposed.

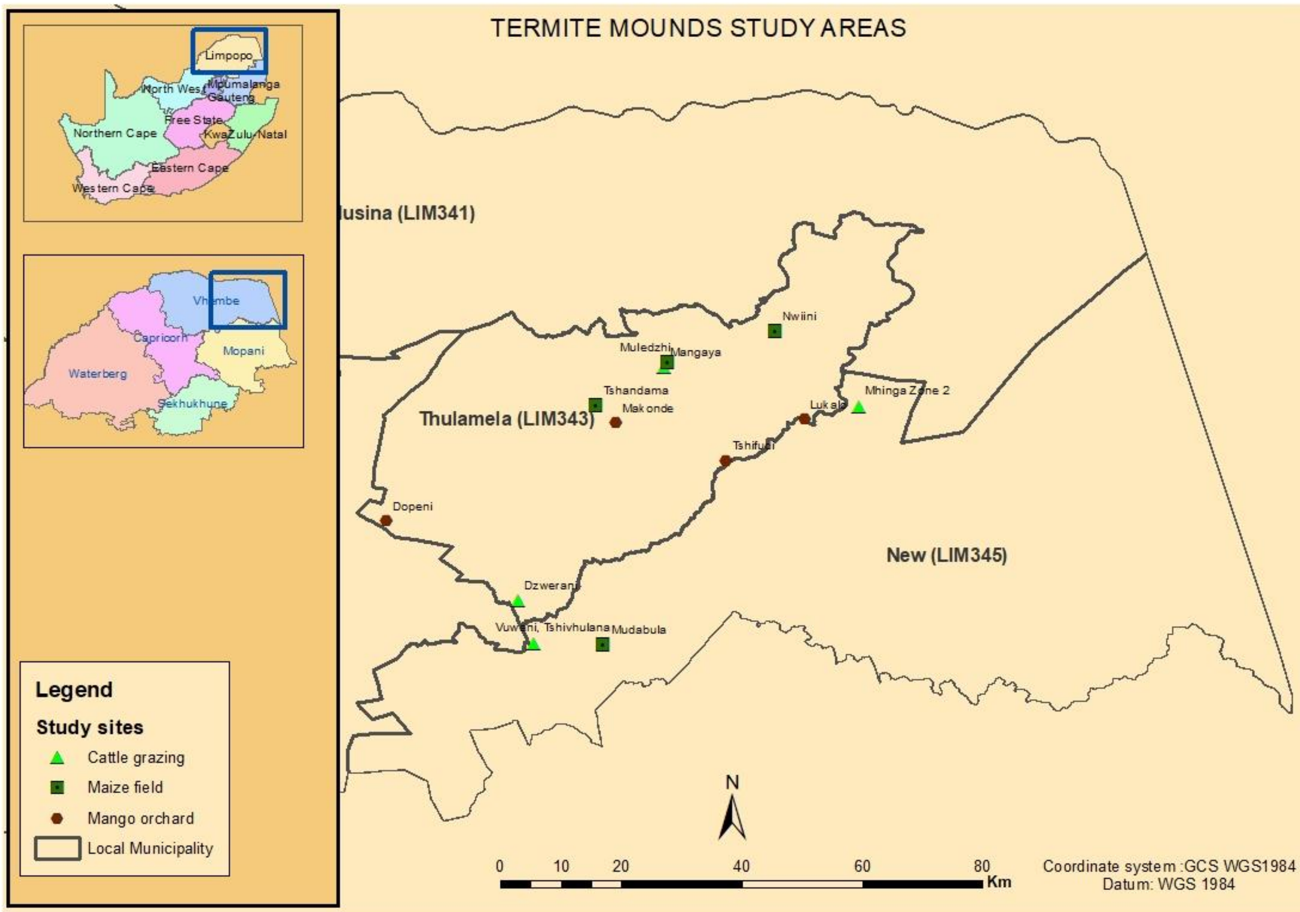

Figure 5.1 Termite mounds study sites in the Vhembe District with local municipal boundaries

A total of 40 mounds of the two most consumed species (*Macrotermes falciger* and *Macrotermes natalensis*) in the Vhembe District (Netshifhefhe et al., 2018) were randomly selected and their dimensions (height, basal circumference and estimation of diameter) were measured using a measuring stick and measuring tape. The widest diameter and circumference were measured at ground level (where change in soil color was visible or where changes in slope were noticeable), the height measured using folded 2-metre ruler (Kelly & Samways, 2011). The mound height was calculted from the soil surface to mound apex.

5.3.3. Data analysis

The mound density in each land-use site was determined by dividing the number of mounds by the area of each sampling site (Meyer et al., 1999; Debelo & Degaga, 2014) using the formula $d = n/s$, where n = number of mounds sampled and s = area sampled. Analysis of variance (ANOVA) of the densities of mounds was determined for each land-use type.

The mound counts per land-use type, size, activity and edibility of termite species were analyzed using the Generalized Linear Model (GLM) regression method, with the Poisson distribution and logarithmic link, to test for differences between three land-use types, three mound sizes, mound activity and species edibility (Payne, 2015). Predicted means were compared using Fisher's protected least significant difference test at the 5% level of significance (Snedecor & Cochran, 1980). Two-way sample t-test at 95% confidence was performed to compare the difference in mound height, diameter and circumference between *M. falciger* and *M. natalensis*. All the data analyses were performed with the statistical program GenStat® (Payne, 2014; 2015).

The distance between the nearest mounds of the same species (Near analysis) in each study site was calculated using coordinates recorded for each mound using ArcGIS. Generalized Linear Model (GLM) analysis was used with the Gamma distribution and reciprocal link to test for differences between the effects of three land-use types, three mound sizes, as well as the type by size interaction.

5.4. RESULTS

5.4.1. Termite mounds distribution and density

A total of 297 epigeal termite mound types were recorded in the 12 study sites with mounds occurring in all land use types (Table 5.1). There were significantly ($P<0.001$) more active mounds (mean number 19.92 ± 1.28) than inactive mounds (mean number 4.83 ± 0.63) in all the plots. The mounds belonged to *Trinervitermes*, *Macrotermes* and *Odontotermes* species. The abundance of termite mounds was highest in communal grazing land and was significantly different ($P<0.05$) from that of maize fields and mango orchards (Table 5.1). The spatial distribution of mounds in three land-use types are presented in Figures 5.2a-2c. The four sampling sites in communal grazing lands exhibited various distribution patterns dominated by random distribution (Table 5.2). Two of the sites also exhibited a tendency towards clustering and clumped by volume. Mango orchards and maize fields also displayed dominant random distribution pattern with one sampling site in each land-use exhibiting a clumped distribution and another site on maize fields showing uniform distribution. Large active termite mounds were randomly regularly distributed in mango orchards and maize fields. In most communal grazing study sites, small mounds occurred closer to larger mounds.

Mounds from the three species of; *Trinervitermes* sp (non-edible), *Macrotermes falciger* (edible) *and Macrotermes natalensis* (edible), were found in all land-use types (Table 5.3). Mounds from one additional species, *Odontotermes* sp, was found in mango orchards and communal grazing lands. Different types of termite mounds occurred at variable densities in each land-use type and species with the highest mound density measured for *Trinervitermes* sp (Table 5.3). *Macrotermes natalensis* mounds were dominant in the maize fields and mango orchards, while *Odontotermes* sp mounds had the lowest density.

Table 5.1 Number of active and non-active termite mounds (with total mean ± SE) recorded from different land use types in Vhembe District Municipality

Land use type	Active mounds	Non-active mounds	Total mounds counted)
Communal grazing lands	180	30	210
Mango orchards	19	9	28
Maize fields	40	19	59
Total	239	58	297
Mean number of mounds over all 12 plots (± SE)	19.92 ± 1.29	4.83 ± 0.63	

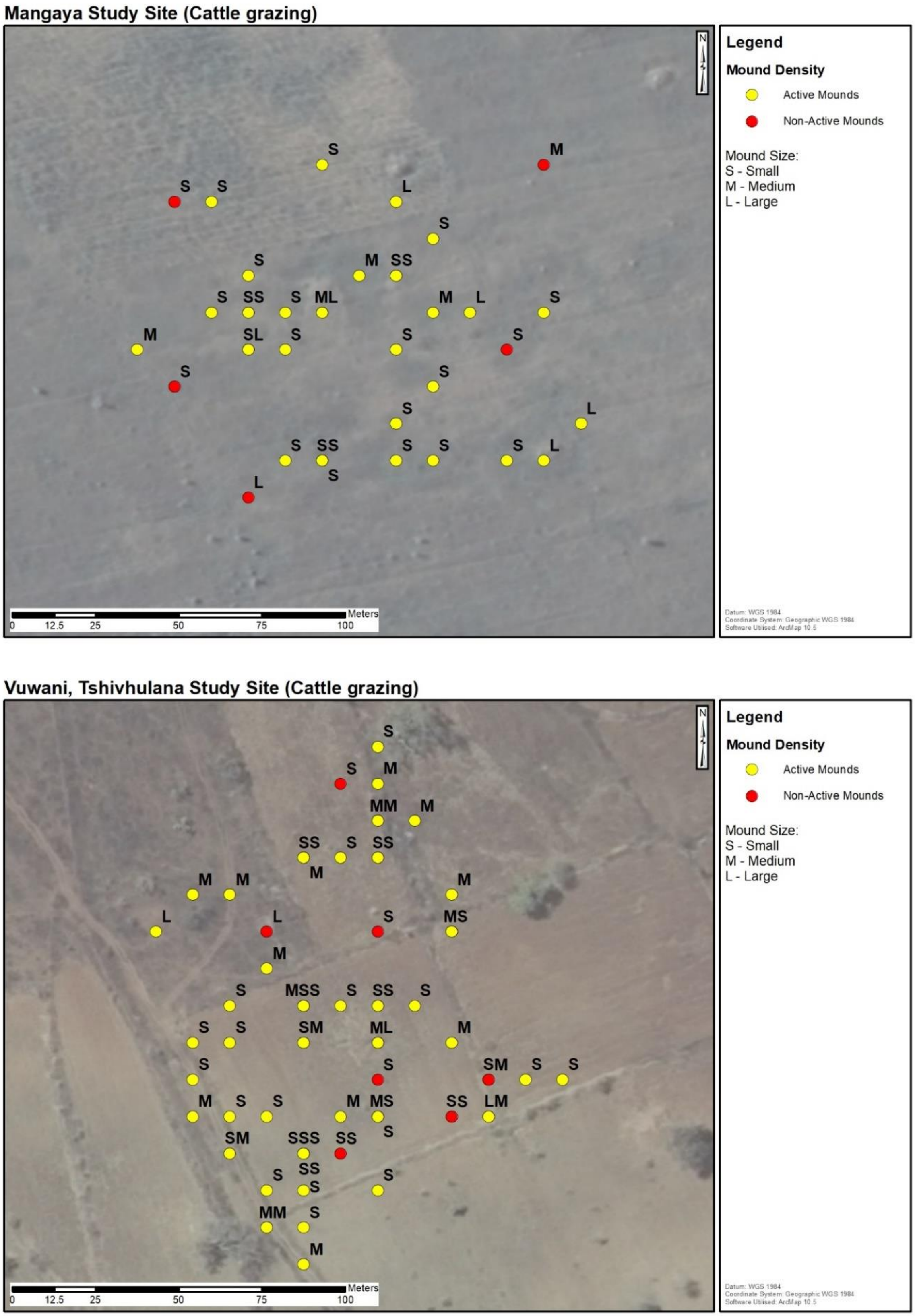

Figure 5.2a Spatial distribution maps of termite mounds on two communal grazing sites

