THE INFLUENCE OF LARGE, VEGETATED TERMITARIA AND LARGE HERBIVORES ON SPIDER (ARANEAE) DIVERSITY IN MIOMBO WOODLANDS

By

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ABSTRACT

This study reports on spider species richness, abundance, and spider species community composition, in relation to differing herbivore impacts in miombo woodlands that have large vegetated termitaria. The chosen woodlands formed a gradient of herbivore impacts from Chizarira National Park that had high herbivore impacts mostly due to the presence of elephants, to Chivero Game Park that had intermediate herbivore impacts and no elephant population, and to the Chivero Bird Sanctuary that had minimal herbivore impacts. Pitfall traps were used to sample spiders on the large termite mounds and in the adjacent woodland matrix, and these spiders were consequently classified into morpho-species. In order to explain any differences in spider species richness, abundance, and spider species community composition the habitat structure was characterized through measuring ground cover, aerial cover, and woody plant species richness. The Welch two sample t-test revealed no significant differences in spider abundance between termite mounds and the woodland matrix in the Bird Sanctuary, a higher abundance in the woodland matrix in the Chivero Game Park, and a higher abundance on the termite mounds in the Chizarira National Park. The same results were observed with spider richness except for a higher richness in the woodland matrix in the Bird Sanctuary.

Generalized linear models showed that no single environmental variable was responsible for observed patterns in spider abundance and richness in all the study areas. Instead, it was established that various variable interactions (of different orders) of the aerial cover, ground cover, woody plant richness, and site (termite mounds/woodland matrix) influence spider richness and abundance differently, with the number of interactions increasing across the herbivore impact gradient, from the least impacted (the Bird Sanctuary) to the most impacted (Chizarira National Park). The importance of termite mounds in determining spider diversity also seemed to increase across this gradient. Non metric multi-dimensional scaling and hierarchical cluster analysis revealed different spider species community composition on termite mounds and in the surrounding woodland matrix, and this difference increased from the lowest herbivore impact area to the highest, with distinct spider assemblages being realized in the most impacted woodland. It was therefore concluded that termite mounds are not hotspots for the diversity of ground spiders as they are to other animals, but rather act as refugia for ground dwelling spiders in highly impacted miombo woodlands.

Keywords

Spiders, Large vegetated termitaria, Diversity, Community composition, Miombo woodland, Herbivory, Refugia

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CHAPTER 1: INTRODUCTION

1.1 General Introduction

Biodiversity is currently undergoing dramatic changes worldwide (Wilson 1993), and lately much emphasis has been placed on conserving and preserving one of the last preserves of wildlife, the protected areas. The managers of these protected areas face many challenges as managing biodiversity is a complex task. Due to the complexity of ecosystems, it is difficult to conserve all wildlife species. Priorities have to be set, and the 'more important' species have to be protected.

In Southern Africa, the problem has been further exacerbated by the current increases in large herbivore populations, particularly, the African elephant (*Loxodanta africana*). Over the past century elephant numbers in Southern Africa have increased from a few thousand to more than 300 000 (Cumming and Jones 2005) resulting in high elephant densities and consequent changes in habitat structure (Anderson and Walker 1974; Cumming *et al.* 1997; Guy 1981, Thomson 1974). Given the potential severity of this situation, it is important to detect biodiversity change or loss early before the changes become irreversible (Barnes 1983).

The current study is part of a larger project entitled; "*Indicators of large herbivore impacts on biodiversity in southern Africa*". This project is an attempt to develop methods of rapidly and effectively detecting biodiversity change using large vegetated termite mounds (termitaria). Termitaria are a conspicuous feature in many savanna ecosystems and act as nutrient hotspots (Holdo and McDowell 2004) in largely dystrophic savanna soils. Due to their high nutrient status they also harbour a higher diversity of animal and plant species than the surrounding matrix (e.g. Fleming and Loveridge 2003; Moe *et al.* 2009).

Termitaria are of particular interest to the project as it has been shown that the high nutrient status of these mounds attracts large herbivores (Loveridge and Moe 2004; Holdo and McDowell 2004). Consequently, in areas of high large herbivore density, particularly elephants, it is expected that the first signs of overutilization will be seen on the mounds well before they become apparent in the surrounding area.

Previous studies have examined woody plant species structure and diversity on termite mounds and in the surrounding matrix (Humphrey 2008, Makumbe 2009); ant and reptile diversity (Skidmore 2010, Heermans 2010); and large termitaria as refugia for hole nesting birds (Joseph 2008, Joseph *et al.* 2011). The primary aim of the current study is to investigate the influence of termitaria and large herbivores on the diversity of spiders (Order - Araneae), in three areas with different levels of herbivore impacts on woody vegetation.

The knowledge of spiders in Southern Africa is largely limited to species description, while their ecology remains relatively unexplored. In the last two decades however, there has been an increase in research into the biodiversity and ecology of spiders in Southern Africa (Haddad and Dippenaar-Schoeman 2002). An opportunity to further explore the biodiversity and ecology of spiders in savanna habitats was therefore presented. The current study places emphasis on spiders as little is known about how spider species abundance and richness are related to landscape/spatial heterogeneity that is created by the large vegetated termite mounds in savanna ecosystems.

It is likely that direct effects of herbivores on vegetation will result in an indirect influence on spider diversity (e.g. Warui *et al.* 2005). Since spiders are generalist predators abundant in most terrestrial ecosystems (Snyder and Wise 1999; Snyder and Wise 2001) the population of other invertebrate taxa is therefore expected to be an indirect function of spider population, as foraging spiders are considered the major agent controlling insect communities in terrestrial ecosystems (Young and Edwards 1990). An investigation into the local spider diversity could therefore reveal the indirect impacts of herbivory on invertebrate taxa.

The general hypothesis that invertebrate diversity reduces with an in increase in disturbance (Warui *et al.* 2005) or decrease in habitat complexity (Robinson 1981; and Balfour and Rypstra 1998), was therefore investigated with spiders as the target invertebrate group. The contribution of large vegetated termitaria to this association between spiders and the level of herbivory was also assessed.

1.2 Main Objective

To assess the influence of the presence of large vegetated termitaria on the diversity of spiders in miombo woodlands subjected to differing levels of herbivore impacts.

1.3 Specific Objectives

1) To determine the spider species richness and abundance on large vegetated termite mounds and in the surrounding woodland matrix in Chizarira National Park, Chivero Game Park, and Chivero Bird Sanctuary; areas with differing levels of large herbivore impacts.
2) To examine the influence of vegetation cover and woody plant species richness on spider species richness, abundance, and spider species community composition on large vegetated termitaria and in the surrounding woodland matrix, in the three locations.

1.4 Hypotheses

Given that the overall objective of this study was to determine the influence of large termitaria and large herbivores, on spider species richness and abundance, the response variables were spider species richness and spider species abundance. The proposed major explanatory variables were therefore location (Chizarira National Park, Chivero Game Park, and Chivero Bird Sanctuary) and site (termite mound and woodland matrix). The different locations and sites were expected to have different habitat characteristics due to the impacts of large mammals on woody plant species richness, aerial cover, and ground cover.

The hypotheses on which this study is based upon are as follows:

1. Spider species richness, abundance, and spider community species composition on termite mounds differ from those in the adjacent woodland.
2. Woody plant species richness, ground cover, and aerial cover on termite mounds are different in the adjacent woodland.
3. The interactions between site (termite mound and woodland matrix), aerial cover, ground cover, and woody plant species richness determine spider species richness, abundance, and spider species community composition.
4. The interaction between ground cover and site determines spider abundance, richness, and composition.
5. Similarity between large vegetated termitaria and woodland matrix spider diversity and community composition diminishes along a gradient of herbivore impacts, from the least impacted to the most impacted area.

CHAPTER 2: LITERATURE REVIEW

2.1 Miombo Woodlands and the Role of Termitaria in These Woodlands

The word miombo is a term used to describe woodlands in the central, southern and eastern parts of Africa, which are dominated by the genera *Brachystegia, Julbernardia* and/or *Isoberlinia*, three closely related genera from the legume family (White 1983). *Brachystegia, Julbernardia* and/or *Isoberlinia* may be the dominant species in miombo woodlands but at any point there can be considerable heterogeneity in plant physiognomy, structure and diversity, reflecting the variation in soils (Campbell and Du *Toit* 1988), rainfall, and the impacts of fire (Lawton 1978), land use (Robertson 1984; Chidumayo 1987), herbivory (Anderson and Walker 1974; Thomson 1974; Guy 1981; 1989) and other disturbances.

These miombo woodlands have been described (Frost 1996) as the most extensive type of tropical seasonal woodland and dry forest formation in Africa (perhaps even globally), covering an estimated 2.7 million km^2 in regions receiving >700 mm mean annual rainfall on nutrient-poor soils. The miombo woodlands are characterised by high plant diversity and endemism (White 1983) and have recently been described as one of the world's biodiversity hotspots (Mittermeier *et al.* 2003).

This juxtaposition of infertile miombo and other, more fertile, moister and productive vegetation types has already been described (Frost and Robertson 1987) as an important factor in maintaining populations of large wild and domestic herbivores in miombo woodlands, dependent on the extent and degree of interspersion of the vegetation types (Frost and Robertson 1987). A number of workers (Wild 1952, Loveridge and Moe 2004, Holdo and

McDowell 2004) have cited the inclusion of habitat islands of non-miombo as an enhancer of overall wildlife diversity in miombo woodlands.

Termites make up the greatest contribution to total soil macro-fauna biomass in many tropical ecosystems, with values comparable to ungulate biomass in African savannas. Termites in the tropical savannas function as ecosystem engineers as do elephants (Jones *et al.* 1994; Laws 1970; Dangerfield *et al.* 1998), by modifying the physical habitat and creating islands of high soil fertility. They do this by influencing the spatial and temporal distribution of water, carbon, and nutrients through their mound structures (Lavelle 1997; Brown *et al.* 2000; Dangerfield *et al.* 1998).

The importance of *Macrotermes* and other Macrotermitinae lies in their dependence on cellulose-decomposing fungi which they cultivate in their mounds. To maintain the fungi the termites forage widely, collecting surface litter and dried grass which is carried back to the mounds and decomposed by the fungi. Because of the ability of the fungi to produce cellulase, almost all of this organic matter is decomposed (Jones 1990).

Termites, especially species of the genus *Macrotermes* construct large epigeal nests and extensive underground gallery systems. Through their foraging behaviour, termites localise nutrients on their mounds thus influencing nutrient flow rates and the spatial distribution of nutrients. They also relocate soil particles for mound construction and maintenance, and as a result influencing soil physical properties (Dangerfield *et al.* 1998). Large termite mounds built by the termite (isopteran) genus *Macrotermes* are conspicuous in the miombo landscape (Malaisse 1978). The presence of these large vegetated termite mounds creates heterogeneity in a largely dystrophic landscape (Scholes and Walker 1993), on which a unique suite of trees, shrubs and grasses occur (Moe *et al.* 2009; Traore *et al.* 2008; Loveridge and Moe 2004).

Termitaria function as islands of local diversity in the miombo system (Fleming and Loveridge 2003). They are an important resource used by small mammals (Fleming and Loveridge 2003) and large ungulates (Holdo and McDowell 2004) and support a higher diversity of plant and animals than the surrounding matrix (Malaisse 1978). The vegetation on the mounds is often the focus of activity for birds (e.g. Joseph *et al.* 2011) and other animals, enabling these species to exist in an otherwise largely unproductive environment (Frost and Robertson 1987).

In particular, the high nutrient content of trees on termitaria makes them attractive to mega herbivores (Loveridge and Moe 2004) such as elephants, giraffes and other large herbivore browsers (Ruggerio and Fay 1994) in nutrient poor savannah systems. Aside from the basic requirement for water, animals respond to spatial variability by selecting patches or areas which offer the highest intake of digestible nutrients (O'Reagain, and Schwartz 1995). It is therefore expected that large herbivores will prefer to browse on these nutrient hotspots and this preferential selection for termitaria vegetation is expected to result in varying impacts on vegetation cover, on and off (Mobaek *et al.* 2005) vegetated termite mounds. Depending on the intensity of herbivore browsing, termitaria may thus provide a simple indicator of large herbivore impacts on biodiversity, and habitat change, and should therefore be considered as a focus of conservation in miombo woodlands.

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2.2 Large Herbivores

Large mammalian herbivores exert a direct impact on vegetation by their consumption of plant parts, and breaking or trampling plants. One indirect impact is the removal of bark (especially by elephants) making the plants more susceptible to fire and attack by wood boring beetles (Owen-Smith 1988). Browsing pressure by large herbivores such as elephant (*Loxodonta africana*), black rhino (*Diceros bicornis*) and giraffe (*Giraffa camelopardalis*) can supress the regrowth of woody plants, and as a result, keeping them within the fire susceptible zone for longer (Owen-Smith 1988).

The African elephant (*Loxodonta africana*) in particular, has been cited as an example of a large, generalist herbivore which has been responsible for considerable transformation of natural habitats in protected areas (e.g. Anderson and Walker 1974; Cumming *et al.* 1997; Guy 1981; and Thomson 1974) where it has been protected from human predation (poaching).

Elephants play a key role in the ecology of their habitats. For example, their feeding habits open up thick bush and forest for grazing species; they also maintain waterholes and keep open forest pathways used by wildlife and humans (Carroll 1988). Trees destroyed by elephants are replaced by regenerating shrubs or grasses that offer more accessible foliage for consumption by smaller herbivores. The mosaic diversity of habitats created by these impacts on vegetation is important in promoting the coexistence of a wide diversity of other mammalian herbivore species; a keystone role (Owen-Smith 1988).

With global human populations being on the rise and doubling in the past 40 years (Cohen 2003), areas previously occupied by wildlife have been taken over by humans (e.g. Blanc *et* *al.* 2003; Gratwicke and Stapelkamp 2006) and as a result shrinking the range available to elephants (Owen-Smith 1988) and other large mammals. The decline in elephant range, accompanied by population increases, has resulted in high elephant densities and a loss of habitat structure (e.g. Fenton *et al.* 1998), as elephants tend to impact heavily on the tall tree component of woodlands and savannas (Laws 1970; Anderson and Walker 1974; and Mapaure 2001). Several studies have shown that high densities of elephants can cause loss of biodiversity (e.g. Cumming *et al.* 1997), substantial changes in tree species composition together with fire (Mapaure 2001), reduction in tree density and biomass (Guy 1981), lowering of bird and ant species richness (Cumming *et al.* 1997), and changes in bird species composition (Herremans 1995), amongst others. Limited biodiversity surveys are therefore a worrying issue, especially in protected areas.

Preserving large populations of elephants whilst at the same time maintaining biodiversity in national parks and protected areas is therefore challenging. In Africa the problem is worsened by the lack of funding for ecological research. Consequently, by the time that elephant and other large herbivore impacts on woodland become obvious it is generally too late (Barnes 1983) to take any corrective measures so that developing early warning systems is important.

2.3 Spiders as Indicators of Habitat Change

According to Bouyer *et al.* (2007), a good ecological indicator should be sensitive to slight ecosystem changes in a predictive manner, thereby allowing the detection and measurement of the effect of various disturbances to the ecosystem. Invertebrates are critical components of ecosystems and can make excellent bioindicators (Kremen *et al.* 1993) of ecosystem health and change as they are sensitive to change, and can be used to index changes in the environment at small, spatial and very short, temporal scales (Ginsberg 1993; and Schroeter *et al.* 1993). The large numbers of invertebrates makes them more amenable to statistical analyses than vertebrate data (Kremen *et al*. 1993).

Many studies, including Downie *et al.* (1999) and New (1999) have demonstrated that spiders in particular are extremely sensitive to small changes in the habitat structure, including habitat complexity, litter depth and microclimate. Spiders are generalist predators abundant in most terrestrial ecosystems (Snyder and Wise 1999, Snyder and Wise 2001) and the population of other invertebrate taxa is therefore an indirect function of spider population.

Thus among arthropods, spiders are probably one of the best target groups for use as indicator species of disturbance or habitat change. They are hyper-diverse yet can be easily sampled and sorted to morphospecies and they are probably the most abundant representatives of the top-predators guild in many habitat types (Cardoso *et al.* 2008). Several studies of ecology and biodiversity have already proven this (Bonte *et al.* 2004; Lambeets *et al.* 2007; Negro *et al.* 2010). In addition to being highly diverse, spiders are abundant and inhabit a wide array of spatial and temporal niches (Juen and Traugott 2004; Vasconcellos-Neto 2005; Entling *et al.* 2007). As a result of their high abundances and insectivorous behavior spiders are useful indicators of the ecological status of biotic communities, and of changes in habitat and landscape structure (Warui *et al.* 2005; Foord *et al.* 2008; and Horvath *et al.* 2009).

2.4 Effects of disturbance and habitat structure on spider diversity

Ecological studies of invertebrates have shown that structural habitat complexity affects species diversity (e.g. Dean and Connell 1987; and Magagula 2003) and therefore any disturbance results in a reduction in complexity leading to reduced species diversity. The diversity of ground beetles, plant hoppers and spiders has already been related to botanical diversity and the structural variability of vegetation (Cherrill and Rushton 1993; Downie *et al.* 1999; Sanderson *et al.* 1995; Dennis *et al.* 1998; Siemann *et al.* 1999). In addition, other researches (Lawton 1983; Halaj *et al.* 2000) have shown that more complex vegetation provides arthropods with sites for shelter, foraging, oviposition, and mating. Such conditions ideally support an increase in spider diversity.