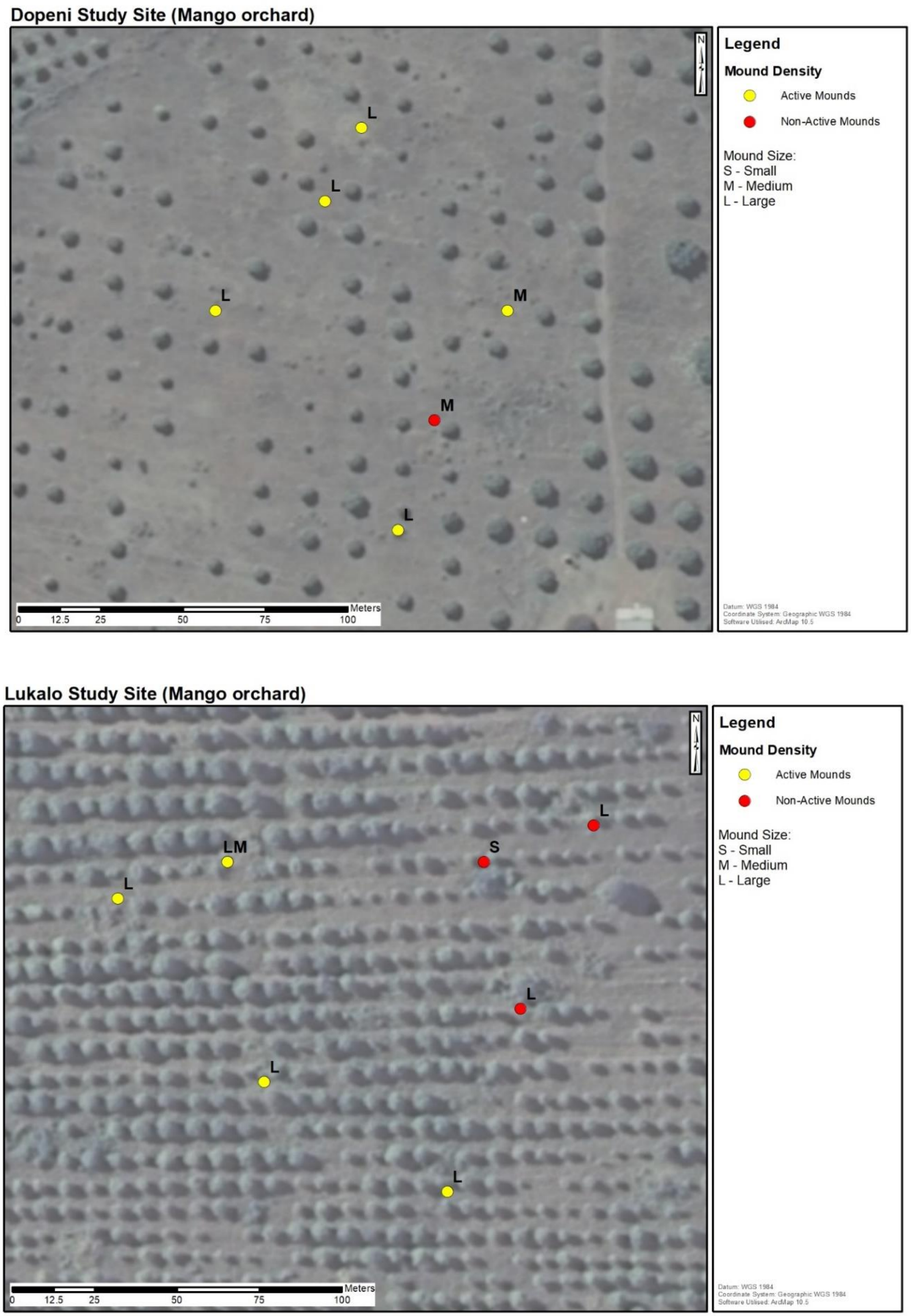

Figure 5.2b Spatial distribution maps of termite mounds on two mango orchard sites

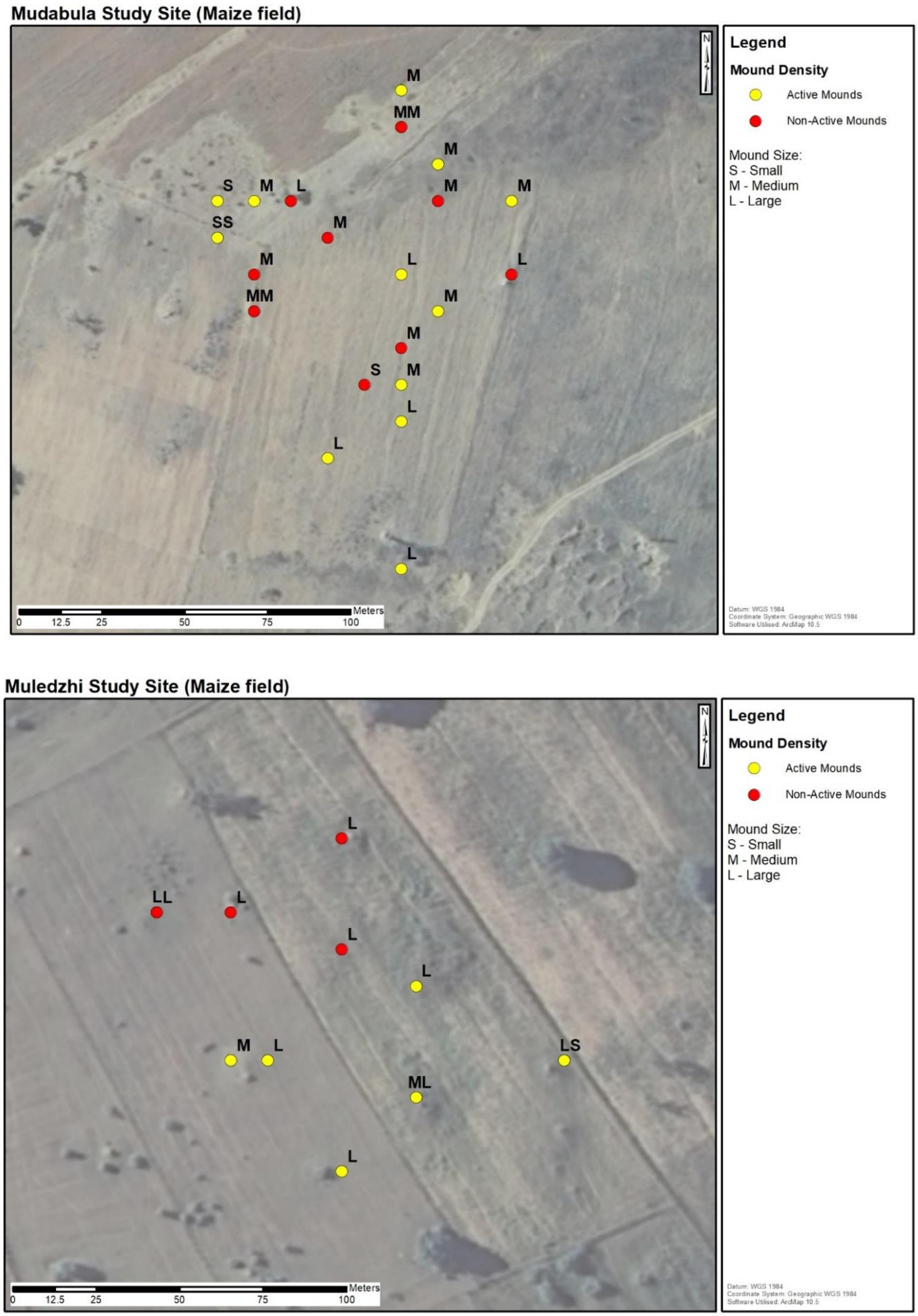

Figure 5.2c Spatial distribution maps of termite mounds on two maize field sites

Table 5.2 The relative abundance and the distribution pattern of termite mounds per land-use type in each of the observation plots

Land-use type	Study site	Number of mounds	Distribution pattern	Average number of mounds per land-use type
Communal grazing lands	Mangaya	39	Random	52.5 (N = 210)
	Dzwerani	66	Random	
	Mhinga Zone 2	36	Random (tendency towards clustering)	
	Vuwani, Tshivhulana	69	Clumped and Random	
Mango orchards	Tshifudi	9	Random	7 (N = 28)
	Dopeni	6	Random	
	Lukalo	8	Clumped	
	Makonde	5	Random	
Maize fields	Mudabula	24	Clumped	14.75 (N = 59)
	Muledzhi	13	Random	
	Nwiini	12	Random	
	Tshandama	10	Random	
Total		297		

Table 5.3 The total number of mounds found for each termite species per land use type

Land-use type / Mound species	Total mounds	Density of mounds (per hectare plot)
Communal grazing lands		
Trinervitermes sp	179	44.75
Macrotermes falciger	5	1.25
Macrotermes natalensis	17	4.25
Odontotermes sp	9	2.25
Maize fields		
Trinervitermes sp	20	5.00
Macrotermes falciger	12	3.00
Macrotermes natalensis	27	6.75
Mango orchards		
Trinervitermes sp	6	1.50
Macrotermes falciger	8	2.00
Macrotermes natalensis	12	3.00
Odontotermes sp	2	0.50

5.4.2. Termite mound sizes

The sizes and number of mounds differed in the three land-use types and are presented in Table 5.4. Communal grazing lands had more mounds but many of these were small to medium sized. The land-use type by mound size interaction was highly significant (p<0.001) with the communal grazing lands having mainly small termite mounds and the mango orchard having mainly medium sized mounds. Large sized mounds were rare in all land-use types. The non-edible termite species mounds were mostly associated with small and medium sized mounds with the edible termites having large mounds. *Trinervitermes* is the only species whose mound height is not greater than 1 meter.

Table 5.4 Mean ± SE number of mounds from the different size categories counted in each land-use type. Total number of mounds are in brackets.

Land-use type	**Mound size**		
	Small	**Medium**	**Large**
Communal grazing lands	30.25±2.75a (121)	16.75±2.05b (67)	5.50±1.17c (22)
Mango orchards	0.75±0.43d (3)	1.75±0.66d (7)	4.50±1.06cd (18)
Maize fields	2.50±0.79d (10)	6.00±1.23c (24)	6.25±1.25c (25)
Total number of mounds	134	98	65

Mean size of mounds for land-use type followed by the same letters within each column did not differ significantly (P>0.05) using Fisher's LSD test.

5.4.3. Termite mound activity

The number of active mounds, 80.5 % of total mounds recorded, differed significantly (p<0.001) from the number of non-active mounds (Table 5.1). The active mounds over 4 hectares in each land use type were mostly found in communal grazing lands (mean number 26.25 ± 1.81) then in maize fields (7.38 ± 0.960) and least in mango orchards (3.50 ± 0.66). A higher proportion of small active mounds (115) were observed from the study as compared to the proportion of medium mounds (98) and large mounds (65).

5.4.4. Status of mounds of edible termite species across land-use types

The edible species recorded were *M. falciger*, *M. natalensis* and *Odontotermes* sp and the non-edible species was *Trinervitermes* sp. Differences in the number of edible and non-edible termite mounds across the three land-use types is presented in Figure 5.3. The number of non-edible termite species mounds were significantly higher than that of edible termite species mounds only in the communal grazing lands. A higher number of mounds belonging to edible termite species were recorded in maize fields (mean number 9.70 ± 1.56 from the 4 hectares sampled).

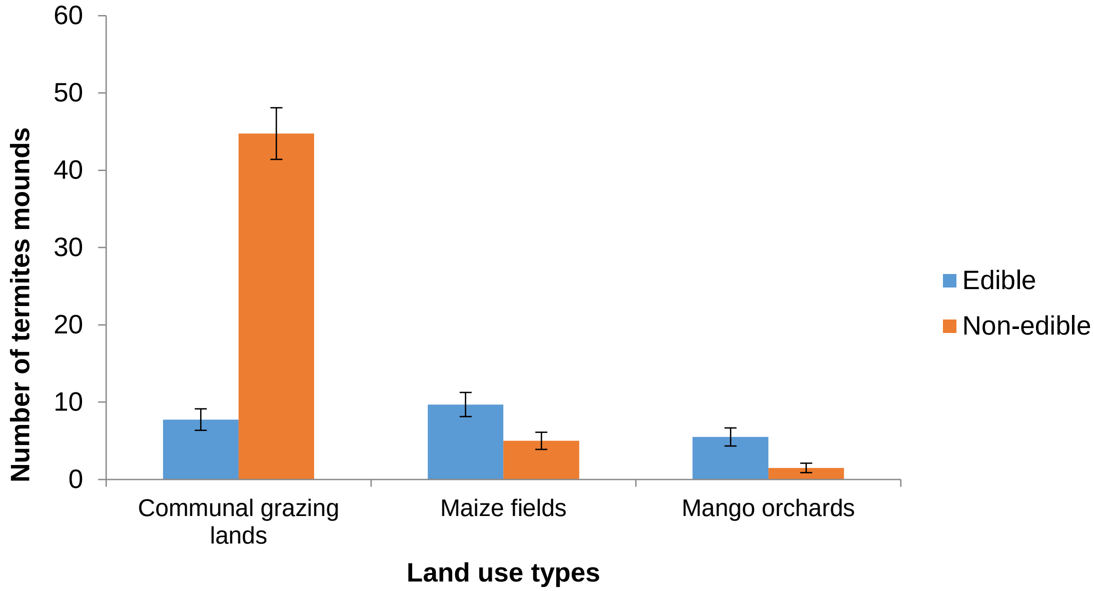

Figure 5.3 Mean number of mounds counted of edible and non-edible termites (± Standard Error) in three land-use types

A total of 81 *Macrotermes* mounds were found in all land-use types, of which there was about twice the number of *M. natalensis* mounds compared to *M. falciger* mounds (Table 5.5). Both the *M. falciger* and *M. natalensis* mounds were found in all land uses. *Macrotermes falciger* mounds were observed on the outside or towards the edges of the plot. Most mounds of *M. natalensis* were active in all land-use types with the number of the active and non-active mounds of *M. falciger* equal in mango orchards and maize fields (Table 5.5). The average density of *M. falciger* and *M. natalensis* mounds was higher in maize fields while very few mounds were found in in communal grazing lands (Table 5.3).

Table 5.5 Number of *Macrotermes* species termite mounds and status in three land use types

Land use type	***Macrotermes* species**			
	M. falciger		*M. natalensis*	
	Active	Non-active	Active	Non-active
Communal grazing lands	3	2	13	4
Maize fields	6	6	18	9
Mango orchards	4	4	8	4
Total	13	12	39	17

Odontotermes sp mounds were mainly recorded in communal grazing lands and none were found in the maize fields (Table 5.3). Approximately half the mounds recorded were active (54.55 %).

5.4.5. *Trinervitermes* mounds

A total of 205 mounds of *Trinervitermes* species were recorded across all three land-use types (Table 5.3) with the highest density in the communal grazing lands. Most of the mounds were small, and surpringly no large mounds were found. In the communal grazing lands, *Trinervitermes* mounds were mainly distributed throughout the areas and consistent. Approximately 89 % of the *Trinervitermes* sp mounds sampled in communal grazing lands were active.

5.4.6. Average nearest neighbour mound distance in three land-use types

The average distance between the nearest neighbour mounds per land-use type is presented in Table 5.6. The mango orchards had the longest distances between mounds and this differed significantly ($P<0.001$) from the maize fields and communal grazing lands. The shortest distances between mounds was found in the abundant mounds of *Trinervitermes* sp in communal grazing lands. The mean distances between the two edible species, *M. falciger* and *M. natalensis*, were generally the longest of all species, but both indicated shorter distances in maize fields between mounds than in mango orchards and communal grazing lands. Differences in distances between mound sizes across land use types were also significantly longer ($P<0.001$) in mango orchards (52.97 m) for large mounds and shorter in communal grazing lands (11.98 m) for small mounds (Figure 5.4). The land-use type by mound size interaction was not significant ($P>0.05$). Whether a mound was active or non-active had no effect on nearest distances between mounds.

Table 5.6 Mean nearest neighbour distances in meters between mounds in each land use type (number of mound observations in brackets)

Characteristics	Land use type		
	Communal grazing lands	Maize field	Mango orchard
Mound status			
Active	13.73 (180)	31.34 (40)	49.00 (19)
Non-active	23.24 (30)	31.88 (19)	43.34 (9)
Mound species			
Trinervitermes sp	10.56 (179)	25.86 (20)	37.12 (6)
Macrotermes falciger	66.28 (5)	32.29 (12)	60.54 (8)
Macrotermes natalensis	46.17 (17)	35.35 (27)	50.96 (12)
Odontotermes sp	18.14 (9)	-	21.53 (2)

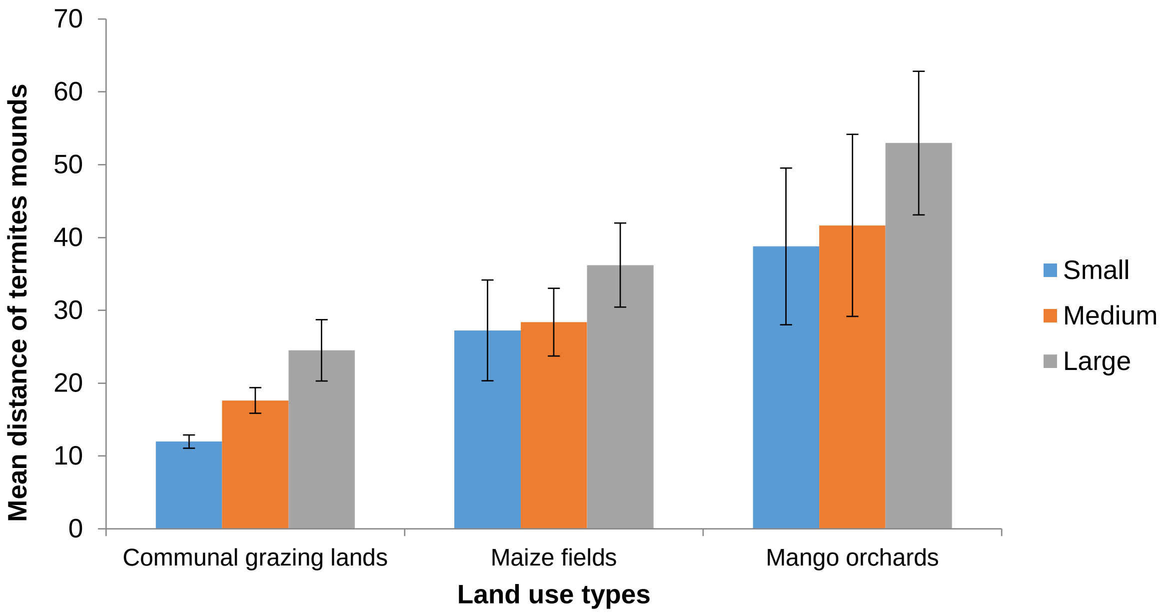

Figure 5.4 Mean distance (± Standard Error) between termite mound nearest neighbour and sizes of termite mounds per land-use type

5.4.7. *Macrotermes* mound dimensions

The mound dimensions observed in the two edible *Macrotermes* species are presented in Table 5.7. Although the heights were roughly the same, the mound diameter and circumference of *M. falciger* was larger than that of *M. natalensis,* thus *M. falciger* takes up more land surface space. *Macrotermes natalensis* are few centimeters (approximately 20 cm) taller. Although significant at 5% level, the relationship between mound circumference and mound height were positively correlated (poor) in *M. falciger* (Pearson's correlation coefficient $r = 0.454$; $p < 0.034$). The linear relationship between *M. natalensis* mound circumference and height is not significant ($r = 0.144$; $p = 0.568$) but variables were not associated with height as expected given that the *M. natalensis* are few centimeters (approximately 20 cm) taller (Table 5.8).

Table 5.7 Descriptive statistics of data of two edible termite species (*Macrotermes falciger* and *Macrotermes natalensis*) mounds dimensions

Parameter	Height (m)	Diameter (m)	Circumference (m)
		Macrotermes falciger	
Minimum	0.75	3.8	16.2
Maximum	1.950	23.9	41.8
Mean	1.225	8.433	22.79
Standard Deviation	0.2821	2.012	6.599
Number of samples	22	22	22
		Macrotermes natalensis	
Minimum	0.85	2.15	4.9
Maximum	2.05	4.8	15.25
Mean	1.452	3.081	9.43
Standard deviation	0.3694	0.745	2.723
Number of samples	18	18	18

Table 5.8 Pearson's correlation coefficients between edible termite species (*Macrotermes falciger* and *Macrotermes natalensis*) for mounds dimensions

	Height	**Width**	**Circumference**
		Macrotermes falciger	
Height	1.0000		
Width	0.2692	1.0000	
Circumference	0.4539*	0.7830***	1.0000
		Macrotermes natalensis	
Height	1.0000		
Width	0.3526	1.0000	
Circumference	0.1442	0.4644	1.0000

* p<0.05; ** p<0.01; *** p<0.001

5.5. DISCUSSION

5.5.1. Mound distribution

The analysis of the distribution of mounds across all the land-use types in this study indicated mostly a random distribution pattern. According to Odum (1971) and Meyer et al. (1999), this reflects a homogeneous environment where many minor factors act together on the population. The random distribution pattern of termite mounds has been interpreted as a result of competition, both within and between species, or between the ecological entities, environmental heterogeneity (Grohmann et al., 2010; Lee & Wood, 1971; Pomeroy, 2005) and as a result of the age or size of colonies (Schuurman & Dangerfield, 1997). The most obvious resources the termites, especially the mound-building termites, might compete for are food, space, and suitable sites for nesting (Lee & Wood, 1971). Old and large nests are consistently more over-dispersed than young and small ones which are often aggregated (Korb & Linsenmair, 2001a). Small active mounds in the communal grazing land of Mhinga Zone 2 in this study showed a deviation from random distribution to a tendency towards clustering. These findings are similar with those of Korb & Linsenmair (2001a) who reported on the aggregation of small mounds. Sparse vegetation cover could lead to clustering of mounds at small scales (Muvengwi et al., 2017; Bonachela et al., 2015). Biotic and abiotic factors control the dynamics of the spatial distribution of termite mounds in cases where the distribution is not random (Lima et al., 2015). The tendency of mounds to be clustered / aggregated and clumped in some of the study sites suggests that factors (presumably grass biomass, basal cover, number of woody plant species, tree canopy cover and topography) may influence their distribution.

5.5.2. Mound density and size

Termite mounds were at higher densities in communal grazing lands compared to the other land-use types, dominated by small *Trinervitermes* mounds. *Trinervitermes* species is widely distributed in southern African (Uys, 2002; Adam *et al*., 2012). These are grass harvesting species which could explain why they are so abundant in the communal grazing areas. Thus this density can be explained by the food resource. Adam (1993) observed that the density of grass-feeding *Trinervitermes trinervoides* was higher in vegetation grass species that was at climax stage of growth compared to a pioneer stage. This higher density was as a result of dense vegetation growth which provided food for the grass feeding termites. Kabeh (2016), in studies conducted in Nigeria, reported that resources such as crop residues provided sites for termite mound establishment. Livestock grazing provides additional forage resources for termites through litter breakup and dung production (Hagan et al., 2017). Continuous ploughing of the maize fields and between the mango orchards in the current study may have destroyed and limited the occurrence of *Trinervitermes* species mounds by destroying termites' nest, runways and tunnels, this and lack of grass would have affected the *Trinervitermes* but not *Macrotermes* sp. Debelo & Degaga (2014) found that repeated ploughing of fields inhibited the establishment of new colonies, which is also consistent with the results obtained by Sileshi et al. (2009), who found soil cultivation by the farmers broke the termite foraging galleries and exposed them to predators and heat, which ultimately affected the mound density negatively. Application of pesticides such as Fipronil (phenylpyrazole) for the control of thrips in mangoes and wood destroying termites and other pests in mango orchards might have contributed to the low mound density in this land-use type. Arifin et al. (2014) reported that high density of termite nests of *Macrotermes gilvus* is associated with land managed without use of pesticides and chemical fertilizers.

Kelly & Samways (2011) found *Trinervitermes trinervoides* in the study conducted in Southern African Savanna Reserve to be more common in areas with good grass cover. *Trinervitermes* species are harvesters and are considered to be pasture pests in southern Africa (Uys, 2002). *Trinervitermes* species are primarily grass feeding and are more abundant in areas where summer grasses are plenty (Adam et al., 2008). The high number of *Trinervitermes* species mounds in the communal grazing lands may be explained by the availability of grass and lack of trees (Uys, 2002). Lee & Wood (1971) reported a greater abundance of *Trinervitermes trinervoides* termite mounds as secondary plant succession advanced from two-year fallow to undisturbed veld in Frankenwald, South Africa. The density of *Trinervitermes* mounds recorded in this study (0.004475 mounds/m^2) in the communal grazing lands is much higher than that reported by Meyer et al. (1999) in Kruger National Park (0.00000174 mounds/m^2) for *Trinervitermes trinervoides* and *Trinervitermes dispar* combined. These large differences in mound density can be attributed to the landscape of the study site. Kruger National Park is characterized by mopane veld (Acocks, 1988), *Trinervitermes species* is a grass feeding termite therefore vegetation may be an important factor in determining its density (Adam, 1993), and this might explain the higher mound densities in communal grazing lands in the present study. Lack of *Trinervitermes* mounds in mango orchards is not surprising given the fact that is a grass harvester which probably reflects the lack of food (grass) available due to weeding between the trees. No large mounds of *Trinervitermes* were found which is unusual in grassland areas and this could reflect that these large mounds are destroyed by the farmers. The communal grazing lands were dominated by small-sized *Trinervitermes* sp mounds while a high number of medium and large sized *Macrotermes* sp mounds were found in maize fields. These findings are similar to that of Hagan *et al.* (2017) who reported that livestock grazing had higher smaller *T. trinervoides* but unclear if these smaller mounds will continue to increase in size. *Trinervitermes trinervoides* builds supplementary mounds interconnected by subterranean tunnels from the main mound during the periods of food shortage (Fuller, 1915). The higher abundance of the small *Trinervitermes* mounds in the communal grazing lands may be attributed to the formation of supplementary mounds used for temporary housing of foraging materials and storing harvested grass (Fuller, 1915; Coaton, 1948). The lack of large *Trinervitermes* mounds in communal grazing lands could be due to large bovines (cattle), donkeys and other animals having trampled and destroyed the mounds as they increased in size. Villagers use soil from the *Trinervitermes* mounds to build and plaster perimeter walls, as well as for seating, (seating wall referred to as “guvha” in Tshivenda) and for the flooring (personal observation). This could also explain the lack of large *Trinervitermes* mounds in all the land-use areas.