Spiders in particular, have been found to be favoured by complex habitats (Robinson 1981; Gunnarsson 1988; Balfour and Rypstra 1998; Raizer and Amaral 2001) while Dean and Connell (1987) showed that increased structural habitat complexity promoted increase in species diversity. Halaj *et al*. (2000) also reported that structural habitat complexity had a profound effect on canopy spiders and other arthropods. Ysnel and Canard (2000) demonstrated that the foliage orientation influences species composition of spider communities. More work supporting importance of habitat complexity on spiders can be found in Greenstone (1984), and Buddle and Rypstra (2003). In an attempt to explain the link between habitat complexity and spider diversity Rypstra (1983) and Wise (1993) found that availability of unique habitat structural features allows more efficient prey capture and may limit spider species populations more than the availability of food itself.

Spiders are predominantly generalist feeders that primarily attack insects, but also eat other arthropods, including spiders (Wise 1993). They possess neurotoxins that enable them to kill prey rapidly. The prey is usually smaller than or similar in size to the spider, but many spiders subdue prey several times their mass (Wise 1993). According to Uetz (1991), there are several reasons why spiders should be more sensitive to structure than other organisms. As a group, spiders perceive their environment using vibratory cues which are mediated through the substrate on which they live. Web spiders must anchor their prey capture device to the appropriate substratum and complex habitats provide appropriate sites for a greater range of sizes and types of webs. Finally, since all spiders are predators that can potentially consume one another, the extent to which they can coexist may strongly depend on their ability to move around and hide in a complex environment. Spider populations are therefore likely to be largely determined by any habitat change or disturbance.

A study by Cumming and Wesolowska (2004) in a suburban area showed that different microhabitats host a consistent and predictable cluster of jumping spider (Salticidae) species, although some species are habitat generalists and occupy a range of habitats. A detailed study (Butler and Haddad 2011) of the relationship between spider assemblages and different litter types also showed that the habitat largely influences spider composition and abundance, as the shallower and more compact litter in shady areas was discovered to support higher abundance and species richness of spiders with similar assemblage structure. It is possible that different litter microhabitats have a varied influences on the microclimate (e.g. temperature and humidity) and prey availability (Uetz 1979) resulting in different spider communities.

A general rule therefore seems to be that as disturbance increases spider species richness declines, as plant community structure, and ecosystem dynamics such as disturbance influence spider assemblages (Bonte *et al*. 2002). Apart from the study by Haddad and Dippenaar-Schoeman (2002) on the influence of *Trinervitermes trinervoides* mound structure on spider diversity, no research on spiders associated with termite mounds has been conducted in southern Africa. Few studies have been conducted on the association of spiders with termites (Dippenaar and Meyer 1980; van den Berg and Dippenaar-Schoeman 1991;

Jocque and Dippenaar-Schoeman 1992; Dippenaar-Schoeman *et al.* 1996; Cumming 1993; and Wesolowska and Cumming, 1999).

Since spiders are sensitive to changes in habitat structure, their diversity on mounds and in the woodland matrix of savanna woodlands may be very sensitive to the effects of large herbivore density and browsing pressure. In the current study it was expected that the presence of herbivores would reduce the relative vegetation cover by trampling, browsing, and grazing, thereby reducing the habitat complexity. This in turn was expected to influence spider diversity.

CHAPTER 3: STUDY AREAS AND METHODS

This study was carried out in three different miombo woodland locations, with different large herbivore systems, and characterized by the presence of large vegetated termitaria. These areas were; Chizarira National Park, Chivero Game Park, and Chivero Bird Sanctuary with high levels of herbivore impact in Chizarira, intermediate levels in the Chivero Game Park and little if any large herbivore impact in the Bird Sanctuary.

3.1 Study Areas

3.1.1 Chizarira National Park

The first part of this study was carried out in Chizarira National Park during the months of October and November 2009. The park is situated in the North West part of Zimbabwe (17°32' - 18°15', 25°35' - 28°13') in the Zambezi Valley and it covers a total area of 1910 km^2 (Thomson 1974) and has an elevation of between 700 and 1400 m (BirdLife International 2011). The park is bounded by communal lands of the Binga and Gokwe Districts and shares a boundary with Chirisa Safari Area to the south.

The area experiences a wet season from November to April, a cool dry season from May to July and a hot dry season from August to November. Mean annual temperature is 20–22.5°C (maxima: October 32.5–35°C, July 22.5–25°C; Torrance 1965 in Joseph *et al*. 2011). Mean annual rainfall is 600–800 mm (annual coefficient of variation of 25–30%; Lineham 1965 in Joseph *et al.* 2011).

The vegetation at Chizarira is dominated by the miombo tree genera *Brachystegia* and *Julbernardia* (Fabaceae, subfamily Caesalpiniodeae). Other common vegetation types within the miombo ecoregion are mixed *Combretum* and *Colophospermum mopane* woodlands

(Campbell *et al*. 1996). In 1972 large areas of *Brachystegia boehmii* woodlands in Chizarira were reduced by elephants and fire and converted into shrublands (Thomson 1974, Cumming 1981). Elephant densities over the past 30 years have tended to be high, at 1 per km^2, and at times as high as 3 per km^2 (Cumming 1981; Dunham *et al*. 2006). A prominent and conspicuous feature in a large part of the park is that large trees are confined to large termite mounds and large trees are seldom found in the open woodland (Figure 3.2).

The impacts of elephants and fire have transformed most of the park's former tall, open woodland to shrubland (Cumming 1981) comprised mainly of *Combretum* species and regenerating *Brachystegia boehmii* in the matrix, with tall trees being largely confined to termitaria.

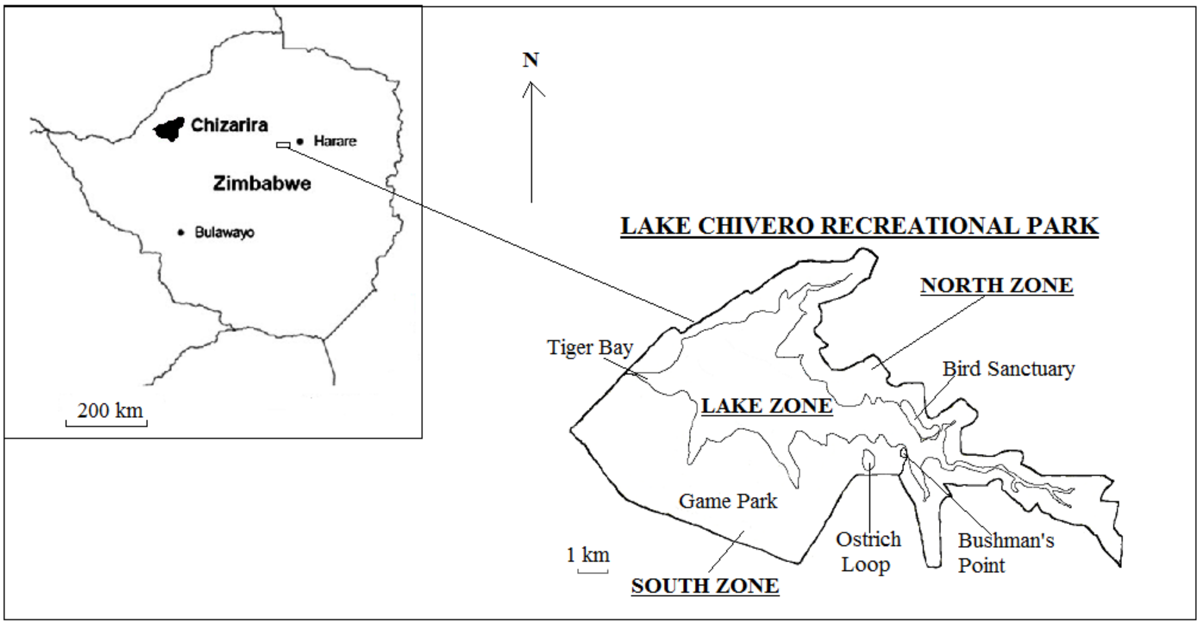

Figure 3.1: A map showing the study areas; Chizarira National Park, and the Lake Chivero Recreational Park; Zimbabwe.

Figure 3.2: A picture showing a large vegetated termite mound surrounded by a heavily impacted miombo woodland with no large trees, in the Chizarira National Park (Taken by David Cumming, 2007).

Figure 3.3: A picture showing a large vegetated termite mound surrounded by a miombo woodland with relatively large trees, in the Chivero Game Park (Taken by Lenin Chari, 2010)

Figure 4.4: A picture showing a large and densely vegetated termite mound surrounded by a miombo woodland with very large trees, in the Chivero Bird Sanctuary (Taken by Lenin Chari, 2010).

Mammalian herbivores in the park include elephant (*Loxodanta africana*), buffalo (*Cyncernus caffer*), sable (*Hippotragus niger*), greater kudu (*Tragelaphus strepsiceros*), waterbuck (*Kobus ellipsiprymnus*), eland (*Tragelaphus oryx*), impala (*Aepyceros melampus*), zebra (*Equus quagga*) and common warthog (*Phacochoerus africana*), with elephant and buffalo having the highest population density (Dunham *et al.* 2006).

3.1.2 Lake Chivero Recreational Park

Lake Chivero Recreational Park is about 6 100 hectares in extent including the 2630 ha lake. In order to maintain an atmosphere appropriate to different forms of park use, and so as to minimize the conflicts between antagonistic forms of use, the park was divided into three major zones (Parks and Wildlife Board 1975). These zones are the south bank that largely consists of the game park, the lake zone that includes the lake and its islands, and the north bank that is largely devoted to outdoor recreation (Figure 3.1). The current study took place in the game park inside the south zone, and in the relatively undisturbed woodland in the Bird Sanctuary on the North bank.

The Chivero area is dominated by miombo woodland; *Brachystegia spiciformis* and *Julbernada globiflora* with associated trees such as *Terminalia sericea, Parinari curatellifolia, Monotes glaber*, and *Burkea africana* (Malinga 2001).

The Game Park of 1867ha extends from the Tiger Bay (Figure 3.1) to the Bushman's point on the South Zone. It was opened in 1962 holds a variety of large mammals; most of which were introduced from the Hwange National Park. Browsers in the Game Park include; giraffe (*Giraffa cameleopardalis*), eland (*Taurotragus oryx*), and greater kudu (*Tragelaphus strepsiceros*). Grazers include tsessebe (*Damaliscus lunatus*), wildebeest (*Connochaetes taurinus*), zebra (*Equus burchelli*), white rhino (*Ceratotherium simum*), sable (*Hippotragus niger*), and waterbuck (*Kobus ellipsipyrimnus*). Mixed feeders present are impala (*Aepyceros melampus*). Grey duiker (*Sylvicarpra grimmmia*) and common warthog (*Phacochoerus africana*) are also present. A part of this study was carried out inside the Game Park within the "Ostrich loop" (17°55.333'S, 30°48.869'E, Figures 3.1 and 3.3).

The Bird Sanctuary (17°54.740'S 30°50.438'E, Figures 3.1 and 3.4) extends into the Lake zone and interests of avifauna are paramount in the area. The management of the sanctuary is aimed at conserving as many birds of the widest possible range of species, particularly of those species dependent on the aquatic environment. Facilities are also provided for bird watching (Parks and Wildlife Board 1975). The only mammalian herbivores present within this area are occasional reed buck (*Redunca arundinum*) sighted close to the lake shore, bush pig (*Potamochoerus porcus*) and common warthog (*Phacochoerus africana*) sighted in the woodland (personal observation). This area has been devoid of large browsers for the past 50 years Cumming (pers. comm.) and therefore acts as the control in this investigation where the effect of herbivory on spider diversity is the objective. The area therefore represents an area with very low disturbance and minimal mammalian herbivory.

The Chivero Game Park and the Bird Sanctuary were included in this study as they provided a miombo study area with two comparable sites with large vegetated termitaria, one with large herbivores but no elephant, and one without large herbivores.

3.2 Field Methods

3.2.1 Sample sites

Aerial photographs were used to select an area with a considerable number of termite mounds within each of the three locations. In each location, a single termite mound was chosen randomly and thereafter every second nearest mound from the first mound was sampled. Sampling of every second nearest mound was done to reduce the effects of spatial autocorrelation. A total of 20 mounds were selected in the Chivero Bird Sanctuary, 30 in Chivero Game Park, and 12 in Chizarira National Park, providing a sample of 62 plots, each comprising a paired mound and matrix site.

For every termite mound selected, an adjacent woodland area, of the same diameter as the mound, was demarcated 25m from the edge of the mound (Fig. 3.2). Each matrix site edge was at least 25m from the mound edge along a cardinal compass bearing. The bearing (N, E, S or W) from the mound plot was determined using random numbers (1-4) from a random numbers table. If another mound was less than 60m away in the chosen direction, an alternative direction was chosen (also randomly). Figure 3.2 clearly illustrates the general layout of study plots and sites within the three locations. The locations of all the mounds and matrices were recorded using a hand held Global Positioning System (GPS) coordinates. The center GPS coordinates of the matrix and the mound were the ones recorded.

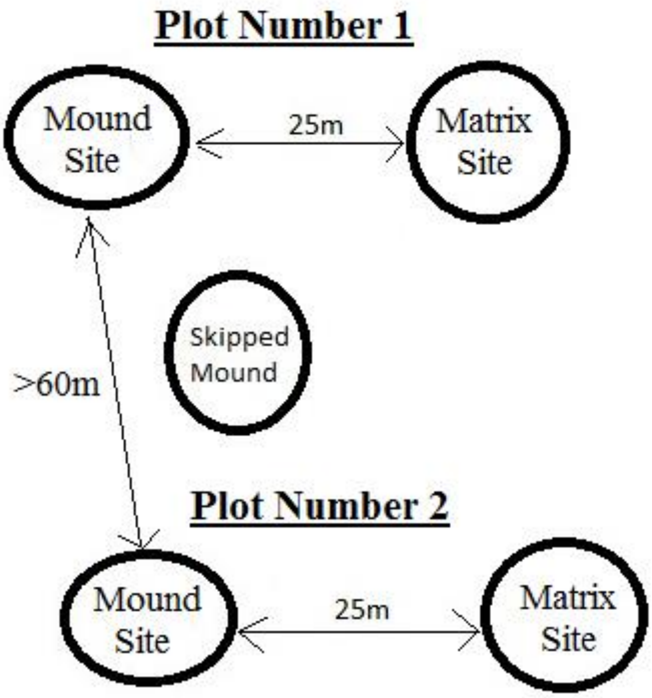

Figure 3.5: Schematic representation of the arrangement of the study plots and sites in the three different study areas, Chizarira National Park, Chivero Game Park, and Chivero Bird Sanctuary.

The heights and diameters of the mounds were measured with a ranging rod and a measuring tape, respectively. The surface area of the mounds was approximated by treating the shape either as a cone or a half sphere and using the arithmetic formula to find the surface area of the respective shapes. A circular plot of the same area as the corresponding mound was demarcated in the adjacent matrix.

3.2.2 Pitfall trapping

Five pitfall traps were placed on each site, at the four cardinal points, north, south, east, and west, and also at the centre (Figure 3.3). The four traps on the cardinal points were installed 20% inside the site boundary (circular sub-plot) and emptied every 24 hours for a 7 day trapping period in Chizarira and 4 day trapping periods in Chivero (Bird Sanctuary and Game Park). Each trap consisted of 2 conical cups with a top diameter of 9.5cm and bottom diameter of 7.5cm and depth of 8.7cm that fitted into each other. Holes were dug in the ground using a soil auger and a garden trowel at the predetermined points. Two cups were slotted into the hole, with one inserted into the other. The mouth of the top cup was levelled with the ground. The cup beneath was used to simply maintain the hole and the one on top was ¼ filled with water. A few drops of detergent were added to the water so as to break the surface tension and allow any spider (or invertebrate) that fell in to sink.

Traps were checked every morning and the catch was placed into appropriately labelled film canisters, 30 ml in volume. All spiders collected from the 5 pitfall traps on each site were put into one container with water to prevent the specimens from desiccating. Spiders from the five traps at each site were pooled in order to reduce stochastic heterogeneity among samples and homogenize sampling effort (Cardoso *et al*. 2008), making each mound site comparable to the adjacent woodland matrix site. Upon collecting the catch from the traps the cups were reinstalled in the ground and refilled with water and detergent added.

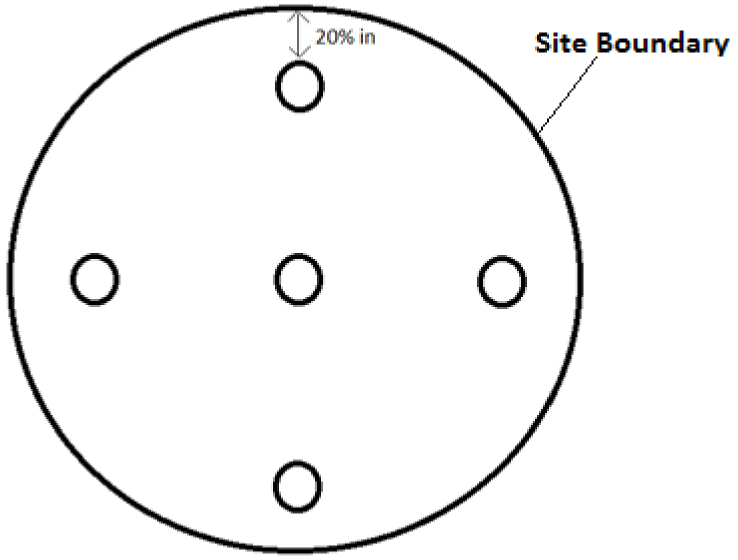

Figure 3.6: Schematic diagram representing the arrangement of the pitfall traps on a single sampling site. Traps at the cardinal point were installed 20% inside the sites as a way of standardizing the placement of traps. The same arrangement was used on all plots in the three different study locations.

After collecting all the catches from all the traps (all the sites), the spiders were separated from the debris and other invertebrates in the catch. This was done in a white tray with the use of forceps to pick out the spiders, and water to wash away the debris. These spiders were examined under a field stereomicroscope and consequently identified to family level and assigned to morpho-species. The spider specimens were consequently put into well labelled 5ml and 2ml cryovials, in 70% ethyl alcohol, for future full taxonomic identification by experienced personal.

In the Chivero area the same procedure as used in Chizarira was employed except that pitfall trap catches on each site were not pooled but kept separate so as to test for intra site heterogeneity at a later stage.

3.2.3 Species Sorting and Identification

Spiders collected were classified up to the family level, a measure commonly used to examine community level patterns (e.g. Whitmore *et al.* 2002). Taxonomic keys used include Filmer (1991), Leroy and Leroy (2003), and Dippenaar-Schoeman (2002).

Spiders were sorted into morphospecies, based on outward morphological characteristics. These features included body colour, pattern, and relative sizes of segments, eye pattern and number, leg spines, hairs and length, and the number and type of spinnerets. Each morphospecies was allocated a family name and number after looking for groups of morphologically indistinguishable spiders, followed by describing briefly the set of characters unique to each group.

Juveniles were not distinguished from adults and it is appreciated that this may have resulted in some juveniles being classified as separate morpho-species. It is well established that juveniles often do not resemble adults and sometimes males may be morphologically distinct from females (Derraik et al. 2002). It is for these reasons that spider abundance carries a greater weighting than the number of species in this study. Further assistance will be sought, in due course, in identifying all spiders sampled.

3.2.4 Vegetation cover

Vegetation cover was estimated in terms of percentage aerial cover and ground cover in all three locations but different methods were employed between Chizarira National Park and the two locations in the Lake Chivero area (the Game Park and the Bird Sanctuary).

In Chizarira National Park, three parallel transects were traversed across each mound and across the adjacent circular matrix site~~.~~ The middle transect was the diameter of the circular site and the other two transects were equidistant from this diameter and 20% inside the circular site. A measuring tape was laid down on each of the 3 transects. Moving along one end of the tape, the intercept distance of any plant (woody or herbaceous) that had any part of its body hanging over the transect, was recorded. The total distance intercepted was added and divided by the total length of each transect, and then multiplied by 100%. This was done for all three transects and the aerial cover estimate of each subplot was obtained by adding and averaging the percentage cover values of the three transects. A single aerial cover estimate was as a result used for each subplot. On the same transects used for aerial cover, ground cover was also estimated. This was done by recording the distance covered by any plant material on the ground, adding it up, and expressing the accumulated distance as a percentage of the transect length. At each site the estimates for the three transects were averaged to produce one estimate.

In the Chivero area, vegetation cover was measured using a modified pin frame method. Only a single pin (instead of a frame with several pins), approximately 4mm thick, was used to place predetermined points on two predetermined transects in each sub-plot (site). One transect was set on the east-west direction and the other on a north-south direction at all sites. These transects were placed at 90 degrees to each other, intercepting each other at the centre of the site. A measuring tape was laid down on each transect and its length (diameter of sub-plot) was divided by 100 and the pin was dropped at each 1/100th point of the transect.

At each 1/100th point of the transect, the wire pin struck the point and a short description of the ground and aerial cover was consequently given (see Appendix E). Plant species, dead leaves, bare ground, wood, or any kind of ground or aerial cover hit, was recorded for each hit. If more than one plant or plant part touched the pin it was still considered as one hit. Relative ground and aerial cover estimates were subsequently obtained by counting the number of hits and expressing them as percentages. Since two transects were traversed per sub plot, the two values were averaged to give a single cover estimate (ground and aerial) for each sub-plot.

Aerial cover was only estimated up to a height of 1m as it was assumed that ground dwelling spiders were not likely to be affected by aerial cover greater than 1m in height. Anything dead or alive touching the 1m long wire was taken as aerial cover and ground cover was taken as anything that the point of the pin hit.

3.2.5 Woody plant species inventory

A complete inventory of all woody plant species in all the study sites was made and plants were classified to species level. In order to characterise woodland structure for each site (mound/matrix) three height classes were constructed and the height class of each woody plant was recorded. The three height classes were as follows; >1m, 1-3m, and >3m, where the plants below 1m were classified as shrubs and those above as trees (1-3m) and tall trees (>3m). The data for plant structure were not used in this study.

Woody plant species were classified to species level with the aid of field identification guides and the help of an expert botanist, Zaccheus Mahlangu. Where species were not identified in the field, leaves, small fruits, and flowers were pressed for later identification at the Harare National Herbarium. Data on plant species for 15 plots in Chivero Game Park and 15 plots in the Chivero Bird Sanctuary were adopted from an earlier study by Makumbi (2009).

3.3 Data Analysis

Statistical analyses were carried out using: (i) PC-ORD 5.1 (McCune and Mefford 2006), (ii) SPSS Version 16.0 for Windows (SPSS Inc. 2007), (iii) Estimates v 7.5 (Colwell 2004), and (iv) R Version 2.12.0 (The R Foundation for Statistical Computing 2010).

3.3.1 Species accumulation curves

Species accumulation curves (Gotelli and Colwell 2001) were plotted using PC-ORD 5.1 (McCune and Mefford 2006), in order to evaluate the adequacy of sample size in the spider community data set. Species accumulation curves and Sorenson distance curves were plotted for each location (Chizarira National Park, Chivero Game Park, and Chivero Bird Sanctuary) using the number of species recorded for each site to determine the adequacy of sampling for species richness (McCune and Mefford 2006).

3.3.2 Welch two sample t-test

The Welch two sample t-test (an unequal variance t-test) was used to test for differences in spider species richness and abundance on mounds and in the matrix, in three locations in order to correct for differences in variance between sites. This test was run in R Version

2.12.0 (The R Foundation for Statistical Computing 2010), upon testing for normality (using Q-Q plots in SPSS Version 16 for Windows) and homogeneity of the variance (Levene's test in SPSS Version 16 for Windows) in the spider data sets of the mounds and the matrix. Means and the corresponding confidence intervals were calculated to enable direct comparison between the mounds and the woodland matrix.

At each location, ground cover estimates, aerial cover estimates and woody plant species richness of termite mounds were compared with those of the woodland matrices. The Welch two sample t-test was also used to ascertain the statistical significance of the differences. This was done in order to determine if there was any variability in terms of vegetation cover and plant species richness between the two types of sites (mound and matrix), in the three locations.

The primary reason for using the Welch t-test (as opposed to a standard t-test) was to compensate for differences in variance (Siegel 1956) between sites. The Welch t-test does this by adjustsing the degrees of freedom. According to Zar (1996) the Student's t-test performs badly when variances are unequal.

3.3.3 Similarity Indices, Multi-Response Permutation Procedure, and Hierarchical cluster analysis

Comparisons of spider community structure, on and off termitaria, were achieved through the use of similarity indices that were compared across the three different locations. The programme ESTIMATES v 7.5 of (Colwell 2004) was used to calculate the new Jaccard corrected index (Chao *et al.* 2005). This index is both abundance and probability based and has been proved (Chao *et al.* 2005) to reduce under-sampling bias by estimating and compensating for the effects of unseen, shared species. Chao *et al.* (2005) also recommended this index (as well as the Sorensen corrected index) for assessing species composition similarity between samples that differ in size, contain numerous rare species, and are suspected (or known) to be undersampled. This study was complicated by all three issues stated above.

The Multi-Response Permutation Procedure (MRPP) was used to investigate differences in spider species composition between mounds and matrices. It was computed using a Sorenson (Bray-Curtis) distance measure and a natural weighting. The MRPP is a non-parametric procedure used to test the hypothesis of no difference between two or more groups of entities (PCORD V5 McCune and Mefford 2006). The MRPP was opted for in place of discriminant analysis as it has the advantage of not requiring the assumptions of multivariate normality and homogeneity of variances, which according to Biondini *et al*. 1985, are rarely met with ecological community data.

The MRPP uses a test statistic; A that is a descriptor of within-group homogeneity. When all items are identical within groups A = 1 (Mielke 1984), the highest possible value for A. If heterogeneity within groups equals expectation by chance, then A = 0 (Mielke 1984). It is therefore expected that the more homogeneous the mounds and matrices were, the higher the A value would be. The statistical significance (p-value) was given for each A value between mounds and matrices, in each location.

A hierarchical cluster analysis (PCORD V5 McCune and Mefford 2006) was used to represent any differences in spider species composition among the sites, on a dendogram. The classification was based upon the Bray-Curtis distance measure, a statistic used to quantify the compositional dissimilarity between two different sites, and the unweighted pair-group average (UPGAMA) was the linkage method used to plot the dendrograms for each location.

3.3.4 Generalized Linear Models and Non Metric Multidimensional Scaling

A Generalized Linear Model (GLM), Type III was performed in order to determine if the proposed explanatory variables; site, aerial cover, ground cover and woody plant species richness had a significant influence on spider species richness and species abundance, the response variables.

According to Crawley (2007) when count datum is the response variable there are often lots of zeros in the data frame and the variance may therefore increase linearly with the mean. Regression analysis could not be used in this study as it assumes that variance is constant. GLMs were appropriate in this study as both the response variables (spider richness and abundance) were count data, and variances were unequal. GLMs were run with a Poisson distribution to account for the non-normality of the count data and a log link function was used to ensure that fitted values were positive (since it is not possible to have counts less than zero).

The Generalized linear model was run as a factorial model taking into account the four explanatory variables and any interactions, of different orders, between the explanatory variables in determining spider species richness and abundance. A stepwise progression from the maximal model through a series of simplifications to the minimal adequate model was made on the basis of deletion tests. The maximal model consisted of all the four explanatory variables and all 2-way, 3-way, and 4-way interactions between the variables. Model simplification was carried out by removing the least significant terms (largest p-value) first starting with the highest-order interactions. These deletion tests were chi-squared tests that assessed the significance of the increase in deviance that resulted when a given term (variable or interaction of variables) was removed from a particular model.

In the final model, the Wald Chi-square test was used to test the true value of the model parameter based on the sample estimate, for each factor in the model. This test was used precisely to test for model effects without emphasising on the actual parameter estimates. The greater the Wald Chi-square the greater the probability of the factor being significant hence the p-value was also given. Degrees of freedom were also displayed.

SPSS Version 16.0 for Windows (SPSS Inc. 2007) was used for the GLM analyses.

Non Metric Multidimensional Scaling (nMDS) ordinations were used to graphically represent the relationship between sites, in terms of spider species community composition, in multivariate space. In addition, nMDS was used to investigate any relationships between spider species community composition and the environmental variables, aerial cover, ground cover and woody plant species richness. According to Clarke and Warwick (1994), the advantages of MDS include giving a good link between the original data and the final picture and representing complex patterns correctly in low-dimensional space. Principal Component Analysis (PCA) has the disadvantage of inflexibility of dissimilarity measure and poor distance-preservation (Clarke and Warwick 1994).

Non Metric Multidimensional Scaling (nMDS) ordinations were constructed in PC-ORD 5.1 (McCune & Mefford 2006). This was achieved with a Bray-Curtis distance measure of 250 runs and 500 iterations and random starting configurations with a maximum of six axes.

Dimensionality was assessed by choosing the solution with the minimum number of axes and lowest stress. The Monte Carlo test result stress was computed in order to compare the stress obtained with the real data against the stress obtained for randomized data. A p-value of less than 0.05 indicates significantly more reduction in stress than expected by chance (McCune & Mefford 2006).

Ordination diagrams of nMDS showed two kinds of entities; the sample units (termite mounds and the woodland matrix sites) and the environmental variables (ground cover, aerial cover, and woody plant richness). Environmental variables were represented as lines radiating from the centroid of the plot and the direction and length of the lines represented the direction and the strength of the relationship with spider composition in the two different sites.

Coefficients of determination (R^2) were calculated for the correlations between ordination distances and distances in the original 2-dimensional space in order to determine how well the ordination represented the original data. The Pearson correlation test (r) was used to evaluate the degree of linear association between the environmental variables and spider community structure (species community composition).

Significance level was set at $p = <0.05$ for all analyses in this study.

CHAPTER 4: RESULTS

4.1 Spider species community composition

Sixty two plots, each with paired sites (mound and adjacent matrix) were sampled, with 20 plots in the Bird Sanctuary, 30 plots in the Chivero Game Park and 12 plots in the Chizarira National Park. A total of 3139 spiders were caught in the three study locations, with 19 families in the Bird Sanctuary, 23 in the Chivero Game Park and 17 in the Chizarira National Park, bringing up to resulting in a total of 28 families in all the three locations (Table 4.1).

The wolf spiders (Lycosidae) were clearly the most abundant family and were highly abundant in all three locations (Table 4.1). Ground spiders (Gnaphosidae) and jumping spiders (Salticidae) were the two other families that were considerably abundant in all three locations.

Table 4.1 gives a summary of the relative abundances for each location, together with the number of morpho-species identified for each location. Families that were found exclusively in Chizarira National Park were Agelenidae, Clubonidae, and Deinopidae. The following families were found exclusively in the Chivero Game Park; Nesticidae, Uloboridae, Dictynidae and Erisidae. The only family exclusive to the Bird Sanctuary was Scytodidae.

Table 4.1: The total numbers of spiders and morpho-species, in each family, in each location (* = not spiders/ Araneae)

Family	**CHIVERO BIRD SANCTUARY**				**CHIVERO GAME PARK**				**CHIZARIRA NATIONAL PARK**				**Total number of spiders**	**Relative family %**
	Termite Mound		**Woodland Matrix**		**Termite Mound**		**Woodland Matrix**		**Termite Mound**		**Woodland Matrix**			
	Number of spiders	**Number of species**	**Number of spiders**	**Number of species**	**Number of spiders**	**Number of species**	**Number of spiders**	**Number of species**	**Number of spiders**	**Number of species**	**Number of spiders**	**Number of species**		
Agelenidae									14	2	3	2	17	0.5
Amaurobiidae	114	2	52	2	25	2	16	1	9	2	2	2	218	6.9
Barychelidae	1	1	10	1	9	1	62	1					82	2.6
Caponiidae					2	1	2	1	2	2	1	1	7	0.2
Clubonidae									1	1	1	1	2	0.1
Cyrtauchenidae	1	1	1	1			4	4					6	0.2
Deinopidae									6	2			6	0.2
Dictynidae					1	1							1	0.0
Erisidae					1	1	1	1					2	0.1
Gnaphosidae	144	12	168	12	100	14	194	4	45	10	26	6	677	21.6
Hahnidae	1	1			1	1			3	1	7	3	12	0.4
Heteropodidae			2	1	1	1	1	1					4	0.1
Loxoscelidae			2	1			2	1	2	1			6	0.2
Lycosidae	111	11	136	10	260	8	246	9	255	20	84	14	1092	34.8
Miturgidae	1	1	1	1							1	1	3	0.1
Nesticidae					1	1							1	0.0
Oonopidae	1	1	3	2	9	3	12	2	1	1	1	1	27	0.9
Oxyopidae	1	1	5	4	12	7	18	4	5	3	6	5	47	1.5
Palpimanidae	3	1	1	1	4	1	1	1	2	1			11	0.4
Pholcidae			1	1	1	1							2	0.1
Pisauridae	3	2	23	3	35	3	156	5					217	6.9
Salticidae	17	8	61	10	104	17	141	20	27	6	17	5	367	11.7
Scytodidae	1	1	1	1									2	0.1
Tetragnathidae					1	1					1	1	2	0.1
Thomisidae	5	3	1	1	1	1	3	2	1	1	2	2	13	0.4
Uloboridae					1	1							1	0.0
Zodariidae	5	3	11	4	110	6	68	10					194	6.2
***Solifugidae**			3	3	4	2	14	3	81	1	18	1	120	3.8
TOTALS	**409**	**49**	**482**	**59**	**683**	**74**	**941**	**70**	**454**	**54**	**170**	**45**	**3139**	**100.0**

4.2 Species Accumulation Curves

The species accumulation curves for all three locations (Figure 4.1) did not level off to a plateau before the Sorensen distance value reached zero. Although a greater sampling effort would have resulted in a greater number of new species, spider sampling was considered acceptable but clearly not completely adequate. In all the curves (Figure 4.1) a gradual deceleration in the acquisition of new species was observed after an initial rapid increase in the number of species.