My recorded *Macrotermes* mound densities of 9.75 ha^{-1} on maize fields were significantly higher than those recorded in an almost pristine environment of the Kruger National Park by Meyer et al. (1999) and Muvengwi et al. (2018) where densities of 6.1 ha^{-1} and 0.73 ha^{-1} respectively were recorded on granite landscape zones. When excluding *Macrotermes* mounds from maize fields and mango orchards, these results are still higher. The densities per *Macrotermes* species mounds were also higher in this study when compared to the results of Meyer et al. (1999) who recorded *M. natalensis* at 0.000027 mounds/m^2 and *M. falciger* 0.0000027 mounds/m^2. Mujinya et al. (2014), in the Democratic Republic of Congo, recorded a density of 0.00026 - 0.00036 mounds/m^2 of *M. falciger* in the secondary grass savanna. The *Macrotermes* mound densities observed from this study however, are lower than those reported from the natural vegetation by Debelo & Degaga (2014) in the Central Rift Valley of Ethiopia (0.000972 mounds/m^2) and Boga et al. (2015) who recorded densities of 0.000899 mounds/m^2 in the forest, in Abidjan, Ivory Coast. The variation in these densities could be attributed to biotic factor (such as competition for resources) caused by greater diversity of species and land use in Meyer et al. (1999) study and more termite food resources in the tropics. Inter- and intra-specific competition between termite species occur due to limited space and food resources (Davies et al., 2014; Pomeroy, 2005). The average densities of *M. natalensis* mounds differed with the land-use type, being higher in maize fields and lowest in mango orchards. This may suggest that the mango trees planted at 200 trees/ha (5 X 10 m) may have acted as obstacles and limited the distribution of *M. natalensis*. As *Macrotermes natalensis* was found in the maize fields, these mounds must be able to survive extensive soil tillage. The mounds that had been left alone could be due to that the farmer not wanting to break his/her equipment as these are not large mechanized farms. The establishment of *M. natalensis* at higher numbers than *M. falciger* in all the three land-use types suggests that the species is not limited by any particular vegetation type. This confirms the observation by Uys (2002) that this species is the most widespread *Macrotermes* species in the sub-region. As *Macrotermes* species are considered to be a major pest of graminaceous crops such as maize and millet (Debelo & Degaga 2014), farmers will sometimes destroy young nests they discover but leave more mature ones alone and this may explain the lack of small *Macrotermes* mounds in maize fields and mango orchards.

The nearest neighbour analysis revealed that mounds of *Macrotermes* species have longer distances between and/or within species irrespective of the land use type, larger in *M. falciger* than *M. natalensis*. This could be due to destruction of small mounds by ploughing to prepare for the planting of crops (Jones et al., 2000). Grohmann et al. (2010), reported that the larger *Macrotermes* mounds tended to be further apart than smaller mounds. Large *Macrotermes* mounds makes the removal an arduous task and are often left in the fields by farmers due to the size and hardness of the mound structure. The farmers may also harvest termites and use the soil from the mound as a natural fertilizer. Anderson & Wood (1984) stated that the redistribution of termite worked soil often modifies the chemical and physical properties of soil. Netshifhefhe et al. (2018) observed that farmers in the Vhembe District do not destroy large *Macrotermes* termite mounds located within the crop fields during ploughing and resorted in planting around the *Macrotermes* mounds, as *M. natalensis* and *M. falciger* soldiers are harvested for human consumption. The results of this study are consistent with those of Akutse et al. (2012) who reported that Ghanaian farmers scattered old termite mound soils on their fields before planting or sowing time as source of nutrients for crops. Watson (1977) found soil of termite mound occupied by *M. falciger* to contain extractable Ca 95%, mineral N 81% extractable K 69%, and available P 69% and this gave higher dry matter yields of perennial ryegrass. In the mango orchards, the *Macrotermes* mounds were found very close to the mango trees. Destroying these mounds could affect the mango trees, and thus most farmers opted not to remove the mounds.

Odontotermes is a very large genus and widespread in southern Africa with a distribution similar to *Macrotermes* (Uys, 2002) and prevalent in the northern Kruger National Park (Meyer *et al.*, 1999). Only a few mounds built by *Odontotermes* species were observed within the study areas. Literature on competition between *Macrotermes* and *Odontotermes* is very scarce, but indicates that *Macrotermes* outcompetes *Odontotermes* in competition for food resources (Korb & Linsenmair, 2001b; Schuurman, 2006). These reports only refer to competition for food resources and no conclusions to the competition pressure for establishing, enlarging or defending nests can be drawn. *Odontotermes* sp density recorded in communal grazing (0.000225 mounds/m^2) was higher than in mango orchards (0.00005 mounds/m^2). These densities were higher than those recorded in the Kruger National Park (Meyer et al., 1999). *Odontotermes* species have been recorded as pests of field crops and fruit trees (Pearce et al., 1995; Sands, 1998). Seedlings, young and mature maize plants are attacked by *Odontotermes* termites (Munthali et al., 1999). Fallen (lodged) maize plants were reported to be further attacked by termites resulting in partial or total destruction of cobs.

5.5.3. *Macrotermes* species mound morphology

The shapes and sizes of *Macrotermes* mounds vary within and amongst species (Ruelle et al., 1975). Members of the *Macrotermes* genus construct large mounds of distinctive structures and patterns, that can reach 6 m in height and 30 m in diameter (Howse, 1970; Meyer *et al.*, 2000). Larger mounds are older and are well-known for their repeated colonization (Watson, 1967; Lee & Wood, 1971; Moore & Picker, 1991) and have higher influence and larger substantial effect on the ecology of an area. Both *M. natalensis* and *M. falciger* build tall mounds but the mounds built by *M. falciger* are more spread out at their base and thus have a larger circumference. This is consistent with the findings by Netshifhefhe et al. (2018) who found *M. falciger* to build characteristic low and wide mounds while those of *M. natalensis* were taller and narrower. These differences in dimension may have been due to population size, termite species, the degree of weathering and the extent of use by the harvesters (Miyagawa et al., 2011). Very little information is available regarding mound dimensions of *M. falciger*. Seymour et al. (2014) measured mounds in miombo woodlands in Chizarira National Park, south of the Zambezi river escarpment in northern Zimbabwe, and found the mean height and diameter of *M. falciger* mounds to be 9 m and 30 m respectively. These dimensions are larger than those observed in this study. The height and circumference of *M. natalensis* recorded from this study are also larger than the average sizes observed by Kitto (1997) of 0.73 m (height) and 5.75 m (circumference) in KwaZulu Natal, South Africa, but corroborates that of Ruelle et al. (1975) of less than 1.5 m in height within the range of 1.5 - 2.7 m in height.

5.6. CONCLUSION

My investigations showed that termite mounds abundance and distribution are strongly linked to land uses. *Macrotermes* mounds were more abundant in the maize fields. The mango orchards had more *Macrotermes falciger* mounds, the most preferred edible species in the district, than communal grazing lands. Therefore, farmers might have realized the importance of termites to food security or ecosystems or the farmers do not have the implements to remove the mounds. Agriculture holds the key to the management of termites and conservation of biodiversity as farmers are stewards of the land. Further research should be conducted on the density and distribution of edible termite species in other agroecosystems.

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5.8. REFERENCES

Acocks, J. P. H. 1988. Veld types of South Africa. 3rd Edition. *Memoirs of the Botanical Survey of South Africa*, 57, 1-146.

Adam, R. A. (1993). Aspects of the biology of the harvester termite *Trinervitermes trinervoides.* Unpublished PhD thesis, University of the Orange Free State, Bloemfontein.

Adam, R.A., Mitchell, J.D. & van der Westhuizen, M.C. (2012). The Role of the Harvester Termite, *Trinervitermes trinervoides* (Termitidae: Nasutitermitinae), in a Semi-Arid Grassland Ecosystem in South Africa: Nest Populations and Caste Composition. *African Entomology*, 20(2), 239-251. https://doi.org/10.4001/003.020.0202

Adam, R. A., Mitchell, J. D., & van der Westhuizen, M. C. (2008). Aspects of foraging in the harvester termite, *Trinervitermes trinervoides* (Sjöstedt) (Termitidae: Nasutitermitinae). *African Entomology*, 16(2), 153-161. doi: https://doi.org/10.4001/1021-3589-16.2.153

Akutse, K. S., Owusu, E. O., & Afreh-Nuamah, K. (2012). Perception of Farmers' Management Strategies for Termites Control in Ghana. *Journal of Applied Biosciences*, 49, 3394-3405.

Anderson, J. M., & Wood, T. G. (1984). Mound composition and soil modification by two soil-feeding termites (Termitinae, Termitidae) in a riparian Nigerian forest. *Pedobiologia*, 26, 77-82.

Arifin, Z., Dahlan, Z., Sabaruddin, Irsan, C., & Hartono, Y. (2014). Characteristics, morphometry and spatial distribution of populations of subterranean termites *Macrotermes gilvus* Hagen (Isoptera: Termitidae) in the rubber plantation land habitat which managed without pesticides and chemical fertilizers. *International Journal of Science and Research*, 3(4), 102-106.

Bandiya, H. M., Majeed, Q., Ibrahim, N. D. & Shindi, H. A. (2012). Density and dispersion pattern of mounds of *Macrotermes bellicosus* [Isoptera: Termitidae] in some Local Government areas of

Sokoto, semi-arid Zone of Nigeria. *Research in Zoology*, 2(1): 1-4. doi: 10.5923/j.zoology.20120201.01

Banjo, A. D., Lawal, O. A., & Songonuga, E. A. (2006). The nutritional value of fourteen species of edible insects in Southwestern Nigeria. *African Journal of Biotechnology*, 5(3), 298-301.

Bignell, D. E., Roisin, Y., & Lo, N. (2010). Biology of Termites: a Modern Synthesis (1st ed.). Dordrecht: Springer.

Boga, J. P., Akpesse, A. A. M., Ouali-N'goran, S. W. M., Trabi, C. S., Kouassi, K. P., Tano, Y., & Yapi, A. (2015). Spatial distribution and density of termite mounds in a protected habitat in the south of Cote D'Ivoire: case of National Floristic Center (CNF) of UFHB of Abidjan. *European Scientific Journal*, 11(3), 241-259.

Bonachela, J. A., Pringle, R. M., Sheffer E., Coverdale, T. C., Guyton, J. A., Caylor, K. K., Levin, S. A., & Tarnita, C. E. (2015). Termite mounds can increase the robustness of dryland ecosystems to climatic change. *Science*, 347, 651-655.

Coaton, W. G. H. (1948). Trinervitermes species – the snouted harvester termite. *Union of South Africa, Department of Agriculture Bulletin,* 261, 1-19.

Davies, A. B., Baldeck, C. A. & Asner, G. P. (2016). Termite mounds alter the spatial distribution of African savanna tree species. *Journal of Biogeography*, 43, 301-313.

Davies, A. B., Levick, S. R., Asner, G. P., Robertson, M. P., van Rensburg, B. J. & Parr, C. L. 2014. Spatial variability and abiotic determinants of termite mounds throughout a savanna catchment. *Ecography*, 37, 852-862.

Debelo D. G., & Degaga E. G. (2014). Studies on ecology of mound-building termites in the Central rift valley of Ethiopia. *International Journal of Agricultural Sciences*, 5(12), 326-333.

Ekundayo, E. O., & Orhue, E. R. (2002). Properties of termite mounds in the Niger Delta region of Southern Nigeria. *International Journal of Scientific & Technology Research*, 14, 15-21.

Fleming, P. A., & Loveridge, J. P. (2003). Miombo woodland termite mounds: resource islands for small vertebrates? *Journal of Zoology*, 259, 161-168.

Fuller, C. (1915). Observations on some South African termites. *Annals of the Natal Museum,* 3, 329-505.

Grohmann, C., Oldeland, J., Stoyan, D., & Linsenmair, K. E. (2010). Multi-scale pattern analysis of a mound-building termite species. *Insectes Sociaux*, 57, 477-486.

Hagan, J., Du Toit, J., & Cramer, M. (2017). Long-term livestock grazing increases the recruitment success of epigeal termites: insights from a >75-year grazing experiment in the Karoo, South Africa. *African Journal of Range & Forage Science*, 1-10. doi: 10.2989/10220119.2017.131498

Holt, J. A., & Lepage, M. (2000). Termites and soil properties. In: *Termites: evolution, sociality, symbiosis, ecology*. Abe, T., Bignell, D.E. &, Higashi, M. (Eds). Kluwer Academic Publishers. Pp. 389-407.

Howse, P. E. (1970). *Termites: a study in social behaviour*. London: Hutchinson.

Jongema, Y. (2015). World list of edible insects. Wageningen University. Netherlands. Pp 1-75. Retrived from http://www.wageningenur.nl/en/Expertise-Services/Chair-groups/Plant-Sciences/Laboratory-of-Entomology/Edible-insects/Worldwide-species-list.htm

Jones, J. A. (1990). Termites, soil fertility and carbon cycling in dry tropical Africa: a hypothesis. *Journal of Tropical Ecology*, 6, 291-305.

Jones, D. T., Susilo, F. X., Bignell, D. E., & Suryo, H. (2000). Terrestrial insects: species richness, functional diversity and relative abundance of termites under different land use regimes. In: *Above-ground biodiversity assessment working group summary report 1996-1999 impact of different land uses on biodiversity*. Gillison, A.N. (Ed). Alternatives to Slash and Burn Project. International Center for Research in Agroforestry, Nairobi, Kenya. Pp. 128-139.