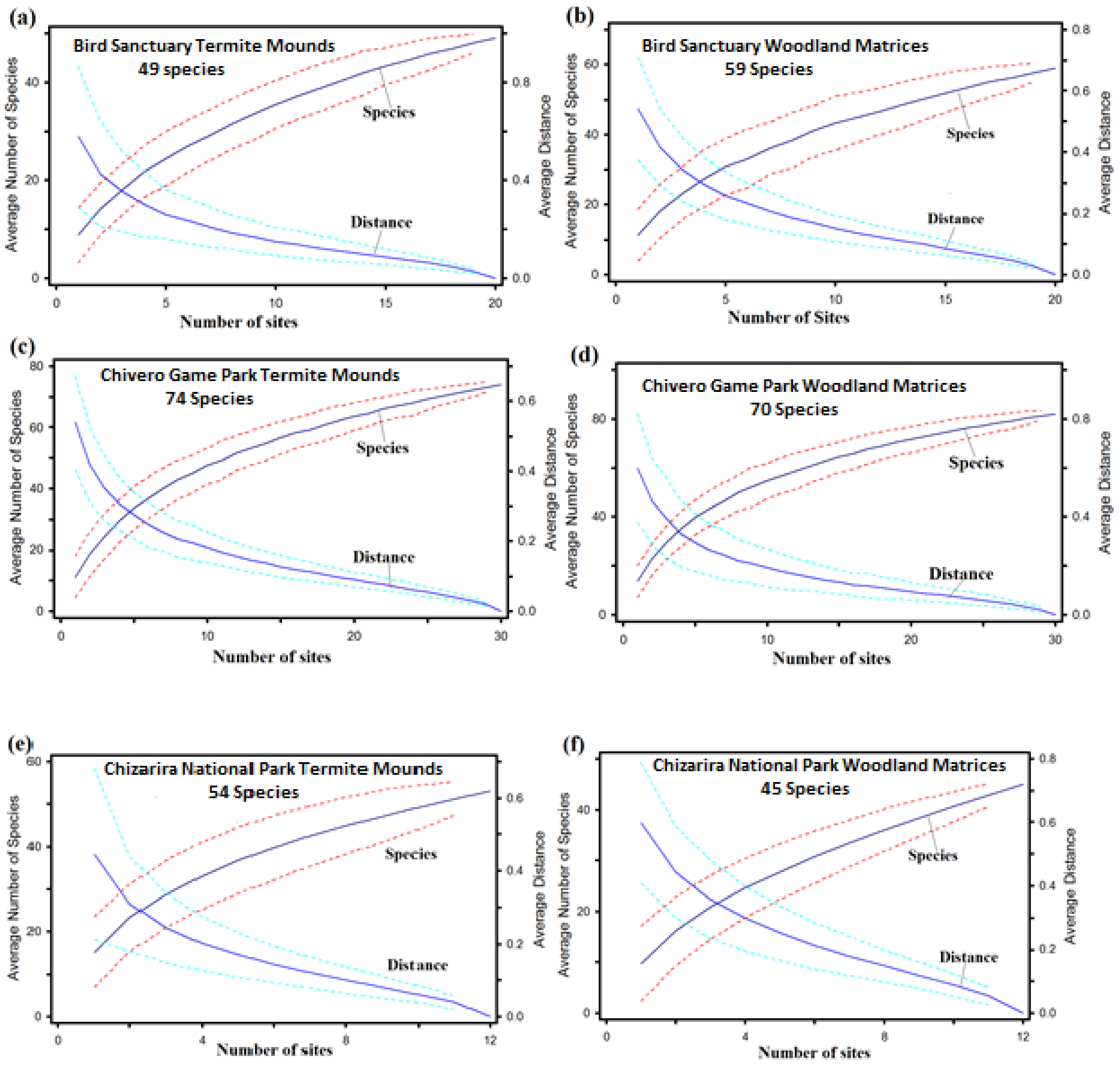

Figure 4.1: Species accumulation curves (rising curves) and distance curves (falling curves) for termite mound and woodland matrix sites sampled in the three study locations. Both curves were adjusted for random sample order. The distance curve represents the average Sorenson distance between the whole sample and subsamples and broken lines represent standard deviations from the mean.

4.3 Differences in Spider Species Abundance and Species Richness, Between Termite Mounds and the Adjacent Woodland Matrix

In the Bird Sanctuary, the average spider species richness and abundance were greater (Table 4.2) in the woodland matrix than on the termite mounds. The Welch two sample t-test confirmed the differences in species richness to be statistically significant (p = <0.05) but the apparent differences in abundance between mounds and matrices were not significant (p = >0.05). In the Game Park (Table 4.3) both spider species richness and abundance were significantly (p = <0.05) higher in the woodland matrix. In Chizarira National Park (Table 4.4) spider species richness and abundance were significantly (p = <0.05) greater on the termite mounds than the adjacent woodland matrix.

Table 4.2 Mean (with standard errors and 95% confidence intervals) spider richness and abundance on termite mounds and in the woodland matrix in the Chivero Bird Sanctuary. The Welch two sample t-test was used to check for statistically significant differences.

					Welch two sample t-test		
Measure	**Site**	**N**	**Mean**	**Standard Deviation**	**t-value**	**d.f.**	**p-value**
Number of Spiders	Termite mound	20	20.45	10.38	-1.21	36.5	0.232
	Woodland Matrix	20	24.10	8.54			
Number of Species	Termite mound	20	8.80	2.82	-2.38	35.0	0.023*
	Woodland Matrix	20	11.3	3.76			

The symbol * represents a statistically significant difference

Table 4.3: Mean (with standard errors and 95% confidence intervals) spider richness and abundance on termite mounds and in the woodland matrix in the Chivero Game Park. The Welch two sample t-test was used to check for statistically significant differences.

					Welch two sample t-test		
Measure	**Site**	**N**	**Mean**	**Standard Deviation**	**t-value**	**d.f.**	**p-value**
Number of Spiders	Termite mound	30	22.73	6.41	-2.42	35.80	0.021*
	Woodland Matrix	30	31.40	18.51			
Number of Species	Termite mound	30	11.17	3.34	-2.92	57.92	0.005*
	Woodland Matrix	30	13.63	3.18			

The symbol * represents a statistically significant difference

Table 4.4: Mean (with standard errors and 95% confidence intervals) spider richness and abundance on termite mounds and in the woodland matrix in Chizarira National Park. The Welch two sample t-test was used to check for statistically significant differences.

					Welch two sample t-test		
Measure	**Site**	**N**	**Mean**	**Standard Deviation**	**t-value**	**d.f.**	**p-value**
Number of Spiders	Termite mound	12	37.75	16.52	4.46	15.65	<0.001*
	Woodland Matrix	12	14.25	7.76			
Number of Species	Termite mound	12	15.17	4.12	3.44	21.74	0.002*
	Woodland Matrix	12	9.67	3.71			

The symbol * represents a statistically significant difference

4.4 Similarity Analysis

In the Bird Sanctuary, a cluster analysis (Figure 4.2) based on spider species community composition showed that there were various groups of termite mounds and woodland matrix sites clustered together.

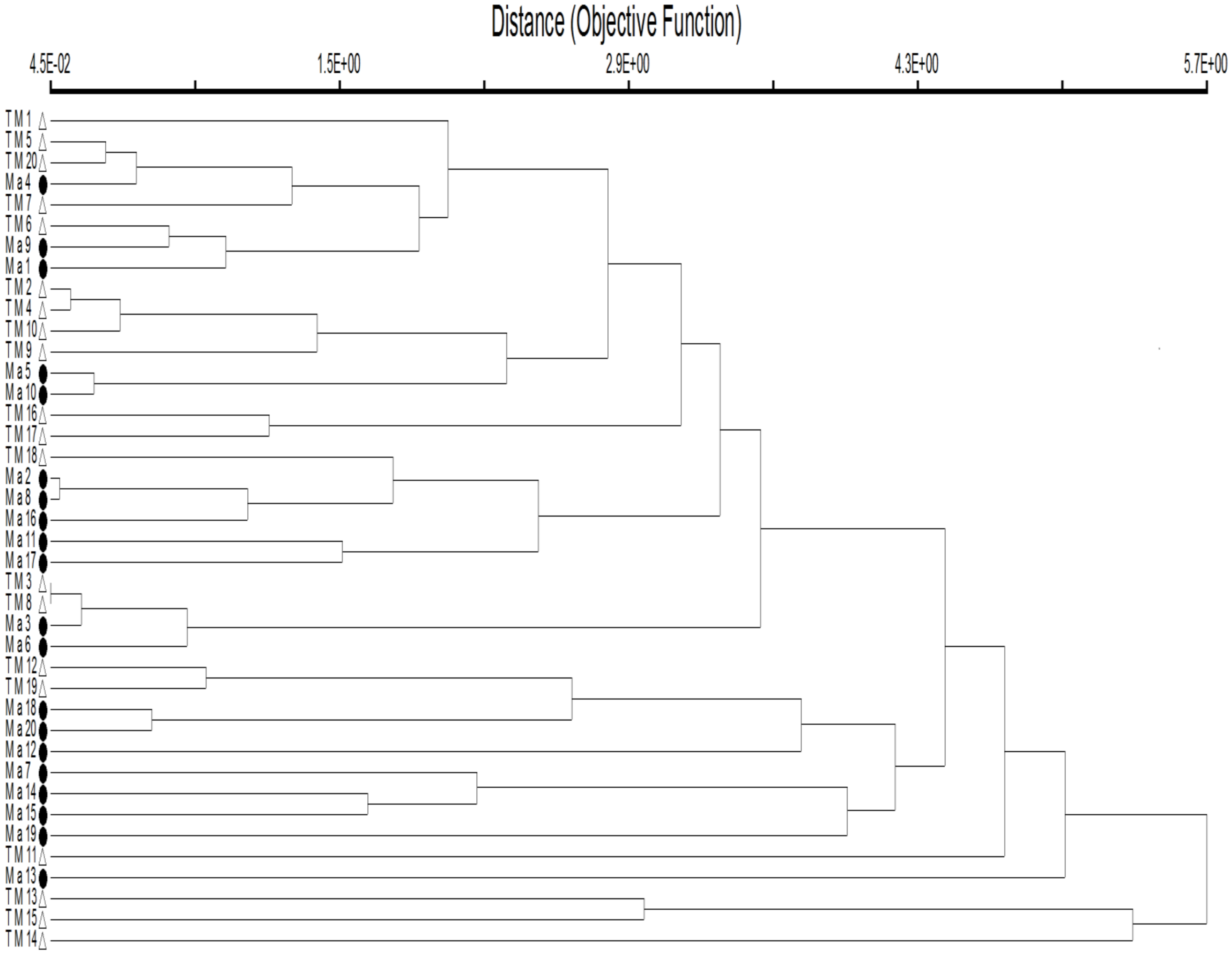

Figure 4.2: Dendogram showing species shared between sites (n=40) in the Chivero Bird Sanctuary. The unweighted pair-group average (UPGAMA) and Bray-Curtis similarity measure were used to plot the dendogram. The symbol ● represents a woodland matrix (Ma) site and ∆ represents a termite mound (TM) site. Numbers following the initials TM and Ma are the plot numbers.

It can therefore be said that in the Bird Sanctuary spider community assemblages differ between the mounds and the woodland matrix, but there also seems to be other factors determining spider species community composition other than just the site (termite mound or woodland matrix).

The Chivero Game Park produced a somewhat similar dendogram (Fig 4.3) to the Bird Sanctuary but with fewer and larger groups of mound and matrix sites. Grouping was much more pronounced in Chizarira National Park (Fig 4.4) as all the termite mounds except termite mound number 2 were clustered together. A closer look at the habitat characteristics shows that mound number 2 was the only mound with no aerial cover (0% cover) and also had a very low ground cover (Appendix D) cover. There therefore seems to be an increase in spider species community composition similarity between the termite mounds and the woodland matrix, from the least impacted to the most impacted miombo woodland, from Chivero Bird Sanctuary to Chizarira National Park.

It was also observed that in the Chizarira National Park dendogram (Figure 4.4) distances between individual termite mounds were much less as compared to those observed in the matrices. This observation was also evident in the Game Park dendogram, but less pronounced, and not identifiable in the Bird Sanctuary spider data. It seems likely that grouping is much closer between termite mounds than between woodland matrix sites, and therefore spider assemblages on termite mounds are more homogeneous and termite mounds harbour somewhat distinct spider assemblages.

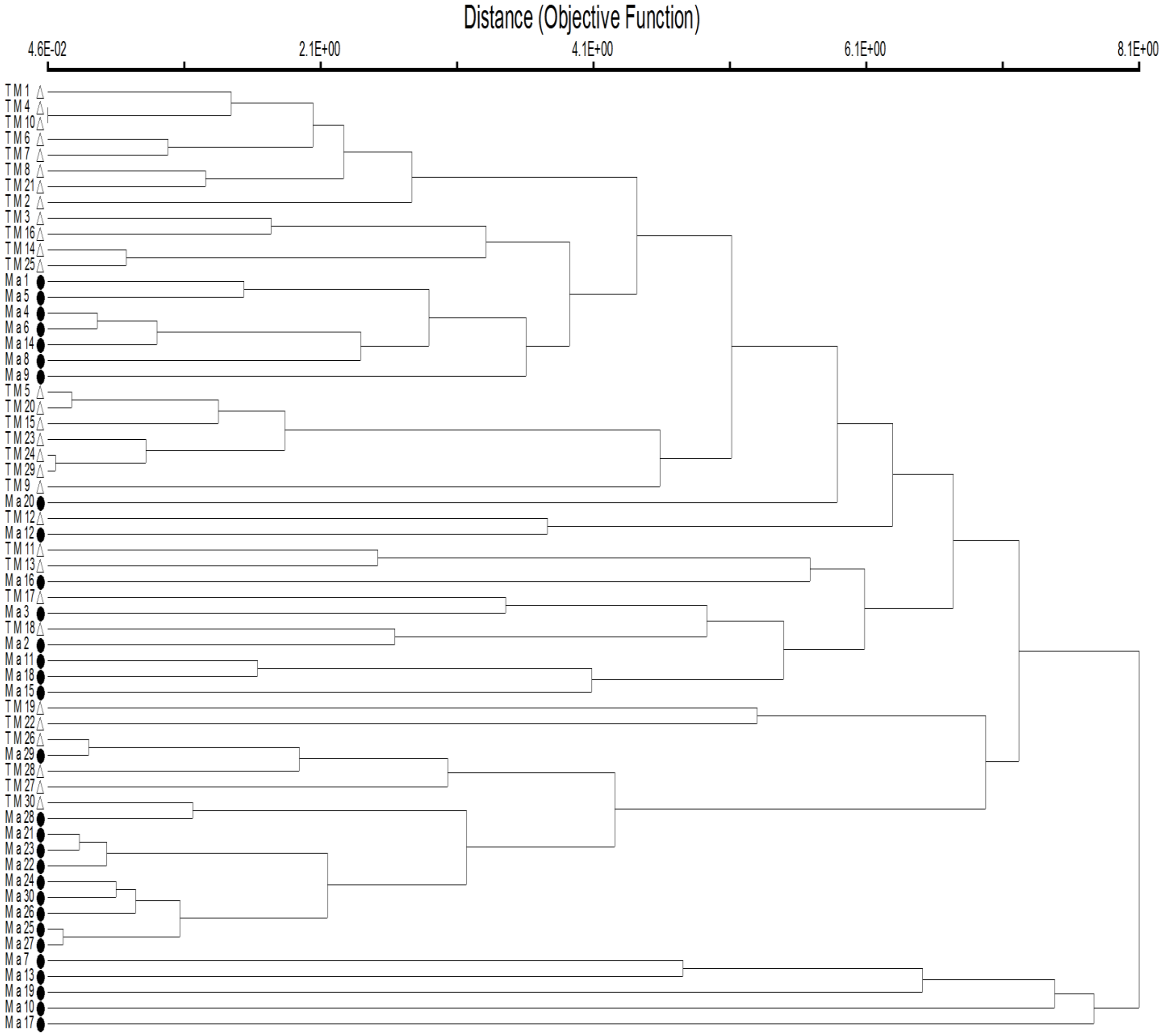

Figure 4.3: Dendogram showing species shared between sites (n = 60) in Chivero Game Park. The unweighted pair-group average (UPGAMA) and Bray-Curtis similarity measure were used to plot the dendogram. The symbol ● represents a woodland matrix (Ma) site and △represents a termite mound (TM) site. Numbers following the initials TM and Ma are the plot numbers.

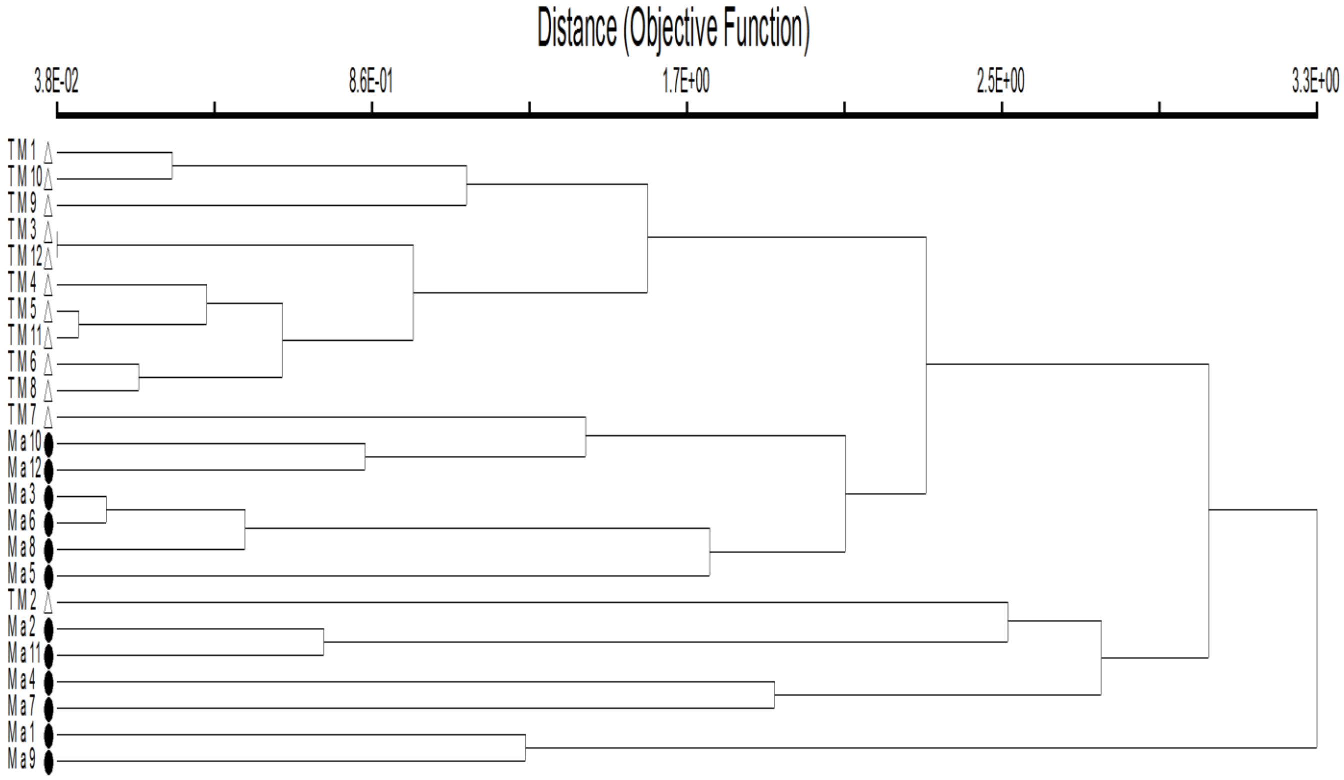

Figure 4.4: Dendogram showing species shared between sites (n = 24) in Chizarira National Park. The unweighted pair-group average (UPGAMA) and Bray-Curtis similarity measure were used to plot the dendogram. The symbol ● represents a woodland matrix (Ma) site and △represents a termite mound (TM) site. Numbers following the initials TM and Ma are the plot numbers.

Multi-Response Permutation Procedures (MRPP) detected differences in spider community assemblages between the termite mounds and the woodland matrix in all the three areas; the Bird Sanctuary (A = 0.016 p = 0.005), the Chivero Game Park (A = 0.028 p = <0.001), and the Chizarira National Park (A = 0.047 p = <0.001).

Although a gradient in similarity was established from the least impacted to the most impacted woodland using hierarchical cluster analysis, simple calculation of the Jaccard abundance corrected index and consequent statistical significance testing did not show any differences in similarity between mound and matrix sites across the different herbivore impact areas. The average Jaccard corrected indices for all the locations were relatively similar (Figure 4.5). Chizarira had an average value (corrected Jaccard similarity index) of 0.45 +/- 0.06 at a 95% confidence interval, the Bird Sanctuary had a value of 0.45 +/- 0.07 at a 95% confidence interval, and Chivero Game Park had a value of 0.48+/- 0.05 at a 95% confidence interval. A Kruskal-Wallis test for independent samples revealed no statistically significant (p = >0.05) difference in similarity across the three locations.

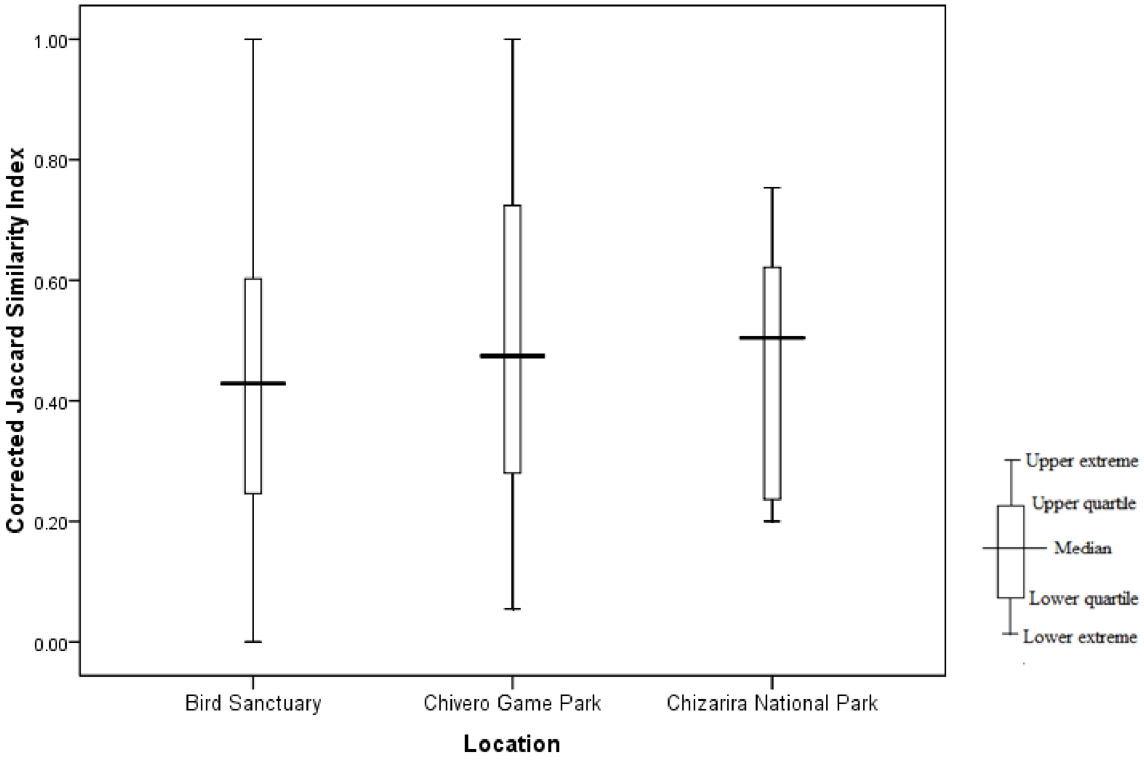

Figure 4.5: Box plot showing the Jaccard corrected similarity indices of the three study locations for similarities in the number of spiders and species shared by termite mounds and matrices. A Kruskal-Wallis for independent samples revealed no statistically significant (X^2 = 0.143, d.f.= 2, p = 0.931) difference in similarity across the three study areas.

Nevertheless, the box plot (Figure 4.5) shows that the data sets from the Bird sanctuary and the Game Park had much greater variability as compared to the data for Chizarira although the means were relatively similar. The data for Chizarira was skewed towards the upper values whilst the data from the Bird sanctuary and the Game Park seemed to be normally distributed. The medians of the three locations were relatively similar but Chizarira National Park had the greatest median followed by the game park, and the bird sanctuary, respectively. These observations show that in the Game Park and the Bird Sanctuary some mounds shared the same number of species and individuals as the adjacent matrices (Jaccard index = 1), whilst some shared none at all (Jaccard index = 0). In Chizarira National Park no mound had the same number of species and spiders as the adjacent matrix and a somewhat more intermediate similarity was portrayed.

4.5 Influence of Ground Cover, Aerial Cover, Woody Plant Species Richness and Site in Determining Spider Species Richness and Abundance

In all the study areas the mean ground cover (Table 4.5 - 4.7) was highest in the woodland matrix sites but the Welch two sample t-test indicated that all these differences were not statistically different ($p = >0.05$). In the Game Park (Table 4.6) and the Bird Sanctuary (Table 4.5), aerial cover was also greatest in the matrices but only the difference in the Chivero Game Park was statistically significant ($p = <0.05$). Termite mounds in Chizarira had a higher aerial cover average value as compared to the matrices, and this difference was statistically significant ($p = <0.05$). Woody plant species richness was greater on the mounds in all three areas and only that in the Bird sanctuary and the Game Park was statistically significant ($p = <0.05$).

Table 4.5: Summary statistics of ground cover, aerial cover, and woody plant species richness measured in the Bird sanctuary. The significance of differences between sites was determined using the Welch two sample t-test.

					Welch two sample t-test		
Measure	**Site**	**N**	**Mean**	**Standard Deviation**	**t-value**	**d.f.**	**p-value**
Ground cover	Termite Mound	20	73.10	11.94	-1.61	37.91	0.117
	Woodland Matrix	20	79.33	12.57			
Aerial cover	Termite Mound	20	32.98	9.53	-0.66	37.32	0.515
	Woodland Matrix	20	35.10	10.87			
Plant species richness	Termite Mound	20	29.35	4.11	8.24	33.35	<0.001*
	Woodland Matrix	20	15.75	6.13			

The symbol * represents statistical significance, p = <0.05

Table 4.6: Summary statistics of ground cover, aerial cover, and woody plant species richness measured in the Chivero Game Park. The significance of differences between sites was determined using the Welch two sample t-test.

					Welch two sample t-test		
Measure	**Site**	**N**	**Mean**	**Standard Deviation**	**t-value**	**d.f.**	**p-value**
Ground cover	Termite Mound	30	60.05	13.36			
	Woodland Matrix	30	65.27	18.84	-1.24	52.29	0.222
Aerial cover	Termite Mound	30	24.38	9.91			
	Woodland Matrix	30	33.82	22.62	-2.09	39.78	0.043*
Plant species richness	Termite Mound	30	17.93	5.48			
	Woodland Matrix	30	10.07	3.67	6.57	50.63	<0.001*

The symbol * represents statistical significance, p = <0.05

Table 4.7: Summary statistics of ground cover, aerial cover, and woody plant species richness measured in the Chizarira National Park. The significance of differences between sites was determined using the Welch two sample t-test.

					Welch two sample t-test		
Measure	**Site**	**N**	**Mean**	**Standard Deviation**	**t-value**	**d.f.**	**p-value**
Ground cover	Termite Mound	12	22.81	15.66	-1.37	18.76	0.188
	Woodland Matrix	12	34.24	24.39			
Aerial cover	Termite Mound	12	53.76	28.54	5.88	11.56	<0.001*
	Woodland Matrix	12	4.66	4.54			
Plant species richness	Termite Mound	12	12.50	3.43	1.15	21.98	0.262
	Woodland Matrix	12	10.92	3.33			

The symbol * represents statistical significance, p = <0.05

After computing various stepwise model simplifications, a Generalized linear model (GLM) was produced for each of the two response variables (spider abundance and richness), at each location. Tables 4.8 to 4.13 are the resultant minimal adequate models showing the influence of explanatory variables and their interactions, on spider species richness and abundance.

In the Bird Sanctuary none of the explanatory variables in the model (X^2 = 24.173, df = 8, p = 0.002) were able to explain variations in spider richness (Table 4.9). The factors influencing spider abundance (Table 4.8) (X^2 = 6.337, df = 8, p = 0.061) were aerial cover and the two way interactions between aerial cover and ground cover, and between site (termite mound and woodland matrix) and woody plant richness.

Table 4.8: Results of a Generalized Linear Model (Type III) run on the Bird Sanctuary data, with spider abundance as the response variable and site, aerial cover, and their interactions as the factors. The model was constructed through a stepwise model simplification and with a Poisson error distribution and a log link function.

Factor	Wald Chi-Square	d.f.	p-value
(Intercept)	0.001	1	0.977
Site	0.232	1	0.63
Aerial cover	3.974	1	0.046*
Site ● Plant richness	6.379	2	0.041*
Aerial cover ● Ground cover	5.078	1	0.024*
Site ● Ground cover	3.395	2	0.183
Site ● Aerial cover	2.39	1	0.122
Aerial cover● Plant richness	2.862	1	0.091
Site ● Aerial cover ● Ground cover	3.502	1	0.061
Site ● Aerial cover● Ground ● Plant richness	3.685	2	0.158

● Represents an interaction between variables. * Represents a significant difference (p = <0.05)

Table 4.9: Results of a Generalized Linear Model (Type III) run on the Bird Sanctuary data, with spider species richness as the response variable and site, aerial cover, and their interactions as the factors. The model was constructed through a stepwise model simplification and with a Poisson error distribution and a log link function.

Source	Wald Chi-Square	d.f.	p-value
(Intercept)	1.196	1	0.274
Site	0.136	1	0.712
Site ● Plant richness	0.202	2	0.904
Site ● Aerial cover	0.517	2	0.772
Site ● Ground cover	0.666	2	0.717
Site ● Ground cover ● Aerial cover	0.654	2	0.721
Site ● Plant richness ● Aerial cover	0.204	2	0.903
Site● Ground cover ● Plant richness	0.635	2	0.728
Site ● Ground cover ● Plant richness ● Aerial cover	0.571	2	0.752

● Represents an interaction between variables.

Table 4.10: Results of a Generalized Linear Model (Type III) run on the Chivero Game Park data, with spider abundance as the response variable and site, aerial cover, ground cover and some interactions including plant richness as the factors. The model was constructed through a stepwise model simplification and with a Poisson error distribution and a log link function.

Source	Wald Chi-Square	d.f.	p-value
(Intercept)	0.04	1	0.842
Site	2.211	1	0.137
Ground ● Plant richness	5.486	1	0.019*
Site ● Ground	13.867	2	0.001*
Site ● Aerial	12.551	2	0.002*
Site ● Plant richness	5.104	2	0.078
Site ● Ground ● Aerial	14.435	2	0.001*
Site ● Ground ● Plant richness	5.898	1	0.015*
Site ● Plant richness ● Aerial	6.541	2	0.038*
Ground ● Plant richness ● Aerial	4.658	1	0.031*
Site ● Ground ● Plant richness ● Aerial	7.243	1	0.007*

● Represents an interaction between variables. * Represents a significant difference ($p = <0.05$)

In the Game Park various two way interactions, 2 three way interactions and a four way interaction between the explanatory variables (Table 4.10) ($X^2 = 43.351$, df = 10, $p = <0.001$) were found to significantly ($p = <0.05$) influence spider abundance, with the majority of the interactions having the variable site. Nevertheless, the factor site on its own was deemed to have an insignificant ($p = >0.05$) influence on spider abundance. It can therefore be said that in the Chivero Game Park spider abundance is determined by a combination of environmental variables, with the presence or absence of termite mounds playing an important role in these interactions. Spider richness (Table 4.11) (X2 = 23.275, df = 10, p = 0.003) on the other hand was proved to be driven by the three way interaction between site, ground cover, and aerial cover, and the four way interaction between site, woody plant richness, ground cover, and aerial cover. The variable site was also a part of both the two way and three way interaction factors. As with spider abundance the site was considered an essential variable as it was in all the interactions.

Table 4.11: Results of a Generalized Linear Model (Type III) run on the Chivero Game Park data, with spider species richness as the response variable and site, aerial cover, and some interactions including plant richness and ground cover as the factors. The model was constructed through a stepwise model simplification and with a Poisson error distribution and a log link function.

Source	Wald Chi-Square	d.f.	p-value
(Intercept)	1.055	1	0.304
Site ● Ground cover	4.943	2	0.084
Site ● Aerial cover	5.69	2	0.058
Site ● Plant richness	1.99	2	0.37
Site ● Plant richness ● Aerial cover	4.883	2	0.087
Site ● Plant richness ● Ground cover	4.941	2	0.085
Site ● Ground cover ● Aerial cover	8.397	2	0.015*
Site ● Plant richness ● Ground cover ● Aerial cover	7.738	2	0.021*

● Represents an interaction between variables. * Represents a significant difference ($p<0.05$)

The generalized linear model for Chizarira National Park ($X^2=133.29$; df = 15, p=0.000) also showed that various factors influence spider abundance. The variable site was also a part of all the interactions except the two way interaction between ground cover and aerial cover. Site and aerial cover were proved to be a significant factor of spider abundance.

Spider richness (Table 4.13) ($X^2 = 30.84$, d.f. = 8, p = <0.001) in Chizarira was also proved to be significantly (p = <0.05) influenced by ground cover, and the two way interactions between site and woody plant richness, between site and aerial cover, and between site and ground cover. Spider richness was also significantly (p = <0.05) influenced by the three way interactions between site, woody plant richness, and aerial cover; and between site, woody plant richness, and ground cover.

Table 4.12: : Results of a Generalized Linear Model (Type III) run on the Chizarira National Park data, with spider abundance as the response variable and site, aerial cover, ground cover, plant richness and some of their interactions as the factors. The model was constructed through a stepwise model simplification and with a linear distribution and a log link function.

Source	Wald Chi-Square	d.f.	p-value
(Intercept)	27.653	1	<0.001*
Site	18.719	1	<0.001*
Aerial	9.665	1	0.002*
Site ● Ground cover	11.331	2	0.003*
Site ● Aerial cover	9.054	1	0.003*
Ground cover ● Aerial cover	4.093	1	0.043*
Site ● Plant richness	2.553	2	0.279
Site ● Ground cover ● Plant richness	5.021	2	0.081
Site ● Aerial cover ● Plant richness	4.003	2	0.135
Site ● Ground cover ● Aerial cover	7.177	1	0.007*
Site ● Ground cover ● Aerial cover ● plant richness	0.435	2	0.805

● Represents an interaction between variables. * Represents a significant difference ($p<0.05$)

Table 4.13: Results of a Generalized Linear Model (Type III) run on the Chizarira National Park data, with spider species richness as the response variable and aerial cover, ground cover and some interactions including site and plant richness as the factors. The model was constructed through a stepwise model simplification and with a Poisson error distribution and a log link function.