Jones, C. G., Lawton, J. H., & Shachak, M. (1994). Organisms as ecosystem engineers. *Oikos*, 69, 373-386.

Jouquet, P., Tavernier, V., Abbadie, L., & Lepage, M. (2005). Nests of subterranean fungus-growing termites (Isoptera, Macrotermitinae) as nutrient patches for grasses in savannah ecosystems. *African Journal of* Ecology, 43, 191-196.

Jude, C. C., & Ayo, O. O. (2008). Influence of termite infestation on the spatial variability in the guinea savanna region of Nigeria. *Geoderma*, 148, 357-363.

Kabeh, J. D. (2016). Agricultural Land Denudation Due to Termites Infestations in the Northern Guinea Savanna Crop Fields of Taraba State, Nigeria. *International Journal of Innovative Agriculture & Biology Research*, 4(3), 1-8.

Kelly, J. A., & Samways, M. J. (2011). Mound-building termite (Blattaria: Isoptera) mound density and ecological correlates in a southern African savanna reserve. *African Entomology*, 19(1), 156-164.

Kitto, S. M. (1997). Studies of the nests of the fungus-growing termite *Macrotermes natalensis* (Isoptera: Macrotermitinae). Unpublished MSc thesis, University of Natal, Pietermaritzburg. 91pp.

Korb, J., & Linsenmair, K. E. (2001a). The causes of spatial patterning of mounds of a fungus growing termite: results from nearest-neighbour analysis and ecological studies. *Oecologia*, 127, 324-333.

Korb, J., & Linsenmair, K. E. (2001b). Resource availability and distribution patterns, indicators of competition between Macrotermes bellicosus and other macro-detritivores in the Comoé National Park, Côte d'Ivoire. *African Journal of Ecology*, 39(3), 257-265.

Lee, K. E., & Wood, T. G. (1971). *Termites and soils.* London: Academic Press.

Levick, S. R., Asner, G. P., Kennedy-Bowdoin, T. & Knapp, D. E. (2010a). The spatial extent of termite influences on herbivore browsing in an African savanna. *Biological Conservation*, 143, 2462-2467.

Levick, S. R., Asner, G. P., Chadwick, O. A., Khomo, L. M., Rogers, K. H., Hartshorn, A. S., Kennedy-Bowdoin, T. & Knapp, D. E. (2010b). Regional insight into savanna hydrogeomorphology from termite mounds. *Nature communications* 1, 1-7.

Lima, S. S., Ceddia, M. B., Zuchello, F., de Aquino, A. M., Mercante, F. M., Alves, B. J. R., Urquiaga, S., Martius, C., & Boddey, R. M. (2015). Spatial variability and vitality of epigeous termite mounds in pastures of Mato Grosso Do Sul, Brazil. *Brazilian Journal of Soil Science*, 39, 49-58.

Low, A. B., & Rebelo, A. G. (1996). Vegetation of South Africa, Lesotho and Swaziland. Department of Environmental Affairs and Tourism, Pretoria.

Meyer, V. W., Crewe, R. M., Braack, L. E. O., Groeneveld, H. T., & van der Linde, M. J. (2000). Intracolonial demography of the mound-building termite Macrotermes natalensis (Haviland) (Isoptera, Termitidae) in the northern Kruger National Park, South Africa. *Insectes Sociaux*, 47, 390-397.

Meyer, V. W., Braack, L. E. O., Biggs, H. C., & Ebersohn, C. (1999). Distribution and density of termite mounds in the northern Kruger National Park, with specific reference to those constructed by *Macrotermes* Holmgren (Isoptera: Termitidae). *African Entomology*, 7(1), 123-130.

Mitsuhashi, J. (2016). Edible insects of the world. Boca Raton: CRC Press. 286pp.

Miyagawa, S., Koyama, Y., Kokubo, M., Matsushita, Y., Adachi, Y., Sivilay, S., Kawakubo, N., & Oba, S. (2011). Indigenous utilization of termite mounds and their sustainability in a rice growing village of the central plain of Laos. *Journal of Ethnobiology and Ethnomedicine*, 7,24

Moe, S. R., Mobæk, R. & Narmo, A. K. (2009). Mound building termites contribute to savanna vegetation heterogeneity. *Plant Ecology*, 202, 31-40.

Moore, J. M. & Picker, M. D. (1991). Heuweltjies (earth mounds) in the Clanwilliam district, Cape Province, South Africa: 4000-year-old termite nests. *Oecologia*, 86, 424-432.

Mpandeli, N. S. (2006). Coping with climate variability in Limpopo Province. Unpublished PhD thesis, University of Witwatersrand.

Mujinya, B. B., Adam, M., Mees, F., Bogaert, J., Vranken, I., Erens, H., Baert, G., Ngogo, M., & Van Ranst, E. (2014). Saptial patterns and morphology of termite (*Mactrotermes falciger*) mounds in the upper Katanga, D.R. *Catena*, 114, 97-106.

Munthali, D., Logan, J., Wood, T., & Nyirenda, G. (1999). Termite distribution and damage to crops on smallholder farms in southern Malawi. *Insect Science and Its Application*, 19(1), 43-49. doi:10.1017/S174275840001657X

Muvengwi, J., Davies, A. B., Parrini, F. & Witkowski, E. T. F. (2018). Geology drives the spatial patterning and structure of termite mounds in an African savanna. *Ecosphere*, 9, 3.

Muvengwi, J., Witkowski, E., Davies, A., & Parrini, F. (2017). Termite mounds vary in their importance as sources of vegetation heterogeneity across savanna landscapes. *Journal of Vegetation Science*, 28, 1008-1017. doi: https://doi.org/10.1111/jvs.12560

Netshifhefhe, S. R., Kunjeku, E. C., & Duncan, F. D. (2018). Human uses and indigenous knowledge of edible termites in Vhembe District, Limpopo, South Africa. *South African Journal of Science*, 114(1/2) 10p. doi: http://dx.doi.org/10.17159/sajs.2018/20170145

Nyamadzawo, G., Gotosa, J., Muvengwi, J., Wuta, M., Nyamangara, J., Nyamugafata, P. & Smith, J. L. (2012). The Effect of Catena position on greenhouse gas emissions from Dambo located termite (*Odontotermes transvaalensis*) mounds from Central Zimbabwe. *Atmospheric and Climate Sciences*, 2, 501-509. doi:10.4236/acs.2012.24044

Odum, E. (1971). Fundamentals of Ecology (3rd ed.) Saunders College Publishing, Philadelphia.

Orhue, E. R., Uzu, O. F., & Osaigbovo, U. A. (2007). Influence of activities of termites on some physical and chemical properties of soils under different land use patterns: A Review. *International Journal of Soil Science*, 2, 1-14.

Payne, R. W. (Ed). (2015). Introduction to GenStat® for Windows™ (18th Ed. Introduction). © 2015. VSN International, UK.

Payne, R. W. (Ed). (2014). Introduction to GenStat® for Windows™ (17th Ed.) VSN International, Hemel Hempstead, Hertfordshire, UK. © 2014 VSN International.

Pearce, M. J., Logan, J. W. M., & Tiben, A. (1995). Termites (Isoptera) from the Darfur region of the Sudan with comments on their pest status. *Journal of Arid Environment*, 30, 197-206.

Pomeroy, D. (2005). Dispersion and activity patterns of three populations of large termite mounds in Kenya. *Journal of East African Natural History*, 94, 319-341.

Pomeroy, D. E., & Service, M. W. (1986). Tropical ecology. Harlow, Essex: Longman Scientific & Technical.

Ruelle, J. E., Coaton, W. G. H., & Sheasby, J. L. (1975). National survey of the Isoptera of Southern Africa. The genus *Macrotermes* (Holmgren) (Termitidae: Macrotermitinae). *Cimbebasia* (A), 3(8), 73-94.

Sands, W. A. (1998). The identification of worker castes of termite genera from soils of Africa and the Middle East. CAB International, Wallingford, vii + 500 pp. [U.K.]

Schuurman, G. (2006). Foraging and distribution patterns in a termite assemblage dominated by fungus-growing species in semi-arid northern Botswana. *Journal of Tropical Ecology*, 22(3), 277-287.

Schuurman, G., & Dangerfield, J. M. (1997). Dispersion and abundance of *Macrotermes michaelseni* colonies: a limited role for intraspecific competition. *Journal of Tropical Ecology*, 13(1), 39-49.

Seymour, C. L., Milewski, A. V., Mills, A. J., Joseph, G. S., Cumming, G. S., Cumming, D. H. M., & Mahlangu, Z. (2014). Do the large termite mounds of Macrotermes concentrate micronutrients in addition to macronutrients in nutrient-poor African savannas? *Soil Biology and Biochemistry*, 68, 95-105. doi: http://dx.doi.org/10.1016/j.soilbio.2013.09.022

Sileshi, G., Nyeko, P., Nkunika, P., Sekematte, B., Akinnifesi, F., & Ajayi, O. (2009). Integrating ethno-ecological and scientific knowledge of termites for sustainable termite management and human welfare in Africa. *Ecology and Society*, 14(1), 48.

Snedecor, G. W., & Cochran, W. G. (1980). Statistical methods (7th ed.). Iowa State University Press. 234pp.

Turner, J. S. (2000). Architecture and morphogenesis in the mound of *Macrotermes michaelseni* (Sjöstedt) (Isoptera: Termitidae, acrotermitinae) in northern Namibia. *Cimbebasia*, 16, 143-175

Uys, V. (2002). A Guide to the Termite Genera of southern Africa. Plant Protection Research Institute Agricultural Research Council, Pretoria. ISBN: 1 86849 216 8.

Watson, J. P. (1967). A termite mound in an Iron Age burial ground in Rhodesia. *Journal of Ecolology*, 55, 663-669.

Watson, J. P. (1977). The use of mounds of the termite *Macrotermes falciger* (Gerstacker) as a soil amendment. *Journal of Soil Science*, 28, 664-672.

CHAPTER 6: SYNTHESIS

6.1. INTRODUCTION

Entomophagy or the practice of consuming insects, contributes to world food security (Rumpold & Schluter, 2013). The most widely eaten insects in Africa are: grasshoppers, locusts, crickets, termites, mopane worms and palm weevil larvae (Kelemu *et al*., 2015). The availability of these insects as human food can be hampered by the usage of land. The main purpose of this study was to evaluate the effects of different land uses on edible termite species and human uses of termites within the Vhembe District Municipality.

Recently insects have been considered a staple and a normal nutritional commodity rather than an alternative food source for many people of the world (Chakravorty, 2014). Thus, there is a renewed interest in consuming insects (Feng *et al*., 2018). The 2014 FAO working group investing insects as an alternative food estimated that over two billion people worldwide rely on insects as a food source (van Huis *et al*., 2013). This FAO working group further suggested that the current farming and agricultural food production practices are unsustainable and that edible insects are a viable, underexploited resource that could help meet the food demands of the world's rising population. Consumption of termites is popular in many countries due to their nutritional value (Banjo *et al*., 2006) and are traditional foods that help to alleviate poverty (Egan, 2013). Databases of edible insect from various countries have been developed (Figueirêdo *et al*., 2015). Termites are important edible insects proved to be a food for many South Africans in the rural areas (Netshifhefhe *et al*., 2018). Vernacular names of edible termites and their various species varied through ethnic groups with the identification of the edible termite species based on the termite size, colour of soldiers and workers and the size of the termite mound. Information such as vernacular or local names, species names and mound types and shapes are important for the development of such edible termite databases. The traditional and indigenous way of harvesting and preserving these edible termites have been documented.

Termite species abundance and richness decline is mainly due to rainfall patterns, but land use patterns and conversion of land for agriculture use also significantly affects the distribution and diversity of termites (Eggleton *et al.*, 2002). A case study of edible termites in the Vhembe District is provided in this thesis. In my study, I indicate that three termite species are consumed all belonging to the *Macrotermes* genus, a mound building termite species whose distinct conical shaped mounds dominate the African savanna (Uys, 2002). Although edible termites occurred throughout the year in the Vhembe District, their densities and diversities are determined by seasonal weather conditions. The main arguments why edible termites could form a good alternative source of human food and source of livelihoods are: nutritional value, sustainable harvesting, indigenous knowledge preservation and sharing, cultural and religious beliefs, livelihood and social benefits and source of income (Chapter 2).

6.2. NUTRITIONAL VALUE

Termites are a food source of high nutritional value; rich in proteins, vitamins, essential amino acids, minerals, fatty acids, dietary fibre and carbohydrates (Akullo *et al*., 2018, Banjo *et al*., 2006; Mbah & Elekima, 2007; Paoletti *et al*., 2003). Banjo *et al. (*2006) in Nigeria found *Macrotermes bellicosus* and *Macrotermes natalensis* to have the highest iron content at 29 mg/100 g and 27 mg/100 g respectively. The winged *M. falciger* was reported to form an important part of diet in many people living in the rural areas of Zambia, also available in urban markets of the country, with the chemical composition of 23.1% crude protein, 46.5% fat and high in energy content (591 kcal/100 g (Chulu, 2015). The studies conducted by Moore (2004) in South Africa on termite nutritional analysis found *M. natalensis* alates to have higher fats (55.3%) as compared to *Odontotermes sp* (49.2%). The crude protein of *M. natalensis* soldiers was 72.8%.