Source	Wald Chi-Square	d.f.	p-value
(Intercept)	5.04	1	0.025*
Site	0.804	1	0.370
Ground cover	4.375	1	0.036*
Site ● Plant richness	17.951	2	<0.001*
Site ● Aerial cover	7.402	2	0.025*
Site ● Ground cover	13.026	1	<0.001*
Plant richness ● Ground cover	3.736	1	0.053
Aerial cover ● Ground cover	0.1	1	0.752
Site ● Plant richness ● Aerial cover	9.788	2	0.007*
Site ● Aerial cover● Ground cover	0.095	1	0.757
Site ● Plant richness ● Ground cover	8.716	1	0.003*
Site ● Plant richness ● Aerial cover ● Ground cover	0.123	2	0.940

● Represents an interaction between variables. * Represents a significant difference ($p<0.05$)

In all the three locations a distinct spider species community composition was evident between matrix and mound sites. Nevertheless, a non-metric Multidimensional Scaling plot for the Bird Sanctuary (Figure 4.6) showed a considerable similarity in the spider composition between mounds and matrices as compared to the plot for Chizarira National Park (Figure 4.8). A degree of overlap in species composition between mounds and matrices was also observed in the Game Park, but at a lesser extent than in the Bird Sanctuary.

In the Bird Sanctuary plot (Figure 4.7), ground cover and woody plant richness appeared in opposite directions showing that in the woodland matrix spider composition is driven mainly by ground cover in a rather weak association and on the termite mounds spider composition is driven mainly by woody plant richness in a strong relationship. In general, the Pearson correlation test (r) shows that in axis 1 ground cover (r = -0.260) had the greatest association with spider community structure followed by aerial cover (r = -0.127) and lastly plant richness (r = -0.024). In axis 2 all the environmental variables, ground cover (r = 0.199), aerial cover (r = 0.159), and plant richness (r = -0.125) had more or less the same degree of linear association with spider community structure.

Woody plant richness was also the major factor determining spider composition on the termite mounds in the Game Park (Figure 4.6) and woodland matrix species composition was mainly driven by aerial cover but a weak relationship was evident from the short line representing aerial cover on the nMDS plot in Figure 4.6. Both termite mound and woodland matrix spider species community compositions were aslo strongly associated with ground cover. In general, the Pearson correlation test (r) shows that in axis 1 ground cover (r = -0.552), had the greatest linear association with spider species community composition followed by plant richness (r = 0,166), and aerial cover (r = 0.063). In axis 2 plant richness (r = 0.420), had the greatest linear association followed by aerial cover (r = -0.144), and ground cover (r = -0.054).

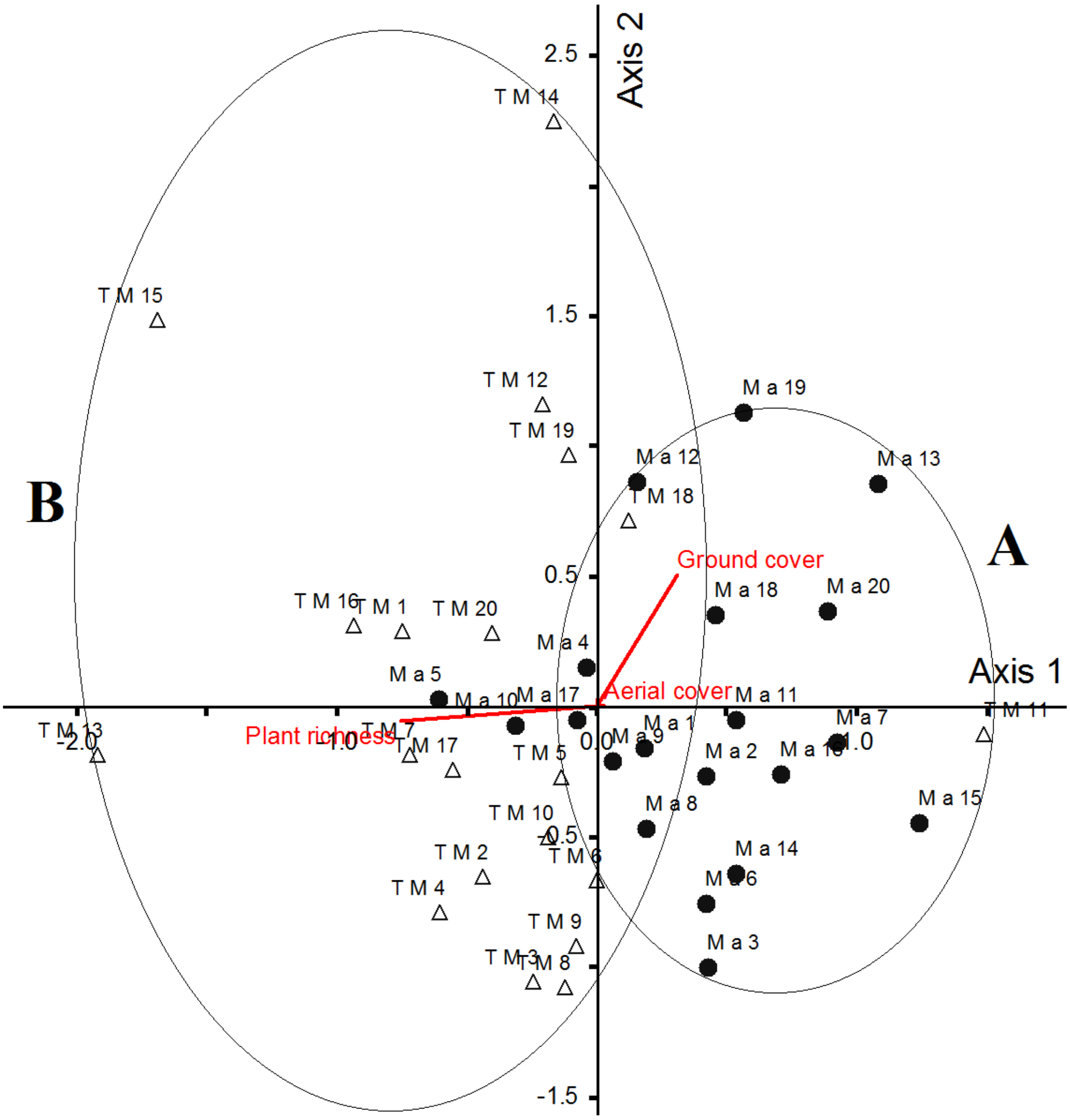

Figure 4.6: Non-metric Multidimensional Scaling plot showing the relationships between spider community species composition and the explanatory variables; aerial cover, ground cover and woody plant species richness, in the Chivero Bird Sanctuary. The symbol ● represents woodland matrix sites and △ represents termite mounds. Ellipses were drawn around similar communities. The group A is primarily composed of woodland matrix sites and the group B is composed of termite mound sites. Monte Carlo test result for mean stress is 48.185 (p = 0.0040) for axis 1 ($R^2 = 0.397$) and 29.716 (p = 0.0040) for axis 2 ($R^2 = 0.237$).

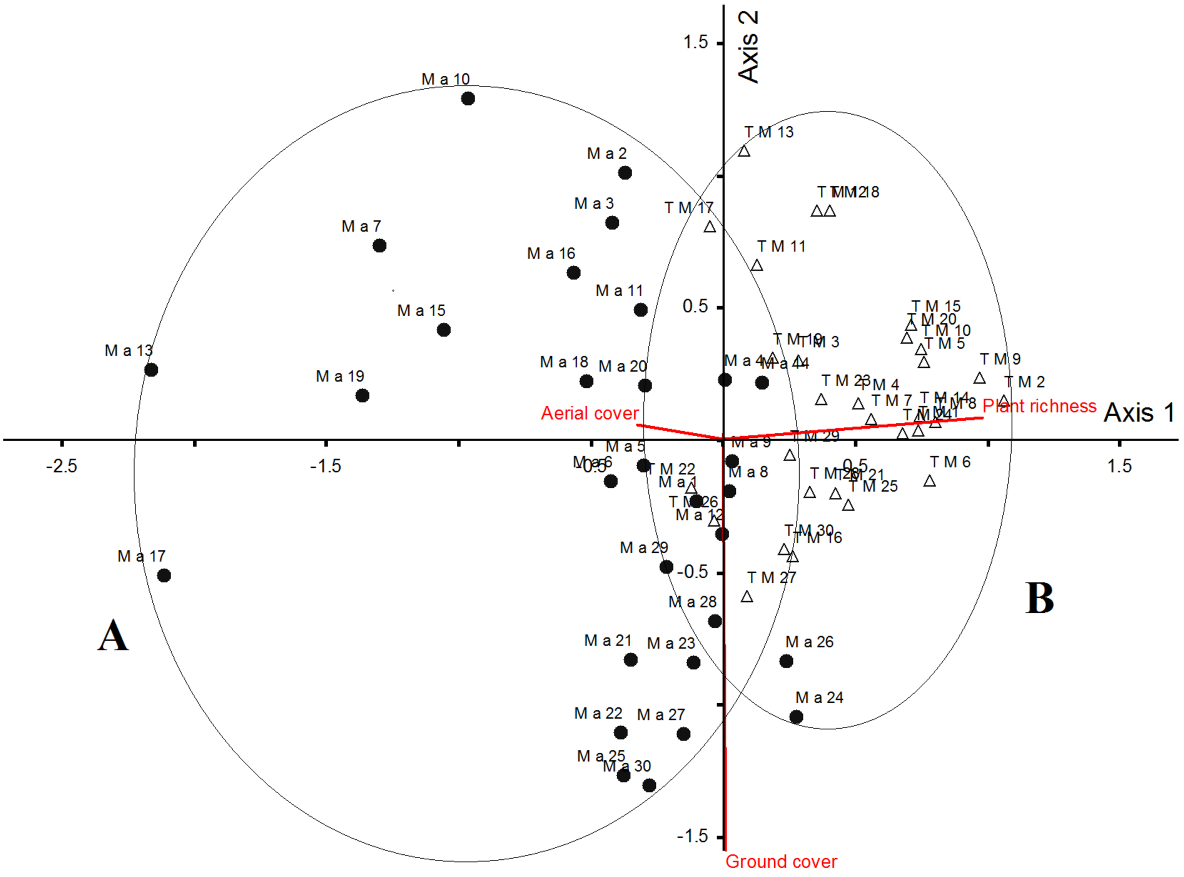

Figure 4.7: Non-metric Multidimensional Scaling plot showing the relationships between spider community species composition and the explanatory variables; aerial cover, ground cover and woody plant species richness, in the Chivero Game Park. The symbol ● represents woodland matrix sites and △represents termite mounds. Ellipses were drawn around similar communities. The group A is primarily composed of woodland matrix sites and the group B is composed of termite mound sites. Monte Carlo test result for mean stress is 48.662 ($p = 0.0080$) for axis 1 ($R^2 = 0.228$) and 31.589 ($p = 0.0040$) for axis 2 ($R^2 = 0.425$).

In Chizarirra National Park the spider composition between mounds and matrices was well separated, with no overlap (Figure 4.8). It was therefore deduced that both aerial cover and plant richness influence species composition on the termite mounds, with aerial cover having a very strong relationship and plant richness having a very weak one. The woodland matrix spider composition has a very weak relationship with ground cover and wooddy plant richness. Pearson correlation test (r) shows that in axis 1 aerial cover ($r = -0.719$) had the greatest linear association with spider species community composition, followed by plant richness ($r = -0.221$) and ground cover ($r = 0.115$). In axis 2, plant richness ($r = -0.419$) had the greatest linear association followed by aerial cover ($r = 0.292$) and ground cover ($r = -0.142$). All the environmental variables therefore had an influence on spider community structure, with aerial cover being the most influential variable in determining spider community structure.

The nMDS plot of Chizarirra also shows tight clustering of the spider community on the termite mounds, which shows that spiders on termite mounds in Chizarira have a strong preference for this particular habitat.

In all the nMDS plots the solutions were stronger than expected by chance ($p = <0.05$) when stress was related to dimensionality (Monte Carlo test for mean stress). All the plots are therefore deemed reliable representations of the actual spider communities in the three locations.

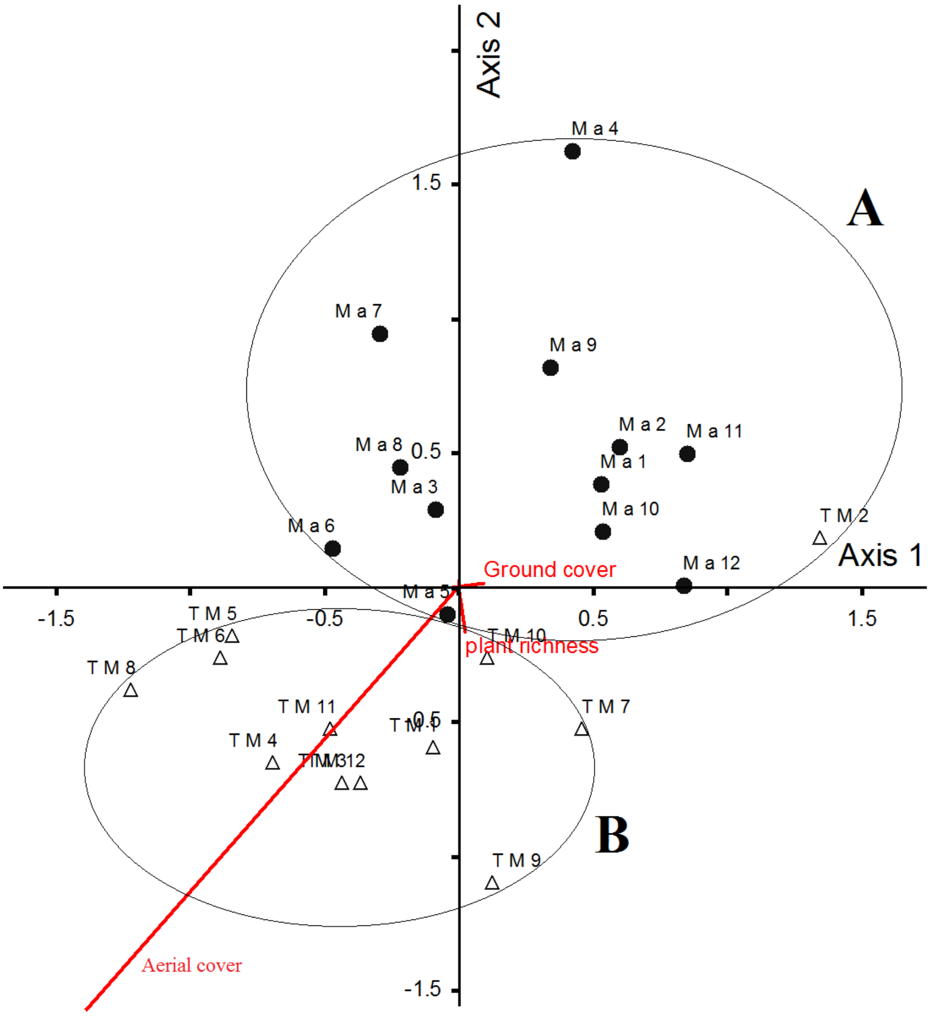

Figure 4.8: Non-metric Multidimensional Scaling plot showing the relationships between spider community species composition and the explanatory variables; aerial cover, ground cover and woody plant species richness, in the Chizarira National Park. The symbol ● represents woodland matrix sites and △ represents termite mounds. Ellipses were drawn around similar communities. The group A is primarily composed of woodland matrix sites and the group B is composed of termite mound sites. Monte Carlo test result for mean stress is 49.213 (p = 0.0040) for axis 1 (R^2 = 0.481) and 26.446 (p = 0.0040) for axis 2 (R^2 = 0.26).

CHAPTER 5: DISCUSSION

5.1 Sampling Adequacy

According to Soberon and Llorente (1993) at any particular time there is only a finite number of species in a given area and for ecological sampling to be considered adequate and representative, a species accumulation curve should be drawn and it should reach an asymptote or plateau where any additional sampling effort should not result in any more new species. However, none of the species-accumulation curves (from all the study locations; Figure 4.1a-f) in this study reached an asymptote. Ugland *et al.* (2003) suggest that this asymptote may be reached for data sets of species that can be identified easily, such as of plants and breeding birds where it is possible to obtain a count of all the species present (Colwell & Coddington 1994). For other habitats (or taxa) one cannot expect to count all the species. This asymptote has not been attained in several studies (eg. Erwin 1988, 1991; Ugland *et al* 2003) and Thompson *et al* (2003) state that this asymptote need not be achieved always for sampling to be adequate but the curve should elbow and begin to rise at a reduced rate for sampling to be considered reasonable. Nevertheless if species richness estimates are required from these curves then much greater sampling effort would have to be employed. Spiders in particular, are a very diverse and highly abundant group of invertebrates and sampling would have to take place over a much longer period of time. Many spider inventory studies (e.g. Whitmore *et al*. 2002; Russell-Smith 1999; Van den Berg and Dippenaar-Schoeman 1991) are evidence of this.

5.2 Patterns of Spider Species Richness, Abundance, and Community Composition

The results from the Bird Sanctuary, an area with minimal herbivore impacts, suggest that termite mounds alone have no influence on the number of ground dwelling spiders. However, in a heavily impacted woodland such as Chizarira National Park, a higher spider richness and abundance was realized on the termite mounds. Based on these observations I therefore make a claim that large termitaria do not serve as hotspots of diversity for ground dwelling spiders, but rather as refugia in highly disturbed and elephant impacted woodlands.

This conclusion is supported by a study done by Joseph *et al.* (2011) in Chizarira National Park, on cavity using birds. They concluded that termitaria in a dystrophic savanna system can contribute to ecosystem resilience by providing refugia for key functional elements such as woody plant species, as woodland matrix quality declines. As a result, a refuge for cavity-using birds is also facilitated. The current study was evidence of this for spiders and results (Table 4.7) show that termite mounds provide greater aerial cover than the adjacent woodland. By providing refugia for animal and plant life, large termitaria could therefore play an important role in sustaining biodiversity in highly disturbed area such as Chizarira National Park.

The results for the Chivero Game Park showed a greater number of spider species and individuals in the woodland matrices than on the mounds. The greater number of species could be due to the fact that there is only intermediate herbivore impact and disturbance in the woodland (Makumbe 2009) and the intermediate disturbance hypothesis (Connell 1978) could explain this. The hypothesis states that species richness is maximized at intermediate levels of disturbance. A fundamental assumption of the hypothesis is that a trade-off exists between the ability of a species to tolerate disturbance and its ability to compete. According to this hypothesis, if disturbance occurs frequently, richness decreases because species intolerance to disturbance becomes locally extinct. If disturbances are too infrequent, richness decreases because dominant species occupy resources and eliminate weak competitors. The intermediate disturbance in the game park woodland could therefore be leading to greater spider richness in the woodland than on the termite mounds. The hypothesis of disturbance driving diversity (Tilman 1994; Petraitis *et al*. 1989) therefore seems to holds in this study.

However, in the Bird Sanctuary a higher spider richness was also found in the woodland and yet herbivore disturbance in the woodland was deemed minimal. This result seems more like a discrepancy but it should be admitted that this study did not examine vegetation structure. A study by Makumbe (2009) has already shown that woody plant species structure differs on and off the termite mounds. So since invertebrate diversity is a function of habitat complexity (Robinson 1981; Gunnarsson 1988; Balfour and Rypstra 1998; Raizer and Amaral 2001), plant structure could have influenced diversity in the woodland in the Chivero Game Park. Another school of thought stems from the debatable use of statistical methods to determine significance of differences rather than assessing ecological or biological significance of differences (Johnson 1999) but this is a discussion for another paper.

Differences in species composition between the termite mounds and the woodland matrices were evident in all the three study areas (Figures 4.6 – 4.8). The study showed that the higher the herbivore impact is, the greater the difference in spider communities on and off termite mounds, as termitaria is impacted differently from the adjacent woodland matrices. Unfortunately, a full analysis of indicator species was not carried out due to lack of expertise in taxonomy. It was also observed that in Chizarira National Park there was a completely different composition of spider species on the mound as compared to the matrix. Less dissimilarity was observed in the woodland with intermediate herbivore impacts, the Chivero Game Park and the least dissimilarity was observed in the minimal herbivore impact area, the Bird Sanctuary. This study has thus provided evidence that in miombo woodlands spider species composition can be tied to herbivore impacts such that the more disturbed the habitat is, the more the dissimilarity in spider species composition between termite mounds and the woodland matrices is observed.

The results of no significant ($p = <0.05$) difference in similarity across the herbivore impact gradient could be interpreted to mean that either there was no pattern of similarity exhibited by ground spiders across the three areas or that there was a highly complex pattern that was not revealed by the corrected Jaccard similarity indices. This result emphasises the importance of ordination methods such as nMDS in place of basic statistics, because of the complexities of communities. The results could also be taken to mean that analysis at community level gives a clearer picture of the state of ecosystems as opposed to simple species (richness) and individuals (abundance) counts. In this study nMDS, an ordination method, gave more information about the differences in spider communities in each study area.

5.3 Influence of Habitat Characteristics

Results on habitat characteristics showed that in the Bird sanctuary only plant richness differed on and off the mounds, plant richness and aerial cover differed in the Game Park, and only aerial cover differed in Chizarira. Spider abundance and richness did not follow this pattern entirely as in the game park a greater aerial cover in the matrix was followed by greater spider abundance and richness in the woodland matrix as well. In Chizarira national park, a greater woody plant species richness was also followed a greater abundance and richness of spiders on termite mounds.

Generalized linear models (Tables 4.8 – 4.13) gave evidence that no one environmental variable alone was responsible for the variation in spider abundance and richness. Instead, various interactions, of different orders, of ground cover, aerial cover, plant richness, and site were the drivers of spider richness and abundance. As a result simply trying to establish a linear relationship between spider abundance or richness and any one of the proposed explanatory variables would not work entirely.

Along the gradient of herbivore impacts, from the Bird Sanctuary to Chizarira National Park, the number of interactions between the explanatory variables seemed to increase. In the Bird Sanctuary no variables or interactions were proved to influence spider species richness. This observation could be a result of high structural complexity in the Bird Sanctuary woodland, which has been removed from herbivore disturbance for the past 50 years (Cumming pers. comm.).

Many ecological studies are complicated by the unavoidable collinearity of explanatory variables and MacNally (2000) points out that this collinearity limits regression analysis adequacy in finding appropriate causal variables. Collinearity (or multicollinearity) is the undesirable situation when one independent variable is a linear function of other independent variables (Jöreskog and Sörbom 1989) and this is undesirable in models such as regression and GLM that are based on the assumption (Jöreskog and Sörbom 1989) that explanatory variables are not linearly related. As such, a possible explanation as to why none of the environmental features (ground cover, aerial cover, plant species richness) in this study were strong factors might be that other factors came into play and influenced spider diversity as well in a somewhat linear fashion. Nevertheless, the full factorial model of GLM used in this study explored all possible interactions and their influences on spider richness and abundance.

According to Crawley (2007) straightforward linear regression methods (assuming constant variance, normal errors) are not appropriate for count data for the following reasons: the linear model might lead to the prediction of negative counts, the variance of the response variable is likely to increase with the mean, the errors will not be normally distributed, and zeros are difficult to handle in transformations. As spider abundance and richness (both count data) were the response variables in this study it was appropriate to use generalized linear models that are able to deal with all these difficulties.

Another possible explanation for this deviation can be pinned down on the habitat specialization and the high diversity of spiders. According to Buchholz (2010), ecological traits of spider in shading may be preferential either for habitat openness or for vegetation cover. Thus, it is possible that in the current study spider species with such contrasting habitat preferences were present. A typical example is provided by a study by Warui *et al*. (2005) on the impacts of wildlife and cattle on the diversity of spiders. In their study they identified one species, *Aelurillus sp*. and concluded that it was probable that the species preferred open habitats, which are less complex because of its mode of feeding which involves hunting, and this could become hindered by a complex habitat. No particular spider community can therefore have all species favouring a particular habitat. This discussion therefore further emphasises the importance of proper taxonomy in similar studies.

It should also be acknowledged that other studies (e.g. Mallis and Hurd 2005) have failed to find convincing correlations between the environment and the occurrence of spiders. These authors claimed that spider communities are stochastic assemblages and habitat conditions as well as niche properties have little influence on their structure and dynamics. Nevertheless, this is essentially a neutral view on spider communities.

Spider community analysis revealed that spider species composition on termite mounds is driven by a different set of factors that determine composition in the matrices, and this becomes more apparent with the increase in the level of herbivore impacts. nMDS results showed that woody plant richness strongly influenced spider species community composition in both the Game Park and the Bird Sanctuary. Previous studies have proved that termite mounds harbour a unique suite of plants in comparison with the surrounding woodland. The Welch two sample test in Tables 4.5 and 4.6 also showed that woody plant richness was significantly higher on the termite mound. A higher plant richness of unique plants therefore translates into greater habitat complexity in relation to the woodland matrix. This is well in accordance with the hypothesis that more complex habitats provide arthropods with sites for shelter, foraging, oviposition, and mating (Lawton 1983, Halaj *et al*. 2000). Results of other authors who have investigated spider communities in relation to vegetation structure (Maelfait and De Keer 1990; Gibson *et al.* 1992; Mc Ferran *et al.* 1994) also show this association between spider communities and the local vegetation structure.

In addition, the niche theory states that differences between species and environmental factors drive the distribution of species and ultimately the composition and diversity of communities (Hutchinson 1958), as so was observed in this study.

It can therefore be said that woody plant species richness is an important driver of spider community structure in miombo woodlands with large termitaria, but as the level of herbivore impacts increase plant richness becomes less important in determining spider community structure, as was shown in Chizarira National Park, a heavily impacted woodland. Instead aerial cover becomes the most important driver of spider community structure on the mounds.

In a woodland matrix with minimal herbivore impacts ground cover seems to be an important driver of spider community structure. In the presence of intermediate impacts both aerial cover and ground cover are the drivers, but in a highly impacted woodland ground cover and plant richness only have weak associations with spider community composition.

Generally, results clearly illustrated the advantages of using ordination methods such as nMDS in place of basic statistics of abundances and species richness's, because of the apparent complexities of spider (or invertebrate) communities. Non metric multidimensional scaling gave more information about spider communities. The results indicate that the two types of sites, termitaria and matrix, have unique species compositions. Additionally, there are many environmental factors that determine the composition at a site and not simply the habitat type.

The hypothesis that disturbance drives diversity (Tilman 1994 Petratis et al. 1989) therefore seems to hold for ground dwelling spiders, although not in the expected linear fashion.

5.4 Limitations of the Study

One of the problems when looking at spider diversity at a coarse level of resolution e.g. at the guild level, is the fact that it is not possible to detect the sensitivity of individual species to disturbances (Buchhloz 2010). Lawton *et al.* (1998) argued that different species vary in their requirements within a natural ecosystem. This was further supported by Goldstein (1999) and

Alonso (2000) who emphasized that individual species always had their unique history that dictated their distribution. Such arguments are against analysis at a coarse level of resolution to detect disturbances and would instead tend to support the species-level approach. The use of morphospecies in this study clearly overlooks this species-level approach but rather assumes that all the species grouped together will respond in a similar way to changes. The failure to properly classify the spiders to species level therefore compromised the accuracy of this study.

In addition, Goldstein (1999) and Alonso (2000) emphasized the need for conservation and management plans that not only incorporate the number of species but also the identity and biology of species present. Nevertheless, such knowledge is still lacking among many African savanna species and the biology and or ecology of the species already identified are still not well documented, which makes understanding of many individual species difficult.

Sampling days: Many ecological studies involving spiders are conducted over long periods of time, due to the high diversity of these invertebrates. As time was a limitation in the current study sampling period was relatively short but highly intensive and this has the advantage that a more robust comparative analysis (Sørensen 2004) can be attained. A short period was also ideal for this study as it reduces the effects of immigration or emigration (Sørensen 2004) of spiders from one patch or site to another.

The use of the morphospecies approach has been used by numerous workers (e.g. Klein 1989; Kremen 1992; Kremen *et al.* 1993) and it has been suggested (Beattie and Oliver 1995) that non-specialists may use this method to classify invertebrates to morphospecies without compromising scientific accuracy. As a result, environmental and conservation surveys can be conducted in the absence of taxonomists, that are usually difficult to come by and require much time for the taxonomic identification of specimens. The morphospecies approach can however be complicated as proper species separation is often possible only with a detailed study that may include dissection of genitalia. In these cases, use of morphospecies can result in underestimation of species richness due to lumping (Derraik 2002). Non-specialists are likely to assume in such situations that the small variation relates to the same species. Another problem comes from overestimation of species by splitting when there is much intraspecific variation, such as sexual dimorphism or large morphological differences between adult and juvenile instars (Derraik 2002). There is therefore clearly no substitute to taxonomy, but this study has shown that in determining the importance of termitaria in miombo woodlands of different herbivore impacts morpho-species worked well, although proper taxonomy would yield a more accurate result.

Besides herbivore impacts, other disturbances such as fire and human activities may impact the woodlands under question as much. It is rather unfortunate that this study was not able to factor them in due to limitations of time and resources. However, the three woodlands (locations) exhibited quite distinct herbivore impact levels, and this alone was sufficient in order to establish the relationship between the level of herbivore impacts and spider richness and abundance, on and off large termitaria.

The present study is a step toward the use of spiders as indicators in the management of Savannah ecosystems, but a better understanding of communities will only be obtained through long-term studies.

CHAPTER 6: CONCLUSION

Based on spider abundance (the most reliable measure in the study), large vegetated termitaria are not hotspots for ground dwelling spiders in miombo woodlands, but in high herbivore impacted miombo woodlands they become refugia for a unique suite of spiders. Spider community composition differs from the termite mounds to the adjacent miombo woodland, and as the level of disturbance increases in the woodland, the two communities (on the mound and in the woodland) become more and more distinct. The level of herbivore impact seems to have an influence on vegetation cover and woody plant species richness that as a result, together drive spider community composition, richness and abundance. These results therefore show the indicator value of spider species richness, abundance, and composition, and justify the use of spiders as bioindicators of habitat change in miombo woodlands that have large termitaria, in future studies.

Nevertheless, more extensive sampling, with full identification of spiders, on a seasonal basis, could uncover dynamic shifts in spider diversity and community structure that could not be detected by this short term study.

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APPENDICES

Appendix A: Global Positioning reference points and vegetation cover data for all sites in the Bird Sanctuary. The dimensions of mound sites are also given

Site	Latitude (S)	Longitude (E)	Mound Height (m)	Diameter 1 (m)	Diameter 2 (m)	Ground cover (%)	Aerial cover (%)
Mound 1	17°54.623'	30°50.373'	3.8	25.8	22.2	60	17.5
Mound 2	17°54.652'	30°50.416'	2.8	23.9	20.65	63	43.5
Mound 3	17°54.707'	30°50.398'	2.8	20.3	12.56	77.5	40.5
Mound 4	17°54.681'	30°50.440'	3.8	24.2	21	81.5	36.5
Mound 5	17°54.740'	30°50.438'	3.2	24.7	21.5	71.5	41
Mound 6	17°54.813'	30°50.451'	3.9	22.5	21.7	51	31.5
Mound 7	17°54.746'	30°50.563'	1.3	12.25	10	68	18
Mound 8	17°54.765'	30°50.503'	2.9	20.79	20.22	77	29.5
Mound 9	17°54.826'	30°50.547'	2.2	15.1	11.31	54.5	20
Mound 10	17°54.805'	30°50.590'	1.5	11.9	9.8	83	26.5
Mound 11	17°54.590'	30°50.311'	3.2	26.9	22.75	68	24
Mound 12	17°54.759'	30°50.651'	2.5	16.2	12.39	92.5	23.5
Mound 13	17°54.650'	30°50.653'	3.4	19.6	15.9	74.5	37
Mound 14	17°54.551'	30°50.796'	3.4	13.63	10.15	95.5	44
Mound 15	17°54.520'	30°50.827'	1.8	12.82	12.08	78	33.5
Mound 16	17°54.781	30°50.461	-	-	-	57	37.5
Mound 17	17°54.708'	30°50.360'	-	-	-	78.5	43.5
Mound 18	17°54.257'	30°50.201'	-	-	-	71.5	50.5
Mound 19	17°54.280'	30°50.312'	-	-	-	74	34.5
Mound 20	17°54.226'	30°50.285	-	-	-	85.5	27
Matrix 1	17°54.633'	30°50.393'	-	-	-	55	35
Matrix 2	17°54.636'	30°50.403'	-	-	-	89.5	46
Matrix 3	17°54.726'	30°50.393'	-	-	-	73	51
Matrix 4	17°54.709'	30°50.429'	-	-	-	83.5	35
Matrix 5	17°54.743'	30°50.464'	-	-	-	67.5	33.5
Matrix 6	17°54.801'	30°50.437'	-	-	-	81	43
Matrix 7	17°54.767'	30°50.557'	-	-	-	74.5	21
Matrix 8	17°54.748'	30°50.508'	-	-	-	68.5	29
Matrix 9	17°54.808'	30°50.545'	-	-	-	70	38
Matrix 10	17°54.806'	30°50.571'	-	-	-	65	13.5
Matrix 11	17°54.597'	30°50.335'	-	-	-	78	45.5
Matrix 12	17°54.762'	30°50.636'	-	-	-	100	12.5
Matrix 13	17°54.656'	30°50.634'	-	-	-	95	35.5
Matrix 14	17°54.530'	30°50.798'	-	-	-	97.5	31
Matrix 15	17°54.507'	30°50.836'	-	-	-	96.5	38
Matrix 16	17°54.792'	30°50.436'	-	-	-	83	30.5
Matrix 17	17°54.708'	30°50.360'	-	-	-	71.5	42
Matrix 18	17°54.254'	30°50.219'	-	-	-	78.5	30
Matrix 19	17°54.265'	30°50.308'	-	-	-	91.5	54
Matrix 20	17°54.230'	30°50.276'	-	-	-	67.5	38

Appendix B: Global Positioning reference points and vegetation cover data for all termite mounds sampled in the Chivero Game Park. The dimensions of the mounds are also given