Understanding the health risks associated with entomophagy is crucial. Entomophagy poses less risks of transmission of diseases to humans in relation to consumption of animal meat (Rumpold & Schlüter, 2013). Although not all termites are edible (Chapters 2 and 4) people did not report any toxic effect from eating termites in this study. Risks such as allergies and upset stomach that maybe associated with consumption of termites should be properly assessed. Differences were found amongst the two most edible species regarding the preparation. *Macrotermes natalensis* is prepared by whisking to release a foam. The chemical/toxin released should be investigated. Soldier castes of termites are the most preferred and regularly eaten in Vhembe District followed by alates. Termites are not only eaten because of health benefits or nutrition, they are also consumed to alleviate poverty, part of customs and for their taste. Linkages with the Department of Food Science and Technology at the University of Venda should be made to assist with edible termite analysis and test product nutritional composition. Partnership with the Limpopo Agro-Food Technology Station (LATS) located at the University of Limpopo can be fostered to assist with product processes and development. Legislation to regulate the edible insects should be developed in South Africa that will take into consideration the multi-dimensional nature of insects as food and feed to cover food safety, consumer protection, nature conservation, traditional food systems, and economic development.

6.3. LIVELIHOOD AND SOCIAL BENEFITS

Most of the rural communities that lie within Vhembe District are characterized by high poverty and unemployment rates, with subsistence farming and communal grazing systems being the main land uses (Munthali, 2007). Edible termites harvesting can offer important livelihood diversification as termites are easily accessible and can be harvested by anyone at no cost required for basic harvesting equipment. Edible termites in this study were processed and sold by the poorest members of the Vhembe society. These activities directly improved diets and provided cash income through the selling of excess production. Partnerships in order to promote sustainable livelihoods in rural areas could be established with the Department of Food Science and Technology (FST) at University of Venda in conducting research on insects for food in Limpopo Province in the fields of insect production, food product development, environmental and livelihood assessments. The Department of Food Science and Technology at the university has people with expertise in food processing and preservation.

Macrotermes falciger termites provide an important income across the district with new niche markets offering growing opportunities for entrepreneurs (Chapter 2). In Zambia, Chidumayo & Mbata (2002) found that edible caterpillars have the potential to generate higher incomes when sold to markets, even higher than the sale of agricultural crops. Rural households in the Vhembe District are better able to access resources of edible insects, including edible termites, to provide food or to generate income. The overall harvest estimate of termites from the 32 harvesters over one season was 3350 liters of dried termites at an annual income of R 227 000. Depending on freshness, cleanliness and grading of the edible termites, a single hardworking marketer can get an annual income of R 17 680 from edible termites. This shows that trading in edible termites in the district can be a lucrative business. Edible termites are second to mopane worms in demand (personal observation) and fetch higher prices than locusts and stinkbugs in the district. These termites are sold at higher prices than vegetable crops and meat (chicken, pork and beef) at markets. In this study, households sell edible termites and other insects to cover food and households expenses, to supplement income, and as a response to the loss of other income sources. For those households harvesting termites themselves (especially poor), use of termites for protein potentially saves them money that they would otherwise have to spend on buying protein. Based on the daily average consumption of 22.27 g, and market prices R 20, the "direct use value" of termites per member of household was R 7 daily, and was the economic contribution of termites to each member of households over-and-above the sale of termites. The households would save R 7 daily per member by harvesting termites free instead of purchasing other protein sources. This chapter demonstrates that *M. falciger* termites should be considered more sustainable source than meat of rural livelihood.

The high price of maize for animal feeds threatens the survival of the poultry farmers (Agriseta, 2018), so the use of termite as substitute for feeds could be explored. The company AgriProtein is leading a new industry based in the Western Cape (www.agriprotein.com) with a new plant to be established in Gauteng specializing in the production and commercializing insects as sustainable feed source of natural protein in Southern Africa. Commitment by government and other stakeholders to make financial resources available is necessary for the rural communities to invest in edible termite trade. The use of insects for feed is very significant, and indirectly benefits food security.

6.4. SUSTAINABLE HARVESTING

Harvesting of edible termites is mainly done by women (Chapter 2). The study found methods of termite harvesting varies from type to type in different areas of the Vhembe District. Fibers from indigenous trees and grasses mainly sedges are used in harvesting soldier termites while alates are mass trapped using rural and indigenous technology (Ayieko *et al*., 2011; Netshifhefhe *et al*. 2018). Sedges dominate the wetland areas (O'Connor & Bredenkamp, 2003) in this district. Sedge dominated vegetation must be considered as sensitive habitats and of high conservation value to preserve wetland which is not considered important in rural communities. In some instances, harvesting may lead to overexploitation of edible insects (Payne & van Itterbeeck, 2017), and their sustainable management could be crucial to ensuring future food security. Many edible caterpillars of mopane worm become extinct due to over-harvesting (Kenis *et al*., 2006). The decline in edible termite populations will make them less available for a large part of the population in the Vhembe District particularly for the people living in the rural areas. Sustainable harvesting of edible termites that promotes employment, entrepreneurship and ecosystem services provision is one of the pillars through which communities within the Vhembe District are expected to benefit. This study (Chapter 2) indeed found that local people and termite harvesters in the local communities of Vhembe District are interested in harvesting edible termites in a sustainable manner, as shown though mound rotations. Further research on the variation of mound yields is recommended. We look forward to future research into sustainable harvesting practices and quantitatively assess if supply can sustainably meet demand in the study villages.

6.5. INDIGENOUS KNOWLEDGE AND CULTURAL BELIEFS

The local people in the Vhembe District rely on the conventional local knowledge to quickly identify which termites are edible and how to harvest them. This traditional knowledge and skills have been passed down from generation to generation. The indigenous local knowledge has, however, gradually declined with changing socio-economic conditions and the influence of new dietary patterns (Chakravorty, 2014), hence the call for the preservation of this indigenous knowledge. Rarely people have reported a toxic effect from eating incorrectly identified termite species in the district.

Sharing of the indigenous local knowledge is supported and facilitated by the Insects for Food and Feed Programme of the Food and Agriculture Organization of the United Nations (FAO). They provide technical expertise and support; knowledge sharing from Technical Cooperation Programme on insects as food and support in international communication. This was evident on the first international conference on insects for food and feed that took place on May 14 - 17, 2014 organized in collaboration between Wageningen University and the FAO held in Wageningen, the Netherlands where researchers shared knowledge from individual countries. South African government has formulated policies that support the indigenous knowledge through the Protection, Promotion, Development and Management of Indigenous Knowledge Systems Bill. The bill is to ensure the future protection, development and management of South Africa's Indigenous Knowledge Systems (IKS) through the documentation and recording of IKS. Efforts should be fast-tracked to document IKS through National Recordal System before losing respected elders, otherwise once an old person dies, the whole library disappears.

6.6. SUSTAINABLE AGRICULTURE

The present study confirmed that edible insects high in nutrition are harvested from agricultural systems (Payne & van Itterbeeck, 2017). Higher abundance of edible termites was recorded in communal grazing with human activities and agriculture causing a significant decline in termite diversity (Chapter 4). The current agricultural practices in most of the African countries focuses more on increasing crop production yields with little consideration of the consequences this may have for the additional harvest and ecology of edible termites. Termites are often considered a pest to agricultural crops (Debelo & Degaga, 2014). Edible *Macrotermes* species have been reported to be pests of maize (Sileshi et al., 2009). The majority of crops grown in South Africa are subjected to intense and frequent soil cultivation practices (Giliomee, 1999). Increasing agricultural production which results in mechanical clearing of land or trees, and increased use of agrochemicals threatens edible termites (Chapter 4). Increased use of pesticides and fertilizers in agriculture also has negative effects on biodiversity (Rundlöf *et al*., 2015). Agricultural management strategies focus on the destruction of pests that attack crops rather than the maintenance of biodiversity. The adoption of pesticides use by crop production farmers threatens the habitat in which many edible termites are found and their future availability. This has implications in rural areas where termites are not only a source of food, but are also a source of livelihoods as income generating activities. The inclusion of the maintenance of edible termites within Integrated Pest Management (IPM) strategies should be advocated. Governments should also look at designing multifunctional landscapes policies that preserves ecosystem function and ecological services. Maize farmers in this study (Chapter 4) were found to plough and plant around the huge mounds of *Macrotermes natalensis*. Compliance to the use of agricultural pesticides not targeting edible insects such as termites should be enforced.

Policies and regulations should be established to ensure that the development and consumption of insects does not affect human health. South Africa has sound agriculture, conservation and environmental acts and policies with non-compliance experienced mainly in rural areas. Conservation of Agricultural Resources Act 43 of 1983 provide for control over the utilization of the natural agricultural resources to promote the conservation of the soil and vegetation. National Environmental Management Act 107 of 1998 supports the principle of sustainable development and also mandated provincial governments to enforce environmental management laws. The similar problems of non-compliance might be experienced in the lately approved Draft Conservation Agriculture Policy for public comment published in February 2018 by the Department of Agriculture, Forestry and Fisheries (DAFF). This policy promotes sustainable land-use through minimal mechanical soil disturbance (i.e. no tillage), maintenance of a mulch of organic matter and rotations or sequences and associations of crops, including trees. Soil formation and nutrient recycling by termite has been well documented (Gras *et al.*, 2016), so termites must be considered as an important ecosystem service.

6.7. INFLUENCE OF LAND USES ON EDIBLE TERMITE DIVERSITY

Various termite sampling methods have shown great variation in termite diversity and abundance in the arid Namibian rangelands (Zeidler *et al*., 2004). Chapter 3 indicated that the transect search method was the most efficient (12 termite species recorded) in determining termite activity and species diversity, followed by cattle dung bait (6 termite species) while the toilet roll bait was least with 3 termite species. Both edible (*Odontotermes*) and non-edible (*Trinervitermes*, *Microtermes* and Lepidotermes) termite species were intercepted by all the methods. It was interesting to observe the three feeding groups (lower termites - mainly wood and grass feeders, higher termites-fungus growing wood feeders/litter feeders) and organic rich soil feeders/ humus feeders detected by the two methods in this chapter. A combination of the transect search method and the cattle dung bait method showed to be the most effective way to measure termite diversity in the savanna. Looking at the location of the study areas in various land use types, optimal protocol for sampling at the time of greatest activity and diversity that will prevent damage, deterioration, and loss including theft and vandalism will have to be used. This is achieved by the two methods proposed.

Chapter 4 investigated the seasonal diversity, density and distribution of edible termites in addition to their importance as a food for human consumption. Observations on the seasonal availability of the edible termites (both soldiers and alates) showed a higher abundance in the rainy season (October - April) than in the dry season (winter: May - July and early spring: September). Chapter 4 reports that the functional termite diversity and abundance of both edible and non-edible termites were higher on communal grazing lands compared with mango orchard and maize field. This chapter confirms my hypothesis that termite species diversity and abundance varied across land use types, with agriculture adversely affecting termite diversity, abundance and distribution. Cattle communal grazing areas were found to be high in nutrient food resources for termites with little to no anthropogenic activities. Communal rangelands are typically considered as being degraded and therefore a low production value (Zerga, 2015; Palmer & Bennet, 2013; Bennet *et al.*, 2012; Palmer *et al*., 1997). However, communal grazing lands still harbor an important diversity of termites which provide important ecosystem services, including food for rural communities. It was interesting to observe the dominance of *M. natalensis* in both the mango orchards and maize fields which is not the most consumed and preferred species in the district. Further investigation on this is recommended. *Macrotermes natalensis* is reported to be the most widespread in the Southern Africa (Uys, 2002) and consumed throughout Africa (van Huis, 2003; Figueirêdo *et al*., 2015; Alamu *et al*., 2013; Netshifhefhe *et al*., 2018).

Although maize fields had the lowest number of termite species, the number of edible species were similar with communal grazing lands. The Vhembe District Municipality is one of the high-potential agricultural areas of the province with rural communities place great emphases on growing maize as their staple food and livestock farming (Musetha, 2016, Whitebread *et al*., 2010). Efforts should be made to improve the sustainability of emerging farmers who operate in crop or livestock farming systems and this will have positive effect on biodiversity and biological regulation of soil processes.

The study found that the land use type had a significant effect on the abundance and distribution of epigeal mounds (Chapter 5). Lower densities were observed in highly disturbed agricultural and cultivated fields due to intensitive agricultural activities and anthropogenic disturbances. However, larger numbers of larger mounds of edible *Macrotermes* termite species were observed in mango orchards and maize fields. It is interesting that any termites or active mounds were found in maize fields at all (including some species that were only found there). This suggest either very high resilience of a number of termite species or an important level of tolerance of termites in fields by farmers. Low and wide mounds characterize *M. falciger* whereas narrower are those of *M. natalensis*. There was no difference in the height of the mounds from these species. Due to the area taken up by the *M. falciger* mounds they are more likely to be destroyed. Some of the smallholder farmers in many African countries welcome the presence of termite mounds in their fields as they regularly harvest parts of termite mounds in order to spread the soil across their fields as fertilizer (Payne & van Itterbeeck, 2017). The overall study demonstrated that the edible termites' availability and distribution varies across land-use types, with less termites on minimally disturbed land compared to agricultural and cultivated/ploughed land. Edible termites are lost from agricultural areas through various agricultural operations taking place such as soil cultivation, mechanical ploughing, chemical fertilization and application of pesticides. These could affect the rural income and food security for many who depend on edible termites for a living.

There were discrepancies between encounter data (Chapter 4) and mound data (Chapter 5) with no *M. falciger* found in encounter data but most abundant edible species in mound data for maize fields. The non-detection of the *M. falciger* in Chapter 4 is similar to the findings by Davies (2010) in the studies conducted in the Kruger National Park and Meyer *et al.* (1999). There was no *M. falciger* detected using baiting and active search by Davies (2010) whereas the similar species was recorded by Meyer *et al*. (1999) during mound surveys. The reasons for these discrepancies are unknown and further studies to look at various sampling methods especially on *M. falciger* is recommended.

6.8. CHALLENGES TO THE STUDY

A number of challenges were encountered during the duration of this study. Due to the large size of the district, I limited my study to only three local municipalities out of four. The Musina Local Municipality was omitted due the lack of markets selling termites. The country experienced one of the worst drought for a very long period of time during the study period. This could have negatively impacted the number of the termite species sampled.

A long time was taken to complete marketer’s questionnaire, because sellers were interviewed at the markets during business hours, there were many interruptions by customers wanting to buy termites. Patience was required, and some sellers withdrew their participation in the middle of the interviews.

Some of the study sites chosen were far apart, not by choice but because of the availability of the harvesters in those villages and also looking for a different land use type in a different local municipality. Some of the harvest and communal grazing sites were difficult to access and we left cars far away and walked for distances due to the poor state of the roads in those areas.

6.9. CONCLUSION AND RECOMMENDATIONS

Termites are not only a food source but are also a source of livelihoods and income generating activities in the rural areas of the Vhembe District. The present study revealed that termite species richness and abundance, mound densities and distribution are determined by the land use. This was evidenced by the differences observed within the three land use types.

The consumption of termites must be promoted in the face of increasing demand for meat in particular in developing countries due to the accelerated growing population. The research on edible termites that will incorporate the indigenous knowledge is needed in the field of: nutritional quality for both food and feed; disease risk, health and food safety (e.g. chemical, toxicological and allergenic risks); processing and value adding; preservation and storage; packaging and marketing; improving knowledge on termites and harvesting methods; interaction of edible termite species with environment; and legislation and regulatory measures. Research on edible termites in various agricultural practices should be further investigated. There is a need for studies that quantify the trade-off between costs or costs benefits (mound destruction versus crop productivity and vice versa), benefits of maintaining termites in agricultural landscapes, and conflicts between crop and protein production.

This thesis highlights the ecological and economic importance of edible termites in existing agricultural systems and has laid the basis for research in insect mass rearing and science-based information to improve efficient collection / trapping and processing of insects. My findings will stimulate greater interest in the commercial and environmental potential of edible termites and will open new ideas for entrepreneurship and business opportunities within food, feed systems and pharmaceutical sectors (e.g. chocolates, sausages, burgers, crackers, muffins, canning, animal feed, etc). *Macrotermes falciger* alates are very high in fats hence the quality of oil and its use should be investigated. Indeed, edible termites could be next on the menu.

6.10. REFERENCES

Agriseta. 2018. Poultry sub-sector skills plan 2018-2019. South African Poultry Association. 38pp

Akullo, J., Agea, J.G., Obaa, B.B., Okwee-Acai, J. & Nakimbugwe, D. 2018. Nutrient composition of commonly consumed edible insects in the Lango sub-region of northern Uganda. *International Food Research Journal* **25**(1): 159-165.

Alamu, O.T., Amao, A.O., Nwokedi, C.I., Oke, O.A. & Lawa, I.O. 2013. Diversity and nutritional status of edible insects in Nigeria: *A review. International Journal of Biodiversity and Conservation* **5**(4): 215-222. DOI: 10.5897/IJBC12.121

Ayieko, M.A., Obonyo, G.O., Odhiambo, J.A., Ogweno, P.L., Achacha J. & Anyango, J. 2011. Constructing and Using a Light Trap Harvester: Rural Technology for Mass Collection of Agoro Termites (*Macrotermes subhylanus*). *Research Journal of Applied Sciences, Engineering and Technology* **3**(2): 105-109.

Banjo, A.D., Lawal, O.A. & Songonuga, E.A. 2006. The nutritional value of fourteen species of edible insects in Southwestern Nigeria. *African Journal of Biotechnology* **5**(3): 298-301.

Bennett, J., Palmer, A.R. & Blackett, M. 2012. Range degradation and land tenure change: insights from a 'released' communal area of Eastern Cape province, South Africa. *Land Degradation and Development* **23**: 557-568.

Chakravorty, J. 2014. Diversity of Edible Insects and Practices of Entomophagy in India: An Overview. *Journal of Biodiversity, Bioprospecting and Development* **1**: 124.

Chidumayo, E.N. & Mbata, K.J. 2002. Shifting cultivation, edible caterpillars and livelihoods in the Kopa area of northern Zambia. *Forests, Trees and Livelihoods* **12**:175-193. DOI: 10.1080/14728028.2002.9752423

Chulu, M.C. 2015. Nutrient composition of the termite Macrotermes falciger, collected from Lusaka District, a potential agent against malnutrition. MSc Dissertation, University of Zambia.

Davies, A.B. 2010. Termite responses to long term burning regimes in southern African savannas: patterns, processes and conservation. MSc Thesis, University of Pretoria.

Debelo D.G. & Degaga E.G. 2014. Termite species composition in the central rift valley of Ethiopia. *Agriculture and Biology Journal of North America* **5**(3): 123-134

Egan, B.A. 2013. Culturally and Economically Significant Insects in the Blouberg Region, Limpopo Province, South Africa. Unpublished PhD thesis, University of Limpopo.

Eggleton, P., Bignell, D.E., Hauser, S., Dibog, L., Norgrove, L. & Madong, B. 2002. Termite diversity across an anthropogenic gradient in the humid forest zone of West Africa. *Agriculture, Ecosystems and Environment* **90**: 189-202.

Feng, Y., Chen, X.M., Zhao, M., He, Z., Sun, L., Wang, C.Y. & Ding, W.F. 2018. Edible insects in China: Utilization and prospects. *Insect Science* **25**: 184-198. DOI: 10.1111/1744-7917.12449

Figueirêdo, R.E.C.Rde, Alexandre, V. Iamara, S.P. & Alves, R.R.N. 2015. Edible and medicinal termites: a global overview. *Journal of Ethnobiology and Ethnomedicine*. **11**:29. DOI: http://dx.doi.org/10.1186/s13002-015-0016-4

Food and Agriculture Organization (FAO). 2014. Insects to feed the world. Summary report of the 1st International Conference 14-17 May 2014, Wageningen, The Netherlands.

Giliomee, J.H. 1999. Agriculture. In: Environmental Management in South Africa. Fuggle, R.F. & Rabie, M.A. (Eds) Juta and Co. Ltd., Cape Town. Pp.739-747.

Kelemu, S., Niassy, S., Torto, B., Fiaboe, K., Affognon, H., Tonnang, H., Maniania, N.K. & Ekesi, S. 2015. African edible insects for food and feed: inventory, diversity, commonalities and contribution to food security. *Journal of Insects as Food and Feed* **1**: 103-119.

Kenis, M., Sileshi, G., Mbata, K., Chidumayo, E., Meke, G. & Mutainte, B. 2006. Towards conservation and sustainable utilization of edible caterpillars of the Miombo. Poster presented at the ZIL Annual Conference, 12th June 2006. Zurich, Switzerland

Mbah, C.E. & Elekima, G.O.V. 2007. Nutrient composition of some terrestrial insects in Ahmadu Bello University, Samaru, Zaria Nigeria. *Science World Journal* **2**(2):17-20. DOI: http://dx.doi.org/10.4314/swj.v2i2.51728

Meyer V.W., Braack L.E.O., Biggs H.C. & Ebersohn C. 1999. Distribution and density of termite mounds in the northern Kruger National Park, with specific reference to those constructed by *Macrotermes* Holmgren (Isoptera: Termitidae). *African Entomology* **7**: 123-130.

Moore, A.J. 2004. African fungus-growing termites and other insects for human and poultry nutrition. MSc Thesis, University of KwaZulu-Natal, Pietermaritzburg, South Africa.

Munthali, S.M. 2007. Transfrontier Conservation Areas: Integrating Biodiversity and Poverty Alleviation in Southern Africa. *Natural Resources Forum* **31**: 51-60.

Musetha, M.A. 2016. The impact of climate change on agricultural crop production in the Vhembe District Municipality, Limpopo Province, South Africa. Unpublished Msc Thesis, University of South Africa.

Netshifhefhe, S.R., Kunjeku, E.C. & Duncan, F.D. 2018. Human uses and indigenous knowledge of edible termites in Vhembe District, Limpopo, South Africa. *South African Journal of Science* 114(1/2) 10p. doi: http://dx.doi.org/10.17159/sajs.2018/20170145

O'connor, T.G. & Bredenkamp, G.J. 2003. Grassland. In: Cowling, R.M., Richardson, D.M. & Pierce, S.M. (Eds). Vegetation of southern Africa. Cambridge University Press.

Palmer, A.R. & Bennett, J.E. 2013. Degradation of communal rangelands in South Africa: towards an improved understanding to inform policy. *African Journal of Range & Forage Science* **30**: 1-2, 57-63. doi: 10.2989/10220119.2013.779596

Palmer, A.R., Tanser, F. & Hintsa, M.D. 1997. Using satellite imagery to map and inventories vegetation status for Eastern Cape Province. Unpublished report, Range and Forage Institute, Grahamstown.

Paoletti, M.G., Buscardo, E., Vanderjagt, D.J., Pastuszyn, A., Pizzoferrato, L., Huang, Y.S., Chuang, L.T., Glew, R.H., Millson, M. & Cerda, H. 2003. Nutrient content of termites (syntermes soldiers) consumed by makiritare amerindians of the altoorinoco of Venezuela. *Ecology of Food and Nutrition* **42**(2): 177-191. doi: 10.1080/036702403902-2255177

Payne, C.L.R. & van Itterbeeck, J. 2017. Ecosystem Services from Edible Insects in Agricultural Systems: A Review. *Insects* **8**: 24. DOI:10.3390/insects8010024

Republic of South Africa. 2017. Draft Conservation Agriculture Policy. Pretoria: Government Printer.

Republic of South Africa. 1998. National Environmental Management Act 107 of 1998. Pretoria: Government Printer.

Republic of South Africa. 1998. Conservation of Agricultural Resources Act 43 of 1983. Pretoria: Government Printer.

Rumpold, B.A. & Schlüter, O.K. 2013. Nutritional composition and safety aspects of edible insects. *Molecular Nutrition and Food Research* **57**(5): 802-23. DOI: 10.1002/mnfr.201200735

Rundlöf, M., Andersson, G.K.S., Bommarco, R., Fries, I., Hederström, V., Hernertsson, L., Jonsson, O., Klatt, B.K. Pedersen, T.R., Yourstone, J. & Smith, H.G. 2015. Seed coating with a neonicotinoid insecticide negatively affect wild bees. *Nature* **521**: 77-80.

Uys, V. 2002. A guide to the Termite Genera of Southern Africa. Plant Protection Research Institute Handbook No. 15. Agricultural Research Council; Pretoria.

van Huis, A., van Itterbeeck, J., Klunder, H., Mertens, E., Halloran, A., Muir, G. & Vantomme, P., 2013. Edible insects: future prospects for food and feed security. In: Food and Agriculture Organization (FAO) Forest. FAO, United Nations, Rome.

Zeidler, J., Hanrahan, S. & Scholes, M. 2004. Determining termite diversity in arid Namibian rangelands – a comparison of sampling methods. *African Zoology* **39**(2): 285-292.

Zerga, B. 2015. Rangeland degradation and restoration: A global perspective. Point Journal of Agriculture and Biotechnology Research 1(2): 037-054.

APPENDIX A: PARTICIPANT INFORMATION SHEET

RESEARCH STUDY

Title of project: The effects of Land-use types on edible termite biodiversity in the Vhembe District Municipality of Limpopo Province

Invitation

You are invited to particiapte in a research study to evaluate the termite species diversity, biomass and human consumption in the Vhembe District Municipality. The study is being conducted by **Shandukani Netshifhefhe** born in Tshaulu village in the Thulamela Local Municipality in the same district munipality, currently studying at the University of Witwatersrand. Your participation will involve interviews using a questionnaire that will be translated into Tshivenda and XiTsonga (local language) by the researchers and the time involved will be about 45 minutes.