Site	Latitude (S)	Longitude (E)	Mound Height (m)	Diameter 1 (m)	Diameter 2 (m)	Ground cover (%)	Aerial cover (%)
Mound 1	17°55.103'	33°49.360'	2.2	11.4	11.4	46	27
Mound 2	17°55.188'	33°49.344'	3.5	21.8	16.3	47	32
Mound 3	17°55.168'	33°49.322'	3	14.1	11.5	51	39.5
Mound 4	17°55.091'	30°49.322'	2.7	11.7	9.1	52.5	16.5
Mound 5	17°55.017'	30°49.295'	1.4	11	8.5	48.5	14
Mound 6	17°55.106'	30°49.239'	4	16.7	16.05	48	8
Mound 7	17°55.031'	30°49.408'	3	13.05	10.55	56.5	20.5
Mound 8	17°54.991'	30°49.377'	3.1	16.9	12.5	47.5	18.5
Mound 9	17°55.287'	30°49.395'	3.4	14.2	13.02	50.5	27
Mound 10	17°55.181'	30°49.39'	3.2	14.5	13.2	61	14
Mound 11	17°54.941'	30°49.273'	3	14.3	11.3	53.5	23.5
Mound 12	17°55.125'	30°49.417'	2.3	10	9.5	52.5	18.5
Mound 13	17°55.113'	30°49.293'	3.95	23.7	19.2	30.5	21.5
Mound 14	17°55.072'	30°49.162'	3	13.8	12.9	46.5	17
Mound 15	17°55.081'	30°49.096'	2.8	18.9	16.6	60.5	20.5
Mound 16	17°55.162'	30°49.087'		20.6	19.6	53	24
Mound 17	17°55.198'	30°49.014	2.2	18.7	15.1	63	24.5
Mound 18	17°55.169'	30°48.970'	1.5	10.1	10	66	16.5
Mound 19	17°55.237'	30°48.100'	1.85	12.9	12.8	71.5	18.5
Mound 20	17°55.331'	30°48.895'	2.3	20.5	19.4	65	52
Mound 21	17°55.399'	30°48.909'	2.8	17.5	17	74	42.5
Mound 22	17°55.441'	30°48.935'	3.4	23.3	21	77	36.5
Mound 23	17°55.501'	30°48.872'	3.3	25.5	23	91	26
Mound 24	17°55.463'	30°48.824'	2.8	22.3	20.5	67.5	17.5
Mound 25	17°55.398'	30°48.842'	2.9	22.2	21	72	23
Mound 26	17°55.348'	30°48.798'	2.5	22.4	20.5	65	22
Mound 27	17°55.310'	30°48.850'	3.25	20.4	18.6	75	16
Mound 28	17°55.274'	30°48.811'	3.1	24	22	83.5	38
Mound 29	17°55.244'	30°48.778'	2.1	14.3	14	51	37.5
Mound 30	17°55.245'	30°48.842'	2.3	16.5	16	75	19

Appendix C: Global Positioning reference points and vegetation cover data for all woodland matrix sites sampled in the Chivero Game Park

Site	Latitude (S)	Longitude (E)	Ground cover (%)	Aerial cover (%)
Matrix 1	17°55.076'	30°49.365'	76	58
Matrix 2	17°55.165'	30°49.341'	42	22.5
Matrix 3	17°55.160'	30°49.323'	50.5	46.5
Matrix 4	17°55.096'	30°49.340'	58	52.5
Matrix 5	17°55.031'	30°49.323'	50	17.5
Matrix 6	17°55.072'	30°49.230'	54	8.5
Matrix 7	17°55.008'	30°49.407'	11	75
Matrix 8	17°54.993'	30°49.365'	64.5	13
Matrix 9	17°55.279'	30°49.426'	60.5	96
Matrix 10	17°55.201'	30°49.400'	57.5	35.5
Matrix 11	17°54.915'	30°49.321'	69	26.5
Matrix 12	17°55.124'	30°49.443'	38	93
Matrix 13	17°55.110'	30°49.311'	48	61.5
Matrix 14	17°55.073'	30°49.138'	68	15
Matrix 15	17°55.080'	30°49.114'	42	17.5
Matrix 16	17°55.145'	30°49.064'	71	34
Matrix 17	17°55.188'	30°49.009'	64	34.5
Matrix 18	17°55.177'	30°48.962'	59	38
Matrix 19	17°55.232'	30°48.922'	71	26
Matrix 20	17°55.333'	30°48.869'	66	29
Matrix 21	17°55.389'	30°48.931'	66	17
Matrix 22	17°55.467'	30°48.930'	75	21.5
Matrix 23	17°55.529'	30°48.864'	91.5	21
Matrix 24	17°55.460'	30°48.851'	96.5	27.5
Matrix 25	17°55.405'	30°48.826'	89.5	15.5
Matrix 26	17°55.338'	30°48.817'	76	20.5
Matrix 27	17°55.295'	30°48.855'	76.5	24
Matrix 28	17°55.296'	30°48.799'	88	26
Matrix 29	17°55.245'	30°48.797'	92.5	19
Matrix 30	17°55.270'	30°48.846'	86.5	22.5

Appendix D: Vegetation cover data for all sites sampled in the Chizarira National Park. The dimensions of mounds are also given

Site	Mound Height (m)	Diameter 1 (m)	Diameter 2 (m)	Ground cover (%)	Aerial cover (%)
Mound 1	1.8	11.8	11	7	19.3
Mound 2	2.3	12.3	12.1	19.9	0
Mound 3	1.6	13	12.85	12.7	38.6
Mound 4	1.85	12.3	11.9	6.2	20.8
Mound 5	2.2	14.3	11.6	34.8	77.4
Mound 6	2.1	14.3	13.05	40.2	74.1
Mound 7	1.65	12.5	11.8	54.9	64.6
Mound 8	2.8	16.1	14.46	38.6	91.1
Mound 9	2.6	14.7	13.45	19.7	59.7
Mound 10	3	16.62	16.12	8.95	61.5
Mound 11	1.2	12.78	12.72	11.7	85.3
Mound 12	2.4	12.54	12.4	19.1	52.7
Matrix 1	-	-	-	46.6	0
Matrix 2	-	-	-	9.6	6
Matrix 3	-	-	-	24.5	0
Matrix 4	-	-	-	10.2	4.3
Matrix 5	-	-	-	36.5	9.4
Matrix 6	-	-	-	20.5	11.3
Matrix 7	-	-	-	34.5	0
Matrix 8	-	-	-	45.1	6.6
Matrix 9	-	-	-	16.8	0
Matrix 10	-	-	-	64.3	11
Matrix 11	-	-	-	12.3	7.3
Matrix 12	-	-	-	90	0

Appendix E: Ground cover and Aerial cover Recording sheet

DATE: ……………. Recorders: …………………………… Locality: ……………….………..

Mound / Matrix Plot No. …… GPS Coordinates: …………… South, ……………East. Photo Nos:

Transect No. ……… Position of transect: ………………………………………………………

…………………………………………………………………………………………………

Point No.	**Ground Cover**	**Aerial Cover**	**Species**	**Point No.**	**Ground Cover**	**Aerial Cover**	**Species**
1				51			
2				52			
3				53			
4				54			
5				55			
6				56			
7				57			
8				58			
9				59			
10				60			
11				61			
12				62			
13				63			
14				64			
15				65			
16				66			
17				67			
18				68			
19				69			
20				70			
….				…			
50				100			

CODES - Ground cover: **BG** - Bare Ground; **St** - Stone: **Wd** - Wood; **Lf** - Leaf; **Gr** – Grass; **Sp** – Seed pod

Aerial cover: Dicot leaf **- DLf**; Twig or branch **- Twg;** Woody stem **- WSt**; Grass leaf **- GLf** :

Grass Stem **- GSt**

NOTES:

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…………………………………………………………………………………………………

Appendix F: Spider recording sheet

DATE: ……………. Recorders: ………………………………….. Locality: ……………….……….. Mound / Matrix Plot No. …… Sheet No……

GPS Coordinates: …………………. South, ………………… East. Photo Nos: ……..…………..

Mound dimensions: Height ………m, Diameter 1 ……….m Diameter 2 ………..m. **Active / Not Active Halo / No Halo Burned/Not Burned**

Diagram of Mound Profile:

Spider No.	**Vial No.**	**Date**	**Site (TM/Ma)**	**Family**	**Morpho-species ID/Name**	**Species ID**	**Identified by:**	**Date**	**Note No.**

NOTES:
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Appendix G: Plant species recorded in the Chivero Bird Sanctuary, on Termitaria and in the woodland matrix

Termitaria	Woodland Matrix
Acacia schweinfurthii	*Acacia schweinfurthii*
Acacia seiberiana	*Albizia amara*
Albizia amara	*Albizia antunesiana*
Albizia antunesiana	*Annona senegalensis*
Allophylus africanus	*Asparagus racemosus*
Asparagus racemosus	*Azanza garckeana*
Azanza garckeana	*Brachystegia glaucescens*
Boscia salicifolia	*Brachystegia spiciformis*
Brachystegia spiciformis	*Burkea africana*
Bridelia mollis	*Catunaregum spinosa*
Cadaba termitaria	*Clerodendrum glabrum*
Canthium lactescens	*Clerodendrum myricoides*
Capparis tomentosa	*Clerodendrum myrtifolia*
Cassia abbreviata	*Clerodendrum transvaalense*
Cassine transvaalensis	*Combretum apiculatum*
Catunaregum spinosa	*Combretum brachypetalum*
Celtis africana	*Combretum collinum*
Clerodendrum glabrum	*Combretum molle*
Clerodendrum myricoides	*Combretum psidioides*
Clerodendrum mytifolia	*Combretum zeyheri*
Clerodendrum transvaalense	*Dichrostachys cinerea*
Combretum apiculatum	*Diospyros lycioides*
Combretum collinum	*Dovyalis zeyheri*
Combretum molle	*Eriosema engleriana*
Combretum zeyheri	*Euclea crispa*
Dichrostachys cinerea	*Faurea saligna*
Diospyros lycioides	*Fluggea virosa*
Dombeya rotundifolia	*Gardenia volkensii*
Dovyalis zeyheri	*Grewia retinervis*
Duranta repens	*Jasiminum fluminense*
Ehretia amoena	*Kochia sp.*
Ehretia rigida	*Lannea discolor*
Euclea crispa	*Lannea edulis*
Euclea divinorum	*Maytenus heterophylla*
Euphorbia ingens	*Maytenus senegalensis*
Ficus natalensis	*Monotes glaber*
Ficus zanzibarica	*Mystroxylon aethiopicum*
Flueggea virosa	*Ochna pulchra*
Gardenia volkensii	*Ochna schweinfurtiana*
Grewia bicolor	*Ozoroa insignis reticulata*
Grewia flavescens flavescens	*Parinari curatellifolia*

Grewia flavescens olukondae
Grewia monticola
Grewia retinervis)
Jacaranda sp.
Jasminum fluminense
Jasminum stenolobum
Lannea discolor
Lantana camara
Maerua juncea
Maerua triphylla
Maytenus heterophylla
Maytenus senegalensis
Mystroxylon aethiopicum
Ochna pulchra
Pappea capensis
Parinari curatellifolia
Pavetta gardenifolia
Pavetta schumanniana
Peltophorum africanum
Pouzolzia mixta
Psychotria kirkii
Psydrax livida
Pterocarpus angolensis
Pterocarpus rotundifolius
Rhoicissus tridentata
Rhus longipes longipes
Rhuus tenuinervis
Schotia brachypetala
Senna singueana
Solanum delagoense
Strychnos cocculoides
Strychnos potatorum
Teclea trichocarpa
Terminalia brachystemma
Vangueria infausta
Vangueria randii
Vangueriopsis lanciflora
Vernonia amygadalina
Ximenia americana
Ziziphus mucronata

Pavetta gardenifolia
Pavetta schumanniana
Peltophorum africanum
Pouzolzia mixta
Protea angolensis
Psorospermum febrifugum
Psydrax livida
Pterocarpus angolensis
Pterocarpus rotundifolius
Rhus longipes
Rhus tenuinervis
Securidaca longipendunculata
Senna singueana
Steganotaenia araliacea
Strychnos cocculoides
Swartzia madagascariensis
Syzygium sp
Teclea trichocarpa
Terminalia brachystemma
Vangueria infausta
Vangueria randii
Vangueriopsis lanciflora
Vangueriopsis lanciflora
Vitex mombassae
Vitex payos
Ximenia americana
Ximenia caffra

Appendix H: Plant species recorded in the Chivero Game Park, on Termitaria and in the woodland matrix

Termitaria	**Woodland Matrix**
Albizia amara	*Albizia antunesiana*
Albizia antunesiana	*Albizia amara*
Allophylus africanus	*Allophylus africanus*
Ehretia amoena	*Annona senegalensis*
Asparagus racemosus	*Brachystegia spiciformis*
Bauhinia thonningii	*Bridelia mollis*
Boscia salicifolia	*Burkea africana*
Brachylaena rotundata	*Canthium lactescens*
Brachystegia spiciformis	*Clerodendrum glabrum*
Bridelia mollis	*Combretum apiculatum*
Burkea africana	*Combretum brachypetalum oatesii*
Cadaba termitaria	*Combretum molle*
Canthium lactescens	*Combretum zeyheri*
Capparis tomentosa	*Dichrostachys cinerea*
Celtis africana	*Diospyros lycioides*
Clerodendrum transvaalense	*Ehretia amoena*
Clerodendrum glabrum	*Faurea saligna*
Clerodendrum myricoides	*Fluggea virosa*
Clerodendrum myricoides	*Gardenia volkensii*
Combretum apiculatum	*Grewia bicolor*
Combretum molle	*Grewia flavescens flavescens*
Combretum zeyheri	*Grewia monticola*
Dichrostachys cinerea	*Grewia retinervis (Grewia flavescens)*
Diospyros lycioides	*Lannea edulis*
Dombeya rotundifolia	*Lapholaena coriifolia*
Dovyalis zeyheri	*Mystroxylon aethiopicum*
Ehretia amoena	*Maytenus senegalensis*
Ehretia rigida	*Monotes glaber*
Euclea crispa crispa	*Ochna pulchra pulchra*
Euclea divinorum	*Ozoroa insignis reticulata*
Euphorbia ingens	*Parinari curatellifolia*
Ficus natalensis	*Pavetta schumanniana*
Ficus zanzibarica	*Peltophorum africanum*
Ficus thonningii	*Pterocarpus angolensis*
Fluggea virosa	*Pterocarpus rotundifolius*
Gardenia volkensii	*Rhus longipes longipes*
Grewia bicolor	*Schotia brachypetala*
Grewia flavescens flavescens	*Securidaca longipendunculata*
Grewia flavescens olukondae	*Senna singueana (cassia singueana)*
Grewia monticola	*Solanum delagoense*
Grewia retinervis (Grewia flavescens)	*Solanum incanum*

Jasiminum stenolobum	*Psorospermum febrifugum*
Lannea discolor	*Strychnos cocculoides*
Lannea edulis	*Strychnos potatorum*
Lantana camara	*Swartzia madagascariensis*
Lapholaena coriifolia	*Syzygium guineense*
Maerua juncea	*Terminalia brachystemma*
Mystroxylon aethiopicum	*Terminalia trichopoda*
Monotes glaber	*Vangueriopsis lanciflora*
Maytenus heterophylla heterophylla	*Vangueria infausta*
Mystroxylon aethiopicum	*Vitex mombassae*
Ochna pulchra pulchra	*Ximenia caffra*
Pappea capensis	*Ziziphus mucronata*
Parinari curatellifolia	
Pavetta gardenifolia	
Peltophorum africanum	
Pouzolzia lucens	
Pterocarpus rotundifolius	
Rhoicissus tridentata	
Rhus longipes longipes	
Rhuus tenuinervis	
Schotia brachypetala	
Senna singueana (cassia singueana)	
Solanum delagoense	
Solanum incanum	
Terminalia brachystemma	
Terminalia trichopoda	
Vangueria randii	
Vangueriopsis lanciflora	
Ximenia americana	
Ziziphus mucronata	

Appendix I: Plant species recorded in the Chizarira National Park, on Termitaria and in the woodland matrix

Termitaria	**Woodland Matrix**
Acacia nilotica	*Acacia nilotica*
Andropogon gayanus	*Andropogon gayanus*
Allophylus africanus	*Aristida bicolor*
Berchemia discolor	*Aristida leucophaea*
Boscia angustifolia	*Brachystegia boehmii*
Boscia salicifolia	*Brachystegia spiciformis*
Brachystegia boehmii	*Bridelia cathatica*
Capparis tomentosa	*Burkea africana*
Cassia abbreviata	*Catuneragum spinosa*
Cissus cornifolia	*Combretum apiculatum*
Combretum apiculatum	*Combretum collinum*
Combretum collinum	*Combretum hereroense*
Combretum hereroense	*Combretum molle*
Combretum molle	*Combretum zeyheri*
Combretum mossambicense	*Crossopteryx febrifuga*
Combretum xeyheri	*Dichrostachys cinerea*
Comiphora mollis	*Diospyros kirkii*
Commiphora mossambicensis	*Diplorynchus condylocarpon*
Dalbergia melanoxylon	*Flacourtia indica*
Dichrostachys cinerea	*Hyparrhenia filipendula*
Diospyros kirkii	*Jubinardia globiflora*
Diospyros quiloensis	*Lannea edulis*
Diospyros senensis	*Lannea discolor*
Erythroxylum zambesiacum	*Lonchocarpus capassa*
Euclea divinorum	*Loudetia flavida*
Feretia aeruginenscens	*Ozoroa insignis*
Flueggea virosa	*Pavetta schumanniana*
Friesoldielsia obovatum	*Progonathria squarrosa*
Grewia monticola	*Pseudolachnostylis maprouneifolia*
Lannea schweinfurthii	*Sclerocarya birrea*
Lannea stuhlmannii	*Terminalia brachystemma*
Lonchocarpus capassa	*Terminalia sericea*
Maerua prittwitzii	*Terminalia sternostachya*
Manilkara mochisia	*Turrea nilotica*
Markhamia zanzibarica	*Xeroderris stuhlmannii*
Pterocarpus rotundifolius	*Ziziphus abyssinica*
Strychnos potatorum	
Xeroderris stuhlmannii	
Ximenia americana	
Ximenia caffra	
Ziziphus mucronata	