What is the purpose of the study?

The main objectives of the study are to identify the edible termite species and to evaluate the effect of land uses on species distribution, diversity and biomass within the Vhembe District Municipality.

Do I have to take part?

Your participation in this study is voluntary. We would like you to consent in writing to participate in this study as we believe that you can make important contribution to the research. You may choose not to participate and may withdraw from this study at any time without having to give an explanation or may refuse to answer questions about which you feel uncomfortable.

What are possible risks, discomforts and potential benefits of taking part?

There are no risks and discomforts related with this research. All the information provided by yourself will be kept confidential at all times. There are also no benefits to you by particpating in this research.

Will my taking part in the study be protected and kept confidential?

We will do everything to protect your privacy. All the information about you will be treated in strict confidence and you will not be named in any written work or publication arising from this study. Under no circumstances will identifiable responses be provided to any third party.

What will happen to the results of the study?

All information provided by you will be stored anonymously on a computer and will be analysed. The results from this analysis will be available in one or more of the following sources; dissertation or thesis, scientific papers in peer reviewed academic journals, presentations at conferences and at seminars. The dissertation or thesis will also be available on the world-wide web.

What if I have questions, complaint or concerns?

If you have any questions or concerns about this study, or if any problems arise, please contact **Shandukani Netshifhefhe** at University of Witwatersrand at 082 728 8896 or **Prof. Frances Duncan** at 011 717 6422.

Thank you for taking time to consider this study.

If you wish to take part in it, please sign the attached consent form.

This information sheet is for you to keep.

APPENDIX B: CONSENT FORM FOR PARTCIPATION IN A RESEARCH STUDY UNIVERSITY OF WITWATERSRAND

Name of researcher: Shandukani Netshifhefhe

Title of project: The effects of Land-use types on edible termite biodiversity in the Vhembe District Municipality of Limpopo Province

Please read and complete this form carefully. If you are willing to participate in this study sign & date the declaration at the end. If you do not understand anything and would like more information, please ask.

- I confirm that I have had the research satisfactorily explained to me in verbal and / or written form by the researcher and have been given the opportunity to ask questions.

- I understand that my partcipation is voluntary and that I may withdraw from the study at any time without having to give an explanation.

- I understand that all information collected about me will be kept strictly confidential and that I will not be named and identified in any report arising from this study.

I generously give my consent to participate in this study and have been given a copy of this form for my own information.

Signed: ____________________________

Date: ______________________________

APPENDIX C: QUESTIONNAIRE ON THE SURVEY OF HUMAN CONSUMPTION OF TERMITES

1. CONSUMERS

1. ADMINISTRATIVE SECTION

Interviewer	
Serial number	
Date of interviews	
District Municipality	
Local Municipality	
Name of Village	
Physical address (Optional)	

2. DEMOGRAPHICS

a. Gender:

1. Male
2. Female

b. Indicate your age group

1. 18 - 24
2. 25 - 39
3. 40 - 49
4. 50 - 59
5. 60 +

c. Indicate your language

1. Tshivenda
2. XiTsonga / Shangaan
3. Sepedi
4. Ndebele
5. Other (specify) ………………

d. Indicate your religion

1. Christian
2. Muslim
3. African tradition
4. Hindu
5. Other (specify) ………………

e. Educational status

1. No schooling
2. Primary schooling
3. Secondary schooling
4. Tertiary education

2.3. INFORMATION SOUGHT

<u>2.3.1. TERMITES CONSUMPTION</u>

a. What are the termites used for?

____

____

b. Do you eat termites?

1. Yes
2. No

c. If yes, how did you start eating termites and at what age?

____

d. If no, why don't you eat termites?

____

e. Any ethnic or religious prohibitions?

____

____

f. How are termites prepared?

____

____

____

g. Frequency of termites consumption

1. Once a week	
2. Twice a week	
3. Occasionally	
4. Much as possible	

h. Way of termites consumption

1. Fresh	
2. Dried / Sun	
3. Grilled	
4. Baked	
5. Boiled	
6. Fried	
7. Roasted	
8. Other (specify) ………………….	

i. How much termites do you eat in a day? (Daily intake of termites)

____

j. How important are termites as food?

____

____

k. Why do you eat termites? (Motivation for termites consumption)

1. Custom ☐
2. Religion ☐
3. Nutrition (Health benefits) ☐
4. Poverty / Starvation ☐
5. Flavours ☐
6. Curiosity ☐
7. Other (specify) ………………………………….. ☐

l. What type of termites do you prefer most?

1. Alates ☐
2. Soldiers ☐
3. Workers ☐
4. Queen ☐

m. Why do you prefer that?

____

2.3.2. KNOWLEDGE OF TERMITES

a. Do you know how to identify the major termite genera and species using vernacular names? Knowledge of termite taxonomy

   1. Yes
   2. No

b. If yes, please provide the genera and species in vernacular names

   ____

c. What is the role of termites in human nutrition and health?

   ____

   ____

d. What is the role of termites in soil fertility?

   ____

e. What other roles do you think termites play?

   ____

f. Which termite species are regularly consumed and why?

   ____

g. Which termite species are not regularly consumed and why?

   ____

QUESTIONNAIRE ON THE SURVEY OF HUMAN CONSUMPTION OF TERMITES

2. HARVESTERS

1. ADMINISTRATIVE SECTION

Interviewer	
Serial number	
Date of interviews	
District Municipality	
Local Municipality	
Name of Village	
Physical address (Optional)	

2. DEMOGRAPHICS

a. Gender:

1. Male ☐
2. Female ☐

b. Indicate your age group

1. 18 - 24 ☐
2. 25 - 39 ☐
3. 40 - 49 ☐
4. 50 - 59 ☐
5. 60 + ☐

c. Indicate your language

1. Tshivenda
2. XiTsonga / Shangaan
3. Sepedi
4. Ndebele
5. Other (specify) ………………

d. Indicate your religion

1. Christian
2. Muslim
3. African tradition
4. Hindu
5. Other (specify) ………………

e. Educational status

1. No schooling
2. Primary schooling
3. Secondary schooling
4. Tertiary education

2.3. INFORMATION SOUGHT

2.3.1. TERMITES CONSUMPTION

a. What are the termites used for?

____

____

b. Do you eat termites?

1. Yes
2. No

c. If yes, how did you start eating termites and at what age?

____

____

d. If no, why don't you eat termites?

____

e. Any ethnic or religious prohibitions?

____

____

f. Frequency of termites consumption

1. Once a week ☐
2. Twice a week ☐
3. Occasionally ☐
4. Much as possible ☐

g. Way of termites consumption

1. Fresh ☐
2. Dried / Sun ☐
3. Grilled ☐
4. Baked ☐
5. Boiled ☐
6. Fried ☐
7. Roasted ☐
8. Other (specify) …………………. ☐

h. How much termites do you eat in a day? (Daily intake of termites)

____

i. How important are termites as food?

____

____

j. Why do you eat termites? (Motivation for termites consumption)

1. Custom
2. Religion
3. Nutrition (Health benefits)
4. Poverty / Starvation
5. Flavours
6. Curiosity
7. Other (specify) ……………………..

k. What type of termites do you prefer most?

1. Alates
2. Soldiers
3. Workers
4. Queen

l. Why do you prefer that?

____

____

2.3.2. KNOWLEDGE OF TERMITES

a. Do you know how to identify the major termite genera and species using vernacular names? Knowledge of termite taxonomy

1. Yes
2. No

b. If yes, provide the species of termites you know in vernacular language

____

____

____

____

c. Please provide in vernacular names the following:

- Termites ____
- Elates ____
- Soldiers ____
- Workers ____
- Queen ____

d. What is the role of termites in human nutrition and health?

____

____

e. What is the role of termites in soil fertility?

____

____

f. What other roles do you think termites play?

____

____

g. Which termite species are regularly consumed and why?

____

____

h. Which termite species are not regularly consumed and why?

____

____

2.3.3. HARVESTING OR CAPTURING OF TERMITES

a. When did you start/end harvesting?

____

b. What was the main reason for starting to harvest?

____

____

c. How do you know that a particular species of termite is edible?

____

____

____

d. How far is the harvesting site from where you live?

____

e. How are termites harvested or captured and what plant species do you use to harvest?

____

____

f. Which termite species are easy to harvest and why?

____

____

g. Which termite species are difficult to harvest and why?

____

____

h. How often does the harvesting / capturing takes place?

____

i. How many / much termites harvested or captured in a single harvest? (Buckets)

j. When is the seasonal availability of termites? (Start, Peak and End of season in month)

k. During Start, Peak and End of seasons, how many times are termites collected in a week and what quantities?

l. Are the termites still available in the wild like before? (Increasing or decreasing over the past five or ten years) Explain

m. What are you doing to prevent the extinction of termites in the wild?

n. How are termites prepared?

o. How are termites preserved?

QUESTIONNAIRE ON THE SURVEY OF HUMAN CONSUMPTION OF TERMITES

3. SELLERS

1. ADMINISTRATIVE SECTION

Interviewer	
Serial number	
Date of interviews	
District Municipality	
Local Municipality	
Name of Village	
Physical address (Optional)	

2. DEMOGRAPHICS

a. Gender:

1. Male
2. Female

b. Indicate your age group

1. 18 - 24
2. 25 - 39
3. 40 - 49
4. 50 - 59
5. 60 +

c. Indicate your language

1. Tshivenda
2. XiTsonga / Shangaan
3. Sepedi
4. Ndebele
5. Other (specify) ………………

d. Indicate your religion

1. Christian
2. Muslim
3. African tradition
4. Hindu
5. Other (specify) ………………

e. Educational status

1. No schooling
2. Primary schooling
3. Secondary schooling
4. Tertiary education

2.3. INFORMATION SOUGHT

2.3.1. TERMITES CONSUMPTION

a. What are the termites used for?

____

____

b. Do you eat termites?

1. Yes
2. No

c. If yes, how did you start eating termites and at what age?

____

____

d. If no, why don't you eat termites?

____

e. Any ethnic or religious prohibitions?

____

____

f. Frequency of termites consumption

1. Once a week
2. Twice a week
3. Occasionally
4. Much as possible

g. Way of termites consumption

1. Fresh
2. Dried / Sun
3. Grilled
4. Baked
5. Boiled
6. Fried
7. Roasted
8. Other (specify) ………………….

h. How much / many termites do you eat in a day? (Daily intake of termites)

____

i. How important are termites as food?

____

____

j. Why do you eat termites? (Motivation for termites consumption)

1. Custom ☐
2. Religion ☐
3. Nutrition (Health benefits) ☐
4. Poverty / Starvation ☐
5. Flavours ☐
6. Curiosity ☐
7. Other (specify) ………………………………….. ☐

k. What type of termites do you prefer most?

1. Alates ☐
2. Soldiers ☐
3. Workers ☐
4. Queen ☐

l. Why do you prefer that?

____

____

2.3.2. KNOWLEDGE OF TERMITES

a. Do you know how to identify the major termite genera and species using vernacular names? Knowledge of termite taxonomy

   1. Yes

   2. No

b. If yes, please provide the genera and species in vernacular names

____

____

c. What is the role of termites in human nutrition and health?

____

____

d. What is the role of termites in soil fertility?

____

____

e. What other roles do you think termites play?

____

____

f. Which termite species are regularly consumed and why?

____

____

g. Which termite species are not regularly consumed and why?

____

____

2.3.3. MARKETING OF TERMITES

a. Who is responsible of organizing transport of termites to the market?

____

____

b. How much termites are transported per batch?

____

c. What are the consumers look for before buying termites? Preferences

____

d. What is the weight or volume of termites per packaging unit?

____

e. What is the type of packing used?

____

f. What are the selling prices of termites? (Minimum, Maximum and Average)

____

____

____

g. Do you have any grading and quality standards (size, aroma, colour, etc). If yes, please explain

____

____

h. What is the effect of different quality standards on price?

____

____

i. Is there any variability of prices between seasons?

____

j. What are the volumes sold daily, monthly and yearly?

k. Are the termites' sales increasing or decreasing? Please explain

APPENDIX D: HUMAN RESEARCH ETHICS CLEARANCE CERTIFICATE

UNIVERSITY OF THE WITWATERSRAND JOHANNESBURG

Research Office

HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)

R14/49 Netshifhefhe

CLEARANCE CERTIFICATE **PROTOCOL NUMBER: H15/0314**

PROJECT TITLE	The effects of land-use types on edible termite biodiversity in the Vhembe District Municipality of Limpopo Province
INVESTIGATOR(S)	Mr SR Netshifhefhe
SCHOOL/DEPARTMENT	Animal, Plant & Environmental Sciences/
DATE CONSIDERED	20 March 2015
DECISION OF THE COMMITTEE	Approved unconditionally
EXPIRY DATE	01 April 2017

DATE 2 April 2015 **CHAIRPERSON** (Professor T Milani)

cc: Supervisor : Professor FD Duncan

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10005, 10th Floor, Senate House, University.

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to completion of a yearly progress report.**

Signature 13 /04 /2015 **Date**

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES